

# **EFFECTS OF THREE HIGHWAY-RUNOFF DETENTION METHODS ON WATER QUALITY OF THE SURFICIAL AQUIFER SYSTEM IN CENTRAL FLORIDA**

**By Donna M. Schiffer**

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# EFFECTS OF THREE HIGHWAY-RUNOFF DETENTION METHODS ON WATER QUALITY OF THE SURFICIAL AQUIFER SYSTEM IN CENTRAL FLORIDA

By Donna M. Schiffer

## ABSTRACT

Water quality of the surficial aquifer system was evaluated at one exfiltration pipe, two ponds (detention and retention), and two swales in central Florida, representing three runoff detention methods, to detect any effects from infiltrating highway runoff. Concentrations of major ions, metals, and nutrients were measured in ground water and bottom sediments from 1984 through 1986.

At each study area, constituent concentrations in ground water near the structure were compared to concentrations in ground water from an upgradient control site. Ground-water quality data also were pooled by detention method and statistically compared to detect any significant differences between methods.

Analysis of variance of the rank-converted water-quality data at the exfiltration pipe indicated that mean concentrations of 14 of 26 water-quality variables are significantly different among sampling locations (the pipe, unsaturated zone, saturated zone, and the control well). Most of these differences are between the unsaturated zone and the other locations. Only phosphorus is significantly higher in ground water near the pipe than in ground water at the control well.

Analysis of variance of rank-converted water-quality data at the retention pond indicated significant differences in 14 of 25 water-quality variables among sampling locations (surficial aquifer system, intermediate aquifer, pond, and the control well), but mean concentrations in ground water below the pond were never significantly higher than in ground water from the control well. Analysis of variance results at other study areas indicated few significant differences in water quality among sampling locations.

Values of water-quality variables measured in ground water at all study areas generally were within drinking water standards. The few exceptions included pH (frequently lower than the limit of 6.5 at one pond and both swales), and iron, which frequently exceeded 300 micrograms per liter in ground water at one swale and the detention pond.

Large concentrations of polyaromatic hydrocarbons were measured in sediments at the retention pond, but qualitative analysis of organic compounds in ground water from three wells indicated concentrations of only 1 to 5 micrograms per liter at one site, and below detection level (1 microgram per liter) at the other two sites. This may be an indication of immobilization of organic compounds in sediments.

Significant differences for most variables were indicated among ground-water quality data pooled by detention method. Nitrate nitrogen and phosphorus concentrations were highest in ground water near swales and the exfiltration pipe, and Kjeldahl nitrogen was highest near ponds. Chromium, copper, and lead concentrations in ground water were frequently below detection levels at all study areas, and no significant differences among detention methods were detected for any metal concentration with the exception of iron. High iron concentrations in ground water near the detention pond and one swale most likely were naturally occurring and unrelated to highway runoff.

Results of the study indicate that natural processes occurring in soils attenuate inorganic constituents in runoff prior to reaching the receiving ground water. However, organic compounds detected in sediments at the retention pond indicate a potential problem that may eventually affect the quality of the receiving ground water.

## INTRODUCTION

Runoff from road surfaces is thought to be a significant source of nonpoint pollution to surface and ground waters (Gupta and others, 1981). Stormwater runoff has been the subject of much research, but only recently has highway runoff been more rigorously investigated as a source of pollution independent of other sources. Normally, stormwater runoff is a composite of runoff from various land-use areas (residential, commercial, and industrial), in addition to road surfaces.

Highway runoff as a potential source of pollution has been recognized by numerous investigators (Sartor and Boyd, 1972; Shaheen, 1975; Novotny and Chesters, 1980; Gupta and others, 1981). The Florida Department of Transportation (FDOT) is the primary agent responsible for the quality of runoff from highways within the State of Florida, and has recognized the need for further study and development of a scientific data base on which to base decisions about highway-runoff management. The FDOT has initiated many investigations cooperatively with State universities and Federal agencies, including the U.S. Geological Survey.

The FDOT's continuing assessment of best management alternatives to prevent any possible degradation of the State's surface waters has been extended to include prevention of degradation of ground water. To investigate the effects on ground water of highway runoff routed through control structures, a study was started by the U.S. Geological Survey in cooperation with the FDOT in late 1983.

### **Background**

The FDOT has the responsibility of treating the first one-half inch of runoff from State roadways (Florida Department of Environmental Regulation, 1986). Treatment is usually accomplished through velocity reduction and by concomitant sedimentation. To accomplish this treatment of runoff, several runoff detention methods are used.

Exfiltration pipes commonly are used in urban areas to comply with the retention requirements of State law. Sometimes called French drains, they are typically made of perforated corrugated aluminum pipe, installed in a trench lined with a permeable fabric wrap, and backfilled with gravel. Unlike a true French drain that lowers ground-water levels, exfiltration pipes are used for routing of runoff into soils that recharge, by infiltration, the ground-water reservoir.

Detention ponds detain runoff for a length of time before the water is released to a receiving body. Retention ponds retain water and have no outflow. The runoff in the pond infiltrates into the soil, then percolates into the local ground-water system.

Swales are grass-covered channels that are primarily considered conveyance systems, but

also are used as a preliminary treatment of runoff. Infiltration through the bottom of the swale reduces the volume of runoff to the outfall, and detention allows some sedimentation of particulates in the runoff before entering the receiving body.

Although these runoff detention methods have been in use since the 1970's by various highway departments, little information has been available on the potential effects of these practices on the quality of ground water near structures.

### **Purpose and Scope**

The purpose of this investigation was to:

- Evaluate the impact on the water quality of the surficial aquifer system near structures used for detention of highway runoff,
- Define any spatial trends in water-quality detected during ground-water monitoring, and
- Define the spatial distribution of constituent concentrations in sediments.

The study, which was 4 years in length, was restricted to five central Florida locations. The runoff detention structures studied were a detention pond, a retention pond, two swales, and an exfiltration pipe. The primary objective of the study was a first-step reconnaissance to detect any significant differences in ground water near the structure and upgradient of the structure (control or background condition). The data for the study were collected from 1984 to 1986.

This report presents the results of the monitoring and analysis of ground-water quality near five structures representing the three runoff detention methods and describes possible effects on the water quality of the surficial aquifer caused by infiltration of runoff from highways.

## **TECHNICAL BACKGROUND**

### **Previous Studies**

Highway runoff generally has been included as part of stormwater studies, but more recently research has isolated runoff from highways for investigation. An early work that commonly is referenced is "Water pollution aspects of street surface contaminants," by Sartor and Boyd (1972). The authors noted that data available on stormwater at that time were not directly relatable to the materials contributed by



street-surface contaminants, and that there was a need to identify the relations between street-surface contaminants, their characteristics, and manner of transport. The study by Sartor and Boyd (1972) resulted in many significant findings, perhaps the most important of which was the association of street-surface contaminants and particle size. The greatest pollution potential is associated with fine-grained particles, 43  $\mu\text{m}$  (micrometers) or smaller in diameter.

Some of the most pertinent reports include the results of a study of urban roadways in the Washington, D.C., area by Shaheen (1975); a study of street dust from eight cities in the United States by Pitt and Amy (1973); an extensive six volume report sponsored by the Federal Highway Administration titled "Constituents of highway runoff," by Gupta and others (1981); and a study of urban runoff in Bellevue, Wash. (Galvin and Moore, 1982), which identified street runoff as a major contributor to stormwater constituent loads.

A journal article by Nightingale (1987) reported on a 2-year study of ground-water quality beneath five retention basins in Fresno, Calif. Nightingale monitored inorganic and organic constituents in water in the unsaturated and saturated zones beneath ponds that received runoff water from basins that were predominately single family residential, with some multiple family residential and commercial areas. He concluded that no significant contamination of percolating soil water or ground water beneath these basins had occurred for constituents monitored in the study, and that concentrations of selected trace metals in the ground-water samples were similar in magnitude to those reported for regional ground water.

### **Chemical Constituents And Water-Quality Measures**

The major component of street-surface contaminants is particulate matter. Nonparticulate soluble and suspendable matter also are present on street surfaces (oils and salts). The magnitude of constituents on highways is dependent on many site-specific variables, such as traffic characteristics (speed, volume of traffic, and amount of braking), climatic conditions (frequency, intensity, and duration of precipitation, and wind), percentage of pervious and impervious areas contributing runoff to the roadway, age and condition of automobiles on the

road, regulations in the area governing emissions and littering, highway maintenance policies (street sweeping, mowing adjacent to highways, and deicing), and the types and amounts of vegetation on the road right-of-way (Gupta and others, 1981).

Chemical constituents associated with highway runoff include heavy metals, nutrients, and complex organic compounds. Heavy metals include cadmium, chromium, copper, iron, lead, zinc, aluminum, and nickel. Nutrients include nitrogen and phosphorus species. Organic compounds include oil and grease and polyaromatic hydrocarbons (PAHs).

Metals commonly are detected in samples of highway runoff. The priority pollutant monitoring project of the Nationwide Urban Runoff Program (NURP) was initiated to evaluate the significance of priority pollutants in urban stormwater. Fifty-one catchments in 19 cities representing different ranges of watershed areas and population densities were sampled. Preliminary results of the study indicated that as a group, toxic metals are by far the most prevalent priority pollutants of urban runoff (Cole and others, 1984). Motor vehicle emissions, and the breakdown of vehicle parts are the major sources of metals in street runoff (Gupta and others, 1981). Although lead-free gasoline dominates the fuel market today, lead is still a component of motor oil and bearings in vehicles, and large concentrations are still detected in runoff samples. Copper, nickel, and chromium are present in brake linings, and zinc is a component of motor oil and tires. Thus, many sources of heavy metals are highway related.

Nutrients in highway runoff generally originate from atmospheric sources and green-belt areas that are fertilized. Phosphorus is a motor oil additive. Miscellaneous sources of nutrients on roadways include bird droppings and animal remains.

The low concentrations of organic priority pollutants (parts per billion or trillion) make detection difficult, and has resulted in very little having been written about the presence of organic compounds in stormwater. Galvin and Moore (1982) determined that 71 to 96 percent of the total extractable organic compounds in urban runoff was associated with particulate matter. The major source of organic compounds in highway runoff is petroleum products, including lubrication oils, fuel, and combustion emissions.

Wakeham and others (1980) speculated that the distribution of PAHs in street dust and runoff originated primarily from the wear of asphalt road surfaces rather than from atmospheric fallout. Asphalt particles are composed of high molecular weight organic compounds, that may also trap other organic toxicants, especially pyrolytic PAHs (Galvin and Moore, 1982). Gasoline contains the following organic compounds: benzene, toluene, phenols, and polyaromatic hydrocarbons. The dominant source of benzo(a)pyrene (a PAH) is the pyrolysis of diesel fuel, although it is also a component of regular gasoline and oil.

PAHs are rapidly adsorbed onto organic particles and inorganic material in receiving waters because of their low solubility and hydrophobic character. For this reason, they would tend to be more frequently detected in sediments rather than in the water column. Once PAHs are deposited, they are less subject to photochemical or biological oxidation, and concentrations in sediments are detected at levels more than a thousand times greater than the overlying water (Galvin and Moore, 1982).

Specific conductance, dissolved oxygen (DO), pH, and temperature are water-quality measures that may function as indicators of overall quality, and of the speciation of dissolved species possible in the environment. These variables, except DO, were measured when collecting ground-water samples during the study.

### **Description of Ground-Water Systems**

In central Florida, the surficial aquifer system is comprised primarily of unconsolidated deposits of quartz sand and some clay and organic material. Typically the water table is within 20 feet of land surface.

The intermediate aquifer, or intermediate confining unit, lies between the overlying surficial aquifer system and the underlying Floridan aquifer system. It is primarily comprised of fine-grained clastic deposits interlayered with carbonate strata. The intermediate confining unit retards the vertical movement of water between the surficial aquifer system and the Floridan aquifer system because of its low permeability.

The primary water-yielding aquifer in central Florida is the Upper Floridan aquifer, the upper aquifer of the Floridan aquifer system. The top of the Floridan aquifer system ranges from 50 to 150 feet below land surface in the study area (Lichtler and others, 1968). The Floridan aquifer system consists mostly of interbedded limestone, dolomitic limestone, and dolomite. The Upper Floridan aquifer is the major source of drinking water in central Florida because it is highly permeable and yields large volumes of water (Miller, 1986, p. B53).

The Floridan aquifer system is recharged by the surficial aquifer system when the water table is above the potentiometric surface of the Floridan aquifer system, which occurred at all study locations during the study. Thus, the quality of the recharge water from the surficial aquifer system may affect the quality of water in the Floridan aquifer system. The advantage of discharging stormwater to the surficial aquifer system rather than directly to the Floridan aquifer system through drainage wells (Schiner and German, 1983) is the improvement in quality as the water moves through the unconsolidated materials of the surficial aquifer system and through the intermediate confining unit.

In central Florida, several earlier studies reported transmissivities of the saturated zone of the surficial aquifer system. Reported transmissivities range from 27 ft<sup>2</sup>/d (feet squared per day) in western Orange County (Watkins, 1977) to 600 ft<sup>2</sup>/d (Bush, 1979) in eastern Orange County. An aquifer test in southwest Orange County yielded a value of 500 ft<sup>2</sup>/d (E.R. German, U.S. Geological Survey, oral commun., 1986). The higher transmissivity values were in aquifers comprised mostly of fine sand. Hydraulic conductivity values computed from these transmissivity values for the surficial aquifer system ranged from 1.9 to 15.8 ft/d. Vertical movement of water in the unsaturated zone is much more rapid, in general, than horizontal movement of water in the saturated zone. Although water continues to move vertically in the saturated zone, the predominant direction of flow is generally more horizontal, because of confining layers and anisotropy.

## Constituent Attenuation Mechanisms in the Subsurface Environment

Runoff water is the vehicle by which constituents in highway runoff are transported in both soluble and particulate forms to ground water, by infiltrating into the soil and percolating through the unsaturated zone to the saturated zone. Constituent loads may be attenuated in the unsaturated zone before reaching the saturated zone through several processes (fig. 1). Some mechanisms by which the constituent loading to the ground water may be decreased include filtering, sorption (adsorption and absorption), precipitation, and ion exchange. Organic constituents may be decomposed through bacterial activity and some inorganic constituents may be utilized by plants. Clays and organic material have high affinities for adsorbing various constituents, particularly heavy metals. Adsorption is the major mechanism for the collection of trace metals on clay and organic material surfaces. Jenne (1976) indicated that material with large

surface areas may serve as mechanical substrates without any chemical interaction between the material and the constituent. Organic matter, hydrous iron, and manganese oxides can deposit on a surface and function as metal collectors.

Heterogeneity of the subsurface material is an important control in the movement of constituents in water in the subsurface environment. Heterogeneities arise from several factors including variation in grain size, and permeability variation caused by stratification that occurred in a particular depositional environment. In general, constituents moving through the unsaturated zone to the saturated zone are in the dissolved form. However, some water infiltrating through the soil surface may move rapidly through the unsaturated zone along preferred paths (pores, cracks, and other interconnected openings that are wide enough not to exert capillary forces on the moving water), making gravity the primary acting force. This may allow the particulate fraction of some constituents to reach the saturated zone.

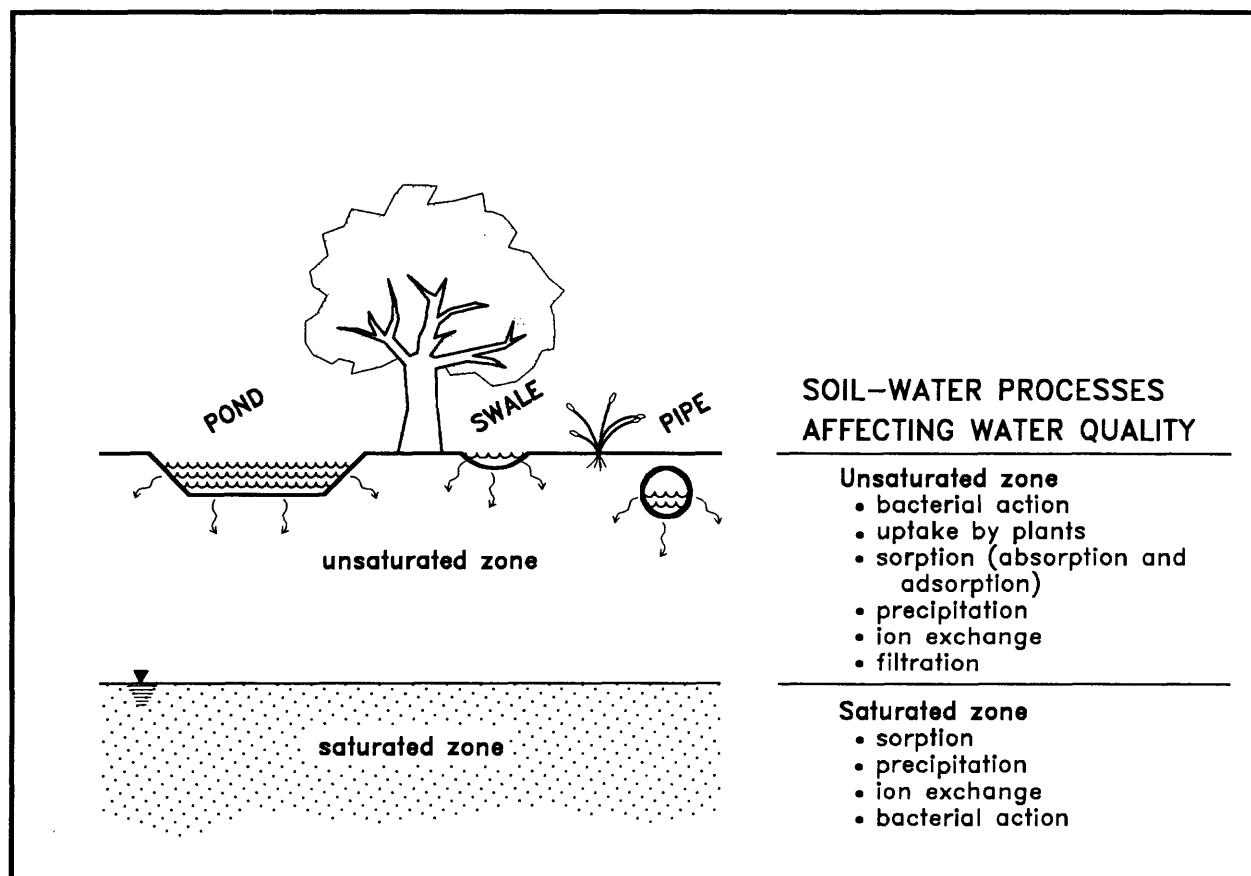


Figure 1.—Ground-water movement and processes affecting water quality.

Although many of the same processes occurring in the unsaturated zone also occur in the saturated zone (sorption, ion exchange, and precipitation), most of the attenuation of loads occurs in the unsaturated zone. One reason for the attenuation is because organic material at the soil surface traps many constituents. Also, oxygen is available in the unsaturated zone for redox reactions (removing constituents from solution by precipitation) and for bacterial activity. Plant roots may take in nutrients in the unsaturated zone, thus reducing the load to the saturated zone. Percolating water may be in contact with the soil longer in the unsaturated zone, as the storage requirements of the unsaturated soil are satisfied, than in the saturated zone, where the hydraulic conductivity (and thus flow rate) increases. Differences in constituent concentrations between the unsaturated zone and the saturated zone also may be caused by dilution, as the infiltrating water enters the saturated zone.

One unknown that concerns the routing of runoff to the subsurface environment is whether the soils will eventually clog, decreasing or eliminating their ability to convey water and remove constituents. This would occur more rapidly in a wastewater treatment operation that uses land spreading, because of the nutrient-rich water associated with secondary treated wastewater. Maintenance of structures used for treatment of runoff is an important factor to the life of the structure, and to the protection of ground-water resources. Removal of sediments after a number of years facilitates infiltration, and prevents the potential release of metals and nutrients from the sediments under changing environmental conditions. Additionally, the maintenance of aerobic conditions in ponds also protects receiving ground-water quality by reducing the concentrations of soluble species that may exfiltrate out of the pond.

## STUDY AREAS

The FDOT structures selected for this study are located in central Florida, a rapidly developing metropolitan area. Traffic in the area has increased dramatically since the early 1970's because of the growing population, and the number of vehicles far exceeds the design capacity of many roads, thus creating an ever increasing source of undesirable constituents in runoff from the road surfaces.

The five structures selected for study (fig. 2), are located near Orlando and Longwood, Fla., and include one exfiltration pipe, two ponds (one detention and one retention), and two swales. A brief description of each study location follows.

An exfiltration pipe located under the street and sidewalk area of a downtown Orlando street (Washington Street) was selected for study (figs. 3 and 4), in part because the pipe was a prototype design for the city. The pipe was designed to provide storage for the first 0.50 inch of runoff from a 1-acre street and parking lot drainage area (Harper and others, 1982).

At the time of the study, the pipe had been in operation for about 5 years. A new parking garage had been built adjacent to the study site and was completed a few months before this study began. An exfiltration system was installed beneath the new parking lot to handle stormwater runoff from the parking garage and lot. The design included an overflow feature such that when the system beneath the parking lot reached a certain storage volume, water would overflow a weir and discharge into the Washington Street exfiltration pipe. Overflow was not observed during the time of the study.

The street is curbed, and runoff enters the pipe from the curb through a drop inlet at one end of the pipe. Sampling sites around the pipe included four wells tapping the saturated zone of the surficial aquifer system, and three lysimeters at varying depths in the unsaturated zone (fig. 3 and table 1), installed in March 1984. Photographs of the street are shown in figure 5. Traffic on the street is light to moderate.

The detention pond in this study, located west of the city of Orlando on Silver Star Road was the subject of an earlier highway runoff study that reported on constituent-load changes through the system (Martin and Smoot, 1986). The quality of the water in the surficial aquifer system near the pond is the subject of the present study. The wetland adjacent to, and receiving outflow from, the pond was the subject of a concurrent study. Locations of the seven wells tapping the surficial aquifer in the vicinity of the pond and wetlands are shown in figure 6. A photograph of the study area is shown in figure 7. The total drainage area is 41.6 acres, of which 33 percent is roadway. The average daily traffic count in 1984 was 22,000 vehicles per day.

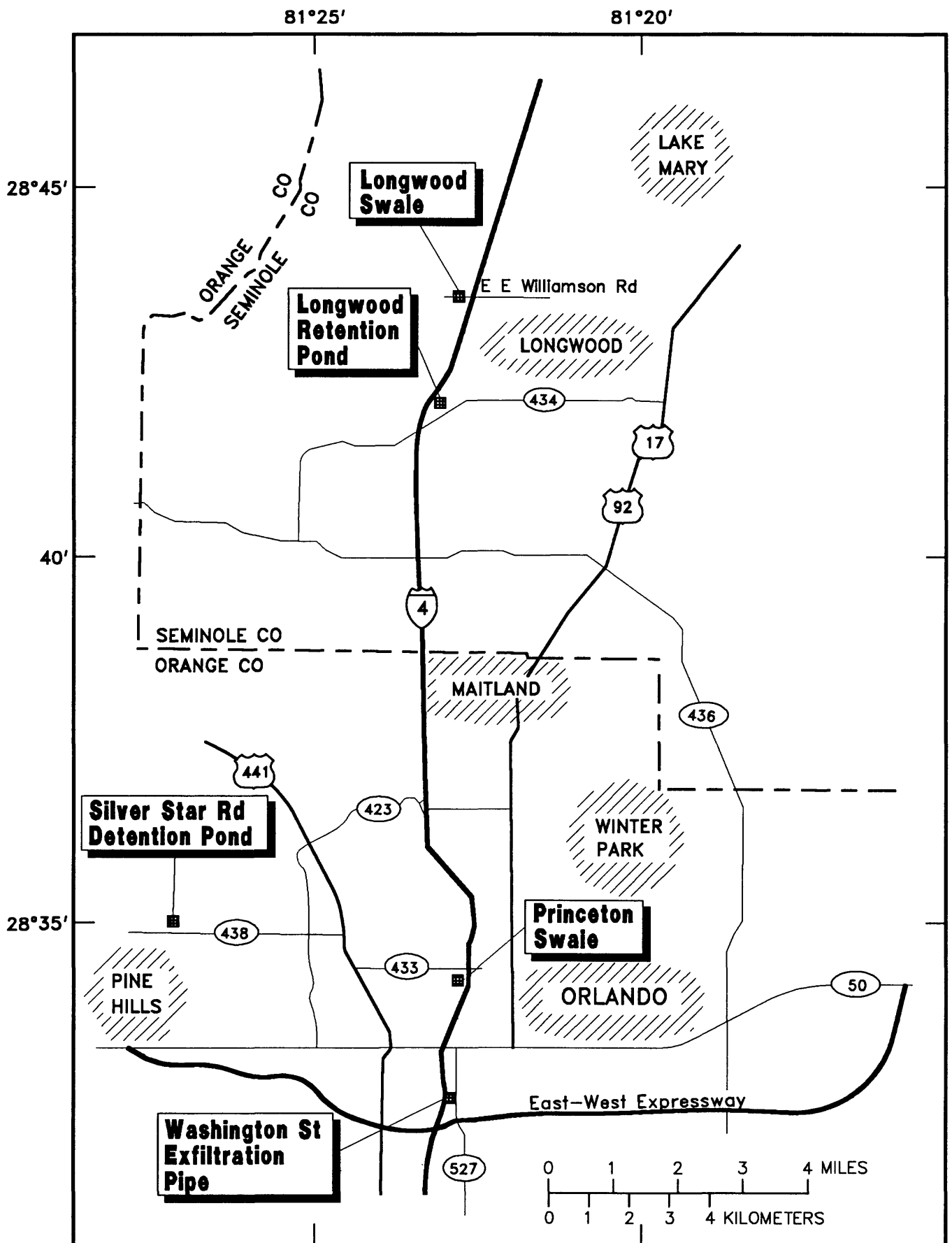
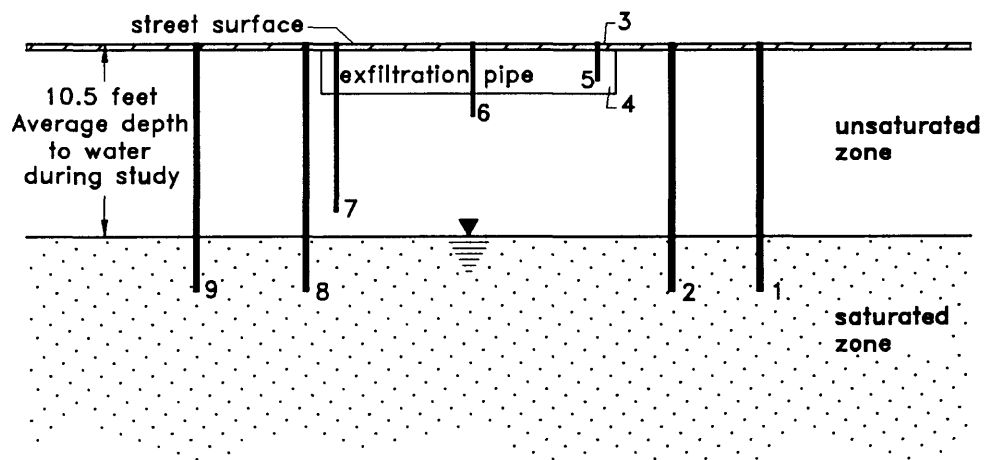
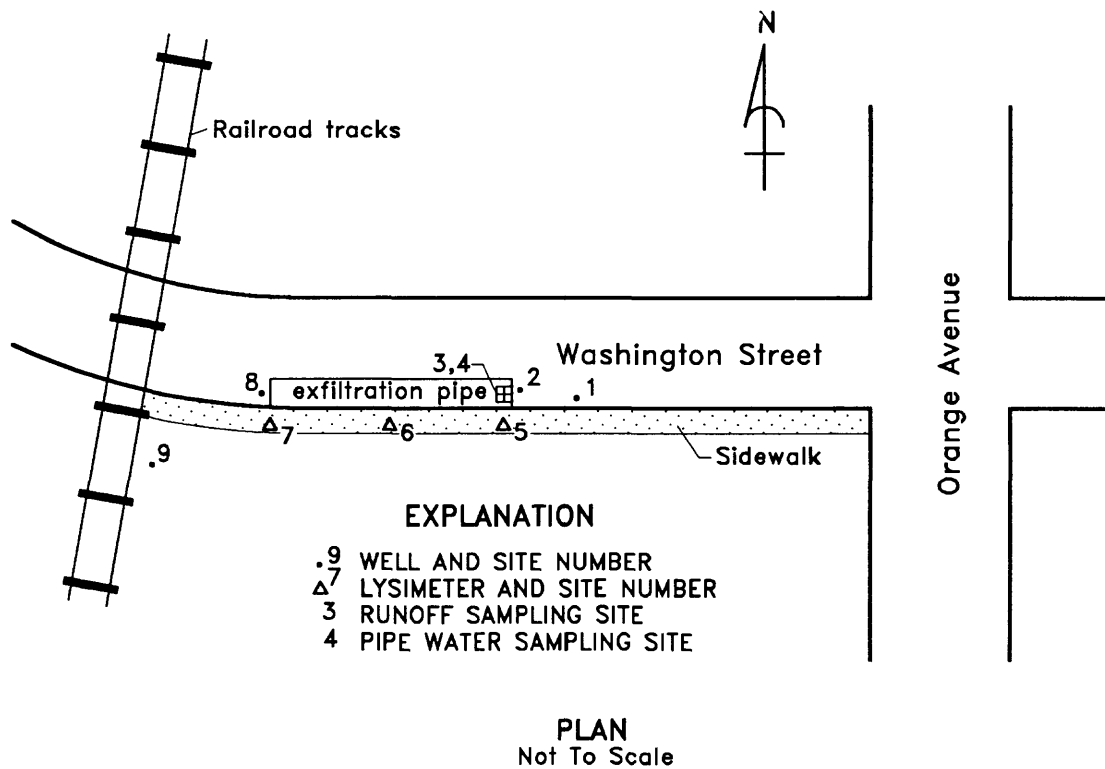
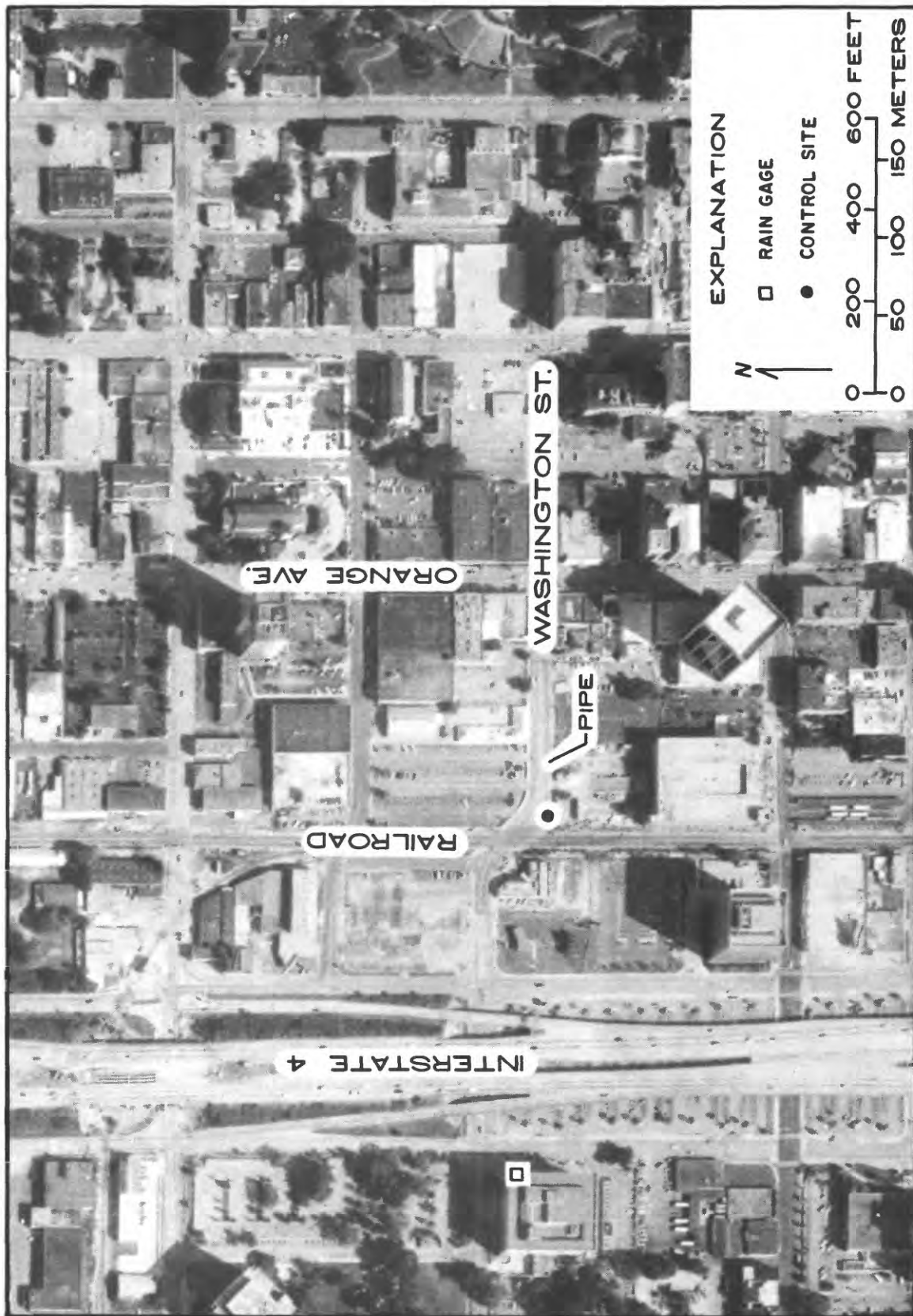


Figure 2.--Location of study areas.



All wells are 18 feet deep.  
Screened interval at 15 to 18 feet below land surface.

Figure 3.--Exfiltration pipe and sampling sites.



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Figure 4.---Aerial photograph of downtown Orlando showing the Washington Street exfiltration study area.

Table 1.--Sampling sites and type of data collected at each study area

| Site No.                                   | Site name                                | Type of data collected  |
|--|--|---|
| <u>Washington Street exfiltration pipe</u> |  |   |
| 1  | Well 10 feet east of exfiltration pipe   | Water quality of the surficial aquifer system                                     |
| 2  | Well 2 feet east of exfiltration pipe    | Do.   |
| 3  | Stormwater to exfiltration pipe          | Runoff water quality  |
| 4  | Exfiltration pipe                        | Runoff water quality, constituent concentrations in sediment                      |
| 5  | 3-foot depth lysimeter, east end of pipe | Unsaturated zone water quality  |
| 6  | 5-foot depth lysimeter, middle of pipe   | Do.   |
| 7  | 8-foot depth lysimeter, west end of pipe | Do.   |
| 8  | Well 2 feet west of exfiltration pipe    | Water quality of the surficial aquifer system                                     |
| 9  | Background well                          | Water quality of the surficial aquifer system (control)                           |
| <u>Silver Star Road detention pond</u>     |  |   |
| 1  | Well number 1                            | Water quality of the surficial aquifer system                                     |
| 2  | do. 2                                    | Do.   |
| 3  | do. 3                                    | Do.   |
| 4  | do. 4                                    | Do.   |
| 5  | do. 5                                    | Do.   |
| 7  | do. 7                                    | Do.   |
| 8  | do. 8                                    | Do.   |
| <u>Longwood retention pond</u>             |  |   |
| 1  | Well number 1                            | Water quality of the surficial aquifer system                                     |
| 2  | do. 2                                    | Do.   |
| 3  | do. 3                                    | Do.   |
| 4  | do. 4                                    | Do.   |
| 5  | do. 5                                    | Do.   |
| 6  | do. 6                                    | Do.   |
| 7  | do. 7                                    | Do.   |
| 8  | do. 8                                    | Intermediate aquifer water quality<br>Grain size analysis                         |
| 9  | Background well                          | Water quality of the surficial aquifer system                                     |
| 10   | South inlet, highway runoff              | Standing water and runoff water quality<br>Constituent concentrations in sediment |
| 11   | North inlet, parking lot runoff          | Standing water quality<br>Constituent concentrations in sediment                  |
| 12   | East inlet, parking lot runoff           | Standing water quality<br>Constituent concentrations in sediment                  |
| <u>Princeton and Interstate 4 swale</u>    |  |   |
| 1  | Well number 2                            | Water quality of the surficial aquifer system                                     |
| 2  | do. 4                                    | Do.   |
| 3  | do. 5                                    | Do.   |
| 4  | do. 6                                    | Do.   |
| 5  | do. 8                                    | Do.   |
| 6  | do. 9                                    | Do.   |
| 7  | do. 10                                   | Do.   |
| 8  | do. 11                                   | Do.   |
| 9  | Background well                          | Do.   |
| 10   | Sediment site west of well 4             | Constituent concentrations in sediment  |
| 11   | do. near well 2                          | Do.   |
| 12   | Stormwater to swale                      | Runoff water quality  |
| <u>Longwood and Interstate 4 swale</u>     |  |   |
| 1  | Well number 1                            | Water quality of the surficial aquifer system                                     |
| 2  | do. 2                                    | Do.   |
| 3  | do. 3                                    | Do.   |
| 4  | do. 4                                    | Do.   |
| 5  | Background well                          | Water quality of the surficial aquifer system (control)                           |
| 6  | Sediment site (near well 3)              | Constituent concentrations in sediment  |
| 7  | Sediment site (near background well)     | Do.   |





**YEAR OF PHOTOGRAPHY: 1984**

Figure 5.—Washington Street exfiltration pipe study area looking east (top) and west (bottom).

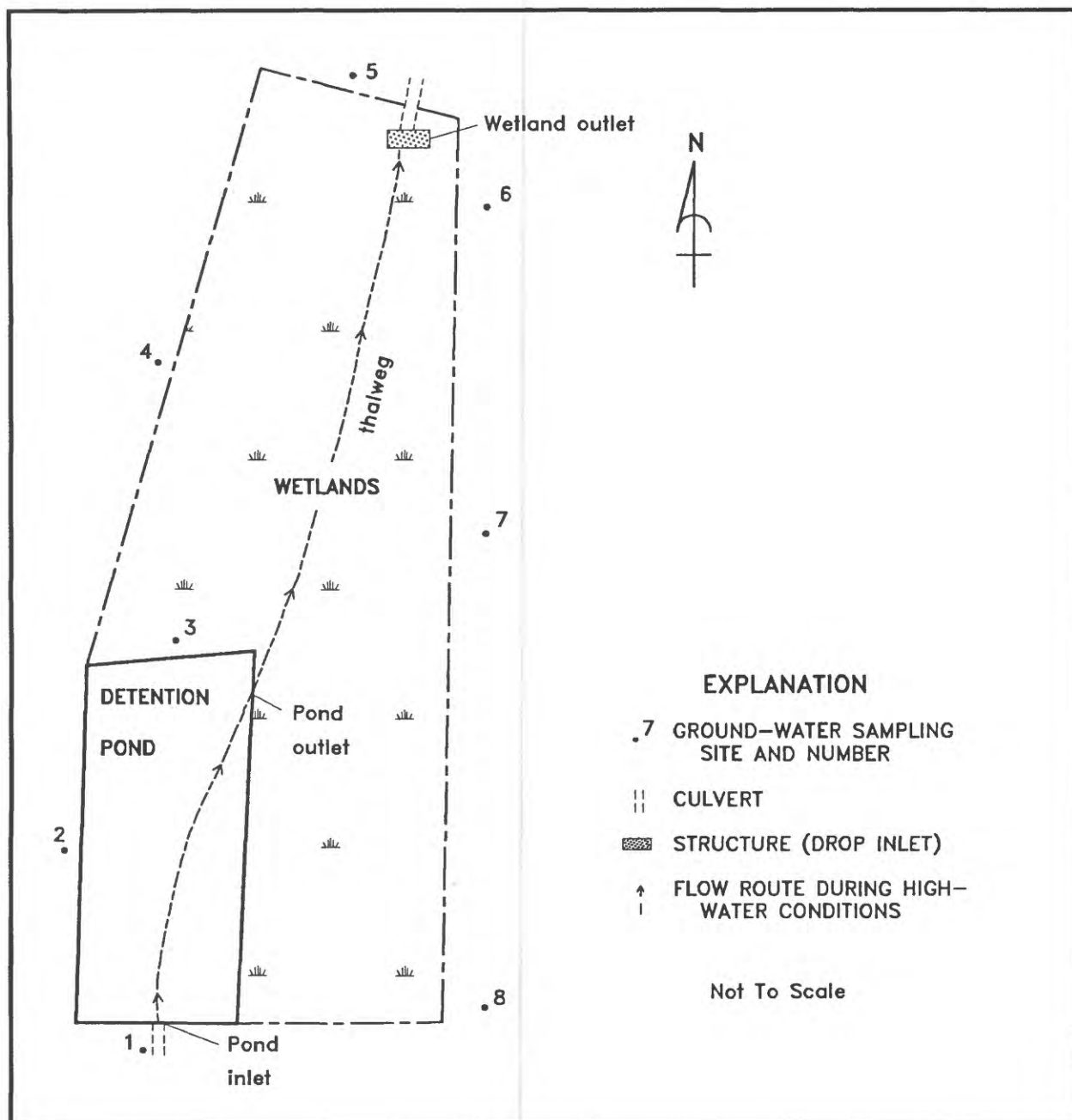


Figure 6.--Silver Star Road detention pond and sampling sites.



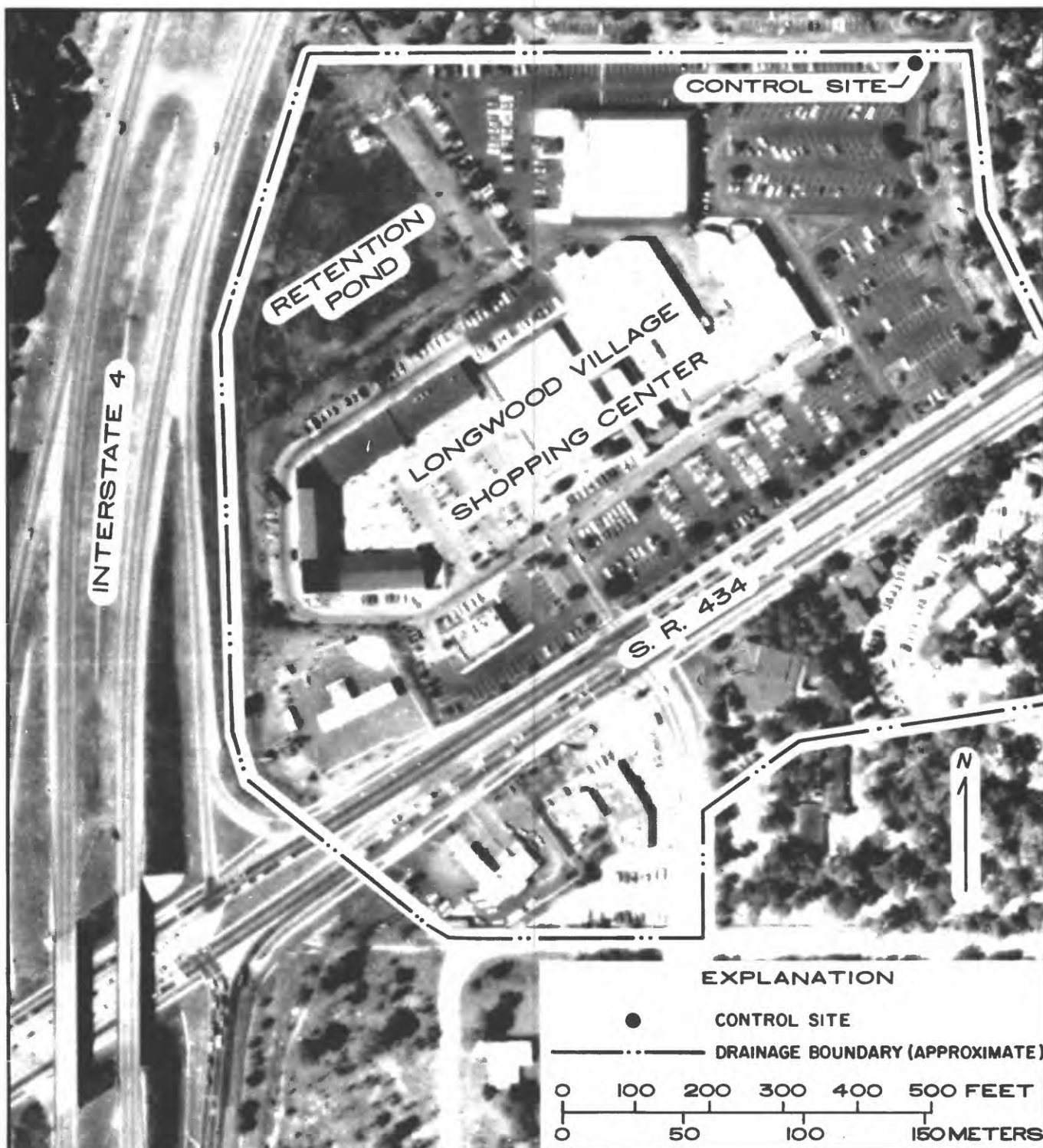
**YEAR OF PHOTOGRAPHY: 1985**

Figure 7.--Silver Star Road detention pond study area, looking north.

A retention pond near Longwood, Fla., in southwest Seminole County was selected for study. The pond is located at the northeast corner of the intersection of Interstate 4 and State Road (SR) 434, behind a shopping center (figs. 8 and 9). The pond is normally dry, but generally fills rapidly during rainstorms from three culverts, the largest of which is from SR 434. The pond drains quickly and often is dry between storms even during the wet summer months. There is no outlet for this pond, and it seems from topographic maps of the area that it may be the location of a relict sinkhole. The pond has a total drainage area of 57.9 acres and receives runoff from SR 434 (3.1 acres), the parking lot of the shopping center (7.4 acres), and a gas station (0.75 acre). The section of SR 434

that drains to this pond is heavily traveled with a traffic count in 1985 of 40,910 vehicles per day; the traffic count on Interstate 4 eastbound at SR 434 is lower--30,307 vehicles per day. During a large part of the day, the traffic on SR 434 is very slow moving or stopped at traffic lights, thus producing a "worst case" scenario for automobile-related constituents to be deposited on road surfaces. Because the pond is often dry, it was possible to install observation wells directly in the pond. The study area and sampling sites are shown in figure 10.

One of the two swale study areas is located along Interstate 4 just north of Orlando, at the Princeton Street westbound Interstate 4 acceleration ramp, and it receives runoff from 0.4 acre of highway (fig. 11). Runoff enters the swale



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Figure 8.--Aerial photograph of the Longwood retention pond study area.



**YEAR OF PHOTOGRAPHY: 1986**

Figure 9.—Longwood retention pond study area, looking north-northwest (top), and east (bottom).

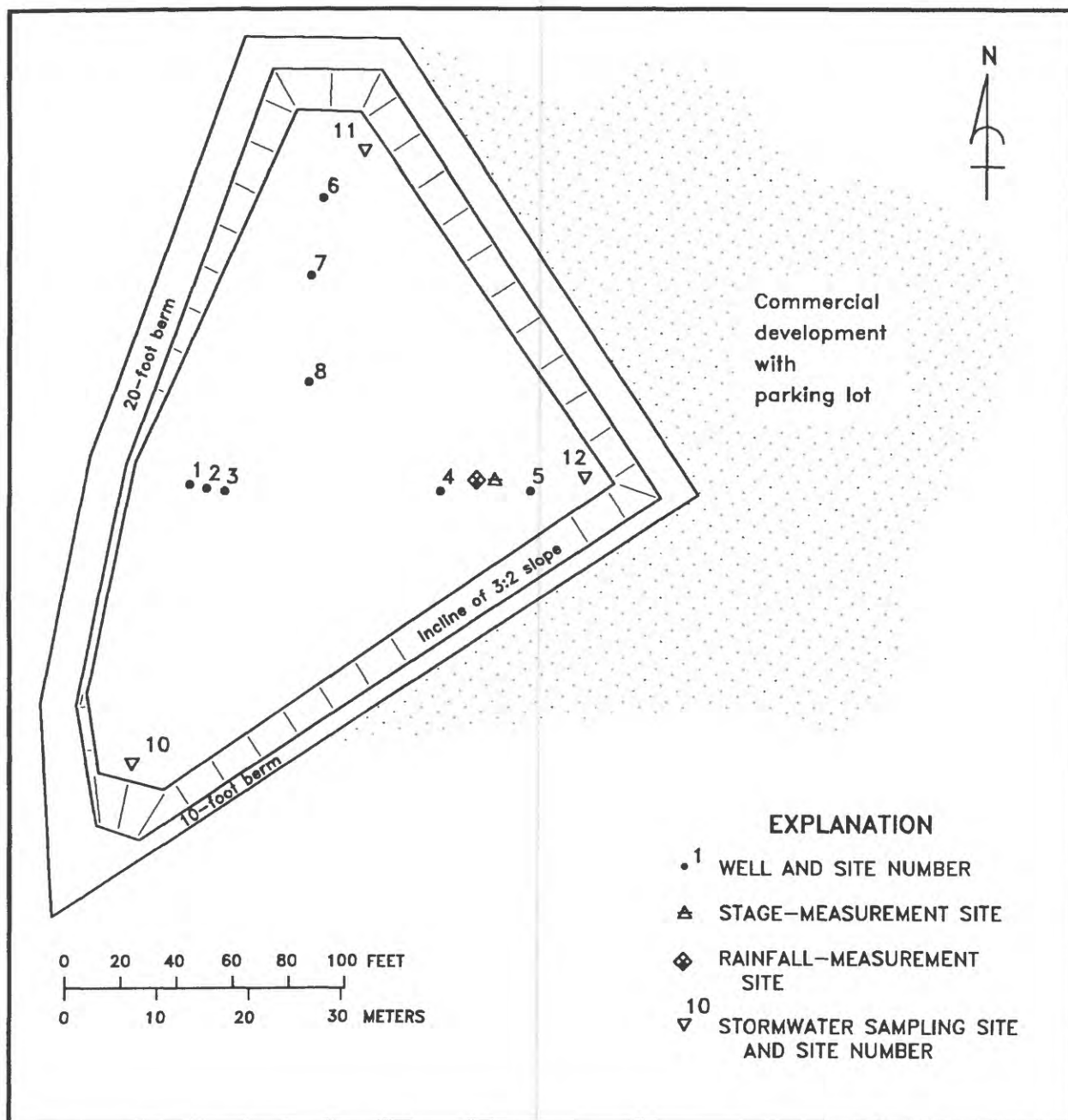
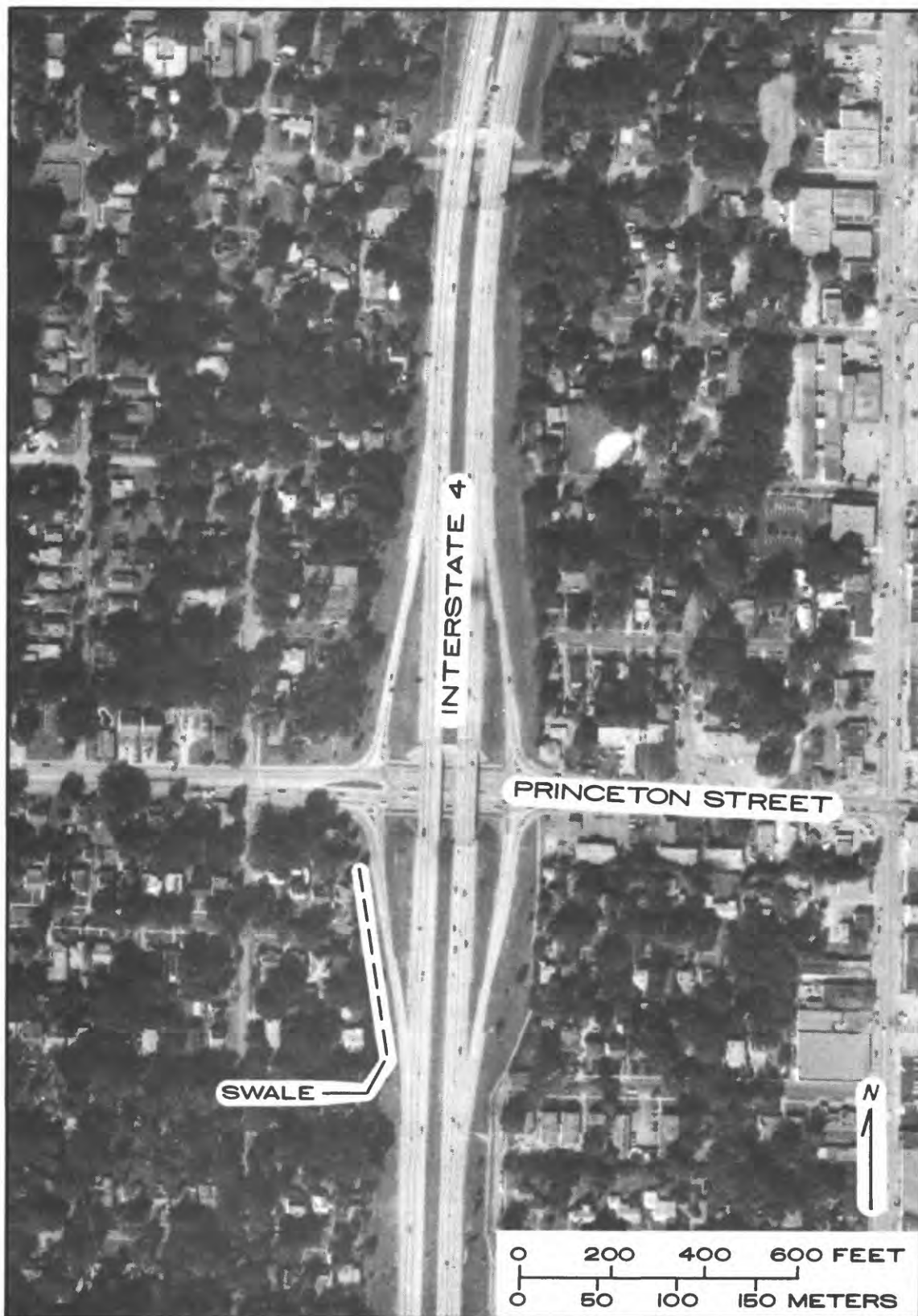


Figure 10.—Longwood retention pond and sampling sites.





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Figure 11.--Aerial photograph of the Princeton Street and Interstate 4  
swale study area.

through a 24-inch culvert at the north end of the swale. The section of highway which drains to the swale (westbound lanes) had a traffic count of 54,066 vehicles per day in 1983, which is in the top five segments of highest traffic count throughout downtown Orlando. In addition to the runoff from Interstate 4, a small amount of overland flow from the adjacent acceleration ramp, and from a small area of nearby residential brick streets also drain into the swale, but the largest

contribution of runoff comes from the highway. Observation wells were installed in the surficial aquifer system in March 1984, and were located longitudinally along approximately 200 feet of the swale in areas of highest infiltration (fig. 12). The configuration of the swale is shown in figure 13.

The second swale study area also was along the Interstate-4 corridor, but was in Seminole County, north of Longwood, Fla., approximately

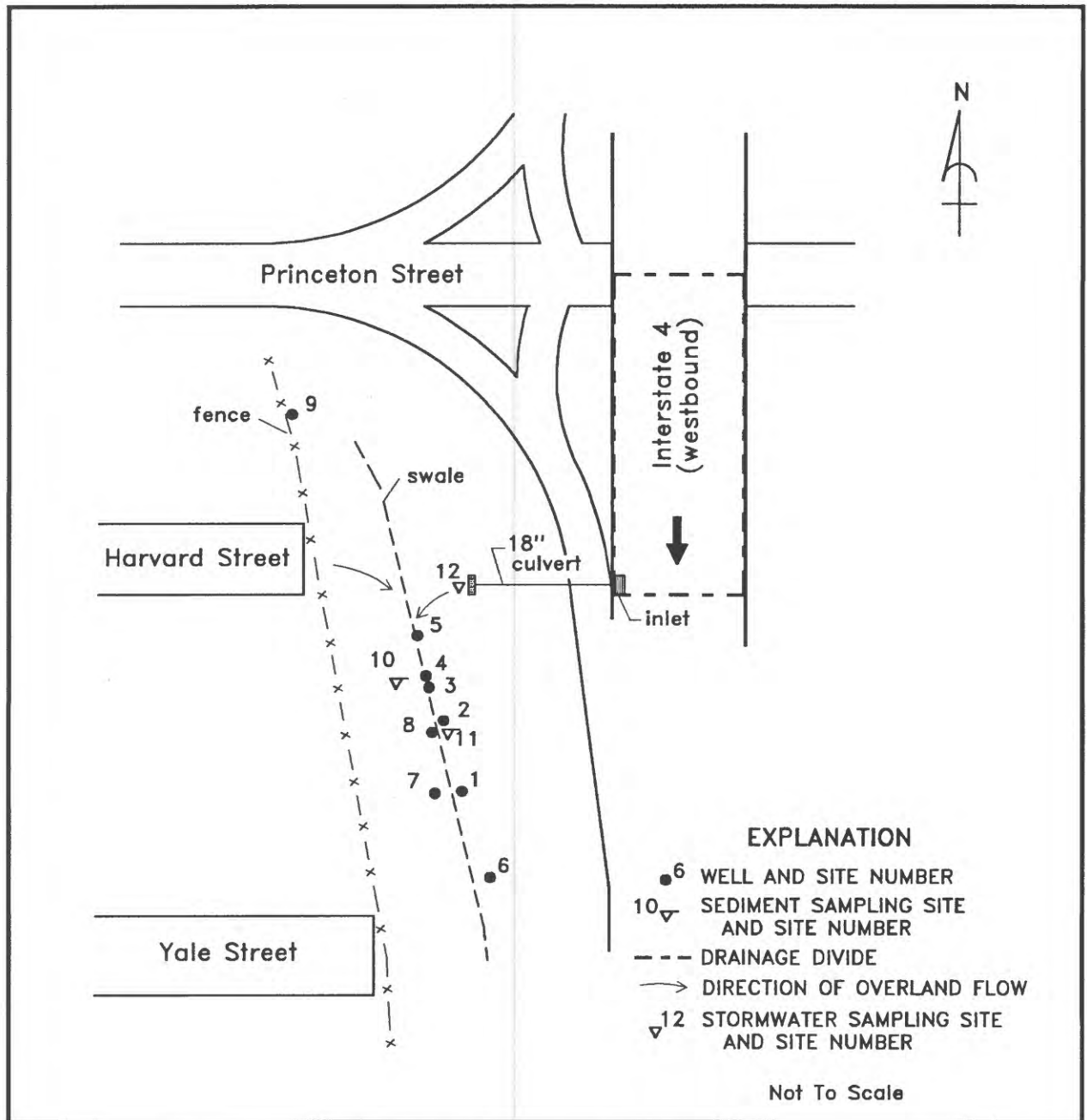


Figure 12.--Princeton Street and Interstate 4 swale and sampling sites.





**YEAR OF PHOTOGRAPHY: 1984**

Figure 13.—Princeton Street and Interstate 4 swale, looking south (top), and north (bottom).

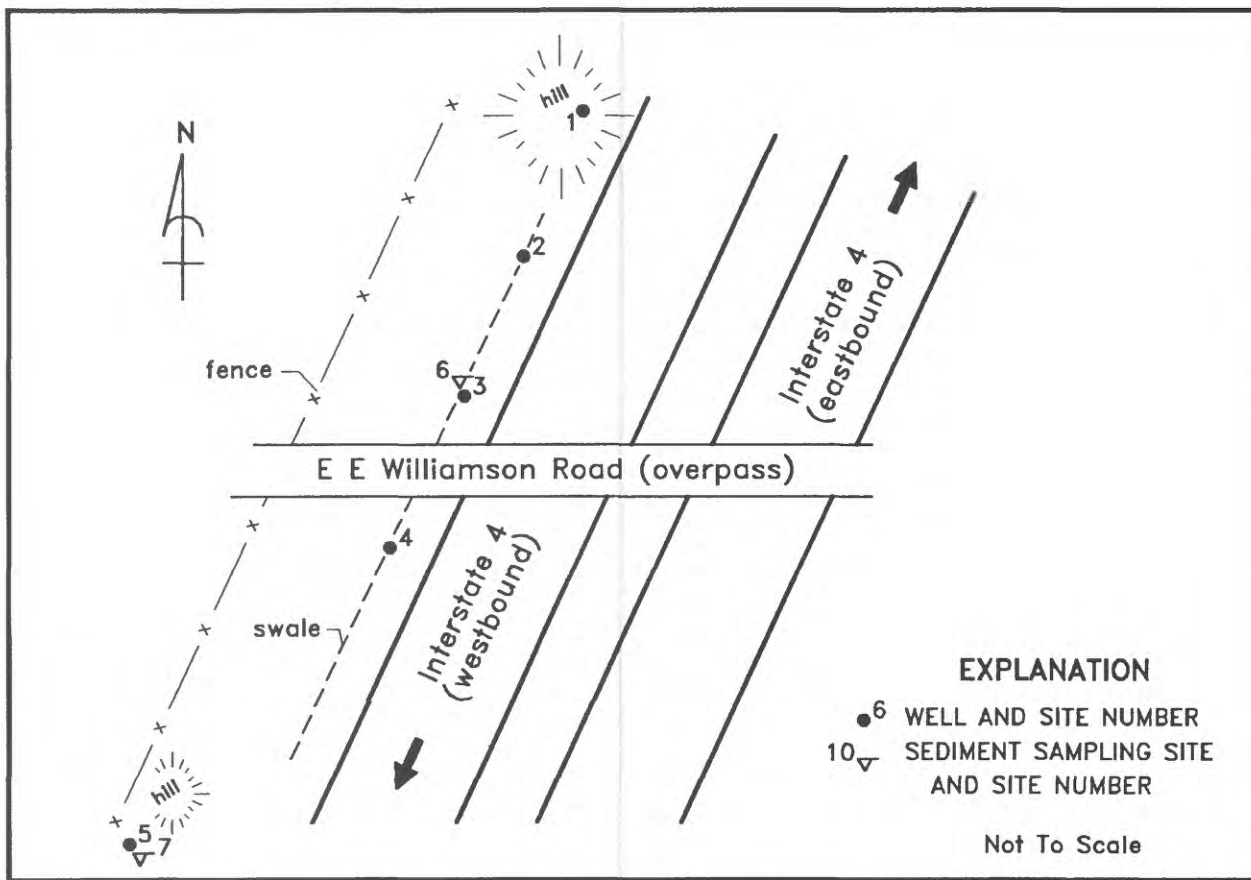


Figure 14.--Longwood and Interstate 4 swale and sampling sites.

midway between two Interstate exits (Longwood and Lake Mary). The average daily traffic was 23,800 vehicles per day in 1985. The drainage area to this swale is approximately 8.8 acres. Surface runoff enters the swale by overland flow from the shoulders of the highway. Approximately 2 acres of the drainage area are road surface and shoulder; the remainder is the grassed surface of the swale. To provide upgradient and downgradient sampling sites, observation wells in the surficial aquifer system were installed along the length of the swale (0.6 mile) in areas that were thought to differ in amounts of infiltrating water (fig. 14). A photograph of the swale is shown in figure 15.

## SAMPLING AND LABORATORY PROCEDURES

### General Sampling Methods

Several wells were installed at each study area to sample water quality and to determine the ground-water gradient. Wells were located upgradient and downgradient of each structure. Polyvinyl chloride casing and screen were used to construct the wells in augered boreholes.

At each study area, one control well was installed for sampling. The control well was located near the structure location, but far enough away to presumably be out of the zone of



**YEAR OF PHOTOGRAPHY: 1986**

Figure 15.--Longwood and Interstate 4 swale, looking north (top), and south (bottom), at the E. E. Williamson overpass.

influence of the structure. It was decided that a control well at each study area would better represent ambient ground-water quality than would a control well in a remote, pristine environment, totally removed from urban influences.

Sampling sites and types of samples collected (ground water, runoff, and sediment) are listed in table 1 for all study areas.

Ground-water samples were collected seasonally, usually one day after a rainstorm. Antecedent conditions varied for specific sampling times. Rainfall data were collected at two locations: the Longwood retention pond and a location near the exfiltration study area in downtown Orlando. Data from the downtown rainfall gaging site also were applicable to the nearby Princeton Street swale location.

Because of the scope of the study, it was not possible to do rigorous, intensive sampling at each site with time to study the effects on ground-water quality from individual rainfalls that generated runoff. In the monitoring of the surficial aquifer system, it cannot be determined with absolute certainty when a volume of water from a particular rainstorm reaches the saturated zone. Water entering the soil from a rainstorm will move downward toward the saturated zone, but soil storage requirements must be satisfied before the water can reach the saturated zone. A rise in the water table may be due to water previously held in soil storage in the unsaturated zone that has just recently been displaced by water infiltrating downward from the most recent storm. Thus, water travels down from the surface in a layered fashion, with recent storms pushing the older water from previous storms downward toward the saturated zone.

In general, the samples collected for this study do not represent any one storm, but probably reflect a general quality of ground water from infiltration of several storms. Because the movement of ground water in the unsaturated zone is, with few exceptions, vertical, water in the saturated zone should be a mixture of waters that have infiltrated from the surface, and not primarily water from off-site (upgradient).

Sediment samples were collected at all sites. At the Silver Star Road detention pond, bed sediment samples were collected with an Eckman dredge. At the Longwood retention pond, samples were collected during a dry period from

the pond bottom, and included only the top 1 inch of soil. The samples from the Longwood retention pond were analyzed for priority pollutants in addition to inorganic constituents and nutrients. Additionally, core samples were collected during the drilling of a 65-foot deep borehole in the middle of the Longwood pond to determine local geology. Sediment samples collected at the two swale study areas were from two depths—one from the upper 2 inches, and one from 4 to 6 inches below the land surface. Samples at each swale were collected at two sites that varied in distance from the highway. These samples were collected to verify, for these swales, what has been reported in other stormwater studies—that concentrations of constituents in soils decrease with depth and with distance from the road surface.

Data from the five study areas were compiled into a data base for analysis. Data analysis included three steps: (1) plot and observe the range and median values of selected constituents at each study area, (2) statistically analyze data by using analysis of variance techniques, and (3) compare measured water-quality data to State drinking water quality standards (Florida Department of Environmental Regulation, 1982).

### Analytical Methods

Ground-water samples for inorganic constituents were collected as follows:

1. Wells were pumped until specific conductance of the discharge water stabilized, and a minimum of two casing volumes was removed.
2. Water samples were processed at the time of collection using standard U.S. Geological Survey procedures (Fishman and Friedman, 1985). Samples for dissolved constituents 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 National Laboratories in Doraville, Ga., and in Arvada, Colo. Samples for nutrients were treated with mercuric chloride and shipped, packed in ice, to the laboratory in Ocala, Fla. The analytical procedures used by the laboratories are described in Wershaw and others (1983) and Fishman and Friedman (1985).

Ground-water samples were collected at four of the five study areas and analyzed for organic constituents using a Flame Ionization Detection (FID) scan. The FID scan is useful as a screening tool to detect the presence of organics (methylene-chloride extractable compounds only) in water samples, but it is not a quantitative technique. Collection of ground-water samples for FID scan analysis requires special handling and materials (glass bottle, Teflon<sup>1</sup> tubing, and stopper). Samples were shipped to the U.S. Geological Survey laboratory in Ocala, Fla., for analysis.

Sediment samples collected at all study areas were analyzed for inorganic constituent concentrations by U.S. Geological Survey laboratories in both Georgia and Colorado, but analysis of organic constituent concentrations in sediments was done only in the Colorado laboratory. Sediment distribution and clay mineralogy analysis of samples was done by the Geology Department of the University of South Florida. Some sediment distribution analysis was done by the author at the University of Central Florida for sediments from the exfiltration pipe study area.

#### Quality Assurance

Although the analytical laboratory of the U.S. Geological Survey maintains its own quality assurance program, several samples were included as part of this study as a test of the data collection. In March 1986, a blank (deionized water) sample was processed in the field in the same manner as ground-water samples. Results of this sampling are shown in table 2. The blank sample ideally should be very low in constituent concentrations. Values of pH varied significantly between laboratory and field measurements, however, the pH of deionized water is difficult to measure because of the limitations of the measurement probes in low ionic-strength water. Most constituent concentrations were at or below laboratory detection limits. Organic nitrogen was higher than expected, but this may be due to error introduced during digestion of the sample in a predominately nitrogen atmosphere.

<sup>1</sup>Use of trade names in this paper is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 2. — *Chemical analysis of a blank sample, March 26, 1986*

[Values in parentheses are reruns of the sample. Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter]

| Constituent or physical property                         | Concentration |
|--|---------------|
| Turbidity (NTU)  |               |
| pH (pH units):   | 0.40          |
| Laboratory   | 5             |
| Field  | 8.4           |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) |               |
| Laboratory   | 1             |
| Field  | 12            |
| Nitrogen, as N:  |               |
| Nitrate  | .01           |
| Ammonia plus organic,                                    | .62           |
| Nitrite plus nitrate                                     | .02           |
| Nitrite  | .01           |
| Ammonia  | .03           |
| Organic  | .59           |
| Orthophosphorus, as P                                    | .01           |
| Phosphorus, as P   | .02           |
| Carbon, total organic                                    | .10           |
| Calcium  | < 1           |
| Magnesium  | < 1           |
| Sodium   | < 1           |
| Potassium  | < .1          |
| Chloride   | < .2          |
| Sulfate  | .4            |
| Alkalinity, total  | < 3           |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | < 1           |
| Cobalt ( $\mu\text{g}/\text{L}$ )                        | 1 (< 1)       |
| Copper ( $\mu\text{g}/\text{L}$ )                        | < 1           |
| Iron ( $\mu\text{g}/\text{L}$ )                          | < 10          |
| Lead ( $\mu\text{g}/\text{L}$ )                          | < 1           |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | 6 (< 1)       |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 10 (< 10)     |

Two replicate samples also were collected during the study (table 3). The only discrepancy in these samples is in the Kjeldahl nitrogen (ammonia plus organic) concentrations; almost all of the difference can be attributed to the organic nitrogen fraction, and again may be due to sample digestion in a nitrogen atmosphere.

### BACKGROUND WATER QUALITY

The quality of ground water near a runoff detention structure will be influenced by the surrounding urban environment in addition to

the infiltrating street runoff. Ground-water quality in an urbanized area would be expected to differ from the quality of ground water in a natural environment, such as a forest. Comparing the water quality near a structure to a pristine environment control site would be of interest, but may not indicate what influence the structure (exfiltrating street runoff) alone is having on the subsurface environment, independent of other urban factors. Therefore, control wells were installed at all study areas but one (Silver Star Road). The purpose of the control well is to determine ambient water quality in the saturated

Table 3.—Results of replicate sampling

[Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter]

| Constituent or physical property                         | Longwood Pond<br>well 8<br>July 10, 1986 |          | Princeton Street swale<br>well 6<br>September 9, 1986 |          |
|--|--|----------|---|----------|
|  | Sample 1                                 | Sample 2 | Sample 1  | Sample 2 |
| Turbidity (NTU)  | 26                                       | 28       | 3   | 2.7      |
| Color (Pt-Co units)                                      | 5  | <5       | <5  | <5       |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | 74                                       | 74       | 138   | 138      |
| Field pH (pH units)                                      | 5.6                                      | 5.6      | 6   | 6        |
| Lab pH (pH units)  | 6  | 6        | 6.4   | 6.4      |
| Nitrogen species, as N:                                  |  |          |   |          |
| Ammonia  | .05                                      | .03      | .03   | .03      |
| Nitrite  | .01                                      | .06      | <.01  | <.01     |
| Ammonia plus organic                                     | .94                                      | .22      | <.20  | .22      |
| Nitrite plus nitrate                                     | .7                                       | .7       | .21   | .22      |
| Phosphorus, as P   | .01                                      | .01      | .08   | .09      |
| Orthophosphorus, as P                                    | .01                                      | .01      | .08   | .08      |
| Total organic carbon                                     | <.01                                     | <.01     | 1.3   | 1        |
| Calcium  | 7  | 7        | 13  | 13       |
| Magnesium  | 1.7                                      | 1.7      | 2.4   | 2.5      |
| Sodium   | 2.2                                      | 2.2      | 6.3   | 6.2      |
| Potassium  | .5                                       | .5       | 1.8   | 1.8      |
| Chloride   | 2.6                                      | 2.7      | 14  | 14       |
| Sulfate  | 7.2                                      | 7.1      | 24  | 23       |
| Alkalinity   | 18                                       | 18       | 15  | 15       |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | <1                                       | <1       | <1  | <1       |
| Copper ( $\mu\text{g}/\text{L}$ )                        | 1  | 1        | 2   | 6        |
| Iron ( $\mu\text{g}/\text{L}$ )                          | 240                                      | 240      | 640   | 640      |
| Lead ( $\mu\text{g}/\text{L}$ )                          | <5                                       | <5       | <5  | <5       |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | <1                                       | <1       | 2   | 5        |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 25                                       | 21       | 18  | 19       |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | <10                                      | 20       | <10   | <10      |



zone in the particular area of land use in which the structure is located, but located far enough away to be unaffected by the structure.

The importance of a control well located near the structure itself is illustrated by the Stiff diagrams (Hem, 1985) of ionic composition (fig. 16). In figure 16, the median values of major ions in ground water in 11 wells in the Ocala National Forest, located about 50 miles north of Orlando, were plotted at the same scale with the control sampling site at each structure location. The variability in composition between the Ocala

ground water and the control sites is apparent, as are the differences in ground water among control sites.

Comparison of other water-quality measurements at control sites to values in the Ocala National Forest surficial aquifer system ground water illustrates further the desirability of a control sampling site at each study location. Median concentrations of nutrients, ions, and metals, and values of selected physical measurements are listed in table 4 for ground water from control sites at four of the five study locations and

Table 4.--Median concentrations of nutrients, major ions, and minor elements for 13 wells in the surficial aquifer system in the Ocala National Forest, and the control sites at the Washington Street exfiltration study area, two swale study areas, and the Longwood retention pond study area

[Concentrations are dissolved, in milligrams per liter, unless otherwise noted. If number of samples = 1, then the median listed is the value for that sample. If number of samples = 2, then the median equals the mean. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter; -- denotes no sample or value]

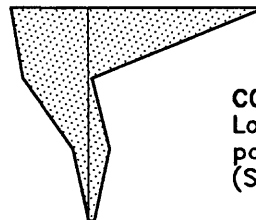
| Constituent or<br>Physical property                         | Ocala National<br>Forest |                  | Washington Street<br>exfiltration pipe |        | Longwood pond     |        | Longwood swale    |        | Princeton swale   |        |
|---|--------------------------|------------------|--|--------|-------------------|--------|-------------------|--------|-------------------|--------|
|   | No. of<br>samples        | Median           | No. of<br>samples                      | Median | No. of<br>samples | Median | No. of<br>samples | Median | No. of<br>samples | Median |
| Turbidity (NTU)   | --                       | --               | 3                                      | 2.65   | 2                 | 500    | 2                 | 454    | 2                 | 4.85   |
| Color (Pt-Co units)   | --                       | --               | 3                                      | <5     | 2                 | <5     | 2                 | <5     | 2                 | <5     |
| Specific conductance<br>( $\mu\text{S}/\text{cm}$ at 25 °C) | 11                       | 27               | 3                                      | 345    | 2                 | 258    | 2                 | 89     | 2                 | 155    |
| Field pH (pH units)   | 11                       | 4.7              | 3                                      | 6.5    | 2                 | 6.7    | 2                 | 5.6    | 2                 | 6.8    |
| Lab pH (pH units)   | 11                       | 5                | 3                                      | 6.7    | 2                 | 7.6    | 2                 | 6.7    | 2                 | 6.8    |
| Nitrogen species, as N:                                     |                          |                  |  |        |                   |        |                   |        |                   |        |
| Ammonia   | 11                       | <sup>1</sup> .01 | 3                                      | .02    | 2                 | .09    | 2                 | .05    | 2                 | .02    |
| Nitrite   | 11                       | <sup>1</sup> .01 | 3                                      | .01    | 2                 | .63    | 2                 | .01    | 2                 | .01    |
| Ammonia plus organic  | --                       | --               | 3                                      | .44    | 2                 | 1.17   | 2                 | .76    | 2                 | .16    |
| Nitrite plus nitrate  | 11                       | <sup>1</sup> .01 | 3                                      | .4     | 2                 | 1.9    | 2                 | .67    | 2                 | .09    |
| Phosphorus, as P  |                          |                  |  |        |                   |        |                   |        |                   |        |
| Orthophosphorus, as P                                       | 11                       | <sup>1</sup> .01 | 3                                      | .03    | 2                 | .51    | 2                 | .23    | 2                 | .02    |
| Total organic carbon  | --                       | --               | 3                                      | 2.7    | 2                 | 1.15   | 2                 | 1.3    | 2                 | 1.35   |
| Calcium   | 11                       | .4               | 3                                      | 50     | 2                 | 24.5   | 2                 | 6.6    | 2                 | 11     |
| Magnesium   | 11                       | .5               | 3                                      | 2.5    | 2                 | 12.5   | 2                 | 4.25   | 2                 | 2.65   |
| Sodium  | 11                       | 2.1              | 3                                      | 7.7    | 2                 | 5.85   | 2                 | 1.95   | 2                 | 8.25   |
| Potassium   | 11                       | .1               | 3                                      | 4.45   | 2                 | .9     | 2                 | .55    | 2                 | 2.3    |
| Chloride  | 11                       | .4               | 3                                      | 4.6    | 2                 | 11     | 2                 | 4.6    | 2                 | 14.5   |
| Sulfate   | 10                       | .62              | 3                                      | 46     | 2                 | 2.35   | 2                 | 7.1    | 2                 | 19.5   |
| Alkalinity  | 5                        | .82              | 3                                      | 76     | 2                 | 135    | 2                 | 27.5   | 2                 | 17.5   |
| Aluminum ( $\mu\text{g}/\text{L}$ )                         |                          |                  |  |        |                   |        |                   |        |                   |        |
| Aluminum ( $\mu\text{g}/\text{L}$ )                         | --                       | --               | 1                                      | <10    | 2                 | <10    | 2                 | 90     | 2                 | <10    |
| Chromium ( $\mu\text{g}/\text{L}$ )                         | 14                       | <sup>1</sup> <1  | 1                                      | <1     | 2                 | <1     | 2                 | <1.5   | 2                 | <1     |
| Copper ( $\mu\text{g}/\text{L}$ )                           | 14                       | <sup>1</sup> 2.5 | 3                                      | <10    | 2                 | 1.5    | 2                 | 2      | 2                 | 3.5    |
| Iron ( $\mu\text{g}/\text{L}$ )                             | 14                       | <sup>1</sup> 40  | 3                                      | 3      | 2                 | 10.5   | 2                 | 90     | 2                 | 1,140  |
| Lead ( $\mu\text{g}/\text{L}$ )                             | 13                       | <sup>1</sup> <1  | 3                                      | <10    | 2                 | <5     | 2                 | <5     | 2                 | <5     |
| Nickel ( $\mu\text{g}/\text{L}$ )                           | 11                       | <sup>1</sup> <1  | 1                                      | <1     | 2                 | <2.5   | 2                 | 3      | 2                 | 6      |
| Zinc ( $\mu\text{g}/\text{L}$ )                             | 14                       | <sup>1</sup> 10  | 3                                      | 15     | 2                 | <3.5   | 2                 | 24     | 2                 | 20.5   |

<sup>1</sup>Concentrations are for total, not dissolved, constituent.

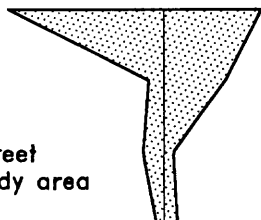
**SURFICIAL AQUIFER  
SYSTEM**  
Ocala National Forest  
11 wells



**CONTROL WELL**  
Longwood retention  
pond  
(Site 9)



**CONTROL WELL**  
Washington Street  
Exfiltration study area  
(Site 9)



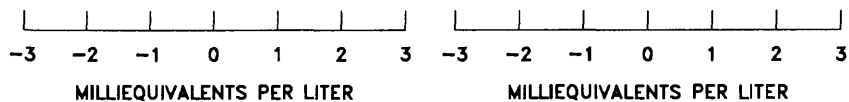
**WELL -  
65 FEET DEEP**  
Longwood retention  
pond  
(Site 8)



**CONTROL WELL**  
Princeton swale  
(Site 9)



**CONTROL WELL**  
Longwood swale  
(Site 5)



### EXPLANATION

|           |   |              |
|-----------|---|--------------|
| Calcium   | — | Bicarbonate  |
| Magnesium | — | Sulfate      |
| Sodium    | — | Chloride     |
| Potassium | — | Nitrate as N |

Figure 16.--Ionic composition of ground water at control sites and surficial aquifer wells in the Ocala National Forest. (Median values used.)



for Ocala National forest surficial aquifer system water. With few exceptions, the ground water at the control sites was dissimilar to the Ocala ground water, as was shown by figure 16. Additionally, the median values vary among control sites at the study areas listed, indicating local influences on ground-water quality.

## STORMWATER RUNOFF QUALITY

The main purpose of this study was to determine whether constituent concentrations were elevated in areas around highway-runoff detention structures. Earlier research has

identified constituents that are of concern, and has made available much information on the concentrations that might be expected in runoff from roads. Therefore, the collection of runoff samples was not a major effort of this study. However, several runoff samples were collected to compare to values cited in the literature.

Table 5 lists mean water-quality values from a report on highway runoff (Kobriger and others, 1981), median values and flow-weighted concentrations in runoff from one sampled storm at Washington Street, values obtained for one runoff sample from two study areas, and median values

Table 5.--Concentrations of nutrients and minor elements in stormwater runoff, values from available literature, Washington Street, Longwood retention pond, Princeton Street and Interstate 4 swale, and median values at Silver Star Road pond inlet

[Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter. -- denotes no value available]

| Constituent or physical measure                          | Nation-wide average value | Washington Street <sup>2</sup> , 09-27-84 | Longwood Pond, 07-22-86 | Princeton and Interstate 4 swale, 07-22-86 | Silver Star Road Pond inlet (Median) |
|--|---------------------------|---|-------------------------|--|--------------------------------------|
| Turbidity (NTU)  | --                        | 1.9/3.42                                  | 3.5                     | 1  | --                                   |
| Color (Pt-Co units)                                      | --                        | 40/68                                     | 50                      | 10   | 40                                   |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | --                        | 115/189                                   | 143                     | 115  | 145                                  |
| pH-field (standard units)                                | --                        | --  | 6.8                     | 6.8  | 7.2                                  |
| pH-lab (standard units)                                  | --                        | --  | 7.0                     | 6.7  | 7.2                                  |
| Nitrogen, as N:  |                           |   |                         |  |                                      |
| Ammonia, total   | --                        | .04/.04                                   | .47                     | .4   | .08                                  |
| Ammonia  | --                        | --  | .44                     | .38  | .06                                  |
| Nitrite, total   | --                        | .02/.06                                   | .06                     | .08  | .01                                  |
| Nitrite  | --                        | --  | .05                     | .08  | .01                                  |
| Ammonia plus organic, total                              | 2.9                       | 1.1/1.5                                   | 3.1                     | 1.1  | 1.1                                  |
| Ammonia plus organic                                     | --                        | --  | 2.1                     | .98  | .7                                   |
| Nitrite plus nitrate, total                              | --                        | .11/.31                                   | 1.6                     | 1.2  | .1                                   |
| Nitrite plus nitrate                                     | --                        | --  | 1.5                     | 1.2  | .1                                   |
| Phosphorus, total, as P                                  | --                        | .22/.25                                   | 1.2                     | .2   | .14                                  |
| Phosphorus, as P   | --                        | --  | .88                     | .16  | .05                                  |
| Orthophosphorus, total, as P                             | .8                        | .09/.13                                   | .58                     | .14  | .06                                  |
| Orthophosphorus, as P                                    | --                        | --  | .49                     | .11  | .02                                  |
| Total organic carbon                                     | 41                        | 13/44                                     | 55                      | 25   | 15                                   |
| Calcium  | --                        | --  | 18                      | 17   | 32                                   |
| Magnesium  | --                        | --  | .99                     | .44  | 1.45                                 |
| Sodium   | --                        | --  | 5.6                     | 1.8  | 3.2                                  |
| Potassium  | --                        | --  | 2.7                     | 1.4  | 1.6                                  |
| Chloride   | 386                       | --  | 4.9                     | 1.4  | 5.3                                  |
| Sulfate  | --                        | --  | 23                      | 19   | 7.8                                  |
| Alkalinity   | --                        | --  | 63                      | 26   | 92                                   |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | --                        | --  | 60                      | 70   | --                                   |
| Cadmium ( $\mu\text{g}/\text{L}$ )                       | 40                        | --  | 1                       | 1  | <1                                   |
| Chromium ( $\mu\text{g}/\text{L}$ ), total               | 40                        | --  | 12                      | 4  | 3                                    |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | --                        | --  | <1                      | <1   | <10                                  |
| Copper ( $\mu\text{g}/\text{L}$ ), total                 | 100                       | --  | 48                      | 23   | 10                                   |
| Copper ( $\mu\text{g}/\text{L}$ )                        | --                        | --  | 12                      | 8  | <10                                  |
| Iron ( $\mu\text{g}/\text{L}$ ), total                   | 10,300                    | --  | 2,100                   | 269  | --                                   |
| Iron ( $\mu\text{g}/\text{L}$ )                          | --                        | --  | 56                      | 28   | --                                   |
| Lead ( $\mu\text{g}/\text{L}$ ), total                   | 960                       | 200/160                                   | 150                     | 46   | 34                                   |
| Lead ( $\mu\text{g}/\text{L}$ )                          | --                        | --  | 6                       | 6  | 7                                    |
| Nickel ( $\mu\text{g}/\text{L}$ ), total                 | 20                        | --  | 10                      | 4  | --                                   |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | --                        | --  | 3                       | 3  | --                                   |
| Zinc ( $\mu\text{g}/\text{L}$ ), total                   | 410                       | 180/195                                   | 290                     | 209  | 60                                   |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | --                        | --  | 59                      | 150  | 20                                   |

<sup>1</sup>Kobriger and others (1981, table 33, p. 89).

<sup>2</sup>Median value and flow-weighted concentration of all samples collected during one storm.

of inlet concentrations at the Silver Star Road detention pond (from an earlier study of the pond). The mean values reported by Kobriger and others (1981) are computed from samples collected during a study from 1977 through 1978, from six highway sites. Three sites were located in Milwaukee, Wisc., and one site was located in each of the following cities: Harrisburg, Pa.; Denver, Colo.; and Nashville, Tenn.

In general, only small differences in water quality are evident among the runoff samples from the study locations listed in table 5. Comparison of average constituent concentrations in the report by Kobriger and others (1981) to those for local study areas indicates that local values are lower, particularly for chloride, iron, and lead. The chloride concentrations reported by Kobriger and others (1981) may be due to deicing of roads with salt in colder climates. Lead concentrations were as high as 910  $\mu\text{g/L}$  (micrograms per liter) at the inlet of the Silver Star Road detention pond site, which is still below the average (960  $\mu\text{g/L}$ ) reported by Kobriger and others (1981). The difference in lead concentrations may be a function of the number of vehicles that use leaded gasoline, which may have been much higher during the time of the national study than for the present study. Additionally, there are few industrial sources of lead in Orlando. Although the constituent concentrations for this study generally are lower than those reported by Kobriger and others (1981), they still represent a potential for contaminating ground water by increasing concentrations above natural conditions.

Five runoff samples were collected across a storm hydrograph for one storm (0.11-inch rainfall) at the Washington Street study area. A statistical summary of the storm runoff data collected at Washington Street and that collected at the inlet to the Silver Star Road detention pond during a 2-year period (1982 through 1984) by Martin and Smoot (1986) is presented in table 6 for comparison.

The drainage basins and associated land uses differ between the Washington Street and Silver Star Road study areas, which may partly explain the higher values at the Washington Street location for selected water-quality measurements. Maximum color and total organic carbon, and median lead and zinc were higher in runoff samples at Washington Street. These results are of interest because the Washington Street data

represent only one storm and one antecedent condition, whereas the Silver Star Road summary represents 12 storms varying in rainfall volume, intensity, and antecedent condition.

## **EFFECTS OF HIGHWAY-RUNOFF DETENTION METHODS ON GROUND WATER**

### **Exfiltration System**

Water from sites at the Washington Street exfiltration study area was sampled during 1984–85. The sites represent street runoff, water standing in the pipe after several storms, and water in the unsaturated and saturated zones. Vacuum lysimeters made of Teflon material were used for sampling water in the unsaturated zone. Teflon material was used because of its relative inertness. A study by Zimmerman and others (1978) showed that Teflon lysimeters consistently recovered 98 to 106 percent of the test standards used for all nutrients. Teflon lysimeters may be left in the sediment for long periods of time without clogging and do not alter nutrient concentrations as do some ceramic cup lysimeters (Hansen and Harris, 1975). Lysimeters were located adjacent to the exfiltration pipe at varying depths corresponding to points of interest relative to the pipe (fig. 17). The objective was to examine changes in quality of water with depth.

One of the primary difficulties in sampling water in the unsaturated zone is the uncertainty of when water collected in the lysimeter actually passed by the lysimeter, because of the many variables involved. Some of these variables include the percentage of saturation of the soil, which has an effect on the rate of movement of water, and the silica flour used as a packing around the lysimeter's porous section. Silica flour is used to maintain hydraulic conductivity between the lysimeter and the surrounding soil, so that a sample may be uniformly drawn into the lysimeter. However, because of its fine grain size, the silica-packing functions like a sponge, and holds water. For this reason, it is necessary to evacuate as much water as possible from the silica and the lysimeter before actual samples of recently exfiltrated pipe water are collected. Thus, if it is desired to collect a sample of water after exfiltrating from the pipe, water in the lysimeter must be evacuated and discarded just before the exfiltrated water moves past the

Table 6. — *Statistical summary of stormwater data at Washington Street and Silver Star Road study areas*

[Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter; -- denotes no sample or value]

| Constituent or physical measure                             | Washington Street storm<br>09-27-84 (5 samples) |        |         | No. of samples | Silver Star Road pond inlet<br>08-20-82 through 06-13-84 |        |         |
|---|---|--------|---------|----------------|--|--------|---------|
|   | Maximum   | Median | Minimum |                | Maximum  | Median | Minimum |
| Turbidity (NTU)   | 6.8   | 1.9    | 1.5     | --             | --   | --     | --      |
| Color (Pt-Co units)   | 160   | 40     | 20      | 7              | 80   | 40     | 10      |
| Specific conductance<br>( $\mu\text{S}/\text{cm}$ at 25 °C) | 370   | 115    | 74      | 61             | 302  | 145    | 35      |
| Solids, total   | 648   | 148    | 72      | --             | --   | --     | --      |
| Solids, dissolved   | 384   | 99     | 57      | --             | --   | --     | --      |
| Nitrogen, total, as N:                                      |   |        |         |                |  |        |         |
| Ammonia   | .08   | .04    | .02     | 44             | .56  | .08    | .01     |
| Nitrite   | .16   | .02    | .01     | 44             | .05  | .01    | < .01   |
| Ammonia plus organic  | 3.4   | 1.1    | .53     | 45             | 3.2  | 1.1    | .4      |
| Nitrite plus nitrate  | .63   | .11    | .09     | 44             | .6   | .10    | < .01   |
| Phosphorus, total, as P                                     | .34   | .22    | .14     | 44             | .52  | .14    | .02     |
| Orthophosphorus,<br>total, as P                             | .30   | .09    | .06     | 44             | .33  | .06    | .01     |
| Carbon,   |   |        |         |                |  |        |         |
| total organic   | 120   | 13     | 7       | 46             | 28   | 15     | 1.8     |
| total inorganic   | 20  | 16     | 10      | --             | --   | --     | --      |
| Lead, total ( $\mu\text{g}/\text{L}$ )                      | 300   | 200    | 33      | 48             | 910  | 34     | 7       |
| Zinc, total ( $\mu\text{g}/\text{L}$ )                      | 350   | 180    | 70      | 50             | 530  | 60     | 10      |

lysimeters, and this evacuated water should be discarded. For this study, when a rainstorm was anticipated, each lysimeter was evacuated prior to the storm. Frequently three or more samples were collected from each lysimeter in succession, representing water percolating through the unsaturated zone for 12 to 18 hours during and after a storm.

#### Water-Quality Variations

To determine the variability in water quality, ranges and median values of selected constituents and specific conductance at individual sampling sites were computed (table 7) and plotted. Summary statistics in table 7 are listed in the order of progression through the system, beginning with the pipe (site 4) and ending in the saturated zone (sites 1, 2, and 3). Water-quality values for stormwater entering the pipe were listed in table 5 and for the control well, in table 4. In general, water-quality values vary more and

are higher in the unsaturated zone than in the saturated zone. Examples include specific conductance, nitrate plus nitrite nitrogen, calcium, alkalinity, and zinc. Plots of the data illustrate this more clearly.

Specific conductance varied considerably in water from the unsaturated zone (fig. 18), particularly in the most shallow lysimeter (3-foot). During most storms, the exfiltration pipe would not fill to capacity, and was frequently less than half-full, because of the rapid exfiltration from the pipe and the relatively large storage volume of the pipe relative to the volume of storm runoff. It is possible that exfiltrated stormwater frequently did not pass by the first lysimeter at the 3-foot depth, adjacent to the pipe center line. Thus, the water being drawn into the lysimeter for a sample may have resided, tightly bound in the soil matrix in the unsaturated zone from earlier storms. It may be that major ions in this water held in the soil becomes more concentrated because of evaporation losses.

The range and median specific conductance of water decreased with depth in the unsaturated zone. The 5-foot lysimeter, located adjacent to the pipe bottom, may not have been in the receiving zone of pipe exfiltrate as frequently as the 8-foot lysimeter, located 2 feet below the bottom of the trench (fig. 3). This may explain the greater variability in specific conductance at this location than at the 8-foot depth.

Other constituents that varied with sampling location at the exfiltration pipe study area are shown in figures 19 and 20. Most of the phosphorus (fig. 19) was in the orthophosphorus form. With the exception of well site 8 (2 feet west of the pipe), all values were equal to or less than 0.2 mg/L (milligrams per liter). Dissolved phosphorus was consistently highest at well site 8. Schiner and German (1983) reported total phosphorus in supply wells in the Orlando area

ranged from 0.01 to 0.30 mg/L, with a median value of 0.07 mg/L. There are no drinking water standards for phosphorus, but Hem (1985) reports that concentrations present in natural water generally are less than a few milligrams per liter.

Most of the nitrogen at all sampling sites was in the form of nitrate nitrogen, but organic nitrogen was the dominant species in the pipe water. Nitrate plus nitrite nitrogen were plotted (fig. 19) to show the variability in the 3-foot and 5-foot lysimeters, and the surprisingly high values in the control well (three samples). If the high values in the control well are representative of a background ground-water quality, the data from this study would seem to indicate that the stormwater is diluting nitrate in the ground water around the pipe.

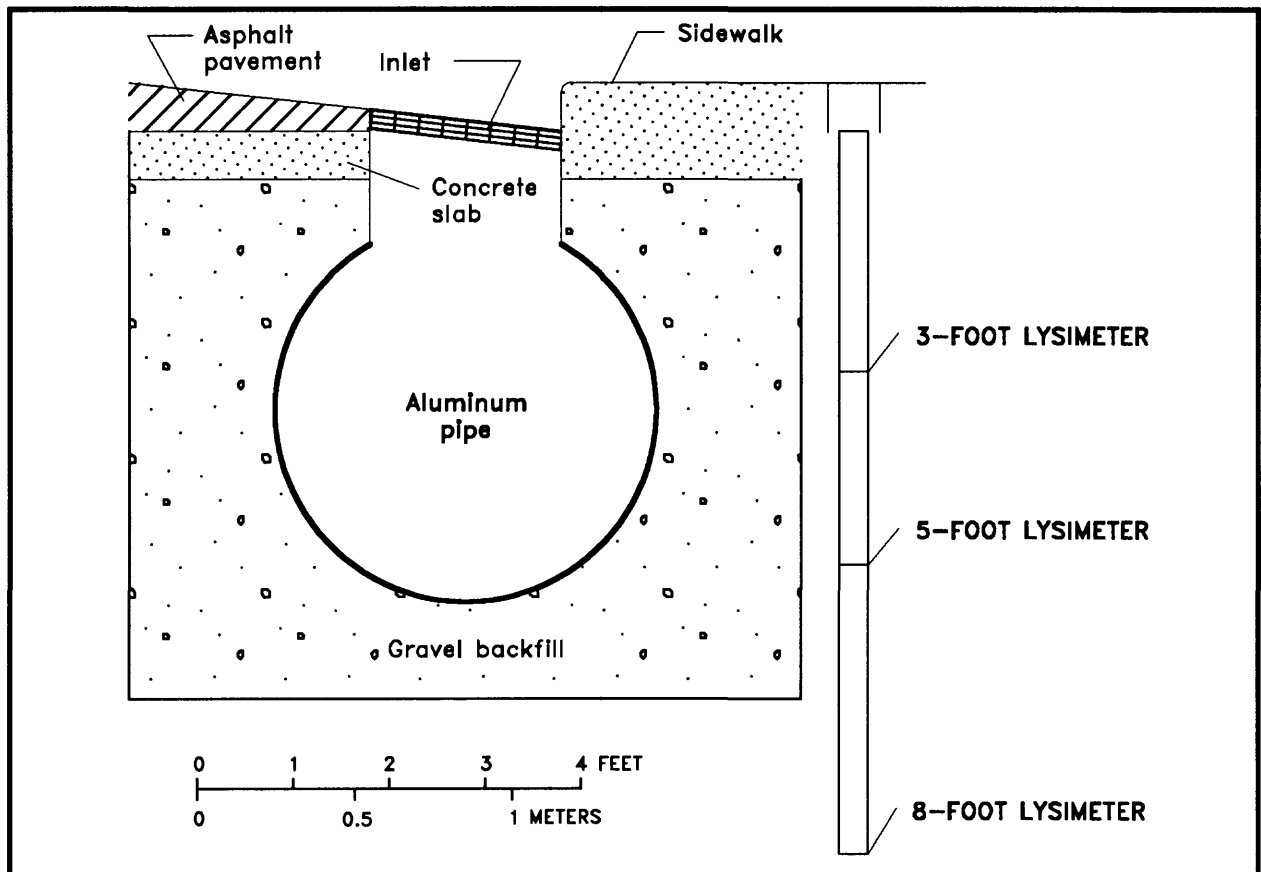


Figure 17.—Cross-sectional view of Washington Street exfiltration pipe showing relative locations of lysimeters.

Table 7.--Statistical summary of water-quality data for Washington Street sampling sites

[Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter; -- denotes no sample or value.]

| Constituent or physical measure                          | Site 4 (exfiltration pipe) |            |        | Site 5 (lysimeter 3 feet deep) |            |        | Site 6 (lysimeter 5 feet deep) |            |        | Site 7 (lysimeter 8 feet deep) |            |        |
|--|----------------------------|------------|--------|--------------------------------|------------|--------|--------------------------------|------------|--------|--------------------------------|------------|--------|
|  | Number of samples          | Range      | Median | Number of samples              | Range      | Median | Number of samples              | Range      | Median | Number of samples              | Range      | Median |
| Turbidity (NTU)  | 6                          | 0.50 - 11  | 3.6    | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Color (Pt-Co units)                                      | 6                          | 5 - 85     | 22.5   | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | 6                          | 72 - 164   | 108    | 30                             | 145 - 675  | 490    | 31                             | 126 - 500  | 320    | 24                             | 136 - 380  | 245    |
| Field pH (pH units)                                      | 1                          | 7.1 - 7.7  | 7.5    | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Lab pH (pH units)  | 5                          | 7.1 - 7.7  | 7.5    | 2                              | 7.9 - 8.1  | --     | 2                              | 7.8 - 7.9  | --     | 2                              | 7.6        | --     |
| Nitrogen species, as N                                   |                            |            |        |                                |            |        |                                |            |        |                                |            |        |
| Ammonia  | 5                          | .04 - .12  | .07    | 4                              | <.01 - .02 | <.01   | 9                              | <.01 - .03 | <.01   | 9                              | <.01 - .04 | <.01   |
| Nitrite  | 5                          | <.01 - .09 | .01    | 4                              | <.01 - .05 | <.01   | 9                              | <.01 - .04 | <.01   | 9                              | <.01 - .05 | <.01   |
| Ammonia plus organic                                     | 5                          | .19 - 1.6  | .41    | 4                              | .20 - 4.5  | 4.1    | 9                              | .1 - 1.7   | .5     | 9                              | .3 - 3.3   | .3     |
| Nitrite plus nitrate                                     | 5                          | .25 - .82  | .44    | 4                              | .84 - 9.4  | 4.15   | 9                              | .64 - 10   | 6.7    | 9                              | .50 - 1.7  | .83    |
| Phosphorus, as P   | 5                          | .05 - .18  | .06    | 2                              | .17 - .21  | --     | 2                              | .13 - .21  | --     | 3                              | .19 - .20  | .20    |
| Orthophosphorus, as P                                    | 5                          | .02 - .16  | .05    | 4                              | .16 - .23  | .19    | 9                              | .14 - .19  | .16    | 9                              | .17 - .21  | .19    |
| Total organic carbon                                     | 5                          | 7 - 43     | 18     | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Calcium  | 5                          | 10 - 19    | 13     | 14                             | 50 - 79    | 71     | 14                             | 44 - 76    | 70.5   | 15                             | 26 - 59    | 51     |
| Magnesium  | 5                          | .19 - .94  | .29    | 14                             | 1.1 - 1.7  | 1.6    | 14                             | .89 - 1.8  | 1.6    | 15                             | .59 - 1.7  | 1.1    |
| Sodium   | 5                          | 1.1 - 9.2  | 5.1    | 1                              | 9.1 - 18   | 16     | 1                              | 2.7 - 5.9  | 4.6    | 1                              | 1.8 - 11   | 7.5    |
| Potassium  | 5                          | 2.4 - 14   | 8.7    | 1                              | 22         | --     | 1                              | 5.6        | --     | 1                              | 4.8        | --     |
| Chloride   | 5                          | 5 - 8.3    | 2.3    | 1                              | 3.2        | --     | 1                              | 2.6        | --     | 1                              | 4.2        | --     |
| Sulfate  | 5                          | 5.6 - 15   | 9.9    | 1                              | 40         | --     | 1                              | 18         | --     | 1                              | 8.1        | --     |
| Alkalinity   | 5                          | 21 - 83    | 48     | 1                              | 187        | --     | 1                              | 129        | --     | 1                              | 74         | --     |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | 2                          | 120 - 170  | --     | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | 2                          | <1 - <10   | --     | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Copper ( $\mu\text{g}/\text{L}$ )                        | 4                          | 4 - 20     | <10    | 16                             | 6 - 80     | <10    | 16                             | 7 - 26     | <10    | 17                             | 9 - 90     | <10    |
| Iron ( $\mu\text{g}/\text{L}$ )                          | 5                          | 14 - 72    | 21     | 13                             | 4 - 71     | 10     | 13                             | <3 - 18    | 6      | 14                             | 3 - 21     | 12     |
| Lead ( $\mu\text{g}/\text{L}$ )                          | 5                          | <1 - <10   | <10    | 18                             | 1 - 30     | <10    | 17                             | 1 - 20     | <10    | 17                             | 2 - 20     | <10    |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | 2                          | 3 - 4      | --     | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 5                          | 13 - 30    | 27     | 18                             | 8 - 94     | 30     | 17                             | 30 - 100   | 42     | 17                             | 30 - 80    | 50     |

| Constituent or physical measure                          | Site 1 (well 10 feet east) |             |        | Site 2 (well 2 feet east) |             |        | Site 8 (well 2 feet west) |             |        |
|--|----------------------------|-------------|--------|---------------------------|-------------|--------|---------------------------|-------------|--------|
|  | No. of samples             | Range       | Median | No. of samples            | Range       | Median | No. of samples            | Range       | Median |
| Turbidity (NTU)  | 6                          | 0.60 - 9.4  | 2.4    | 6                         | 0.5 - 13    | 2.5    | 5                         | 0.8 - 48    | 2.8    |
| Color (Pt-Co units)                                      | 6                          | <5 - 5      | <5     | 6                         | <5 - 5      | <5     | 5                         | <5 - 5      | <5     |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | 7                          | 185 - 250   | 210    | 7                         | 195 - 200   | 270    | 7                         | 168 - 224   | 172    |
| Field pH (pH units)                                      | 2                          | 6.8 - 7.1   | --     | 2                         | 6.9 - 7.2   | --     | 2                         | 6.2 - 7.1   | --     |
| Lab pH (pH units)  | 7                          | 6.9 - 7.3   | 6.9    | 7                         | 6.9 - 7.4   | 7      | 7                         | 6.1 - 6.9   | 6.2    |
| Nitrogen species, as N                                   |                            |             |        |                           |             |        |                           |             |        |
| Ammonia  | 7                          | .02 - .03   | .02    | 7                         | .02 - .04   | .02    | 6                         | .01 - .03   | .02    |
| Nitrite  | 7                          | <.01 - <.01 | <.01   | 7                         | <.01 - <.01 | <.01   | 6                         | <.01 - <.01 | <.01   |
| Ammonia plus organic                                     | 7                          | .06 - .25   | .14    | 7                         | .05 - .42   | .17    | 6                         | .08 - .38   | .19    |
| Nitrite plus nitrate                                     | 7                          | .20 - .72   | .40    | 7                         | .12 - 1.2   | .40    | 6                         | 1 - 1.3     | 1.2    |
| Phosphorus, as P   | 7                          | .12 - .18   | .15    | 7                         | .28 - .49   | .32    | 6                         | .04 - .09   | .06    |
| Orthophosphorus, as P                                    | 7                          | .09 - .15   | .14    | 7                         | .28 - .47   | .31    | 6                         | .04 - .06   | .05    |
| Total organic carbon                                     | 6                          | 3 - 5       | 3.2    | 6                         | 3 - 5.5     | 3.8    | 5                         | 1.5 - 8     | 2.1    |
| Calcium  | 7                          | 28 - 38     | 33     | 7                         | 30 - 49     | 39     | 7                         | 18 - 33     | 21     |
| Magnesium  | 7                          | .54 - .96   | .73    | 7                         | .84 - 2     | 1.2    | 7                         | 1.2 - 1.8   | 1.7    |
| Sodium   | 7                          | 2.6 - 8     | 5.1    | 7                         | 2.5 - 10    | 7      | 7                         | 3.3 - 11    | 10     |
| Potassium  | 6                          | 5.1 - 7.6   | 5.8    | 6                         | 3.1 - 6.8   | 5.6    | 6                         | 2.3 - 10    | 3.2    |
| Chloride   | 6                          | .7 - 20     | 9.2    | 6                         | .9 - 17     | 10     | 6                         | 1.1 - 12    | 5      |
| Sulfate  | 6                          | 13 - 17     | 13.5   | 6                         | 12 - 16     | 13     | 6                         | 31 - 40     | 31.5   |
| Alkalinity   | 6                          | 64 - 84     | 74     | 6                         | 58 - 109    | 94.5   | 6                         | 26 - 59     | 37     |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | 2                          | <10 - 20    | --     | 2                         | 40 - 80     | --     | 2                         | <10 - 40    | --     |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | 2                          | <1 - <10    | --     | 2                         | <1 - 10     | --     | 2                         | <1 - 10     | --     |
| Copper ( $\mu\text{g}/\text{L}$ )                        | 6                          | 1 - <10     | <10    | 6                         | 2 - 10      | 4      | 6                         | <1 - <10    | <10    |
| Iron ( $\mu\text{g}/\text{L}$ )                          | 7                          | <3 - 7      | <3     | 7                         | <3 - 8      | 4      | 7                         | <3 - 21     | 3      |
| Lead ( $\mu\text{g}/\text{L}$ )                          | 7                          | <1 - <10    | <10    | 7                         | <1 - 10     | <10    | 7                         | <1 - <10    | <10    |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | 2                          | <1 - 1      | --     | 2                         | 2 - 3       | --     | 2                         | <1 - 1      | --     |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 7                          | <3 - 69     | 18     | 7                         | 5 - 35      | 22     | 7                         | 5 - 58      | 16     |

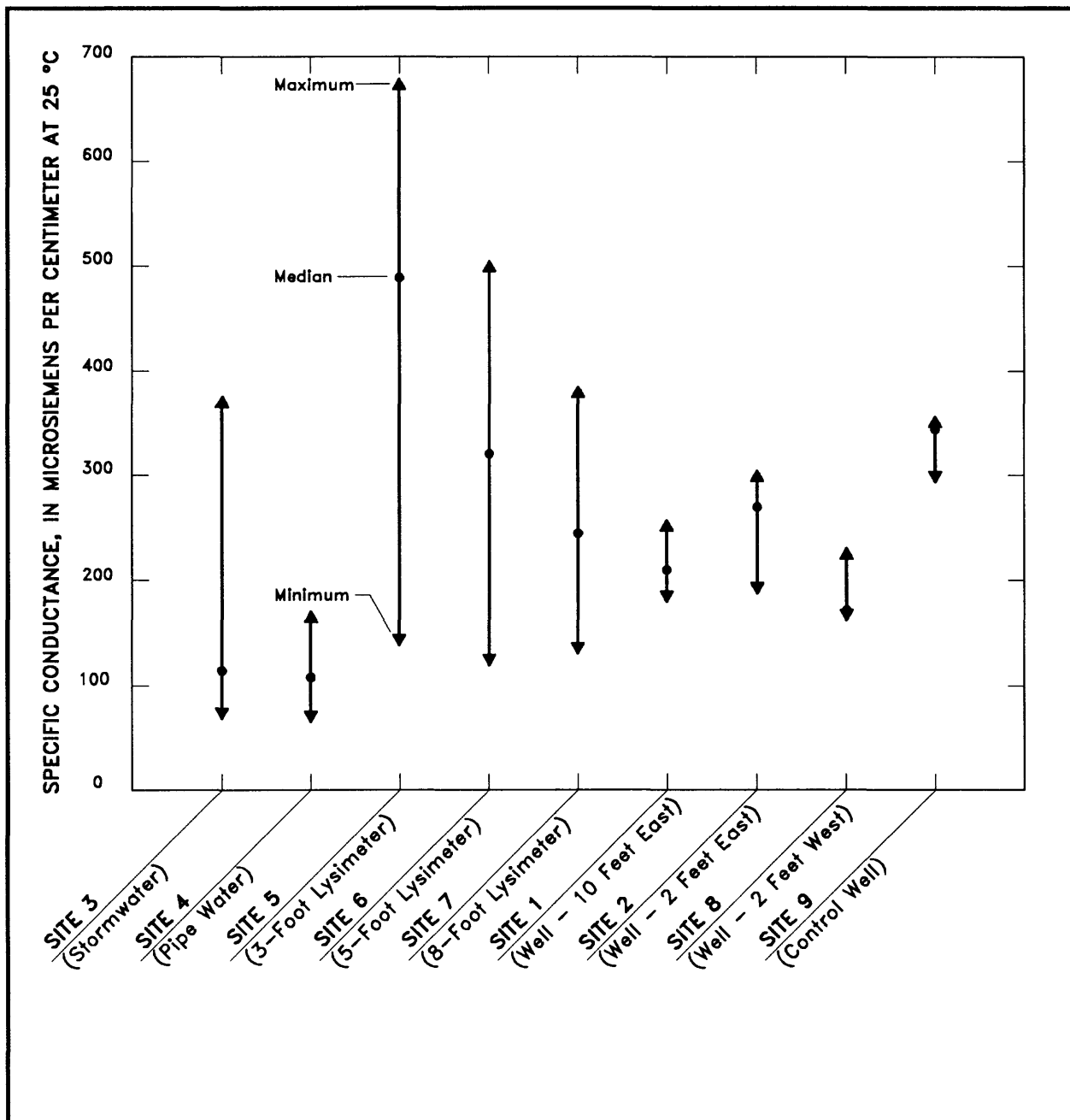


Figure 18.--Specific conductance at sampling sites at the Washington Street exfiltration study area.

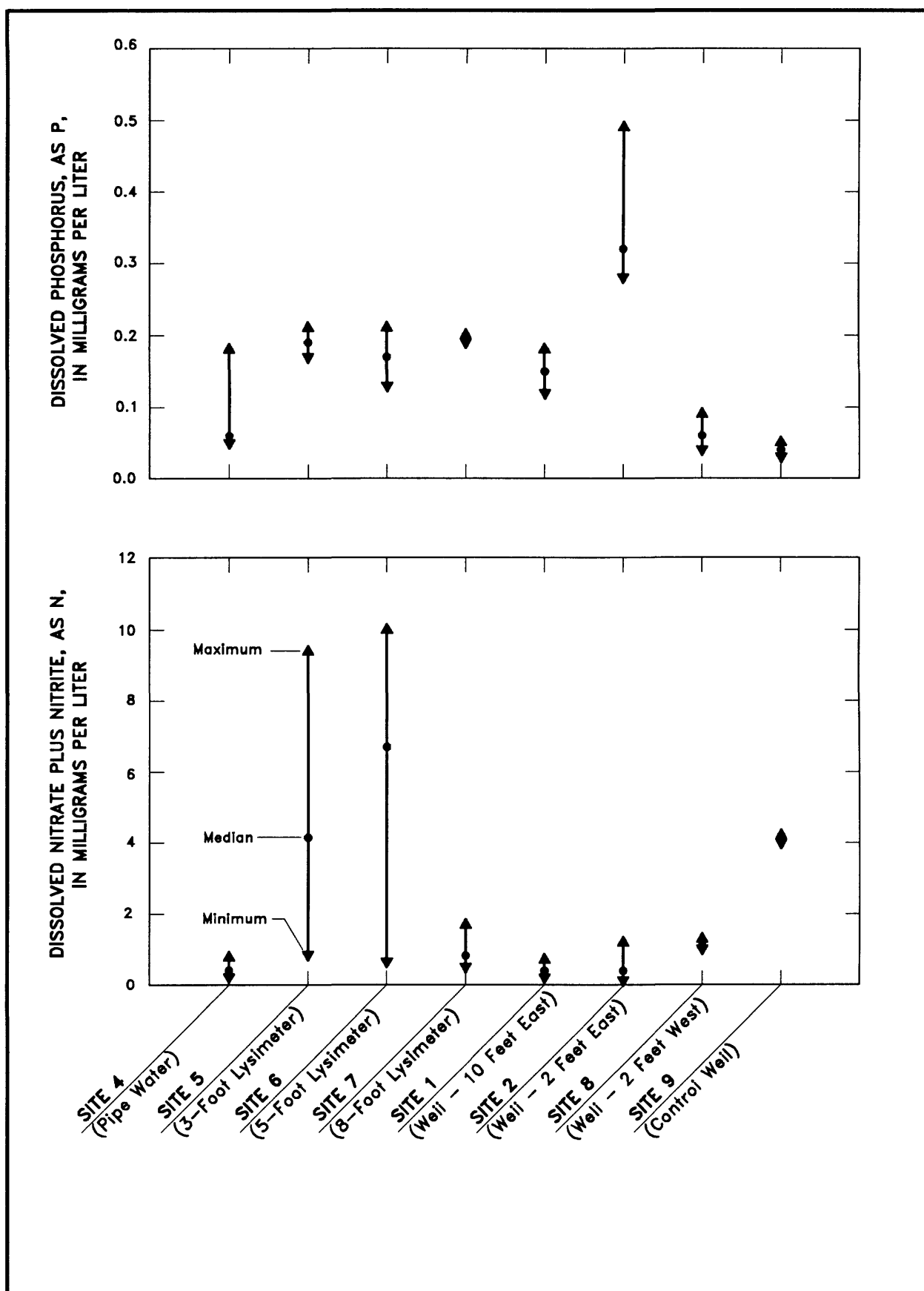


Figure 19.--Dissolved nitrate plus nitrite nitrogen and dissolved phosphorus at sampling sites at the Washington Street exfiltration study area.

Concentrations of dissolved copper at the sampling sites in the exfiltration study area are shown in figure 20. Dissolved copper in most samples was below detection limits (1 or 10  $\mu\text{g/L}$ ). The maximum values shown for the 3-foot and 8-foot lysimeters occurred in August 1985. Dissolved zinc (fig. 20) fluctuated through a wide range in all ground-water samples, with the exception of the control site. Median values for dissolved zinc, however, were highest in the unsaturated zone. Median values in ground water in the vicinity of the pipe and downgradient of the pipe were not appreciably higher than in the control well, and were lower than in the pipe water.

Stiff diagrams (Hem, 1985, p. 175) and Piper diagrams (Hem, 1985, p. 178) were compiled for sampling sites at the Washington Street study area (figs. 21 and 22). These diagrams are useful for analysis of major ionic composition of the sampled waters, and can indicate basic differences in water quality that may be a result of the influence of street runoff. Median values of ions were used for the plots except for the lysimeters, which were sampled only once for major ions. The most obvious difference in ionic composition indicated by figure 21 is the magnitude of the calcium and bicarbonate in water from the unsaturated zone (sites 5 and 6) compared to water in the saturated zone (sites 1, 2, and 8). Calcium and bicarbonate seem to increase after initially exfiltrating from the pipe into the soil (note the magnitude of these ions in the pipe water), but decrease with vertical movement through the subsurface system. Site 7 is the exception to this general observation, as it resembles saturated zone samples in ionic composition. One possible reason for the difference between the upper unsaturated zone and the saturated zone may be the material used as backfill around the pipe, which may have concrete rubble (high in calcium bicarbonate) or other nonnative materials. Runoff from road surfaces generally is alkaline from contact with pavement materials. Much of the calcium and bicarbonate in waters at this study location probably originated from leaching of lime materials in concrete used for the sidewalk and curbs. Soils 12 feet below land surface (depth at which well screens were placed) may be relatively undisturbed compared to the area directly around the pipe (where lysimeters were placed).

The ionic composition of water at different locations around the pipe also can be compared graphically using a Piper diagram (fig. 22). This figure indicates that water at the different sampling sites basically is similar, with the exception of sites 7 and 9 (control well and 8-foot lysimeter), which have a greater percentage of sulfate than the other sites.

### Statistical Comparisons

Statistical procedures were used to further evaluate the effects of infiltration of street runoff on the receiving ground water. The objective of using statistical methods was to determine if significant differences in water quality exist among sampling locations. Observed significant differences in water quality between stormwater entering the pipe or pipe water, and water in either the unsaturated or saturated zones would indicate either attenuation of constituents or increasing concentrations upon entering the subsurface system. Further comparisons of water quality among ground-water sampling sites and the control well site might indicate increasing constituent concentrations near the exfiltration pipe above what is "typical" for the location.

Dissolved concentrations of constituents in surface-water (runoff and pipe water) samples were used for comparison to concentrations from other locations. More significant differences probably would have been detected had total concentrations at surface-water sites been used for statistical tests. However, very little of the particulate fraction of constituents in runoff entering the exfiltration pipe will enter the unsaturated or saturated zones because of settling in the pipe and filtering through the rock backfill and filter fabric surrounding the pipe. Thus, the dissolved fraction of constituents in runoff and pipe water are most important when comparing concentrations among sampling locations.

Water-quality data frequently are not normally distributed. For this reason, data were converted to rank values before testing because statistical methods based on ranks do not require the assumption of normality (Helsel, 1983). The Statistical Analysis System (SAS) procedure General Linear Models (GLM) was used for analysis of variance (ANOVA), with the TUKEY option for multiple comparisons to detect where differences occurred (SAS Institute, Inc., 1982, p. 139-151).



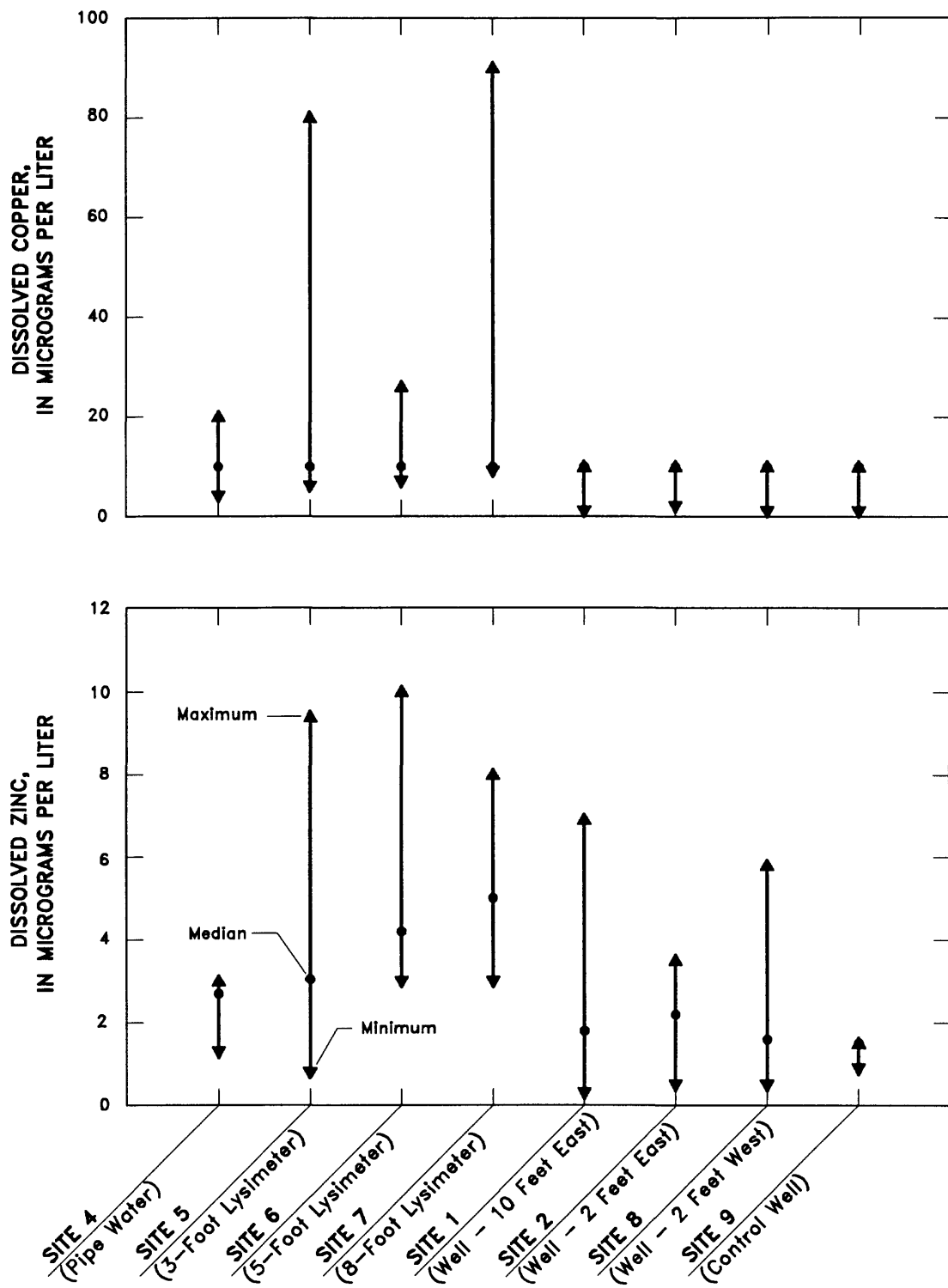
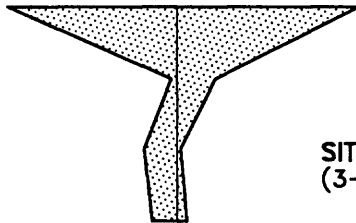


Figure 20.--Dissolved zinc and dissolved copper at sampling sites at the Washington Street exfiltration study area.

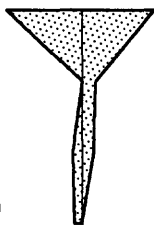
**SITE 4**  
(Pipe Water)



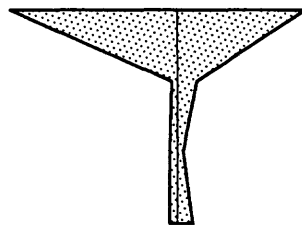
**SITE 5**  
(3-Foot Lysimeter)



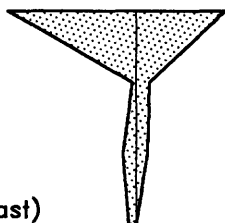
**SITE 1**  
(Well - 10 Feet East)



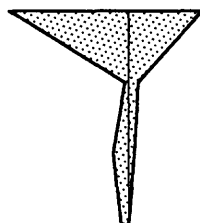
**SITE 6**  
(5-Foot Lysimeter)



**SITE 2**  
(Well - 2 Feet East)



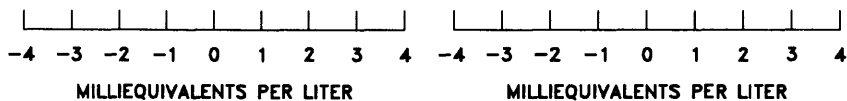
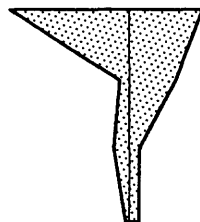
**SITE 7**  
(8-Foot Lysimeter)



**SITE 8**  
(Well - 2 Feet West)



**SITE 9**  
(Control Well)



### EXPLANATION

|           |   |              |
|-----------|---|--------------|
| Calcium   | — | Bicarbonate  |
| Magnesium | — | Sulfate      |
| Sodium    | — | Chloride     |
| Potassium | — | Nitrate as N |

Figure 21.—Ionic composition of water from sampling sites at the Washington Street exfiltration study area. (Median values used except for lysimeters.)

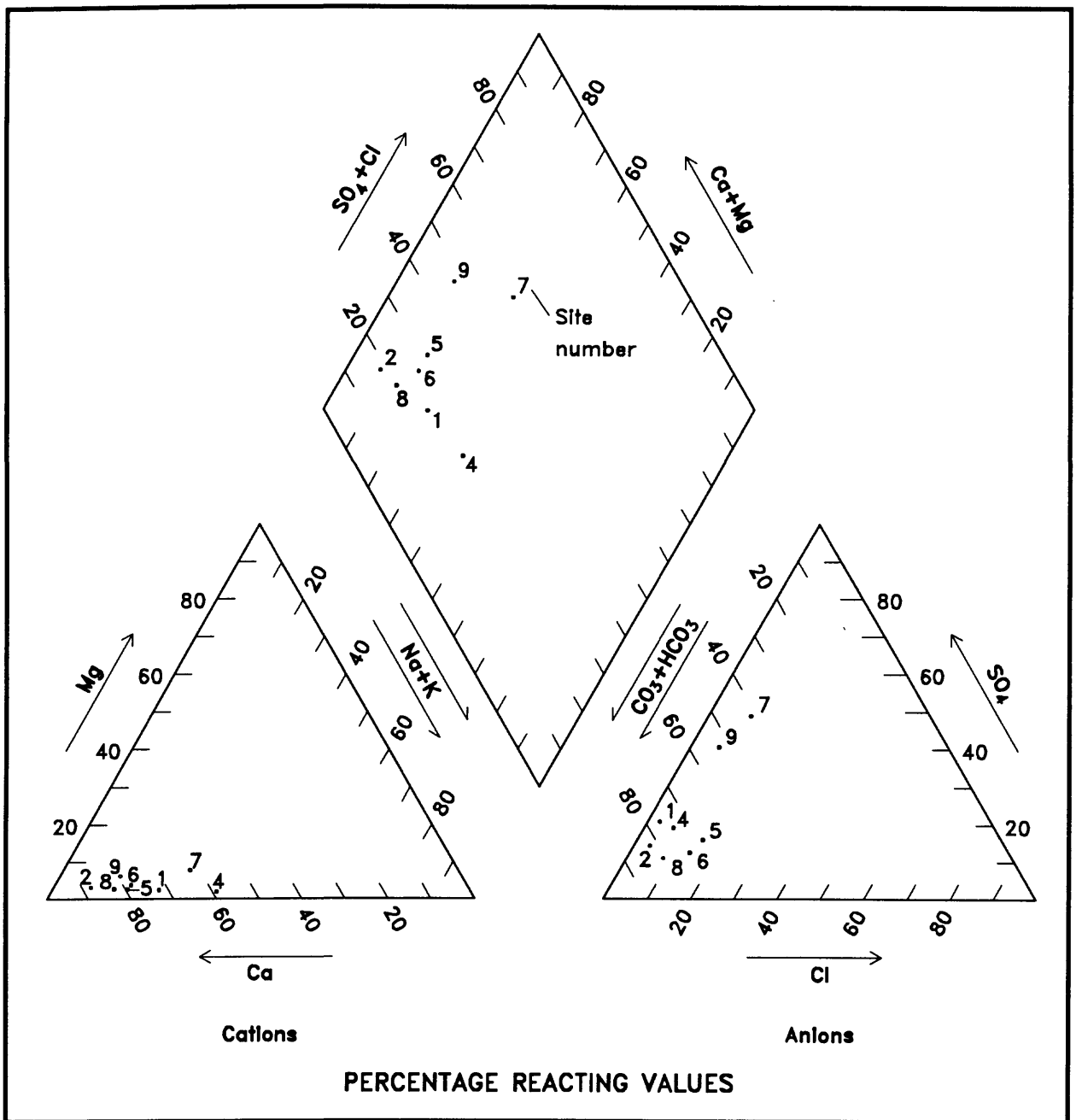


Figure 22.—Ionic composition of water from sampling sites at the Washington Street exfiltration study area. (Median values used.)

These statistical procedures test for significant differences among mean values of data that are grouped by sampling location. The first test, ANOVA, indicates whether the means of the data are significantly different among sampling locations, without identification of specific locations. The multiple comparison test is used when a significant difference is indicated by the ANOVA test, and identifies which locations differ, and the direction of the difference (for example, mean concentrations of a particular constituent might be higher in runoff and pipe water than in ground water).

To identify changes in water quality with sampling location, data were pooled into groups according to data "type" by sampling location. Data types at the exfiltration study area included surface waters (runoff and pipe water), unsaturated zone water, ground water around the structure, and ground water at the control well site. Included in the statistical testing were 26 water-quality variables. Results of ANOVA and multiple comparisons are listed in table 8.

Of the 26 water-quality measures, 14 were significantly different among the data types corresponding to sampling location (table 5). As was noted in figure 18, specific conductance values are significantly higher in water from the unsaturated zone than in incoming surface waters and water in the saturated zone. The difference in test results for laboratory and field pH is due to the inclusion of pH values for the unsaturated zone in the laboratory pH measurements, which biased the distribution of the laboratory values. Because of the small volume of water available for analysis, very few field pH measurements were made on water samples collected from the unsaturated zone. The mean pH of water in the unsaturated zone is higher than the mean pH of water in the saturated zone near the structure and at the control well site. Dissolved iron concentrations differed significantly with location. Dissolved iron concentrations are significantly higher in runoff and pipe water than in ground water and decrease with downward movement of water through the system, perhaps due to continuing precipitation of iron or complexation into nonsoluble species.

Zinc is the only metal other than iron for which significant differences among data types are indicated. Zinc is more soluble than other

metals, particularly lead, and commonly is found in higher concentrations than other metals in ground water. Mean zinc concentrations were highest in water from the unsaturated zone.

### Sediment Analysis

The distribution of particle sizes was determined for selected sites at the exfiltration study area. Material from the saturated and unsaturated zone, obtained during installation of wells and lysimeters, respectively, and accumulated sediment in the pipe were analyzed for size distribution (table 9). A study by Sartor and Boyd (1972, p. 146) found an association between the finer particle sizes in street sweepings and constituent concentrations. In their study, the less than 43- $\mu\text{m}$  fraction of street sweepings accounted for only 5.9 percent of the total solids, but it also accounted for 51.2 percent of the heavy metals, 73 percent of the pesticides, and 33 to 50 percent of the nutrients. Sartor and Boyd (1972) reported that 15.6 percent of total solids by weight were less than 104  $\mu\text{m}$  in size, which agrees with the value reported for 150  $\mu\text{m}$  or less for site 4, sediments accumulated in the pipe (table 9). The primary reason for the association of constituents with the finer particle sizes is the larger surface area (ratio of surface area to volume increases as diameter of particle decreases) available for adsorption. Horowitz (1984) cites numerous references in which researchers have determined that one of the most significant factors controlling sediment capacity for retaining trace metals is grain size. The small fractions of sediments in the < 74  $\mu\text{m}$  size at sites 1, 2, 5, and 6 indicate little silt or clay are available for adsorption, so it is not as likely to be the primary removal mechanism for constituent attenuation.

Sediment from street runoff settles in the exfiltration pipe and accumulates with time. The Washington Street exfiltration pipe had been in use for 5 years prior to this study, and sediments had never been removed from the pipe. The accumulation of sediments in an exfiltration pipe eventually will decrease the rate of exfiltration by clogging the holes in the pipe and the rock backfill around the pipe. Additionally, allowing sediments to collect for a long period of time may allow for resuspension of particulate matter, or dissolution of previously bound chemical

Table 8.—*Results of analysis of variance of rank data, grouped by data types, and multiple comparisons for the Washington Street exfiltration pipe study area*

[p-value, the probability that observed differences are due to chance rather than to the sampling location. Lysimeter data are included in the tests unless indicated with an asterisk (\*)]

Hypothesis being tested by analysis of variance: Means of the k data types are equal.

Alternate hypothesis: At least two of the data type means differ.

Data types are: S = runoff or pipe water; U = unsaturated zone; G = surficial aquifer system near the exfiltration pipe; and C = control well.

The less than (<) and greater than (>) symbols indicate the direction of the difference between the groups indicated in that column. For example, a ">" symbol for color under the S:G column means that color was significantly higher in runoff or pipe water than in water from the surficial aquifer system. If no symbol is shown, the test result indicated no significant difference.

| Dissolved constituent<br>or physical measure | Significant<br>difference | p-value | Multiple comparisons |     |     |     |     |     |
|--|---------------------------|---------|----------------------|-----|-----|-----|-----|-----|
|  |                           |         | S:U                  | S:G | S:C | U:G | U:C | G:C |
| Turbidity                                    | No *                      | 0.06    |                      |     |     |     |     |     |
| Color  | Yes *                     | .0001   |                      | >   | >   |     |     |     |
| Specific conductance                         | Yes                       | .0001   | <                    |     | <   | >   |     |     |
| pH—field                                     | No *                      | .3319   |                      |     |     |     |     |     |
| pH—lab                                       | Yes                       | .0001   |                      | >   |     | >   | >   |     |
| Ammonia                                      | Yes                       | .0001   | >                    | >   | >   | <   |     |     |
| Nitrite                                      | No                        | .3746   |                      |     |     |     |     |     |
| Ammonia and organic nitrogen                 | Yes                       | .0001   |                      | >   |     | >   |     | <   |
| Nitrite and nitrate nitrogen                 | Yes                       | .0001   | <                    |     | <   | >   |     | <   |
| Phosphorus                                   | Yes                       | .0049   |                      |     |     |     | >   | >   |
| Orthophosphorus                              | Yes                       | .0003   | <                    |     |     |     | >   | >   |
| Total organic carbon                         | Yes *                     | .0001   |                      | >   | >   |     |     |     |
| Calcium                                      | Yes                       | .0001   | <                    |     | <   | >   |     |     |
| Magnesium                                    | Yes                       | .0001   | <                    | <   | <   |     |     | <   |
| Sodium                                       | No                        | .6673   |                      |     |     |     |     |     |
| Potassium                                    | No                        | .5679   |                      |     |     |     |     |     |
| Chloride                                     | No                        | .4896   |                      |     |     |     |     |     |
| Sulfate                                      | Yes                       | .0098   |                      |     | <   |     |     |     |
| Alkalinity                                   | No                        | .0903   |                      |     |     |     |     |     |
| Aluminum                                     | No *                      | .0511   |                      |     |     |     |     |     |
| Chromium                                     | No *                      | .7290   |                      |     |     |     |     |     |
| Copper                                       | No                        | .1345   |                      |     |     |     |     |     |
| Iron   | Yes                       | .0001   | >                    | >   | >   | >   | >   |     |
| Lead   | No                        | .4262   |                      |     |     |     |     |     |
| Nickel                                       | No *                      | .0764   |                      |     |     |     |     |     |
| Zinc   | Yes                       | .0001   | <                    |     |     | >   | >   |     |

Table 9.—*Particle size distribution in sediments at the Washington Street exfiltration pipe study area*

[Sieve size indicated in parentheses]

| Site No.       | Percent (by weight) passing indicated sieve size |                   |                  |
|----------------|--|-------------------|------------------|
|                | 250 $\mu$ m (60)                                 | 150 $\mu$ m (100) | 74 $\mu$ m (200) |
| 1              | 84   | 12                | 2                |
| 2              | 82   | 16                | 2                |
| <sup>1</sup> 4 | --   | 15                | --               |
| 5              | 54   | 17                | 2                |
| 6              | 74   | 29                | 6                |

<sup>1</sup>Sediment analyzed by University of South Florida, Department of Geology, Tampa, Florida.

constituents, which may then travel out of the pipe and enter the ground water. Sediment from the pipe was sampled twice to determine constituent concentrations (table 10). Sediment concentrations usually are much higher than concentrations in the water column, and are highly variable.

The predominant form of nitrogen in sediment from the exfiltration pipe is organic. Much of the nitrogen in the urban environment originates from nitrogen fixation from the atmosphere and from precipitation (Novotny and Chesters, 1980).

Metal concentrations in sediments reported by Galvin and Moore (1982) collected from a control structure (catchment) serving a detention basin in Bellevue, Wash., are listed in table 10. Mean metal concentrations in street dust from 12 stormwater studies nationwide reported by Bradford (1977) also are listed for comparison with concentrations in the exfiltration pipe sediment. Comparison of the values in sediments at the exfiltration pipe to the national averages for street dust showed that only cadmium is about the same as the national average. The other metals (chromium, copper, nickel, lead, and zinc) are less than 10 percent of the reported average concentrations. Generally, the constituent concentrations in sediments from the Washington Street exfiltration pipe are lower than concentrations in catchment sediments from Bellevue, Wash. Although the samples for this study were of sediment that had accumulated in the pipe for 5 years, the street is not a major highway, and not as heavily travelled as were those highways used in the 12 studies summarized by Bradford (1977), so lower concentrations would be expected.

## Ponds

### Silver Star Road Detention Pond

The Silver Star Road detention pond was chosen as a study area because prior research had been done and was continuing at that location. Originally, eight wells were installed for water-quality sampling, but one location (shown as site 6 in fig. 6) was destroyed. This was the first study area selected and instrumented, and a control well was not planned. However, well 4 is upgradient of the wetland and pond, and was used as a control well site. The general direction of ground-water flow at the site is east-northeast, across the pond and wetland and towards a drainage canal on the east and north sides of the study area. Well depths range from 8 to 12 feet. The depth to the water table below land surface ranged from 1 foot (at site 4) to 4.8 feet (site 5). Well screens are 3 feet in length, and the water table ranges from 3.6 to 9 feet above the well screen. Thus, ground-water samples were collected from depths that ranged from 3.6 to 12 feet below the water table. Sites 1, 2, and 3, adjacent to the pond, probably do not receive much recharge water from the pond because the native soils are very clayey.

### Longwood Retention Pond

The Longwood retention pond was chosen as a study area because it may represent a "worst case" situation; there is no surface outflow, and there is high traffic volume on SR 434. Sites 1, 2, and 3 were located near the point at which highway runoff enters the pond, and these wells range in depth from 15 feet (site 1) to 25 feet (site 3). The objective of the depth selection was to detect

possible vertical differences in water quality. Sites 4, 5, 6, and 7 (all at the same depth as site 1, 15 feet) were located in the pond to obtain areal coverage of ground water beneath the pond (fig. 10). Site 8, which is deeper than the other wells (65-feet deep), was used to determine the lithology of the sediments beneath the pond, to monitor the water quality of the intermediate aquifer, and to detect any downward movement of constituents.

Data from the control well site at the Longwood retention pond presented some interpretive problems. Although the well was constructed to sample background water quality of the surficial aquifer system, drill cuttings and water-level measurements indicate that water from the well may be from the intermediate aquifer system or the Upper Floridan aquifer. The control well is located in a small grassy area

at the edge of the parking lot (fig. 8), about 700 feet from the pond. The land surface at the control well is 78 feet above sea level, and the pond bottom is 47.2 feet above sea level. The bottom of the control well is 20 feet above sea level (fig. 23). Ground-water levels beneath the pond ranged from 36.3 feet to 46.1 feet above sea level. When the control well was drilled, the water level initially was 24 feet above sea level, but rose approximately 4 feet shortly thereafter, indicating that the aquifer was semiconfined. These water levels indicate a gradient from the pond toward the control site.

Clay was found at 26 feet above sea level during the drilling of the control well. Clay also was found when drilling the 71.5-foot deep borehole for site 8 (65-foot deep well in the pond), at 24 feet below sea level, or 50 feet below the clay layer found in the control well borehole

Table 10.— *Concentrations of selected constituents in sediments in the Washington Street exfiltration pipe and reported values from two other studies*

[Nutrient concentrations are in milligrams per kilogram; minor element concentrations are in micrograms per gram. -- denotes no sample or value]

| Constituent                         | August 30,<br>1984 | May 28,<br>1985 | Catchment<br>sediment, <sup>1</sup><br>Bellevue, Wash. | Street<br>dust <sup>2</sup><br>(mean) |
|-------------------------------------|--------------------|-----------------|--|---------------------------------------|
| <b>Nutrients:</b>                   |                    |                 |  |                                       |
| Nitrogen, total ammonia, as N       | 3.8                | 2.2             | --   | --                                    |
| Nitrogen, ammonia and organic, as N | 710                | 1,000           | --   | --                                    |
| Nitrogen, nitrate and nitrite, as N | 8                  | 2               | --   | --                                    |
| Phosphorus, as P                    | 390                | 110             | --   | --                                    |
| <b>Minor elements:</b>              |                    |                 |  |                                       |
| Aluminum                            | 550                | --              | --   | --                                    |
| Cadmium                             | 4                  | 2               | 1.4  | 4.2                                   |
| Chromium                            | 20                 | 9               | 20   | 225                                   |
| Cobalt                              | --                 | 10              | --   | --                                    |
| Copper                              | 7                  | 9               | 35   | 133                                   |
| Lead                                | 140                | 20              | 600  | 3,440                                 |
| Manganese                           | --                 | 23              | --   | --                                    |
| Mercury                             | .05                | .23             | .11  | --                                    |
| Nickel                              | 130                | --              | 20   | 48                                    |
| Zinc                                | 60                 | 100             | 310  | 520                                   |

<sup>1</sup>Galvin and Moore, 1982, p. 3-87.

<sup>2</sup>Galvin and Moore, 1982, p. 3-49, mean values for street dust from 12 commercial areas reported originally by Bradford, 1977.

(site 9). The occurrence of clay layers at different depths (26 feet above sea level, and 24 feet below sea level) indicates discontinuous confining layers are present in the study area.

Drill cuttings near the bottom of the control well contained iron and phosphatic rock pebbles, indicative of the Hawthorn Formation of the intermediate aquifer system. Tibbals (1977) reports that the top of the Floridan aquifer system in the study area ranges from 0 to 25 feet below sea level, or 25 to 50 feet below the bottom of the control well (fig. 23).

The Longwood retention pond apparently is a relict sinkhole that has been naturally plugged and stable for many years. According to Tibbals (1977), the pond area is shown as a high-rate recharge area. The area just southeast of the pond is characterized by karst topography with many small sinkhole lakes, which are typical of a high-rate recharge area underlain by

discontinuous confining layers. Clays probably occur in lenses in the unconsolidated sediments above the consolidated rock of the Floridan aquifer system. This is probably the case in the vicinity of the Longwood retention pond, as evidenced by the occurrence of clay at different altitudes at sites 8 and 9. Because of these discontinuous confining layers, a true water table (at atmospheric pressure) may not exist at the control well site, but only directly below and in the immediate vicinity of the pond because of the infiltration of runoff water.

Under normal conditions (no runoff routed to the pond), the gradient of the water table would be expected to be toward the relict sinkhole (the retention pond), and dewatering of the surficial aquifer system in the vicinity of this relict sinkhole might occur. However, the routing of highway and parking lot runoff to the relict sinkhole causes mounding of the ground water beneath

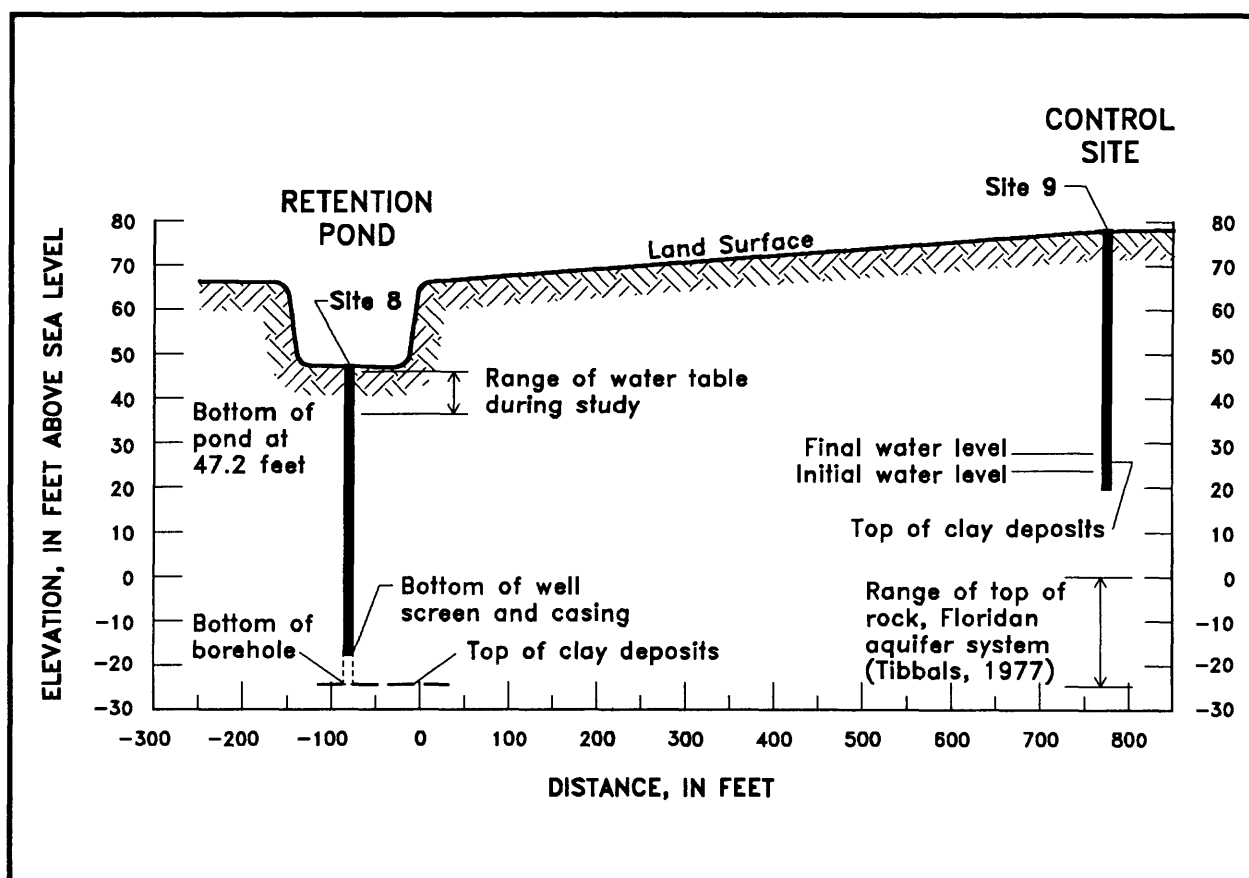


Figure 23.—Relation of control site to Longwood retention pond.



the pond, resulting in a gradient away from the pond. Water levels measured in the control well and in wells located in the pond during this study indicate that mounding occurs, even during the dry season. More observation wells would be needed to better define the ground-water system in this area. The potentiometric surface of the Floridan aquifer system in this vicinity is 30 feet above sea level (Tibbals, 1977), which is below the lowest measured water level beneath the pond, resulting in a downward gradient toward the Floridan aquifer system. The overall ground-water gradient in the surficial aquifer system in the area is to the west, so it is possible that ground water initially moves to the east, but eventually flowlines probably curve back to the west.

Quality of water from the control well site was used for comparison because the well is in the vicinity of the pond and is located in the first saturated zone in the subsurface system. The well may not be entirely independent of the mounding effects of water beneath the retention pond, and may also be more representative of the intermediate aquifer system. Comparison of water quality between the control well site and well sites in the pond may offer clues as to the original source of water sampled at the control well site.

The two ponds used in this ground-water study had one significant difference that could affect their impact on ground-water quality—the Silver Star Road pond detains water and has a surface outlet, whereas the Longwood pond is a retention pond, with no surface outlet. Water entering the Longwood pond must either evaporate or infiltrate. Soluble constituents must either migrate down to the underlying ground water or be removed from the water phase by chemical, physical, or biological interactions. The pond often is dry for a sufficiently long duration to allow vegetation to grow on the pond bottom.

Because the Longwood pond may have a more severe impact on ground-water quality, additional work was initiated at this study area to determine some characteristics of the pond, that include infiltration rates, and the response of the pond to rainfall. Stage in the Longwood pond was monitored to determine infiltration rates after storms, and rainfall was measured at the site. Stage responded quickly to rainfall, as might be expected from a drainage basin with a high percentage of impervious area. Infiltration rates

in the pond varied from 0.13 in/hr to 0.36 in/hr during summer months, and increased during winter months to as much as 0.60 in/hr. Green and Ampt (1911) described the rate of infiltration as a function of the hydraulic conductivity, capillary suction head, and depth from soil surface to wetting front. The higher infiltration rate during winter months probably is due to an increase in capillary suction head in the unsaturated zone as moisture content decreases. Even during summer months when rainfall occurred almost daily, the pond would frequently be dry in just a few days. During this study, the water table was always below the pond bottom, even when water in the pond was 2 feet or more deep (fig. 23). Thus, an unsaturated zone existed under the pond throughout the study.

The Longwood pond was surveyed during a dry period to obtain stage-volume information. From the pond stage data, rainfall data, and the stage-storage curve, response curves were plotted for the pond (fig. 24). The change in storage due to rainfall was computed from the stage-storage relation and stage data, and is shown as the middle plot in figure 24. Most of the rainfalls during the study were 1 inch or less, and storage volume changes were less than 1 acre-ft (acre-foot).

An attempt was made to estimate loads of selected constituents to the pond. First, a regression line was fitted to the data for the storage-rainfall relation. Then, using the equation that describes this relation, and rainfall for the period of August 1985 through July 1986, during which most of the well water-quality data were collected, the total volume of water that entered the pond was estimated. The rainfall for the period was 52.42 inches, which corresponded to a storage volume of 13.04 acre-ft. Using data from table 5, estimates of loads of selected constituents were obtained. The annual load of nitrogen is 166.5 pounds; phosphorus, 42.5 pounds; zinc, 10.3 pounds; lead, 5.3 pounds; and copper, 1.7 pounds. The estimated loads indicate the amount of material that is either retained in the pond sediments or may have moved into the surficial aquifer system beneath the pond.

#### Water-Quality Variations

Data for pH, specific conductance, and selected constituents are shown in figures 25 through 29 for ground-water sampling sites at both pond study locations. These figures

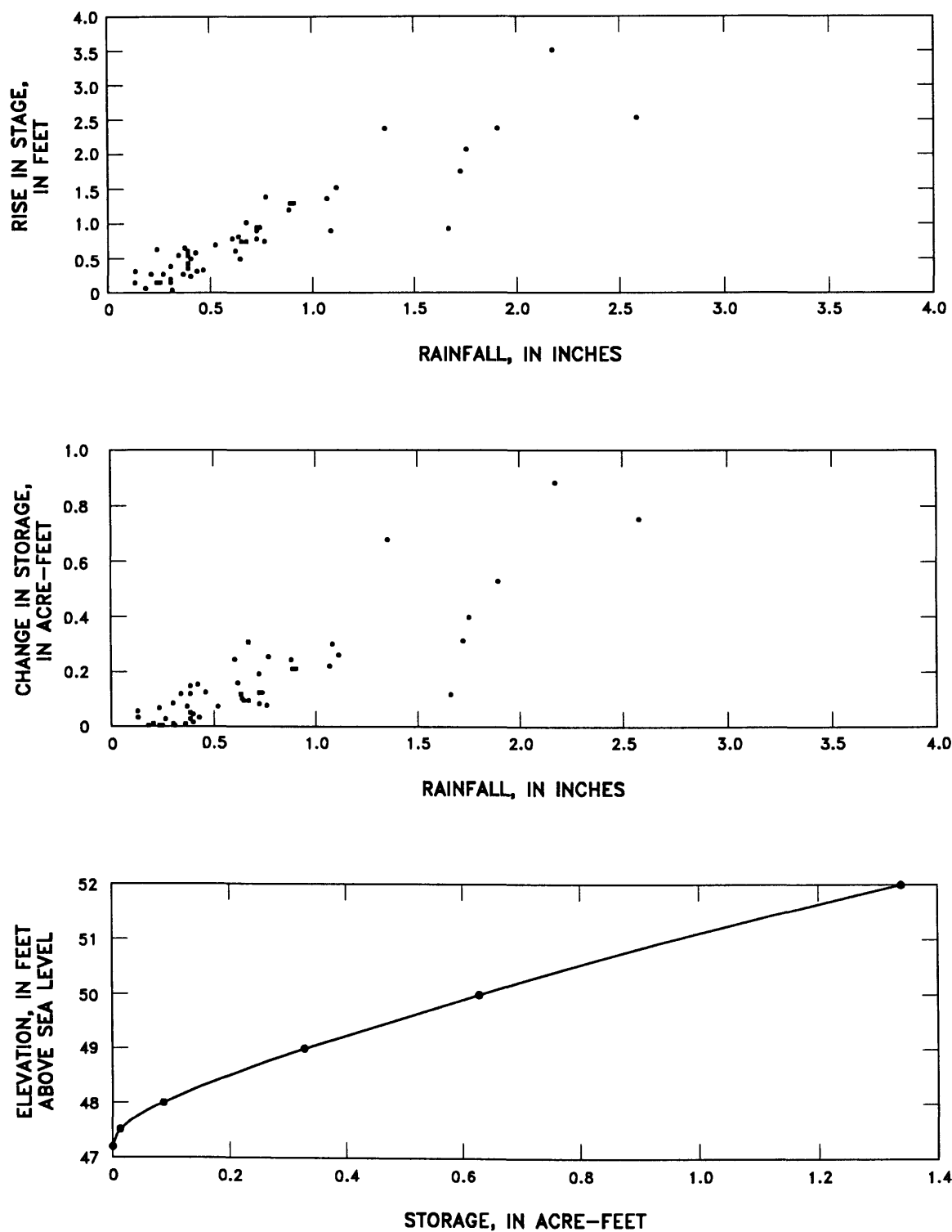


Figure 24.--Rainfall, stage, and volume relations at the Longwood retention pond.

illustrate the variability in data among sampling sites at the Longwood and Silver Star Road study areas, and between the two ponds.

Water-quality data for ground water at both ponds are summarized in table 11. All ground-water sites are included for the Silver Star Road pond, and all but the control well site at the Longwood pond. The sites at the Silver Star Road pond were combined because, although site 4 is used later for statistical comparisons, it was not originally located as a control well site, and may be located near enough to the wetland to be affected by the wetland. In general, ammonia, organic nitrogen, sodium, chloride, iron, and aluminum were present in higher concentrations in ground water at the Silver Star Road pond, and nitrate nitrogen, calcium, and alkalinity were higher in ground water at the Longwood pond. Ground water at the Silver Star pond also was more colored than the

Longwood pond ground water, possibly because of the proximity of the cypress wetlands that leach organic matter.

Specific conductance and pH are more variable in ground water at the Longwood pond (fig. 25). Only two samples were collected from each well at the Silver Star Road pond. In most cases the data from the two samples show little difference, although ground water at the Silver Star Road pond is more acidic than at Longwood. At the Longwood pond, the three sites displaying the most variation in specific conductance values are those located close to the inlet to the pond (sites 1, 2, and 3), in the path of incoming stormwater that initially has high dissolved solids concentrations. The two sites displaying the least variability at the Longwood pond are the deep well in the pond (site 8) and the control well (site 9), both of which may be in the intermediate aquifer.

Table 11.--Statistical summary of water-quality data for ground water at the Silver Star Road and Longwood pond study areas

[Control site for Longwood listed independently. Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter; -- denotes no sample or value]

| Constituent or physical property                         | Silver Star Road Pond |       |        |       |    | Longwood Pond      |       |        |  |                |
|--|-----------------------|-------|--------|-------|----|--------------------|-------|--------|--|----------------|
|  | Ground-water sites    |       |        |       |    | Ground-water sites |       |        |  |                |
|  | No. of samples        | Range | Median |       |    | No. of samples     | Range | Median |  | Control Median |
| Turbidity (NTU)  | 7                     | 5.5 - | 95     | 35    | 35 | 0.8 -              | 2,000 | 12     |  | 500            |
| Color (Pt-Co units)                                      | 7                     | 5 -   | 480    | 240   | 33 | <5 -               | 800   | <5     |  | 2.5            |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | 14                    | 105 - | 300    | 180   | 35 | 124 -              | 504   | 290    |  | 258            |
| Field pH   | 7                     | 5.3 - | 5.8    | 5.6   | 21 | 6.3 -              | 7.5   | 6.8    |  | 6.7            |
| Lab pH   | 14                    | 5.4 - | 7.3    | 5.9   | 34 | 6.7 -              | 8.2   | 7.5    |  | 7.6            |
| Nitrogen species, as N:                                  |                       |       |        |       |    |                    |       |        |  |                |
| Ammonia  | 14                    | .1 -  | 5.8    | .5    | 35 | .01 -              | .35   | .03    |  | .09            |
| Nitrite  | 14                    | .01 - | .02    | .01   | 35 | <.01 -             | 1.1   | <.01   |  | .05            |
| Ammonia plus organic                                     | 14                    | .33 - | 9.5    | 1.65  | 35 | .05 -              | 19    | .37    |  | 1.17           |
| Nitrate plus nitrite                                     | 14                    | .01 - | .1     | .06   | 35 | .01 -              | 3     | .33    |  | 1.90           |
| Phosphorus, as P   | 14                    | .02 - | 1.1    | .06   | 34 | .01 -              | .08   | .02    |  | .63            |
| Orthophosphorus, as P                                    | 14                    | .01 - | 1.1    | .04   | 35 | .01 -              | .06   | .01    |  | .51            |
| Total organic carbon                                     | 8                     | 11 -  | 60     | 28    | 35 | .1 -               | 34    | 1.8    |  | 1.15           |
| Calcium  | 14                    | 3.3 - | 23     | 11.55 | 35 | 21 -               | 100   | 51     |  | 24.5           |
| Magnesium  | 14                    | 1.3 - | 5.5    | 2.55  | 35 | .3 -               | 5.5   | 1.2    |  | 12.5           |
| Sodium   | 14                    | 3.4 - | 35     | 26    | 35 | 1 -                | 13    | 2.8    |  | 5.85           |
| Potassium  | 14                    | .3 -  | 2.6    | .9    | 35 | .3 -               | 7.7   | .9     |  | .9             |
| Chloride   | 14                    | 5.8 - | 74     | 29.5  | 35 | 1.1 -              | 14    | 2.7    |  | 11             |
| Sulfate  | 14                    | 3.2 - | 30     | 7.65  | 35 | 1.4 -              | 30    | 6.4    |  | 2.35           |
| Alkalinity, as $\text{CaCO}_3$                           | 14                    | 6 -   | 101    | 26.5  | 35 | 51 -               | 245   | 124    |  | 135            |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | 7                     | 50 -  | 500    | 200   | 32 | 10 -               | 90    | 15     |  | 10             |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | 13                    | <1 -  | 2      | <1    | 27 | <1 -               | 1     | <1     |  | <1             |
| Copper ( $\mu\text{g}/\text{L}$ )                        | 13                    | <1 -  | 5      | <1    | 35 | <1 -               | <10   | <1     |  | 1.5            |
| Iron ( $\mu\text{g}/\text{L}$ )                          | 7                     | 270 - | 5,100  | 1,700 | 34 | 3 -                | 1,300 | 19.5   |  | 10.5           |
| Lead ( $\mu\text{g}/\text{L}$ )                          | 14                    | <5 -  | 12     | <5    | 35 | <5 -               | <10   | <5     |  | <5             |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | 7                     | 2 -   | 85     | 3     | 28 | <1 -               | 3     | <1     |  | 2.5            |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 14                    | 5 -   | 220    | 35    | 40 | 3 -                | 140   | 20     |  | 3.5            |

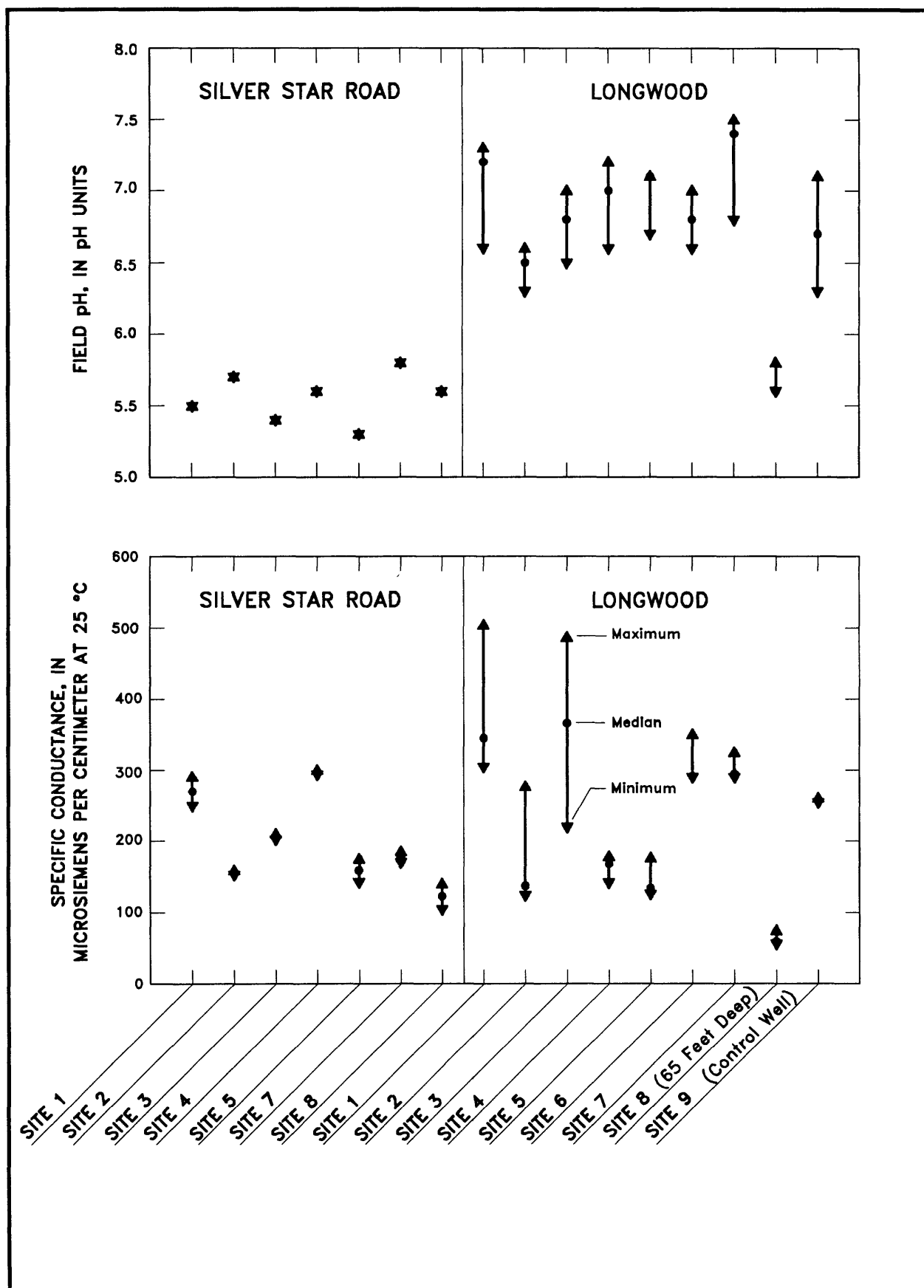


Figure 25.--Field pH and specific conductance at sampling sites at the Silver Star Road detention pond and the Longwood retention pond.

Selected nitrogen species are shown for both locations in figure 26. Again, the Longwood pond shows the greatest variability for both Kjeldahl (ammonia plus organic) nitrogen and nitrate plus nitrite nitrogen. Nitrogen in ground water at the Longwood pond primarily is in the organic form. The cause of the unusually high nitrate concentrations in the control well water is not apparent. Schiner and German (1983) reported only 0.29 mg/L maximum for nitrate nitrogen in supply wells in the Orlando area, but as much as 2.4 mg/L in drainage wells. The three maximum values of Kjeldahl nitrogen at the Longwood pond occurred at the same sampling time (March 1986), but not in all wells.

Dissolved orthophosphorus in ground water at both pond locations generally is present in low concentrations, and most of the phosphorus was in the orthophosphorus form (inorganic) (fig. 27). At the Longwood pond, phosphorus is highest in the water from the control well, but the cause for this is unknown. Although phosphatic pebbles were obtained from the control well, phosphorus is very insoluble, and the higher phosphorus in the water probably is not a result of dissolution of aquifer materials. The minimum and maximum values for dissolved orthophosphorus in water from site 2 (0.4 and 1.1 mg/L, respectively) at the Silver Star Road pond is higher than the second highest value obtained in drainage wells in Orlando (0.33 mg/L) (Schiner and German, 1983). This observation is of note because drainage wells receive stormwater directly, unlike ground water at the Silver Star Road study area, at which stormwater is detained, then filtered as it percolates down to the surficial aquifer system. Total organic carbon is more variable in ground water at the Silver Star Road study area than at the Longwood study area.

Aluminum in ground water is higher at the Silver Star Road pond than at the Longwood pond (50 to 500  $\mu\text{g/L}$  versus 10 to 90  $\mu\text{g/L}$ ) and more variable (fig. 28). Highest concentrations are in water from sites 7 and 8, in the area between the wetlands and the drainage canal. The soil materials around the pond are clayey, and this combined with a slightly acidic pH, may be the reason for higher soluble aluminum near the pond.

Dissolved zinc, in general, is more variable in ground water at the Longwood pond, and concentrations are higher in water beneath the

pond than in water from the control well. Zinc was highest in water from sites 1 and 8 at the Silver Star Road pond, closest to the highway. Median values in the Silver Star Road pond water are lower for dissolved and total zinc (20 and 60  $\mu\text{g/L}$ , respectively) (Martin and Smoot, 1986) than the median dissolved zinc in water at well sites 1 and 8. The maximum dissolved zinc concentration measured in the pond water at Silver Star Road was only 100  $\mu\text{g/L}$ , which is lower than the maximum measured values at well sites 1 and 8.

Dissolved iron concentrations (fig. 29) in ground water are significantly higher and more variable among sampling sites at the Silver Star Road pond. Snoeyink and Jenkins (1980, p. 379-382) define three "zones" for iron in ground water based on a  $\text{pe-pH}$  diagram that includes the interaction of iron with sulfide and bicarbonate. Two of these zones are characterized by low soluble iron concentrations, and a third, an intermediate zone between the other two, that is characterized by significantly higher dissolved iron concentrations. The solubility of iron in the intermediate zone is controlled by the mineral ferrous carbonate, which can have a much higher dissolved iron content than waters in equilibrium with ferrous hydroxide (upper zone) or ferrous sulfate (lower zone). The higher concentrations of dissolved iron at the Silver Star Road pond either are due to the location of the well intakes in this intermediate zone described by Snoeyink and Jenkins (1980), or possibly to iron in organic complexes.

Stiff and Piper diagrams are used to graphically show the water-quality variability in ground water at each pond, and for comparison between ponds. Stiff diagrams of median values of major ions in ground water at the Longwood retention pond (fig. 30) indicate that most of the ground water beneath the pond is a calcium bicarbonate type, with some variability with location. The Stiff diagram of water from the control well (site 9) looks very similar to the diagram of water from supply wells tapping the Floridan aquifer system (Schiner and German, 1983), with the exception of some magnesium replacing calcium. This supports the hypothesis that water in the control well is from the Upper Floridan aquifer. Rainfall values at Lake Hope, Maitland, Fla., a few miles south of the Longwood site, were plotted at the same scale to show the contribution of rainfall (very small) to the ionic makeup of the water.

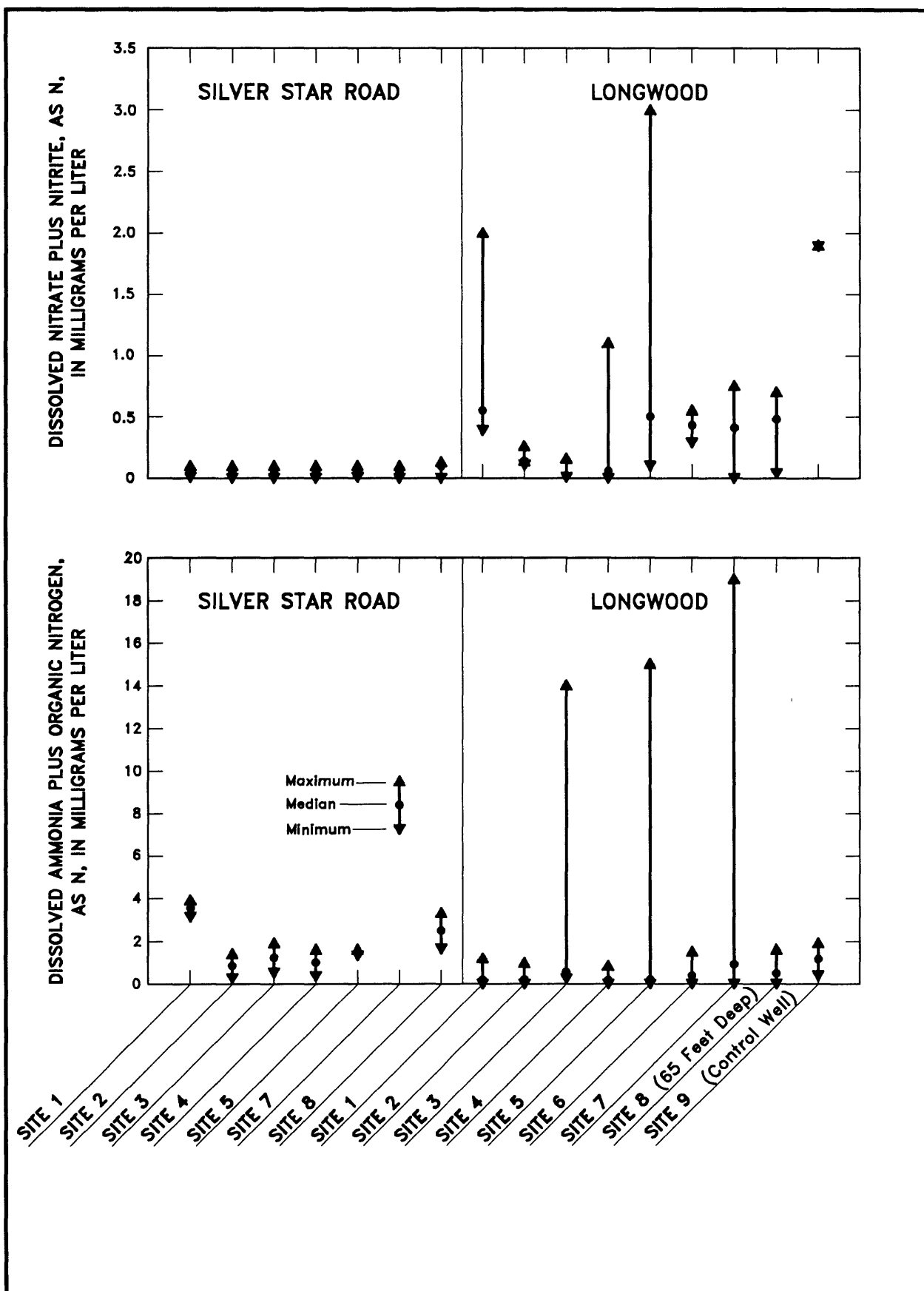


Figure 26.—Dissolved nitrate plus nitrite nitrogen, and dissolved ammonia plus organic nitrogen at sampling sites at the Silver Star Road detention pond and the Longwood retention pond.

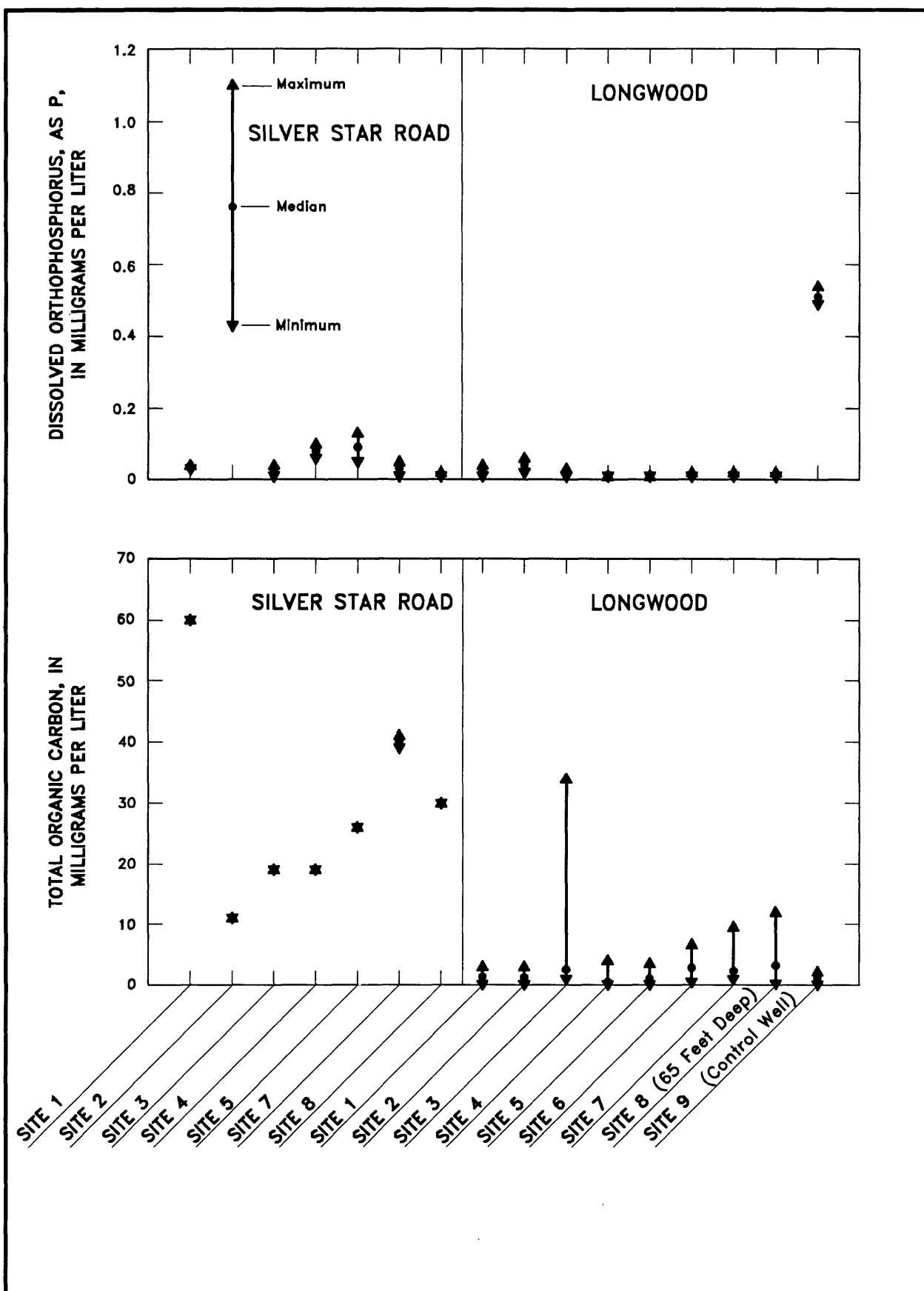


Figure 27.--Dissolved orthophosphorus and total organic carbon at sampling sites at the Silver Star Road detention pond and the Longwood retention pond.

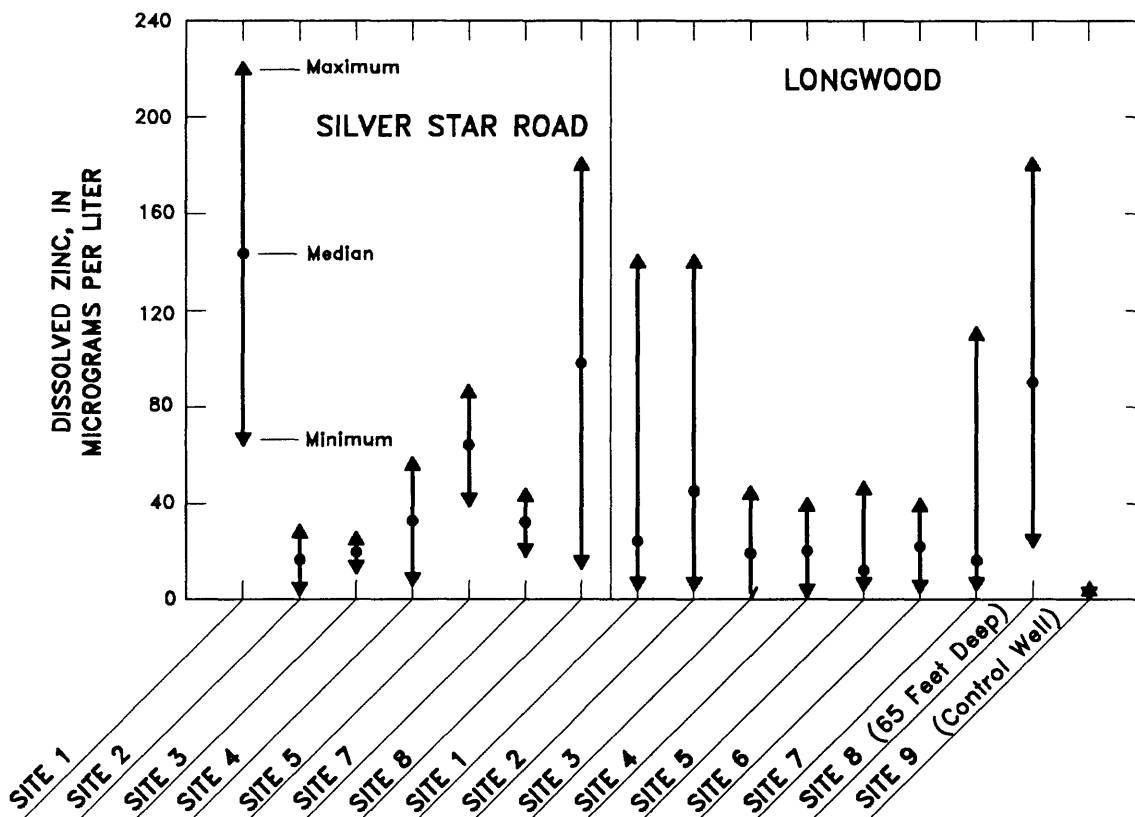
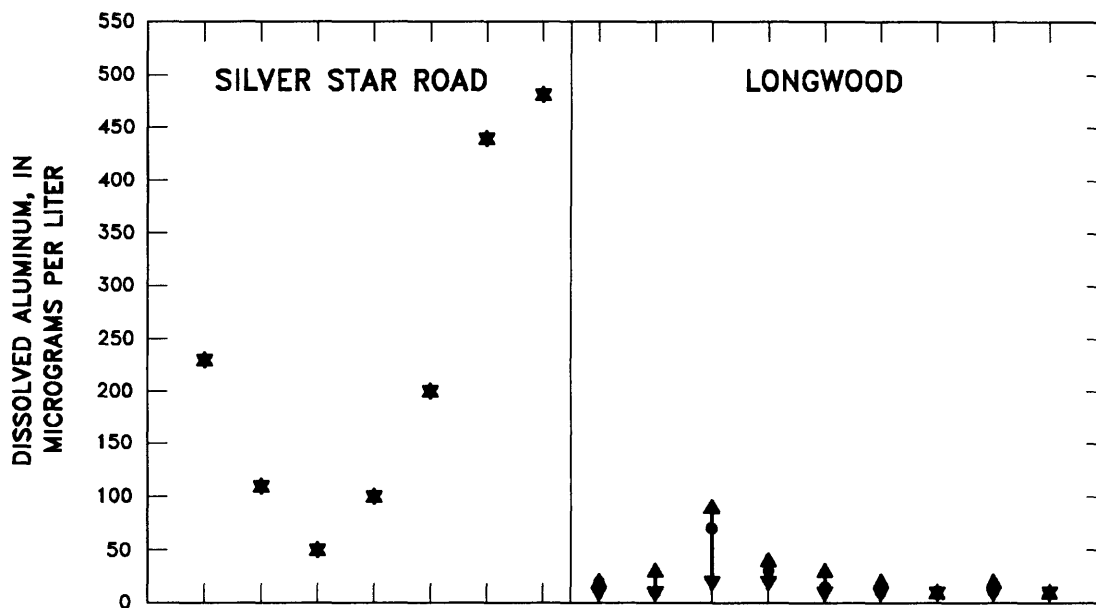


Figure 28.--Dissolved aluminum and dissolved zinc at sampling sites at the Silver Star Road detention pond and the Longwood retention pond.



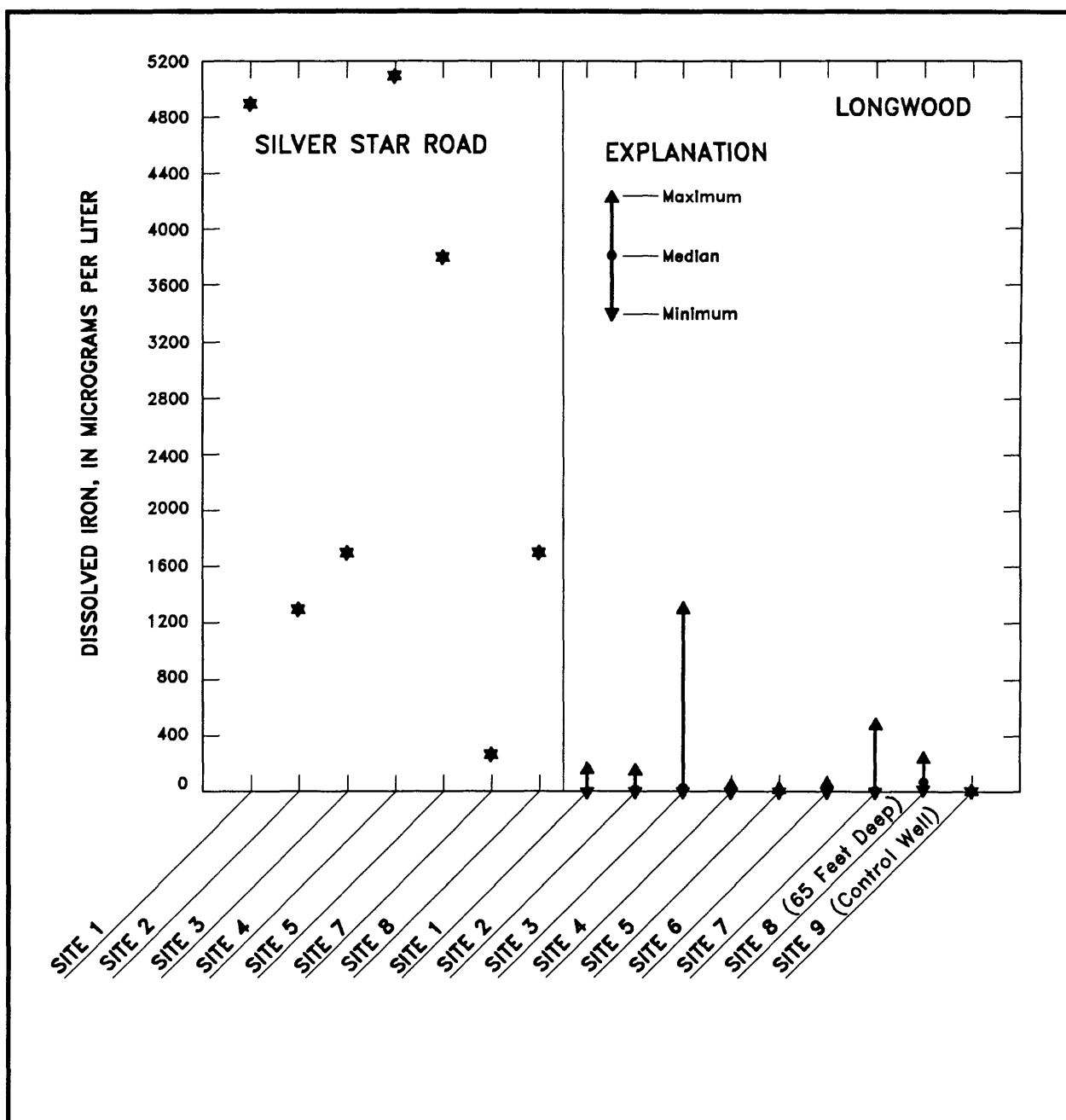


Figure 29.--Dissolved iron at sampling sites at the Silver Star Road detention pond and the Longwood retention pond.

**RAINFALL**  
Lake Hope, Maitland, Florida  
Mean of 19 samples

**FLORIDAN AQUIFER  
SYSTEM**  
Median values from  
65 supply wells in  
Orlando, Florida

**SITE 1**

**SITE 6**

**SITE 2**

**SITE 7**

**SITE 3**

**SITE 8**  
(65 Feet Deep)

**SITE 4**

**SITE 9**  
(Control Well)

**SITE 5**

**SITE 10**  
(Runoff)

-4 -3 -2 -1 0 1 2 3 4  
MILLIEQUIVALENTS PER LITER

-4 -3 -2 -1 0 1 2 3 4  
MILLIEQUIVALENTS PER LITER

### EXPLANATION

|           |  |              |
|-----------|--|--------------|
| Calcium   |  | Bicarbonate  |
| Magnesium |  | Sulfate      |
| Sodium    |  | Chloride     |
| Potassium |  | Nitrate as N |

Figure 30.—Ionic composition of water from sites at the Longwood retention pond. (Median concentrations used except at rainfall site.)

In contrast to the calcium bicarbonate water at the Longwood pond, ground water at the Silver Star Road pond is predominately a sodium chloride type (fig. 31). Water quality of sites 7 and 8, between the wetland and the drainage canal, differ significantly from the water quality of ground water west and north of the pond (more calcium and bicarbonate, and less sodium and chloride), possibly reflecting the influence of exfiltrating water from the wetland.

Relative distributions of ions in ground water at both pond study areas are shown in figure 32. The variability in ionic composition at the Silver Star Road pond is evident from this figure, but no real pattern related to location is discernible. The ionic composition of ground water under the Longwood pond is much more uniform. The 65-foot deep well (site 8) in the pond and the control well (site 9) differ from sites in the pond, primarily with higher magnesium concentrations at both sites, and additionally, for site 8, sulfate.

#### Statistical Comparisons

*Among data types.*--The same procedure used for statistical analysis of water-quality data for the exfiltration pipe study area also was used for analysis of ground-water quality around the two study ponds. For the Silver Star Road detention pond, ground-water quality data were divided into two groups, one control group (consisting of well site 4 only) and one group comprised of well sites 1 to 3 and 5 to 8. Site 4 was used as a control because it is located in the most upgradient and distant location from the pond and wetland.

Twenty water-quality measures were used in the statistical testing (table 12). Significant differences occurred in specific conductance measurements, sodium, and chloride. The test results indicate that the mean values for these variables were significantly higher in the upgradient control well (site 4) than in ground water closer to the pond and wetland. Specific conductance plotted in figure 25 seems to be higher at site 4 (Silver Star pond) than at other locations in the vicinity of the pond and wetland. The lower values in ground water near the pond and wetlands may indicate some dilution by exfiltrating stormwater that has smaller concentrations of sodium, chloride, and other ions than what is in the surficial aquifer system.

The outcome of the statistical test for sodium and chloride probably was due to the calcium-bicarbonate water at sites 7 and 8.

Water-quality data were divided into four types for the Longwood study area. Data from one runoff sample and four pond water samples were grouped together as a surface-water type. Data from well sites 1 to 7, representing the water quality of the surficial aquifer system, comprised the second type. Data from site 8, representing the intermediate aquifer, is the third type, and data from the control well (site 9) is the fourth type or group.

Values for 25 physical measures and constituents were statistically tested, and of these, 14 were significantly different among the data types (table 13). The results shown in table 13 indicate where these differences occurred. Comparison of water quality of the surficial aquifer system beneath the pond to the quality of water at the control well site may indicate increasing concentrations below the pond due to infiltration of highway runoff.

Results of the TUKEY multiple comparison test indicate only phosphorus and orthophosphorus (which comprises the majority of the phosphorus) concentrations differed significantly between water in the surficial aquifer system beneath the pond and at the control well site. The mean concentrations of phosphorus and orthophosphorus are significantly higher at the control well site, which is not affected by highway runoff. This result may be related to other differences between the control site and the ground-water sites located in the pond (see the discussion in this report of the difference between the water levels of ground water beneath the pond and at the control site, and the difference in ionic composition).

Another indicator of possible effects on receiving ground water from highway-runoff infiltration would be the observation of significant changes in water quality with depth below the water table. Results of the TUKEY multiple comparison test between water quality of the surficial aquifer system (sites 1 to 7) and that of the intermediate aquifer water (site 8) indicate significant differences for specific conductance, pH, calcium, potassium, and alkalinity (all higher in the surficial aquifer system). Differences in values of these variables are probably related only to differences in aquifer materials. Water in the intermediate aquifer

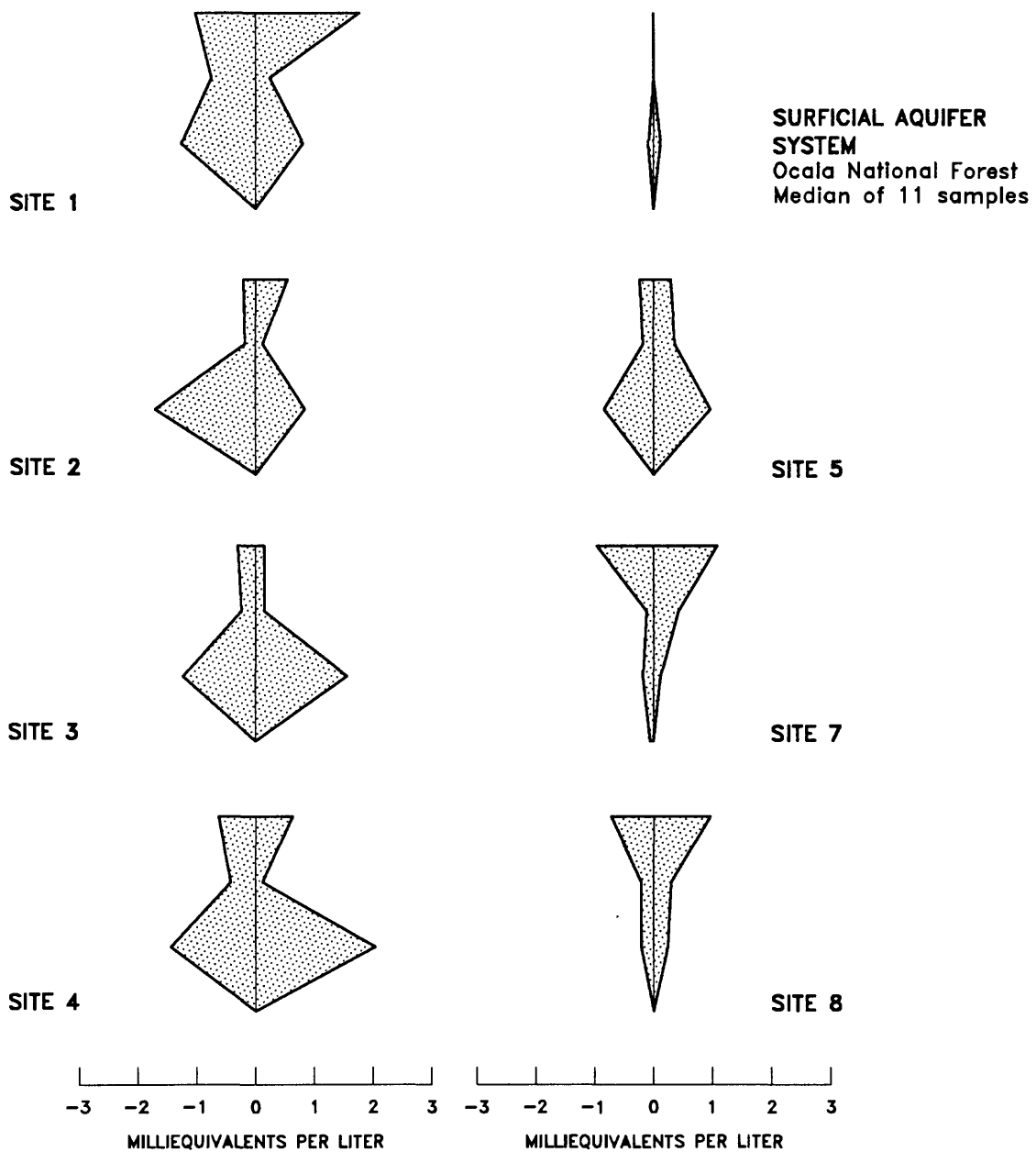


Figure 31.—Ionic composition of water from sites at the Silver Star Road detention pond. (Median values used.)

beneath the pond (site 8) may not originate from water directly above (in the pond). The time and distance needed for chemical changes to occur in water, between the surficial aquifer system 15 feet below the pond, and the intermediate aquifer 65 feet below the pond, which would modify the quality of water as indicated by these tests does not seem sufficient. Therefore, water from site 8

probably originated from somewhere other than the retention pond, and may have resided in the formation for many years.

The mean zinc concentration for the intermediate aquifer was significantly higher than the mean value for the surficial aquifer system, an unexpected test result. The maximum value of 180  $\mu\text{g/L}$  at site 8 (fig. 28) occurred twice.

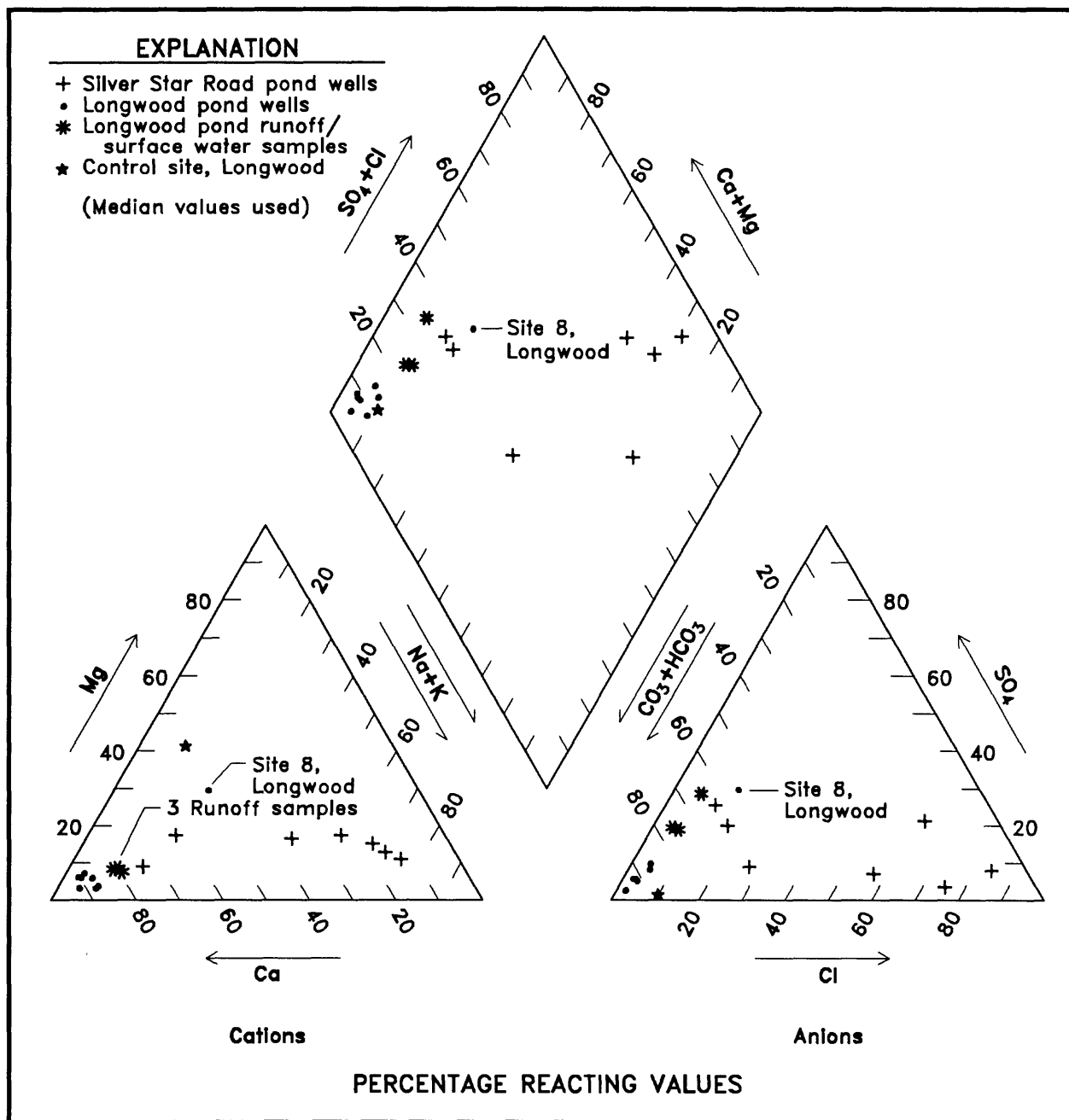


Figure 32.—Ionic composition of water from sampling sites at the Silver Star Road and Longwood pond study areas.

Table 12. — *Results of analysis of variance of rank data, grouped by data type, and multiple comparison test (TUKEY), Silver Star Road detention pond study area*

[p-value, the probability that observed differences are due to chance rather than to the sampling locations]

Hypothesis being tested by analysis of variance: Means of the two groups are equal.

Alternate hypothesis: One of the two group means differs.

Group G: Sites 1, 2, 3, 5, 7, 8.

Group C: Site 4 (control well).

An "x" in a column means that a significant difference was indicated between the means of the rank values of the groups indicated at the top of the column. For example, test results indicate that specific conductance (mean of rank values) was significantly higher in water from the control well site than in water from wells adjacent to the pond and wetland. If no symbol is shown, the test result indicated no significant difference.

| Dissolved constituent<br>or physical measure | Significant<br>difference | p-value | Multiple comparison test results |       |
|--|---------------------------|---------|----------------------------------|-------|
|  |                           |         | G > C                            | C > G |
| Specific conductance                         | Yes                       | 0.0212  |                                  | x     |
| pH—lab                                       | No                        | .5988   |                                  |       |
| Ammonia                                      | No                        | .2910   |                                  |       |
| Nitrite                                      | No                        | .5690   |                                  |       |
| Ammonia plus organic nitrogen                | No                        | .2494   |                                  |       |
| Nitrite plus nitrate nitrogen                | No                        | .8504   |                                  |       |
| Phosphorus                                   | No                        | .1493   |                                  |       |
| Orthophosphorus                              | No                        | .2870   |                                  |       |
| Total organic carbon                         | No                        | .4219   |                                  |       |
| Calcium                                      | No                        | .7302   |                                  |       |
| Magnesium                                    | No                        | .0808   |                                  |       |
| Sodium                                       | Yes                       | .0210   |                                  | x     |
| Potassium                                    | No                        | .8623   |                                  |       |
| Chloride                                     | Yes                       | .0210   |                                  | x     |
| Sulfate                                      | No                        | .1503   |                                  |       |
| Alkalinity                                   | No                        | .9315   |                                  |       |
| Chromium                                     | No                        | .3678   |                                  |       |
| Copper                                       | No                        | .2237   |                                  |       |
| Lead   | No                        | .1392   |                                  |       |
| Zinc   | No                        | .6317   |                                  |       |

However, this value is not high relative to State standards (5,000  $\mu\text{g/L}$ ) for drinking water (Florida Department of Environmental Regulation, 1982). The zinc concentrations at site 8 also were significantly higher than at the control well (site 9), but no significant difference was detected in mean concentrations between the group that included sites 1 to 7 (surficial aquifer system) and the control site. Because zinc is an ubiquitous element, the concentrations at site 8 probably are due to natural sources.

*Between study areas.*—A statistical test for differences in ground-water quality between the Silver Star Road pond area and the Longwood pond area also was used in data analysis. Any differences detected may be due to a number of factors, including land use, drainage area, traffic volume, and the design of the pond (wet or dry and detention or retention), which will affect the length of time water remains in the pond for sedimentation and biological and chemical processes to take place. Differences in water

Table 13.—*Results of analysis of variance of rank data, grouped by data type, and multiple comparison test (TUKEY), Longwood retention pond study area*

[p-value, the probability that observed differences are due to chance rather than to the sampling location]

Hypothesis being tested by analysis of variance: Means of the k data types are equal.

Alternate hypothesis: At least two of the data type means differ.

Data types are: S = runoff or water standing in pond; G = ground water under the pond, sites 1-7; D = ground water from site 8 (65-feet deep); C = ground water from site 9 (control well).

The less than (<) and greater than (>) symbols indicate the direction of the difference between the groups indicated at the top of the column. For example, a "<" symbol for specific conductance under the S:G column means that specific conductance was significantly lower in runoff or water standing in the pond than in water from the surficial aquifer system directly below the pond. If no symbol is shown, the test result indicated no significant difference.

| Dissolved constituent<br>or physical measure | Significant<br>difference | p-value | Multiple comparison test results |     |     |     |     |     |
|--|---------------------------|---------|----------------------------------|-----|-----|-----|-----|-----|
|  |                           |         | S:G                              | S:C | S:D | G:C | G:D | D:C |
| Turbidity                                    | No                        | 0.1073  |                                  |     |     |     |     |     |
| Color  | No                        | .0581   |                                  |     |     |     |     |     |
| Specific conductance                         | Yes                       | .0001   | <                                |     |     |     | >   |     |
| pH—field                                     | Yes                       | .0142   |                                  |     |     |     | >   |     |
| pH—lab                                       | Yes                       | .0003   |                                  |     |     |     | >   | <   |
| Ammonia                                      | No                        | .1938   |                                  |     |     |     |     |     |
| Nitrite                                      | Yes                       | .0087   | >                                |     |     |     |     |     |
| Ammonia plus organic nitrogen                | No                        | .4817   |                                  |     |     |     |     |     |
| Nitrite plus nitrate nitrogen                | No                        | .1704   |                                  |     |     |     |     |     |
| Phosphorus                                   | Yes                       | .0001   | >                                |     | >   | <   |     | <   |
| Orthophosphorus                              | Yes                       | .0001   | >                                |     | >   | <   |     | <   |
| Total organic carbon                         | No                        | .1689   |                                  |     |     |     |     |     |
| Calcium                                      | Yes                       | .0001   | <                                |     |     |     | >   |     |
| Magnesium                                    | Yes                       | .0294   |                                  | <   |     |     |     |     |
| Sodium                                       | Yes                       | .0470   |                                  | <   |     |     |     |     |
| Potassium                                    | Yes                       | .0211   |                                  |     | >   |     | >   |     |
| Chloride                                     | No                        | .0931   |                                  |     |     |     |     |     |
| Sulfate                                      | Yes                       | .0603   |                                  | >   |     |     |     |     |
| Alkalinity                                   | Yes                       | .0001   | <                                |     |     |     | >   | <   |
| Aluminum                                     | No                        | .0939   |                                  |     |     |     |     |     |
| Copper                                       | Yes                       | .0408   | >                                |     |     |     |     |     |
| Iron   | No                        | .1000   |                                  |     |     |     |     |     |
| Lead   | No                        | .2290   |                                  |     |     |     |     |     |
| Nickel                                       | No                        | .1704   |                                  |     |     |     |     |     |
| Zinc   | Yes                       | .0022   |                                  | >   |     |     | <   | >   |

quality may be related to aquifer materials, but in central Florida, most of the surficial aquifer system is fairly uniform throughout the area, and is comprised of quartz sand, with varying amounts of clay and shell (Lichtler, 1972). For statistical testing, ground-water data at sites 1 to 3 and 5 to 8 were pooled for the Silver Star Road pond, and at sites 1 to 7 for the Longwood pond.

Twenty-five constituents and physical measurements (the same as were listed in table 13) were tested. Chromium is not included in this

list because concentrations were always less than the laboratory detection limit of 1 µg/L (dissolved). Mean concentrations of ammonia and Kjeldahl nitrogen are significantly higher in ground water near the Silver Star Road pond than in ground water beneath the Longwood pond, but nitrate nitrogen is higher in ground water beneath the Longwood pond. This may be the result of a wet pond (Silver Star Road), which may have a reducing environment at the soil-water interface, compared to a dry pond

(Longwood), with an abundance of oxygen at the soil surface (oxidizing environment), which allows the oxidation of nitrogen to nitrate nitrogen. Also higher in ground water at the Silver Star Road pond than in ground water at the Longwood pond are mean concentrations of sodium and chloride (this also is indicated in the Piper and Stiff diagrams in figs. 30 and 32), total organic carbon, nickel, and aluminum. At the Longwood pond, only pH, nitrate nitrogen, and alkalinity values were significantly higher than in ground water at the Silver Star Road pond.

### Sediment Analysis

Sediment samples were collected at both pond study areas and analyzed for constituent concentrations. Nine locations in the pond at the Silver Star Road pond were sampled three times, for a total of 27 samples, and three locations were sampled once each at the Longwood pond. A statistical summary of the analyses is shown in table 14. Sediments serve as a reservoir for many constituents, retarding the migration of constituents to ground water. Values for most

constituents were higher in sediments in the Silver Star Road pond (table 14), with the exception of manganese.

At the Longwood pond, other sediment-related work also was completed, including the analysis of sediments from three locations for priority pollutants, sediment sizing and analysis of clay mineralogy for cores obtained during drilling of the 65-foot deep well (site 8). High concentrations (in the range of thousands of micrograms per kilogram) of several organic compounds were present in all three sediment samples. All the organic compounds were PAHs, specifically, fluoranthene, chrysene, benzo-A-pyrene, benzo-K-fluoranthene, benzo-A-anthracene, and other related compounds. Most of these compounds are petroleum or coal-tar derivatives (associated with pavement), and also are related to fossil fuel combustion (automobiles), which indicates that the most likely source of these compounds is the highway and parking lot runoff entering the pond. However, identification of these organic compounds in the sediment does not indicate their presence in the underlying ground water.

Table 14. — *Range of concentrations of selected constituents in bottom sediments at both detention and retention pond study areas*

[Concentrations are in micrograms per gram, unless otherwise noted. mg/kg, milligrams per kilogram; --, denotes no sample or value]

| Constituent                  | Silver Star Road<br>detention pond (9 sites) |    |        |       | Longwood<br>retention pond (3 sites) |    |        |        |
|------------------------------|--|----|--------|-------|--------------------------------------|----|--------|--------|
|                              | Range  |    | Median |       | Range                                |    | Median |        |
| Volatile solids (mg/kg)      | --   | -- | --     | --    | 13,300                               | -- | 55,400 | 32,300 |
| Nitrogen, as N               |  |    |        |       |                                      |    |        |        |
| Ammonia (mg/kg)              | 15   | -- | 230    | 92    | 6.6                                  | -- | 13     | 8.1    |
| Ammonia plus organic (mg/kg) | 470  | -- | 33,000 | 4,100 | 1,300                                | -- | 3,000  | 1,600  |
| Nitrite plus nitrate (mg/kg) | 2  | -- | 110    | 9     | --                                   | -- | --     | --     |
| Phosphorus, as P (mg/kg)     | 280  | -- | 1,800  | 1,100 | --                                   | -- | --     | --     |
| Cadmium                      | 1  | -- | 9      | 6     | 1                                    | -- | 1      | 1      |
| Chromium                     | 2  | -- | 240    | 20    | 3                                    | -- | 6      | 4      |
| Cobalt                       | 10   | -- | 10     | 10    | --                                   | -- | --     | --     |
| Copper                       | 1  | -- | 130    | 49    | 4                                    | -- | 18     | 13     |
| Lead                         | 10   | -- | 2,000  | 620   | 20                                   | -- | 470    | 200    |
| Manganese                    | 23   | -- | 35     | 29    | 60                                   | -- | 580    | 250    |
| Zinc                         | 1  | -- | 1,100  | 250   | 52                                   | -- | 120    | 100    |
| Iron                         | 1,800  | -- | 4,900  | 4,400 | 180                                  | -- | 1,300  | 830    |



FID scans of water samples from sites 1, 2, and 6 at the Longwood pond indicated possible concentrations of some organics in ground water at concentrations ranging from 1 to 5  $\mu\text{g/L}$  in water from site 1, and less than detection levels (1  $\mu\text{g/L}$ ) at sites 2 and 6. From this limited sampling, it seems that the organic compounds detected in the sediments have not yet migrated to the ground water.

Sediment cores were obtained during drilling of the deep well at the Longwood pond (site 8), and selected cores were analyzed for particle-size distribution and clay mineralogy by the Department of Geology, University of South Florida. The description of the sediment cores and sediment-size distribution information is listed in table 15. Three cores were analyzed for clay mineralogy: 0 to 1 foot, 5 to 6.5 feet, and 70 to 71.5 feet below land surface. The clays in the upper cores were predominately kaolinite (70 to 85 percent), and showed evidence of having been formed under acidic soil environments. The clays in the 70- to 71.5-foot deep core were predominately smectite (80 percent), a clay that has much greater adsorption properties and very low permeability. The cation exchange capacity of the upper 12 inches of soil was estimated to be only 1 milliequivalent per hundred grams of sample, but the smectite in the 70- to 71.5-foot sample raised the cation exchange capacity to 15 milliequivalents per hundred grams of sample. The small percentage of clays in the upper soils of the pond bottom probably do not account for much of the attenuation of constituents as water moves downward, but the high percentage of sand-sized particles allow rapid infiltration, which was observed during the study.

### Swales

Ground-water samples were collected for water-quality analysis from wells at the Princeton Street swale study area from June 1984 through April 1986. One runoff sample was collected in July 1986 (table 5). Water-quality samples were collected from wells at the swale study area north of Longwood, during the third year of the study (1986), but no runoff sample was obtained at this location. Sediment samples were collected at both swale areas, and one sample was collected at each swale for FID scan analysis.

Well depths at the Princeton Street swale study area vary from 13 feet (sites 1, 2, 3, and 5) to 24 feet (sites 6, 7, and 8). The well at site 4 is 19-foot deep, and at site 9 the well is 20-foot deep.

Drill cuttings indicated a thin (less than 1 foot) clay layer at the southern end of the swale, approximately 14 feet below land surface. However, clay was not found at the other sites (sites 3 and those north of site 3). Some water-quality differences between sites at different depths may be due to the presence of this clay layer.

All wells at the Longwood swale are 23 feet deep, except the control well, which is 34.5 feet deep. Mounding due to stormwater infiltration was evident from water-level measurements (fig. 33). The sampling depth below the water table varied among the wells. The greatest depth in the saturated zone that was sampled was at site 3, and sampling sites nearest the water table were sites 1 and the control site.

### Water-Quality Variations

Ranges in values of selected constituents and water-quality measures for sites at the Princeton Street and Longwood swale locations are shown in figures 34 through 36. One stormwater sample collected at the Princeton swale study area also is shown in the figures. Sites at Princeton are grouped by depth, thus sites 1, 2, 3, and 5 are listed before site 4 and sites 6 through 9.

A trend is not apparent in specific conductance of ground water in the more shallow wells at Princeton, but conductance apparently increases downgradient in the deeper wells (sites 8, 7, and 6) (fig. 34). Ground water below the swale tends to have lower specific conductance values than ground water upgradient at the control well site, probably because of the volume of water infiltrating at the swale compared to what infiltrates naturally at the control site. Although stormwater runoff may initially have high specific conductance values, after the initial "first flush" of water off road surfaces, specific conductance values tend to decrease and eventually approach values found in rainfall. This also may be the reason for the higher specific conductance values at site 1 at the Longwood swale. Site 1, which is halfway up a hillside that forms part of the swale (fig. 33), has the greatest depth to water of all the wells located in the swale (18 feet), and is not in a location where water would tend to pond, as it does at sites 2, 3, and 4. The control site (site 5) does not have similarly high conductance values, although it also does not receive infiltrating runoff and has a greater depth to water (33 feet) than site 1. Specific conductance values at sites 2 to 4 are similar to values at the control well site.

Table 15.—*Description of core samples and grain size analysis, Longwood retention pond, site 8*

[Analysis done by University of South Florida, Department of Geology, Tampa, Florida.  
-- denotes no data.]

Size categories:

Sand: 2–0.063 millimeters  
Silt: 63–3.9 micrometers  
Clay: < 3.9 micrometers

| Depth below<br>land surface | Description of sediments   | Percentage |      |      |
|-----------------------------|--|------------|------|------|
|                             |  | Sand       | Silt | Clay |
| 0 inch to 0.5 inch          | Brown silty sand, abundant leaf fragments.   | --         | --   | --   |
| 0.5 inch to 1 inches        | Clean sand.  | --         | --   | --   |
| 1 inch to 2 inches          | Organic peat, clayey, black.   | --         | --   | --   |
| 2 inches to 12 inches       | Sand, medium to fine, angular to subangular, light gray to gray, occasional orange stained horizons - contains clay layer at approximately 1/2 inch intervals.   | 88         | 3    | 9    |
| 5 feet to 6.5 feet          | Slightly clayey fine sand, very pale orange to very pale orange brown, faintly laminated with darker zones (more clay) approximately 1/4 inch thick.   | 89         | 3    | 8    |
| 10 feet to 10.33 feet       | Sand, medium to fine, subangular to subrounded, pale range gray, becoming slightly darker.   | --         | --   | --   |
| 10.33 feet to 10.83 feet    | Sand, medium to fine, light orange gray.   | 92         | 0    | 8    |
| 10.83 feet to 11.5 feet     | Sandy, muddy, mottled, medium gray to tan, clay content variable, faintly laminated.   | --         | --   | --   |
| 15 feet to 16.5 feet        | Sand, medium to fine, light brown to very light brown, mottled nonlaminated, but faintly laminated near bottom of interval.  | 95         | 2    | 3    |
| 16.5 feet to 70 feet        | Cores not analyzed - all seem to be same as 15 feet to 16.5 feet interval.   | --         | --   | --   |
| 70 feet to 71.5 feet        | Clay, sand, phosphatic, pale grayish green mottled with limonite zone and white blebs aluminum phosphate species. No internal primary depositional features apparent, dry core, dense and rocklike, slacks rapidly on wetting. | 68         | 3    | 29   |

The same pattern seen in specific conductance values at the Longwood swale also is evident for field pH values, although the range in values is greater at sites 2 to 5 (fig. 34). Ground water at both swales is acidic, sometimes reaching values below 4.5. Values of pH generally are lower in water from the deeper wells at the Princeton swale than in ground water at shallower depths, possibly indicating a more reducing environment below the clay layer.

Dissolved phosphorus values at both swales generally are low (<0.2 mg/L), but occasionally high values were found at site 1, Princeton Street, and site 5, Longwood (fig. 35). Although higher dissolved phosphorus was measured at site 1 (Princeton Street swale), the median value was

not much different from medians at other sites. The high concentrations measured in ground water at the control site (0.42 to 1.5  $\mu\text{g/L}$ ), Longwood swale, may have originated from fertilizer leaching from an adjacent abandoned orange grove.

The predominate form of nitrogen in ground water at the Princeton Street swale study area is nitrate nitrogen (table 16). Nitrite nitrogen frequently was below detection limits, so most of the nitrate plus nitrite is nitrate nitrogen. Nitrate is the main form in which nitrogen occurs in ground water (Freeze and Cherry, 1979). Nitrate values are more variable at sites at the Princeton Street swale than at individual sites at the Longwood swale, although the highest nitrate

values were measured at site 2 at the Longwood swale. With the exception of site 2, the majority of nitrogen in ground water at the Longwood swale is in the Kjeldahl form, and of this, organic nitrogen is dominant. Although not shown, Kjeldahl nitrogen concentrations are similar at all sites at the Longwood swale (including site 2).

Dissolved zinc in ground water at the swale study areas generally is less than  $100 \mu\text{g/L}$  (fig. 36). Zinc values are slightly more variable in ground water beneath the swale than at the control site at Princeton Street.

Higher and more variable zinc values were measured at site 1 than at other sites at the Longwood swale. This pattern, seen in specific conductance and pH values, also occurs in dissolved iron values (fig. 36). Dissolved iron concentrations under the Longwood swale vary more ( $180$  to  $1,500 \mu\text{g/L}$ ) and median values are higher than all dissolved iron concentrations at the control well site ( $40$  to  $140 \mu\text{g/L}$ ). Whereas

iron values also are more variable in ground water under the Princeton Street swale than at the control well site of that swale, iron tends to be much lower in ground water beneath the swale. These dissolved iron concentrations are much higher than what is allowed ( $300 \mu\text{g/L}$ ) by drinking water standards (Florida Department of Environmental Regulation, 1982), but iron commonly is present at higher concentrations in water in the surficial aquifer system than in water in the Floridan aquifer system. The iron in highway runoff (in the suspended form, which dissolves after entering the swale or pond) may be contributing to these high values, but it also may be a natural occurrence.

From these figures no clear trend is apparent in constituent concentrations or physical measures in the ground water near these swales. Occasionally, higher concentrations were measured in samples from the control wells (phosphorus at the Longwood swale and iron at the Princeton Street swale).

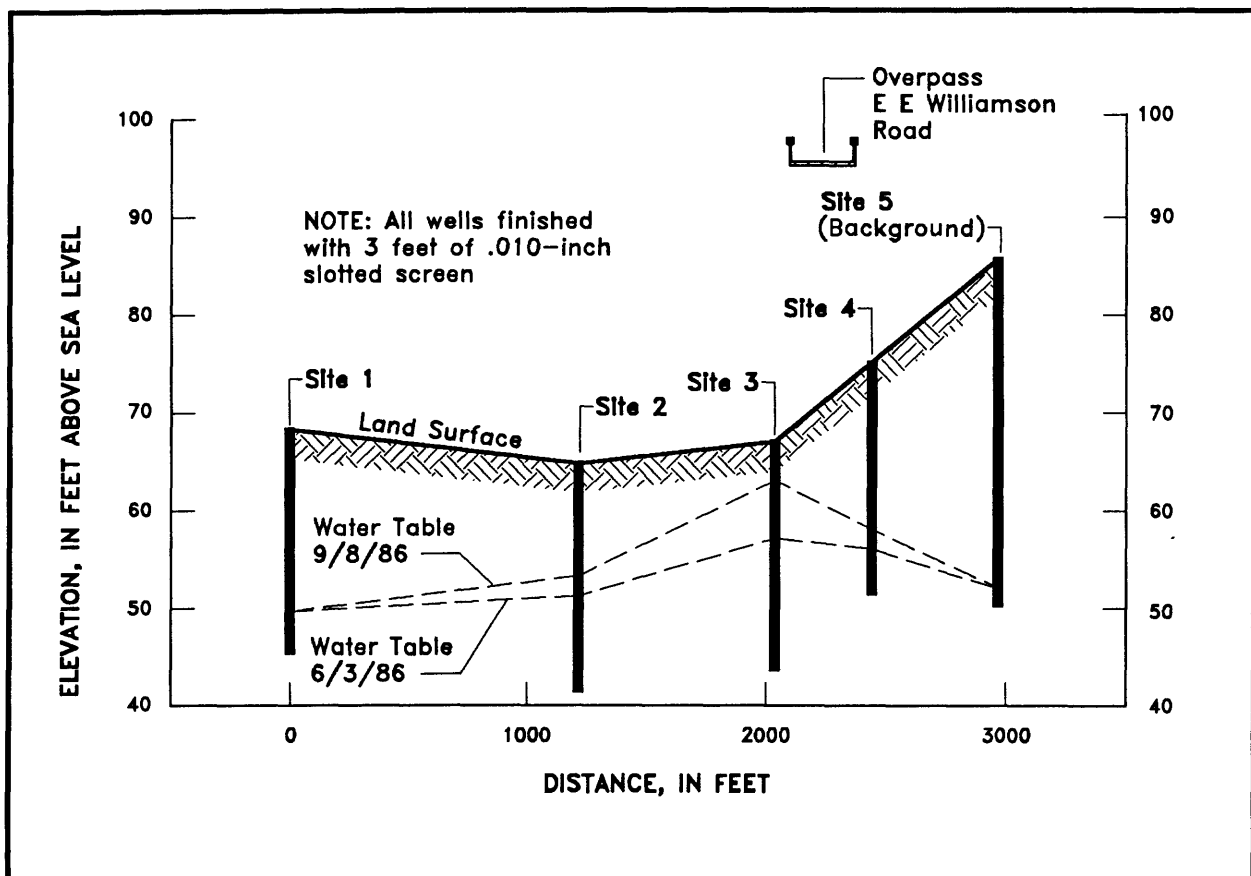


Figure 33.--Longitudinal section of Longwood swale.

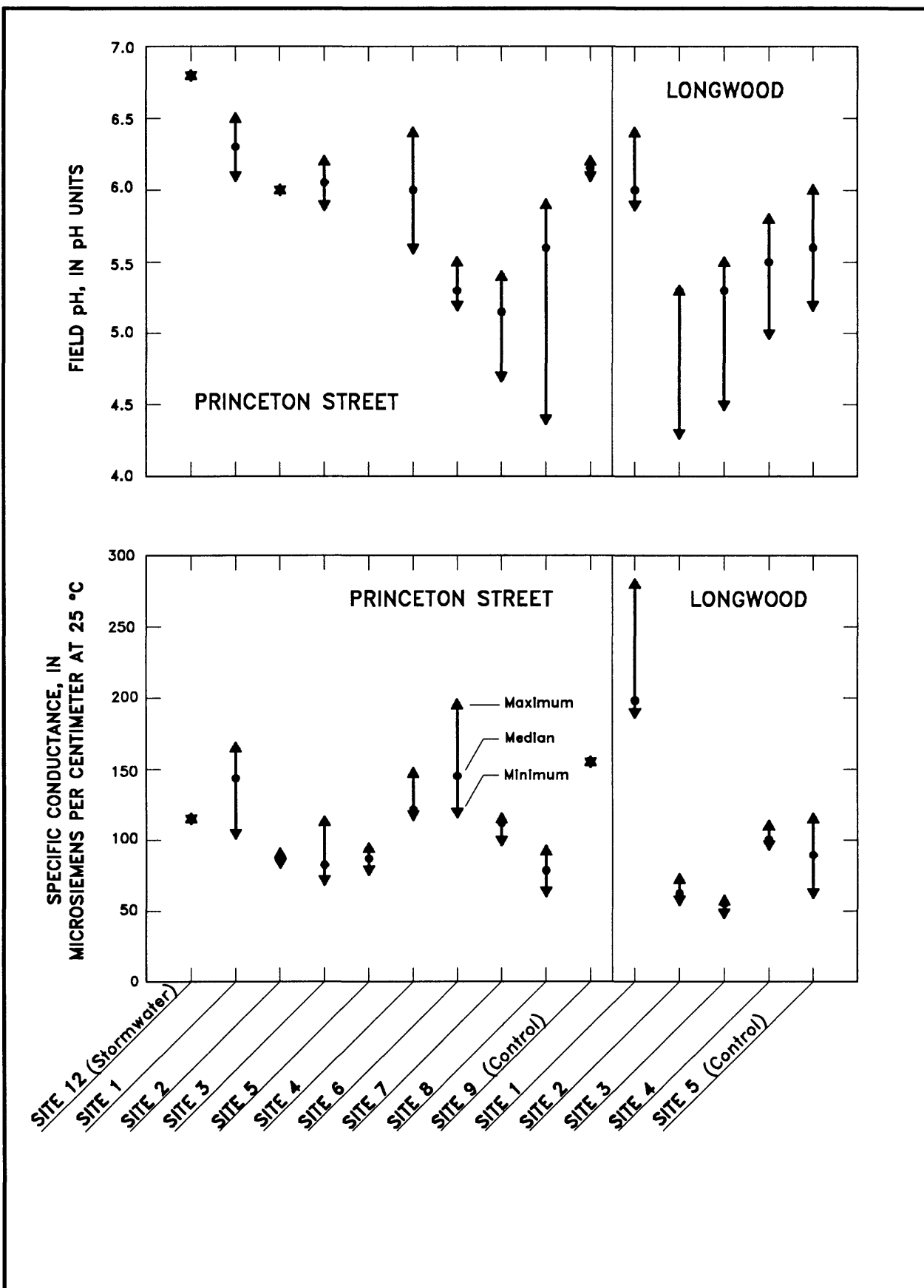


Figure 34.—Field pH and specific conductance at sampling sites at the two swale study areas.

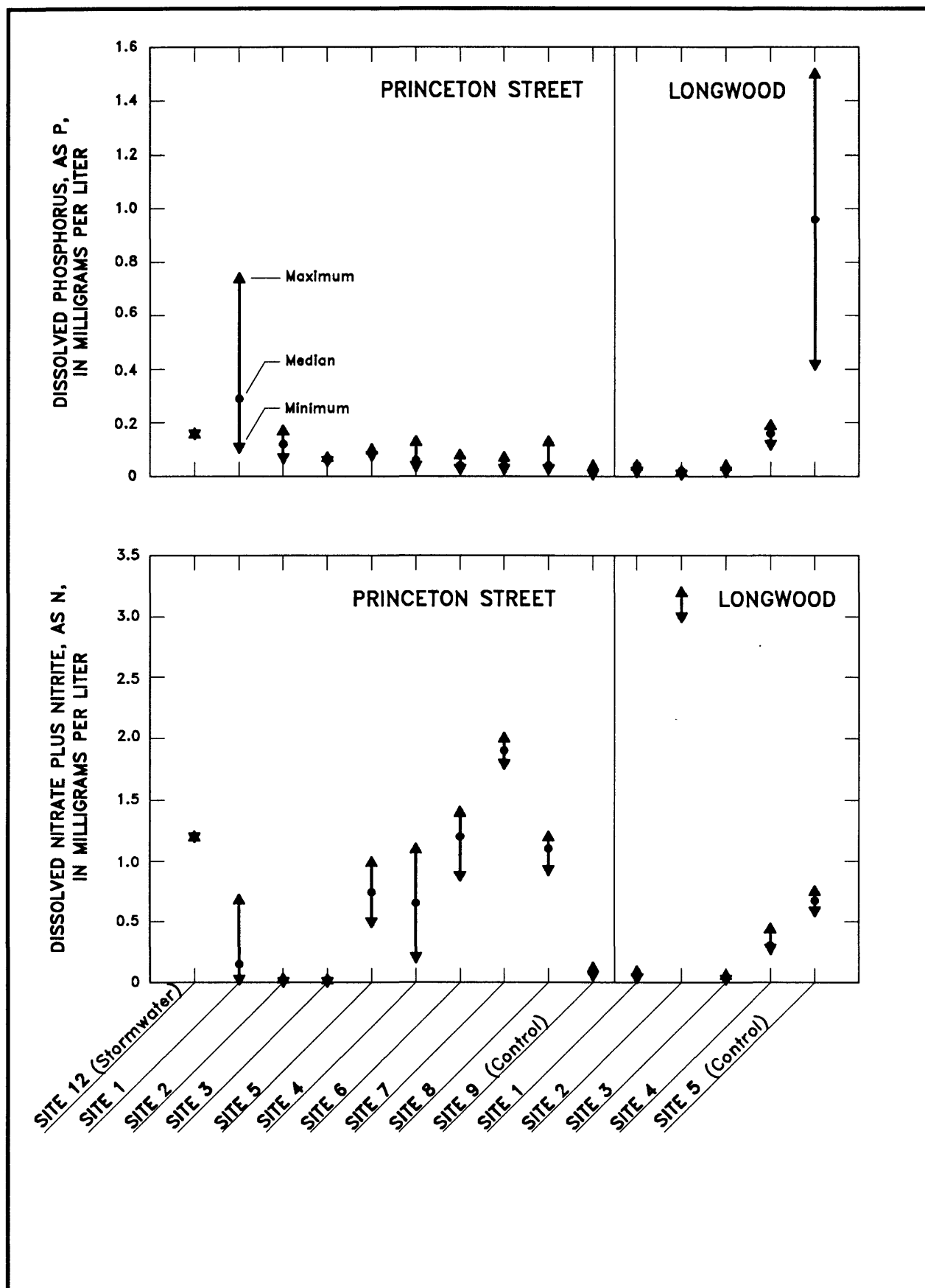


Figure 35.--Dissolved nitrate plus nitrite nitrogen and dissolved phosphorus at sampling sites at the two swale study areas.

Table 16. — *Statistical summary of concentrations of selected constituents in ground water at Princeton Street and Longwood swale study areas*

[Control sites are not included. Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter]

| Constituent or physical property                         | Princeton Street swale |       |   |      |        | Longwood swale     |       |   |       |        |
|--|------------------------|-------|---|------|--------|--------------------|-------|---|-------|--------|
|  | Ground-water sites     |       |   |      |        | Ground-water sites |       |   |       |        |
|  | No. of samples         | Range |   |      | Median | No. of samples     | Range |   |       | Median |
| Turbidity (NTU)  | 38                     | 0.2   | — | 370  | 4      | 12                 | 0.5   | — | 150   | 3.05   |
| Color (Pt-Co units)                                      | 37                     | < 5   | — | 10   | < 5    | 12                 | < 5   | — | 10    | < 5    |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | 40                     | 64    | — | 195  | 113    | 12                 | 49    | — | 280   | 84     |
| Field pH (pH units)                                      | 22                     | 4.4   | — | 6.5  | 5.6    | 12                 | 4.3   | — | 6.4   | 5.4    |
| Lab pH (pH units)  | 39                     | 4.9   | — | 6.7  | 5.8    | 11                 | 5.1   | — | 6.8   | 5.9    |
| Nitrogen species, as N:                                  |                        |       |   |      |        |                    |       |   |       |        |
| Ammonia  | 39                     | .01   | — | .14  | .02    | 12                 | .01   | — | .34   | .03    |
| Nitrite  | 40                     | < .01 | — | .07  | < .01  | 12                 | < .01 | — | .01   | < .01  |
| Ammonia plus organic                                     | 39                     | .05   | — | .70  | .15    | 12                 | .12   | — | .53   | .20    |
| Nitrite plus nitrate                                     | 40                     | < .01 | — | 2    | .98    | 12                 | .03   | — | 3.2   | .18    |
| Phosphorus, as P   | 40                     | .03   | — | .74  | .06    | 12                 | .01   | — | .19   | .03    |
| Orthophosphorus, as P                                    | 40                     | .01   | — | .39  | .03    | 12                 | .01   | — | .18   | .02    |
| Total organic carbon                                     | 39                     | < .1  | — | 11   | 1.10   | 12                 | .1    | — | 6.5   | .5     |
| Calcium  | 40                     | .37   | — | 18   | 5.15   | 12                 | .98   | — | 35    | 3.05   |
| Magnesium  | 40                     | .47   | — | 2.7  | 1.75   | 12                 | .97   | — | 6.4   | 3.25   |
| Sodium   | 40                     | 1.5   | — | 29   | 9.2    | 12                 | 2     | — | 5.3   | 2.75   |
| Potassium  | 39                     | .2    | — | 3.4  | .9     | 12                 | .2    | — | 2.8   | .7     |
| Chloride   | 39                     | 1.8   | — | 29   | 14     | 12                 | 3.4   | — | 11    | 7.25   |
| Sulfate  | 39                     | .7    | — | 32   | 18     | 12                 | 1.1   | — | 16    | 8.6    |
| Alkalinity, as $\text{CaCO}_3$                           | 39                     | 1     | — | 23   | 8      | 12                 | 3     | — | 115   | 6      |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | 27                     | < 10  | — | 160  | 20     | 12                 | < 10  | — | 100   | 30     |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | 35                     | < 1   | — | 30   | < 1    | 12                 | < 1   | — | 2     | < 1    |
| Copper ( $\mu\text{g}/\text{L}$ )                        | 36                     | < 1   | — | 8    | 2      | 12                 | < 1   | — | 9     | < 2.5  |
| Iron ( $\mu\text{g}/\text{L}$ )                          | 40                     | 3     | — | 980  | 22     | 12                 | 180   | — | 1,500 | 815    |
| Lead ( $\mu\text{g}/\text{L}$ )                          | 40                     | < 1   | — | < 10 | < 1    | 12                 | 2     | — | < 5   | < 5    |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | 35                     | < 1   | — | 6    | < 1    | 12                 | < 1   | — | 7     | 2      |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 40                     | 4     | — | 740  | 19     | 12                 | 10    | — | 170   | 34.5   |

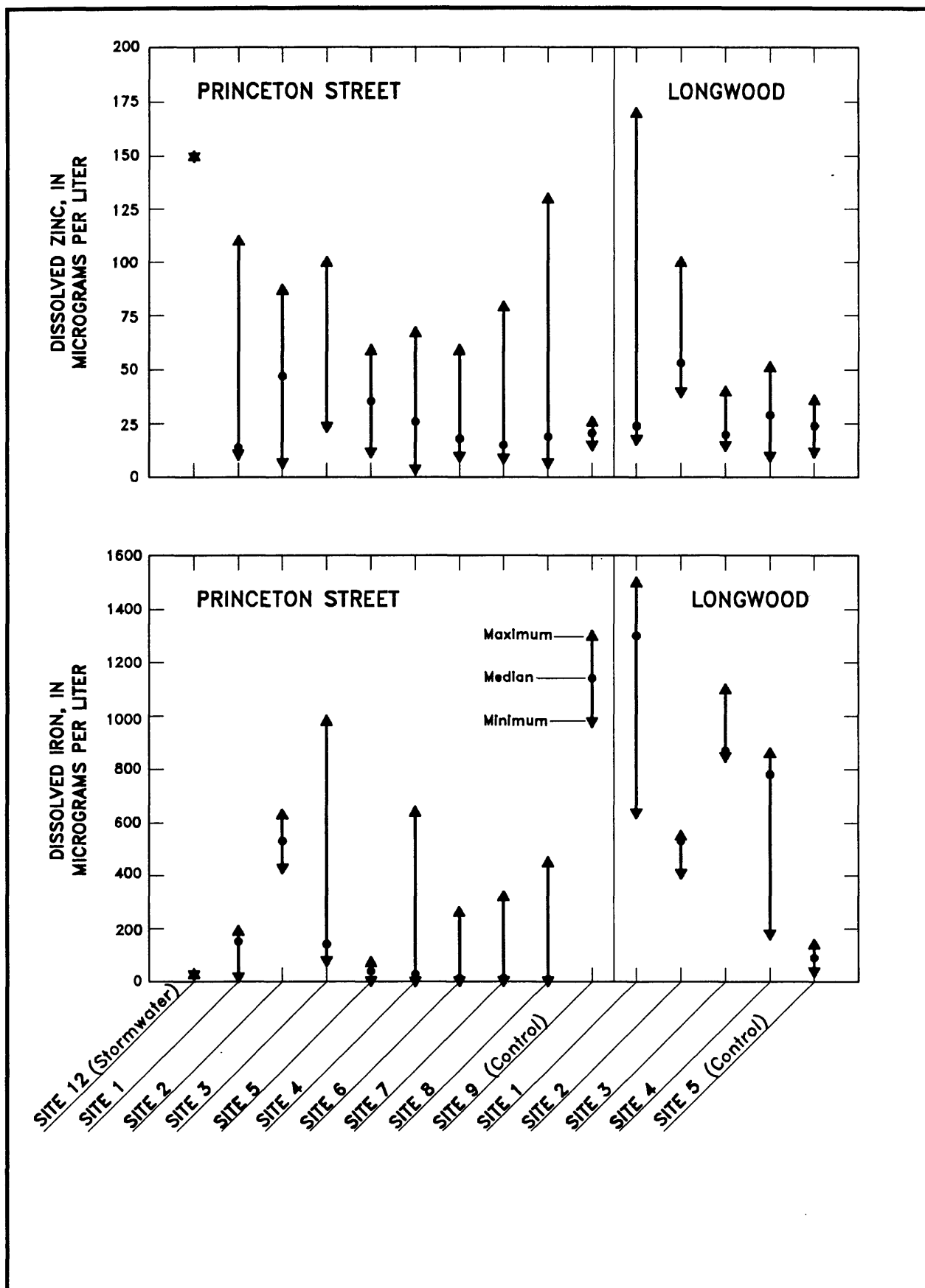


Figure 36.—Dissolved Iron and dissolved zinc at sampling sites at the two swale study areas.

Concentrations of major ions in ground water at both swales also were measured, and these may more reliably indicate changes in water quality than other constituents because of their conservative nature. Stiff diagrams are shown for both swale study areas in figures 37 and 38.

Major ions in ground water at the Princeton Street swale are shown in figure 37. Sites 1 to 3 and site 5 are all the same depth, and all have similar distributions of ions in water samples from the sites. Site 4 is slightly deeper, but the ionic composition of water is also similar to that of the other shallow wells, and all of these resemble the diagram for stormwater (site 12). Water from sites 8, 7, and 6 (moving downgradient) have higher sodium chloride concentrations than water from the shallower wells, and may be indicating the difference in water quality above and below the observed clay layer at this swale. The pattern displayed by the ionic composition of water from site 1 differs from that shown for water from site 7, although they are almost in the same location in the swale. This also is true for sites 2 and 8. This ionic difference may be a result of differing well depths (sites 1 and 2, 13 feet, and sites 7 and 8, 24 feet). This difference was not detected between ground water from sites 3 and 4, possibly because no clay was found during drilling at these sites. The ionic composition of ground water from shallower depths (sites 1 to 5) is more similar to the ionic composition of the incoming runoff (site 12), which is a calcium bicarbonate water. However, ground water from greater depths (sites 6 to 8) seems to be a sodium chloride type. Water from the control well site seems to be more evenly distributed ionically (roughly equal parts calcium and sodium cations, and bicarbonate and sulfate anions).

The distribution of major ions in ground water beneath the Longwood swale (fig. 38) is dissimilar among sampling sites. Concentrations of ions in rainfall at Lake Hope, Maitland, Fla., were plotted to show the type of distribution commonly found in rainwater--primarily calcium carbonate with some sodium and chloride. However, the concentrations in rainwater are much lower than what is typical of ground water.

The wells at the Longwood swale differ from each other in the depth of screened interval below the water table. At site 1, the screen is 2 feet below the water table, but at site 3, the water level is only 4 feet below land surface, and the

screened interval is 13 feet below the water table (fig. 33). The screened interval at site 2 is 8 feet below the water table, and the depth of the screened interval at site 4 is similar to that at site 1 (3 feet below the water table). Some differences in water quality might be attributable to depth in the surficial aquifer system. The Stiff diagram for water from site 3, the deepest well in reference to the water table, resembles the Stiff diagrams for water from sites at the Princeton Street swale that also tapped greater depths in the aquifer (sites 6 to 8). The high nitrate nitrogen concentrations measured at site 2 of the Longwood swale makes a noticeable contribution to the Stiff diagram. All the Stiff diagrams for ground water beneath the swale seem to significantly differ from the diagram for water from the control well site.

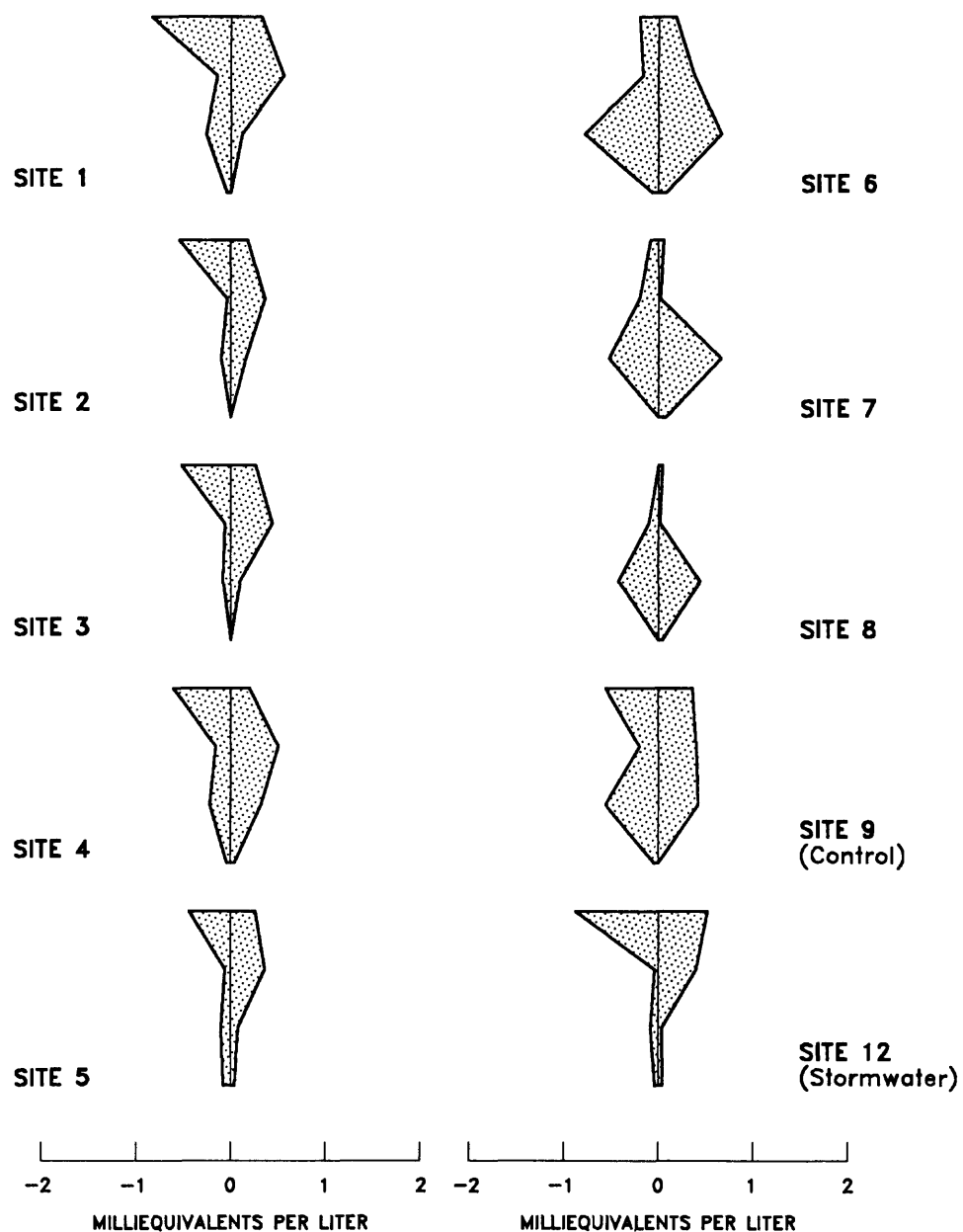
The quality of ground water below the Princeton Street and Longwood swales is summarized in table 16. This summary includes all ground-water sampling sites near each swale, excluding the control well sites. Only a few isolated values are high and were discussed previously in this report. Most metals, with the noticeable exception of iron, are present in low concentrations beneath the swales.

In August 1986 ground-water samples were collected at each swale study area for FID scan analysis. Site 3 was sampled at the Longwood swale, and site 5 at the Princeton Street swale. The water sample from the Longwood swale contained detectable concentrations of organic compounds estimated in the 1 to 20  $\mu\text{g/L}$  range and, based on the scan, these compounds are probably PAHs. The water sample from the Princeton Street swale did not contain detectable concentrations of organic compounds.

### Statistical Comparisons

*Among data types.*--Statistical techniques were again utilized to detect any significant differences among sampling locations (denoted as data types for analysis). Analysis of variance methods were used to detect significant differences among data types, then TUKEY's multiple comparison technique was used to determine where differences occurred. As before, values of selected water-quality variables were converted to rank values before statistical testing proceeded. As expected, the statistical test results generally verified what was observed about the data from the figures already presented.

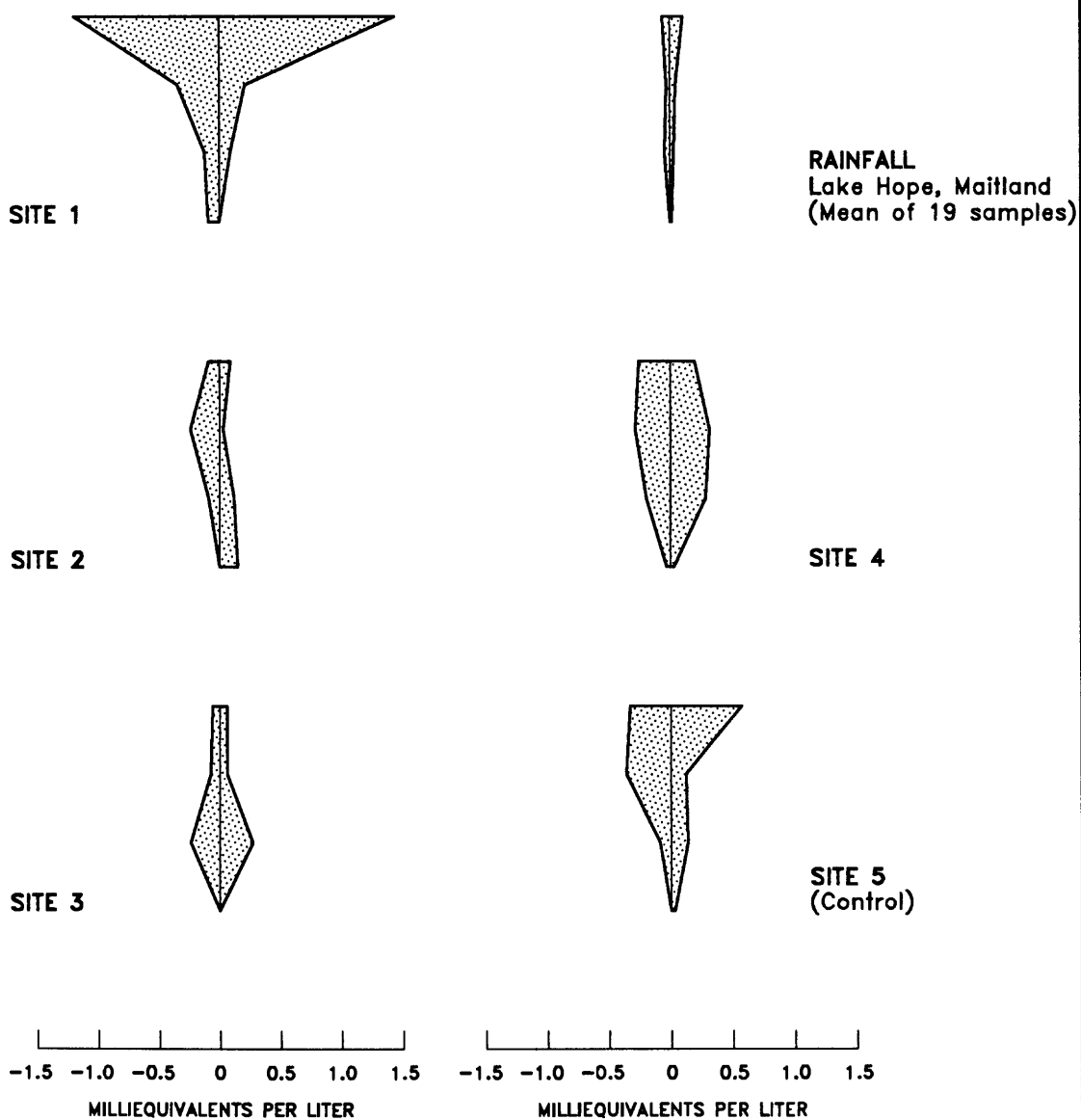




#### EXPLANATION

|           |   |              |
|-----------|---|--------------|
| Calcium   | — | Bicarbonate  |
| Magnesium | — | Sulfate      |
| Sodium    | — | Chloride     |
| Potassium | — | Nitrate as N |

Figure 37.—Ionic composition of water from sampling sites at the Princeton Street and Interstate 4 swale. (Median values used except for stormwater.)



#### EXPLANATION

|           |   |              |
|-----------|---|--------------|
| Calcium   | — | Bicarbonate  |
| Magnesium | — | Sulfate      |
| Sodium    | — | Chloride     |
| Potassium | — | Nitrate as N |

Figure 38.--Ionic composition of water from sampling sites at the Longwood swale. (Median values used except for rainfall.)

At the Longwood swale study area, only two data types were available for testing--ground water beneath the swale and ground water from the control well site. Data for sites 1 to 4 were pooled and compared to data for site 5 (control well). Results of the ANOVA test and TUKEY's test are listed in table 17. Mean concentrations of 4 of the 26 water-quality variables are significantly different between ground water near the swale and ground water from the control well site: phosphorus, orthophosphorus, sodium, and iron. The difference in phosphorus has already been noted in figure 35 as has the difference in iron (fig. 36). Mean sodium concentrations in water from sites 3 and 4 (5 and 4 mg/L, respectively) are twice the mean sodium concentration of water from the control well (2.0 mg/L); this difference probably led to the significant test result for sodium between the two groups (ground water below the swale and water from the control well).

At the Princeton Street swale study area, ground water at the swale was treated as one data type and compared to ground water at the control site, and runoff entering the swale. Water-quality data for sites 1 to 8 were pooled for the analysis. In some isolated cases, the ANOVA test sometimes indicated significant differences although the TUKEY test procedure did not (table 18). This situation occurred for laboratory pH and alkalinity values at this study area, but did not occur during statistical testing at any of the other four study areas. The reason for this result is the difference between the two tests (ANOVA and TUKEY) in how they control the error rate (which is a maximum of alpha, the test significance level). This is discussed in the SAS reference, and will not be covered here (refer to SAS Institute, Inc., 1982, p. 170-171).

There were no significant differences in mean concentrations among locations, with a few exceptions. The mean nitrite nitrogen concentration is significantly higher in runoff than in ground water (beneath the swale and at the control well site), an expected result because nitrite is converted to nitrate very rapidly, and usually is present in very low concentrations in ground water. The concentration of magnesium is higher in runoff than the mean concentration in ground water at the control site, but no difference was indicated between magnesium in ground water beneath the swale and from the control

well site. Of the metals, only mean iron concentrations are significantly different among the data types, and are higher in ground water at the control site than in ground water beneath the swale, also indicated in figure 36.

**Between study areas.**--A t-test was used to statistically test data at both swale study areas to determine if there are significant differences between ground water quality beneath the two swales. As with the ground water near the ponds, it is recognized that many factors may be responsible for any significant differences that may be detected. Rank data for 25 water-quality variables were tested. Chromium (dissolved) was not included because earlier analyses (at Princeton Street swale) had a higher detection level (10  $\mu\text{g/L}$ ), and could not be compared to values obtained at the Longwood swale (detection level of 1  $\mu\text{g/L}$ ). Ground-water quality data at each swale study area were pooled, excluding data from the control well site at each. At the Princeton Street swale, this included sites 1 to 8, and at the Longwood swale, sites 1 to 4.

Mean concentrations of 6 of the 25 water-quality variables were significantly higher in ground water at the Princeton Street swale study area. These dissolved constituents are: Kjeldahl nitrogen, phosphorus, orthophosphorus, sodium, chloride, and sulfate. Some of these differences may be due to the amount of traffic on the highway at the Princeton Street swale area and the culvert flow (compared to overland flow at the Longwood swale). Only dissolved iron was higher in ground water beneath the Longwood swale than beneath the Princeton Street swale.

### Sediment Analysis

Sediment samples were collected at both swale study areas, at two locations and at two depths at each location. The locations of the sediment sampling sites are shown in figure 12 (Princeton swale) and figure 14 (Longwood swale). At each of these sampling sites, sediment from the top 2 inches of soil, and 4 to 6 inches below the land surface was collected for analysis of nutrients and metals. Generally, constituent concentrations in sediments are lowest at the sampling site furthest from the highway, and concentrations decrease from the top 2 inches to the 4- to 6-inch interval (table 19). There are some exceptions to this, notably the phosphorus

Table 17. – *Results of analysis of variance of rank data, grouped by data type, and multiple comparison test (TUKEY), Longwood swale study area*

[p-value, the probability that observed differences are due to chance rather than to the sampling location]

Hypothesis being tested by analysis of variance: Means of the two groups are equal.

Alternate hypothesis: One of the two group means differ.

Group G: Sites 1-4.

Group C: Site 5.

An "x" in a column means that a significant difference was indicated between the means of the rank values of the groups indicated at the top of the column. For example, the mean of the ranks of dissolved phosphorus concentrations were significantly greater in water from the control site (site 5) than in water from the surficial aquifer system beneath the swale (sites 1-4). If no symbol is shown, the test result indicated no significant difference.

| Dissolved constituent<br>or physical measure | Significant<br>difference | p-value         | Multiple comparison test results |       |
|--|---------------------------|-----------------|----------------------------------|-------|
|  |                           |                 | G > C                            | C > G |
| Turbidity                                    | No                        | 0.1508          |                                  |       |
| Color  | No                        | .9235           |                                  |       |
| Specific conductance                         | No                        | .7305           |                                  |       |
| pH – field                                   | No                        | .7950           |                                  |       |
| pH – lab                                     | No                        | .1146           |                                  |       |
| Ammonia                                      | No                        | .5268           |                                  |       |
| Nitrite                                      | <sup>1</sup> --           | <sup>1</sup> -- |                                  |       |
| Ammonia and organic nitrogen                 | No                        | .0862           |                                  |       |
| Nitrite and nitrate nitrogen                 | No                        | .2898           |                                  |       |
| Phosphorus                                   | Yes                       | .0187           |                                  | x     |
| Orthophosphorus                              | Yes                       | .0137           |                                  | x     |
| Total organic carbon                         | No                        | .9292           |                                  |       |
| Calcium                                      | No                        | .6034           |                                  |       |
| Magnesium                                    | No                        | .7305           |                                  |       |
| Sodium                                       | Yes                       | .0498           | x                                |       |
| Potassium                                    | No                        | .8626           |                                  |       |
| Chloride                                     | No                        | .4869           |                                  |       |
| Sulfate                                      | No                        | .8634           |                                  |       |
| Alkalinity                                   | No                        | .2859           |                                  |       |
| Aluminum                                     | No                        | .6001           |                                  |       |
| Chromium                                     | No                        | .1383           |                                  |       |
| Copper                                       | No                        | .5884           |                                  |       |
| Iron   | Yes                       | .0212           | x                                |       |
| Lead   | No                        | .5424           |                                  |       |
| Nickel                                       | No                        | .5283           |                                  |       |
| Zinc   | No                        | .3835           |                                  |       |

<sup>1</sup>All values were less than, or equal to, the detection limit for dissolved nitrite.

Table 18. — *Results of analysis of variance of rank data, grouped by data type, and multiple comparison test (TUKEY), Princeton Street swale study area*

[p-value, the probability that observed differences are due to chance rather than to the sampling location]

Hypothesis being tested by analysis of variance: Means of the k data types are equal.

Alternate hypothesis: At least two of the data type means differ.

Data types are:

S: runoff to swale

G: sites 1-8

C: site 9

The less than (<) and greater than (>) symbols indicate the direction of the difference between the groups indicated in that column. For example, a "<" symbol for nitrite under the G:S column means that the mean of the ranks of dissolved nitrite concentrations was significantly lower in water from the surficial aquifer system (sites 1-8) than in runoff to the swale. If no symbol is shown, the test result indicated no significant difference.

| Dissolved constituent<br>or physical measure | Significant<br>difference | p-value            | Multiple comparison test results |     |     |
|--|---------------------------|--------------------|----------------------------------|-----|-----|
|  |                           |                    | G:S                              | G:C | S:C |
| Turbidity                                    | No                        | 0.4543             |                                  |     |     |
| Color  | No                        | .1648              |                                  |     |     |
| Specific conductance                         | No                        | .1288              |                                  |     |     |
| pH – field                                   | No                        | .0676              |                                  |     |     |
| pH – lab                                     | Yes                       | <sup>1</sup> .0259 |                                  |     |     |
| Ammonia                                      | No                        | .1433              |                                  |     |     |
| Nitrite                                      | Yes                       | .0002              | <                                |     | >   |
| Ammonia plus organic nitrogen                | No                        | .2189              |                                  |     |     |
| Nitrite plus nitrate nitrogen                | No                        | .2196              |                                  |     |     |
| Phosphorus                                   | No                        | .0752              |                                  |     |     |
| Orthophosphorus                              | No                        | .2926              |                                  |     |     |
| Total organic carbon                         | No                        | .2356              |                                  |     |     |
| Calcium                                      | No                        | .1766              |                                  |     |     |
| Magnesium                                    | Yes                       | .0367              |                                  |     | <   |
| Sodium                                       | No                        | .3061              |                                  |     |     |
| Potassium                                    | No                        | .0792              |                                  |     |     |
| Chloride                                     | No                        | .2423              |                                  |     |     |
| Sulfate                                      | No                        | .8472              |                                  |     |     |
| Alkalinity                                   | Yes                       | <sup>1</sup> .0234 |                                  |     |     |
| Aluminum                                     | No                        | .2092              |                                  |     |     |
| Chromium                                     | No                        | .5079              |                                  |     |     |
| Copper                                       | No                        | .8113              |                                  |     |     |
| Iron   | Yes                       | .0599              |                                  | <   |     |
| Lead   | No                        | .7344              |                                  |     |     |
| Nickel                                       | No                        | .0512              |                                  |     |     |
| Zinc   | No                        | .2783              |                                  |     |     |

<sup>1</sup>Although ANOVA results indicate a significant difference among data types, TUKEY's multiple comparison test resulted in no significant differences between any two data types, at a significance of 0.05.

Table 19. — *Values of selected nutrients and minor elements in sediments at two swale study areas*

[Nutrients are in milligrams per kilogram; minor elements are in micrograms per gram. Sample interval, in inches below land surface, indicated in parentheses]

| Constituents                         | Princeton Street swale |       |         |       | Longwood swale |       |        |       |
|--------------------------------------|------------------------|-------|---------|-------|----------------|-------|--------|-------|
|                                      | Site 11                |       | Site 12 |       | Site 6         |       | Site 7 |       |
|                                      | (0-2)                  | (4-6) | (0-2)   | (4-6) | (0-2)          | (4-6) | (0-2)  | (4-6) |
| <b>Nutrients:</b>                    |                        |       |         |       |                |       |        |       |
| Nitrogen, ammonia, as N              | 31                     | 8.5   | 6.6     | 6.3   | 21             | 9.7   | 6.7    | 4.4   |
| Nitrogen, ammonia plus organic, as N | 2,600                  | 1,900 | 1,200   | 310   | 5,700          | 1,000 | 900    | 220   |
| Nitrogen, nitrite plus nitrate, as N | < 4                    | < 4   | < 4     | < 4   | 33             | 9     | < 4    | < 4   |
| Phosphorus, as P                     | 1,100                  | 260   | 650     | 1,100 | 300            | 290   | 45     | 190   |
| <b>Minor elements:</b>               |                        |       |         |       |                |       |        |       |
| Cadmium                              | 1                      | < 1   | < 1     | < 1   | 1              | 1     | < 1    | < 1   |
| Chromium                             | 90                     | 90    | 40      | 30    | 130            | 90    | 20     | 20    |
| Cobalt                               | < 10                   | < 10  | < 10    | < 10  | < 10           | < 10  | < 10   | < 10  |
| Copper                               | 90                     | 110   | 50      | 20    | 120            | 150   | 30     | 40    |
| Iron                                 | 660                    | 590   | 330     | 410   | 1,800          | 1,900 | 130    | 370   |
| Lead                                 | 440                    | 130   | 130     | 10    | 450            | 40    | 40     | < 10  |
| Zinc                                 | 120                    | 40    | 40      | < 10  | 130            | 20    | 10     | < 10  |

concentration in the 4- to 6-inch sample at site 12, Princeton Street swale, and the same interval at site 7, Longwood swale. Phosphorus concentrations in the sediments do not show the same rate of reduction with depth as organic nitrogen (most of the nitrogen in the sediments is organic).

Concentrations of metals in sediments at the two swales are similar with the exception of iron, which is almost three times higher in the sediment near the road (site 6) at the Longwood swale than at site 11, Princeton Street swale (1,800  $\mu\text{g/g}$  (micrograms per gram) compared to 660  $\mu\text{g/g}$ , respectively). Concentrations of lead in these sediments are much higher than zinc, the reverse of the pattern observed in the ground water. For example, at site 11, Princeton Street swale, the concentration of lead in the top 2 inches of soil is 440  $\mu\text{g/g}$ , but zinc is only 120  $\mu\text{g/g}$ . These numbers are very close to the concentrations measured in the top 2 inches at site 6, Longwood swale--450  $\mu\text{g/g}$  lead and 130  $\mu\text{g/g}$

zinc. This may be because of the low solubility of lead relative to that of zinc.

The results from this limited sampling of sediments at both swales agree with results from other research--that constituent concentrations decrease with distance from the highway and with depth in the soils. Lagerwerff and Specht (1970) sampled soil and vegetation at four heavily traveled highway sites, as a function of depth and distance from the roadway, and reported that cadmium, nickel, lead, and zinc all decreased with distance from the road and with depth in the soil profile. Concentrations reported in the top 5 centimeters (or roughly 2 inches, as in this study), for two roadway sites in Maryland were about the same or slightly higher than those found for the two swales in this study. The other two roadways studied by Lagerwerff and Specht (1970) had lower concentrations in the top 5 centimeters (8 meters, or 26 feet, from the road) than those found for this study.

## COMPARISON AMONG DETENTION METHODS

One of the primary purposes of this study was to determine the effect on receiving ground-water quality caused by three runoff-detention methods. The three methods, also referred to here as structures, are exfiltration pipes, detention or retention ponds, and swales. Study areas included one exfiltration pipe, two ponds, and two swales. From the data collected at the five locations for the three structure types, it was desired to determine whether any one of the three methods of runoff detention affected ground water more than the other two.

The depth to the water-table varied among locations. The largest water table fluctuation (1.1 feet to 10.9 feet below land surface) occurred at the Longwood retention pond. Water-table fluctuations at the other sites were 2 to 5 feet during the study. The water table at the Silver Star Road detention pond was nearest the land surface of all the study locations, ranging from 0.8 feet to 2.3 feet below land surface. The larger depths to the water table at the other sites (over 10 feet) provided a thicker unsaturated zone through which soil processes might act to attenuate constituents before reaching the receiving ground water. Soils at all locations are similar.

Removal of constituents by settling occurs in all of the structures, but the greatest amount of settling probably occurs in ponds. Vegetative uptake and bacterial action in ponds and swales also contribute to the reduction of constituents. Of the three structures studied, exfiltration pipes probably provide the least amount of preliminary treatment (settling) of runoff prior to entering the subsurface system.

The effect on ground-water quality that any of these structures might have depends on numerous variables, such as the age of the structure, soil type, drainage basin area and percent impervious surface area relative to the structure size, traffic volume, age of the roadway, and other factors. A comparison of the quality of ground water based on structure type is by its nature a rough estimate, and the other factors involved should be considered when interpreting the results.

## Statistical Comparisons

Ground-water quality data for each structure type (pond, swale, pipe) were pooled, excluding control sites, unsaturated zone sites, and site 8 (intermediate aquifer) at the Longwood pond. The same statistical methods used earlier (analysis of variance and multiple comparisons, based on rank values) were again used. The statistical tests were used to detect possible higher values of some constituents in ground water near a particular structure type.

The analysis of variance test resulted in significant differences in mean concentrations among the three structure types for most of the 26 water-quality variables tested. Those variables not significantly different among the structure types are nitrite nitrogen, nickel, aluminum, chromium, copper, lead, and zinc (table 20). Only differences that were significant at the 0.05 level of confidence are discussed here.

Of the physical measurements, turbidity and color are significantly higher in ground water in the vicinity of the ponds, and specific conductance and pH are lowest beneath the swales.

Nitrogen species dominance differs by structure type. Mean concentrations of Kjeldahl nitrogen are significantly higher in ground water near ponds than beneath swales, and nitrite plus nitrate nitrogen is significantly higher in ground water beneath swales and near the exfiltration pipe than near ponds. Although the multiple comparison results indicate that nitrite plus nitrate nitrogen concentrations are lowest in ground water near ponds, the median concentration in ground water beneath the Longwood pond (0.33 mg/L) is five times greater than in ground water near the Silver Star Road pond (0.06 mg/L); this median concentration in ground water beneath the Longwood pond is similar to those concentrations found in ground water near the swales and exfiltration pipe. Although Kjeldahl nitrogen is the predominant species of nitrogen in ground water at both ponds, it is only slightly greater than the nitrite plus nitrate fraction at the Longwood pond. The low nitrite plus nitrate nitrogen concentration in ground water near the Silver Star Road pond may be due to the low concentrations in

Table 20. — *Results of analysis of variance of rank data and multiple comparison test (TUKEY) for data grouped by structure*

[Control well sites are not included]

An "x" in a column means that a significant difference was indicated between the means of the rank values of the groups indicated at the top of the column. For example, the mean of the ranks of turbidity measurements were significantly greater in water from the surficial aquifer system in the vicinity of ponds than beneath swales. A blank denotes no significant difference was indicated ]

| Constituent or<br>physical property | Significant differences in mean concentrations<br>between ground water at structures (based on rank values) |                   |                 |                 |                  |                  |
|-------------------------------------|---|-------------------|-----------------|-----------------|------------------|------------------|
|                                     | Pond ><br>Swales  | Swales ><br>Ponds | Ponds ><br>Pipe | Pipe ><br>Ponds | Swales ><br>Pipe | Pipe ><br>Swales |
| Turbidity                           | x   |                   | x               |                 |                  |                  |
| Color                               | x   |                   | x               |                 |                  |                  |
| Specific conductance                | x   |                   |                 |                 |                  | x                |
| Field pH                            | x   |                   |                 |                 |                  | x                |
| Lab pH                              | x   |                   |                 |                 |                  | x                |
| Nitrogen species:                   |   |                   |                 |                 |                  |                  |
| Ammonia                             | x   |                   | x               |                 |                  |                  |
| Nitrite                             |   |                   |                 |                 |                  |                  |
| Ammonia plus organic                | x   |                   | x               |                 |                  |                  |
| Nitrite plus nitrate                |   | x                 |                 | x               |                  |                  |
| Phosphorus                          |   | x                 |                 | x               |                  | x                |
| Orthophosphorus                     |   | x                 |                 | x               |                  | x                |
| Total organic carbon                | x   |                   |                 |                 |                  | x                |
| Calcium                             | x   |                   |                 |                 |                  | x                |
| Magnesium                           |   |                   |                 |                 | x                |                  |
| Sodium                              |   | x                 |                 | x               |                  |                  |
| Potassium                           |   |                   |                 |                 |                  | x                |
| Chloride                            |   | x                 |                 | x               | x                |                  |
| Sulfate                             |   |                   |                 |                 |                  | x                |
| Alkalinity                          | x   |                   |                 |                 |                  | x                |
| Aluminum                            |   |                   |                 |                 |                  |                  |
| Chromium                            |   |                   |                 |                 |                  |                  |
| Copper                              |   |                   |                 |                 |                  |                  |
| Iron                                |   |                   | x               |                 | x                |                  |
| Lead                                |   |                   |                 |                 |                  |                  |
| Nickel                              |   |                   |                 |                 |                  |                  |
| Zinc                                |   |                   |                 |                 |                  |                  |
| Totals                              | 10  | 5                 | 5               | 5               | 3                | 10               |



stormwater entering the pond (median dissolved concentration is 0.10 mg/L) and to anaerobic conditions in the pond.

Phosphorus and orthophosphorus concentrations are significantly higher in ground water near the exfiltration pipe than in ground water near swales, and concentrations are greater near swales than near ponds. The low phosphorus concentrations in ground water near the Silver Star Road pond is due in part to the low concentrations in stormwater entering the pond. Phosphorus concentrations in stormwater entering the Longwood pond are higher than at the Silver Star Road pond, so the low concentrations in ground water beneath the Longwood pond may be due to vegetative or biological uptake of phosphorus in the pond before infiltration.

Calcium is the predominant major ion in ground water near ponds and the exfiltration pipe. Sodium is significantly higher in ground water near the swales and the exfiltration pipe than near the ponds, and potassium is highest (significant difference) in ground water near the exfiltration pipe. Of the anions measured, chloride is highest and alkalinity is lowest in ground water below the swales. Sulfate is highest in ground water at the exfiltration pipe. The significance of these results is, at present, unknown.

Iron is the only metal that was significantly different in ground water among the three structure types. Iron in ground water near the exfiltration pipe is lower than in ground water near the other two structure types. High iron concentrations were measured in ground water at the Longwood swale (median is 815  $\mu\text{g/L}$ ) and the Silver Star Road pond (median is 1,700  $\mu\text{g/L}$ ). The iron concentrations probably are due to the surrounding native soils and are not a result of structure type. Other metals, such as chromium and copper, frequently were less than detection levels (1  $\mu\text{g/L}$ ), with the exception of one value of 30  $\mu\text{g/L}$  in water from a well at the Princeton swale. Lead also was typically less than detection levels.

Significant differences in ground-water quality data were detected most frequently between swales and the other structure types. These statistical results imply that generally, values of water-quality variables tend to be lowest beneath swales. The predominant form of nitrogen in ground water near swales and the exfiltration pipe is nitrate nitrogen, whereas organic nitrogen

predominates in ground water near the detention and retention ponds. However, organic nitrogen is only slightly higher than nitrate nitrogen in ground water beneath the Longwood pond.

Highest phosphorus and orthophosphorus concentrations were detected in ground water near the exfiltration pipe, and lowest values were detected in ground water beneath the Longwood pond. The uptake of phosphorus at the Longwood pond may be the reason for the lower concentrations found in ground water beneath the pond, and the higher concentrations found in the unsaturated and saturated zones at the Washington Street study area may be due to the dissolution of phosphorus to the dissolved state as the stormwater exfiltrates, or to nonnative backfill in the vicinity of the pipe. Highest chloride, but lowest alkalinity values were detected in ground water beneath swales. Potassium and sulfate concentrations are highest in ground water near the exfiltration pipe.

The significant difference in iron concentrations in ground water at different structure locations likely is due to native materials and not to infiltration of highway runoff. Other metals measured in ground water near structures do not seem to be a problem because nearly all concentrations are below the detection level of the analytical laboratory tests.

### Comparison to State Water-Quality Standards

Constituent concentrations obtained from this study were compared to Florida Department of Environmental Regulation drinking water standards (Florida Department of Environmental Regulation, 1982). Although standards for drinking water are not available for all the constituents in this study, and do not actually apply to the surficial aquifer system, they are more applicable than surface-water standards (Class III, recreation, propagation and management of fish and wildlife) that take into account the effect of water quality on fish. With a few exceptions, most notably iron, constituent concentrations in ground water near the structures studied are well within the drinking water standards.

The limit for nitrate nitrogen in drinking water is 10 mg/L; this value was exceeded in only one sample collected from the unsaturated zone at the Washington Street study area (exfiltration

pipe). Drinking water standards indicate a minimum pH value of 6.5 must be maintained for a water supply, with no set maximum. The pH values in ground water near the Longwood pond and the exfiltration pipe were within this standard, but the pH in ground water beneath the swales and near the Silver Star Road pond were frequently more acidic than 6.5. Chloride and sulfate concentrations were always less than 75 mg/L, well below the standard of 250 mg/L.

Chromium and lead each have limits in drinking water supplies of 50  $\mu\text{g/L}$ . The maximum chromium concentration measured in this study was 30  $\mu\text{g/L}$ , in ground water from site 6, Princeton Street swale, and the maximum lead value was also 30  $\mu\text{g/L}$ , measured in water at site 5, in the unsaturated zone at the Washington Street exfiltration pipe. The standard for copper, 1,000  $\mu\text{g/L}$ , was never exceeded in any sample. The highest copper values detected were in the unsaturated zone at Washington Street: 80  $\mu\text{g/L}$  (site 5) and 90  $\mu\text{g/L}$  (site 7). The standard for zinc in drinking water is 1,000  $\mu\text{g/L}$ , and this value was never exceeded in samples from this study. The maximum zinc concentration measured was 220  $\mu\text{g/L}$ , site 1, Silver Star Road pond. No standards are available for nickel in drinking water, but the standard for Class III waters is 100  $\mu\text{g/L}$ , and the maximum value measured during the study was 85  $\mu\text{g/L}$  (site 5, Silver Star Road pond). Nickel concentrations at other study areas were always less than 10  $\mu\text{g/L}$ .

The standard for iron in drinking water is 300  $\mu\text{g/L}$ , which commonly was exceeded in ground water near structures in this study. Iron concentrations in ground water are highest at the Silver Star Road pond, but these high values probably are not due primarily to the effects of highway runoff, particularly in view of the low concentrations of other constituents detected during the study.

## SUMMARY AND CONCLUSIONS

Ground-water quality was sampled at five study areas representing three highway-runoff detention methods to detect any effects from infiltrating runoff. All five study locations were in central Florida and included one exfiltration pipe, two ponds, and two swales. Water-quality variables measured primarily were inorganic constituents, but water from selected wells were sampled for qualitative analysis of organic compounds. Sediment samples were collected at

all sites, and nutrient and metal concentrations in the sediments were measured. Priority pollutants were measured in sediments from one pond study area.

At each study area, a control well site was established for comparative purposes. Variability in the quality of ground water was analyzed statistically at each study area, between study areas for similar structures, and among unlike structures. Values of water quality variables obtained from the study were compared to drinking water standards.

Data were compared by structure type to determine any discernible differences between the different runoff-detention methods. Analysis of variance of ranks of pooled ground-water quality data (grouped by type of structure) excluded control sites and unsaturated zone sites. Significant differences were indicated for most water-quality variables at a significance level of 0.05.

Turbidity and color are significantly higher in ground water near ponds, and specific conductance and pH are lower in ground water below swales than near ponds or near the exfiltration pipe. Nitrate nitrogen, the most mobile of the nitrogen species in ground water, is significantly higher in ground water beneath the swales and the exfiltration pipe than near the ponds, and Kjeldahl nitrogen is highest near the ponds. Phosphorus (and orthophosphorus) concentrations are significantly higher in ground water near the exfiltration pipe than beneath swales and near ponds.

Concentrations of major ions in ground water differ among all three structure types and include calcium, sodium, potassium, chloride, and alkalinity (bicarbonate ion). Of the metals, only iron is significantly higher in ground water beneath swales and near ponds than near the exfiltration pipe, most likely because of the high iron concentrations measured in ground water at the Silver Star Road pond and the Longwood swale. Chromium, copper, and lead frequently were below detection levels, and no significant differences were detected in concentrations of any other metals, including zinc.

Values of water-quality variables measured in ground water for this study, with very few exceptions, were within drinking water standards. At both swale locations and at the Silver Star Road detention pond, the pH of ground water

frequently was lower than the minimum standard for drinking water (6.5), and the standard for iron, 300  $\mu\text{g/L}$ , was frequently exceeded, particularly in ground water at the Longwood swale and Silver Star Road pond. However, the high iron values are not completely attributable to highway runoff.

Results of this study indicate that natural processes occurring in soils do much to attenuate constituents prior to reaching the receiving ground water. Results from sampling unsaturated-zone water near the exfiltration pipe indicate that higher concentrations are present above the water table than in the saturated zone; this indicates a need to monitor the unsaturated zone at other locations to detect any migration of constituents from infiltrating runoff early enough for remedial measures. Where land is available, retention ponds are useful for attenuation of constituents through

physical, chemical, and biological processes prior to entering the subsurface system. Swales and exfiltration pipes do not provide as much pretreatment (settling) as a retention pond. However, the distance to water, and type of soils available are two critical factors to the success of a runoff detention structure in the attenuation of loads to ground-water resources.

Organic compounds detected in sediments at the Longwood retention pond indicate a potential problem that is a relatively new area of research in runoff studies. The detection of organic compounds in water from the unsaturated and saturated zones is difficult, particularly in the case of volatile organic compounds, but these may present a much greater potential problem to ground-water resources than the inorganic constituents that have been the focus of this and many earlier runoff studies.

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# EFFECTS OF THREE HIGHWAY-RUNOFF DETENTION METHODS ON WATER QUALITY OF THE SURFICIAL AQUIFER SYSTEM IN CENTRAL FLORIDA

By Donna M. Schiffer

## ABSTRACT

Water quality of the surficial aquifer system was evaluated at one exfiltration pipe, two ponds (detention and retention), and two swales in central Florida, representing three runoff detention methods, to detect any effects from infiltrating highway runoff. Concentrations of major ions, metals, and nutrients were measured in ground water and bottom sediments from 1984 through 1986.

At each study area, constituent concentrations in ground water near the structure were compared to concentrations in ground water from an upgradient control site. Ground-water quality data also were pooled by detention method and statistically compared to detect any significant differences between methods.

Analysis of variance of the rank-converted water-quality data at the exfiltration pipe indicated that mean concentrations of 14 of 26 water-quality variables are significantly different among sampling locations (the pipe, unsaturated zone, saturated zone, and the control well). Most of these differences are between the unsaturated zone and the other locations. Only phosphorus is significantly higher in ground water near the pipe than in ground water at the control well.

Analysis of variance of rank-converted water-quality data at the retention pond indicated significant differences in 14 of 25 water-quality variables among sampling locations (surficial aquifer system, intermediate aquifer, pond, and the control well), but mean concentrations in ground water below the pond were never significantly higher than in ground water from the control well. Analysis of variance results at other study areas indicated few significant differences in water quality among sampling locations.

Values of water-quality variables measured in ground water at all study areas generally were within drinking water standards. The few exceptions included pH (frequently lower than the limit of 6.5 at one pond and both swales), and iron, which frequently exceeded 300 micrograms per liter in ground water at one swale and the detention pond.

Large concentrations of polyaromatic hydrocarbons were measured in sediments at the retention pond, but qualitative analysis of organic compounds in ground water from three wells indicated concentrations of only 1 to 5 micrograms per liter at one site, and below detection level (1 microgram per liter) at the other two sites. This may be an indication of immobilization of organic compounds in sediments.

Significant differences for most variables were indicated among ground-water quality data pooled by detention method. Nitrate nitrogen and phosphorus concentrations were highest in ground water near swales and the exfiltration pipe, and Kjeldahl nitrogen was highest near ponds. Chromium, copper, and lead concentrations in ground water were frequently below detection levels at all study areas, and no significant differences among detention methods were detected for any metal concentration with the exception of iron. High iron concentrations in ground water near the detention pond and one swale most likely were naturally occurring and unrelated to highway runoff.

Results of the study indicate that natural processes occurring in soils attenuate inorganic constituents in runoff prior to reaching the receiving ground water. However, organic compounds detected in sediments at the retention pond indicate a potential problem that may eventually affect the quality of the receiving ground water.

## INTRODUCTION

Runoff from road surfaces is thought to be a significant source of nonpoint pollution to surface and ground waters (Gupta and others, 1981). Stormwater runoff has been the subject of much research, but only recently has highway runoff been more rigorously investigated as a source of pollution independent of other sources. Normally, stormwater runoff is a composite of runoff from various land-use areas (residential, commercial, and industrial), in addition to road surfaces.

Highway runoff as a potential source of pollution has been recognized by numerous investigators (Sartor and Boyd, 1972; Shaheen, 1975, Novotny and Chesters, 1980; Gupta and others, 1981). The Florida Department of Transportation (FDOT) is the primary agent responsible for the quality of runoff from highways within the State of Florida, and has recognized the need for further study and development of a scientific data base on which to base decisions about highway-runoff management. The FDOT has initiated many investigations cooperatively with State universities and Federal agencies, including the U.S. Geological Survey.

The FDOT's continuing assessment of best management alternatives to prevent any possible degradation of the State's surface waters has been extended to include prevention of degradation of ground water. To investigate the effects on ground water of highway runoff routed through control structures, a study was started by the U.S. Geological Survey in cooperation with the FDOT in late 1983.

### **Background**

The FDOT has the responsibility of treating the first one-half inch of runoff from State roadways (Florida Department of Environmental Regulation, 1986). Treatment is usually accomplished through velocity reduction and by concomitant sedimentation. To accomplish this treatment of runoff, several runoff detention methods are used.

Exfiltration pipes commonly are used in urban areas to comply with the retention requirements of State law. Sometimes called French drains, they are typically made of perforated corrugated aluminum pipe, installed in a trench lined with a permeable fabric wrap, and backfilled with gravel. Unlike a true French drain that lowers ground-water levels, exfiltration pipes are used for routing of runoff into soils that recharge, by infiltration, the ground-water reservoir.

Detention ponds detain runoff for a length of time before the water is released to a receiving body. Retention ponds retain water and have no outflow. The runoff in the pond infiltrates into the soil, then percolates into the local ground-water system.

Swales are grass-covered channels that are primarily considered conveyance systems, but

also are used as a preliminary treatment of runoff. Infiltration through the bottom of the swale reduces the volume of runoff to the outfall, and detention allows some sedimentation of particulates in the runoff before entering the receiving body.

Although these runoff detention methods have been in use since the 1970's by various highway departments, little information has been available on the potential effects of these practices on the quality of ground water near structures.

### **Purpose and Scope**

The purpose of this investigation was to:

- Evaluate the impact on the water quality of the surficial aquifer system near structures used for detention of highway runoff,
- Define any spatial trends in water-quality detected during ground-water monitoring, and
- Define the spatial distribution of constituent concentrations in sediments.

The study, which was 4 years in length, was restricted to five central Florida locations. The runoff detention structures studied were a detention pond, a retention pond, two swales, and an exfiltration pipe. The primary objective of the study was a first-step reconnaissance to detect any significant differences in ground water near the structure and upgradient of the structure (control or background condition). The data for the study were collected from 1984 to 1986.

This report presents the results of the monitoring and analysis of ground-water quality near five structures representing the three runoff detention methods and describes possible effects on the water quality of the surficial aquifer caused by infiltration of runoff from highways.

## **TECHNICAL BACKGROUND**

### **Previous Studies**

Highway runoff generally has been included as part of stormwater studies, but more recently research has isolated runoff from highways for investigation. An early work that commonly is referenced is "Water pollution aspects of street surface contaminants," by Sartor and Boyd (1972). The authors noted that data available on stormwater at that time were not directly relatable to the materials contributed by

street-surface contaminants, and that there was a need to identify the relations between street-surface contaminants, their characteristics, and manner of transport. The study by Sartor and Boyd (1972) resulted in many significant findings, perhaps the most important of which was the association of street-surface contaminants and particle size. The greatest pollution potential is associated with fine-grained particles, 43  $\mu\text{m}$  (micrometers) or smaller in diameter.

Some of the most pertinent reports include the results of a study of urban roadways in the Washington, D.C., area by Shaheen (1975); a study of street dust from eight cities in the United States by Pitt and Amy (1973); an extensive six volume report sponsored by the Federal Highway Administration titled "Constituents of highway runoff," by Gupta and others (1981); and a study of urban runoff in Bellevue, Wash. (Galvin and Moore, 1982), which identified street runoff as a major contributor to stormwater constituent loads.

A journal article by Nightingale (1987) reported on a 2-year study of ground-water quality beneath five retention basins in Fresno, Calif. Nightingale monitored inorganic and organic constituents in water in the unsaturated and saturated zones beneath ponds that received runoff water from basins that were predominately single family residential, with some multiple family residential and commercial areas. He concluded that no significant contamination of percolating soil water or ground water beneath these basins had occurred for constituents monitored in the study, and that concentrations of selected trace metals in the ground-water samples were similar in magnitude to those reported for regional ground water.

### **Chemical Constituents And Water-Quality Measures**

The major component of street-surface contaminants is particulate matter. Nonparticulate soluble and suspendable matter also are present on street surfaces (oils and salts). The magnitude of constituents on highways is dependent on many site-specific variables, such as traffic characteristics (speed, volume of traffic, and amount of braking), climatic conditions (frequency, intensity, and duration of precipitation, and wind), percentage of pervious and impervious areas contributing runoff to the roadway, age and condition of automobiles on the

road, regulations in the area governing emissions and littering, highway maintenance policies (street sweeping, mowing adjacent to highways, and deicing), and the types and amounts of vegetation on the road right-of-way (Gupta and others, 1981).

Chemical constituents associated with highway runoff include heavy metals, nutrients, and complex organic compounds. Heavy metals include cadmium, chromium, copper, iron, lead, zinc, aluminum, and nickel. Nutrients include nitrogen and phosphorus species. Organic compounds include oil and grease and polycyclic aromatic hydrocarbons (PAHs).

Metals commonly are detected in samples of highway runoff. The priority pollutant monitoring project of the Nationwide Urban Runoff Program (NURP) was initiated to evaluate the significance of priority pollutants in urban stormwater. Fifty-one catchments in 19 cities representing different ranges of watershed areas and population densities were sampled. Preliminary results of the study indicated that as a group, toxic metals are by far the most prevalent priority pollutants of urban runoff (Cole and others, 1984). Motor vehicle emissions, and the breakdown of vehicle parts are the major sources of metals in street runoff (Gupta and others, 1981). Although lead-free gasoline dominates the fuel market today, lead is still a component of motor oil and bearings in vehicles, and large concentrations are still detected in runoff samples. Copper, nickel, and chromium are present in brake linings, and zinc is a component of motor oil and tires. Thus, many sources of heavy metals are highway related.

Nutrients in highway runoff generally originate from atmospheric sources and greenbelt areas that are fertilized. Phosphorus is a motor oil additive. Miscellaneous sources of nutrients on roadways include bird droppings and animal remains.

The low concentrations of organic priority pollutants (parts per billion or trillion) make detection difficult, and has resulted in very little having been written about the presence of organic compounds in stormwater. Galvin and Moore (1982) determined that 71 to 96 percent of the total extractable organic compounds in urban runoff was associated with particulate matter. The major source of organic compounds in highway runoff is petroleum products, including lubrication oils, fuel, and combustion emissions.

Wakeham and others (1980) speculated that the distribution of PAHs in street dust and runoff originated primarily from the wear of asphalt road surfaces rather than from atmospheric fallout. Asphalt particles are composed of high molecular weight organic compounds, that may also trap other organic toxicants, especially pyrolytic PAHs (Galvin and Moore, 1982). Gasoline contains the following organic compounds: benzene, toluene, phenols, and polyaromatic hydrocarbons. The dominant source of benzo(a)pyrene (a PAH) is the pyrolysis of diesel fuel, although it is also a component of regular gasoline and oil.

PAHs are rapidly adsorbed onto organic particles and inorganic material in receiving waters because of their low solubility and hydrophobic character. For this reason, they would tend to be more frequently detected in sediments rather than in the water column. Once PAHs are deposited, they are less subject to photochemical or biological oxidation, and concentrations in sediments are detected at levels more than a thousand times greater than the overlying water (Galvin and Moore, 1982).

Specific conductance, dissolved oxygen (DO), pH, and temperature are water-quality measures that may function as indicators of overall quality, and of the speciation of dissolved species possible in the environment. These variables, except DO, were measured when collecting ground-water samples during the study.

### **Description of Ground-Water Systems**

In central Florida, the surficial aquifer system is comprised primarily of unconsolidated deposits of quartz sand and some clay and organic material. Typically the water table is within 20 feet of land surface.

The intermediate aquifer, or intermediate confining unit, lies between the overlying surficial aquifer system and the underlying Floridan aquifer system. It is primarily comprised of fine-grained clastic deposits interlayered with carbonate strata. The intermediate confining unit retards the vertical movement of water between the surficial aquifer system and the Floridan aquifer system because of its low permeability.

The primary water-yielding aquifer in central Florida is the Upper Floridan aquifer, the upper aquifer of the Floridan aquifer system. The top of the Floridan aquifer system ranges from 50 to 150 feet below land surface in the study area (Lichtler and others, 1968). The Floridan aquifer system consists mostly of interbedded limestone, dolomitic limestone, and dolomite. The Upper Floridan aquifer is the major source of drinking water in central Florida because it is highly permeable and yields large volumes of water (Miller, 1986, p. B53).

The Floridan aquifer system is recharged by the surficial aquifer system when the water table is above the potentiometric surface of the Floridan aquifer system, which occurred at all study locations during the study. Thus, the quality of the recharge water from the surficial aquifer system may affect the quality of water in the Floridan aquifer system. The advantage of discharging stormwater to the surficial aquifer system rather than directly to the Floridan aquifer system through drainage wells (Schiner and German, 1983) is the improvement in quality as the water moves through the unconsolidated materials of the surficial aquifer system and through the intermediate confining unit.

In central Florida, several earlier studies reported transmissivities of the saturated zone of the surficial aquifer system. Reported transmissivities range from 27 ft<sup>2</sup>/d (feet squared per day) in western Orange County (Watkins, 1977) to 600 ft<sup>2</sup>/d (Bush, 1979) in eastern Orange County. An aquifer test in southwest Orange County yielded a value of 500 ft<sup>2</sup>/d (E.R. German, U.S. Geological Survey, oral commun., 1986). The higher transmissivity values were in aquifers comprised mostly of fine sand. Hydraulic conductivity values computed from these transmissivity values for the surficial aquifer system ranged from 1.9 to 15.8 ft/d. Vertical movement of water in the unsaturated zone is much more rapid, in general, than horizontal movement of water in the saturated zone. Although water continues to move vertically in the saturated zone, the predominant direction of flow is generally more horizontal, because of confining layers and anisotropy.

## Constituent Attenuation Mechanisms in the Subsurface Environment

Runoff water is the vehicle by which constituents in highway runoff are transported in both soluble and particulate forms to ground water, by infiltrating into the soil and percolating through the unsaturated zone to the saturated zone. Constituent loads may be attenuated in the unsaturated zone before reaching the saturated zone through several processes (fig. 1). Some mechanisms by which the constituent loading to the ground water may be decreased include filtering, sorption (adsorption and absorption), precipitation, and ion exchange. Organic constituents may be decomposed through bacterial activity and some inorganic constituents may be utilized by plants. Clays and organic material have high affinities for adsorbing various constituents, particularly heavy metals. Adsorption is the major mechanism for the collection of trace metals on clay and organic material surfaces. Jenne (1976) indicated that material with large

surface areas may serve as mechanical substrates without any chemical interaction between the material and the constituent. Organic matter, hydrous iron, and manganese oxides can deposit on a surface and function as metal collectors.

Heterogeneity of the subsurface material is an important control in the movement of constituents in water in the subsurface environment. Heterogeneities arise from several factors including variation in grain size, and permeability variation caused by stratification that occurred in a particular depositional environment. In general, constituents moving through the unsaturated zone to the saturated zone are in the dissolved form. However, some water infiltrating through the soil surface may move rapidly through the unsaturated zone along preferred paths (pores, cracks, and other interconnected openings that are wide enough not to exert capillary forces on the moving water), making gravity the primary acting force. This may allow the particulate fraction of some constituents to reach the saturated zone.

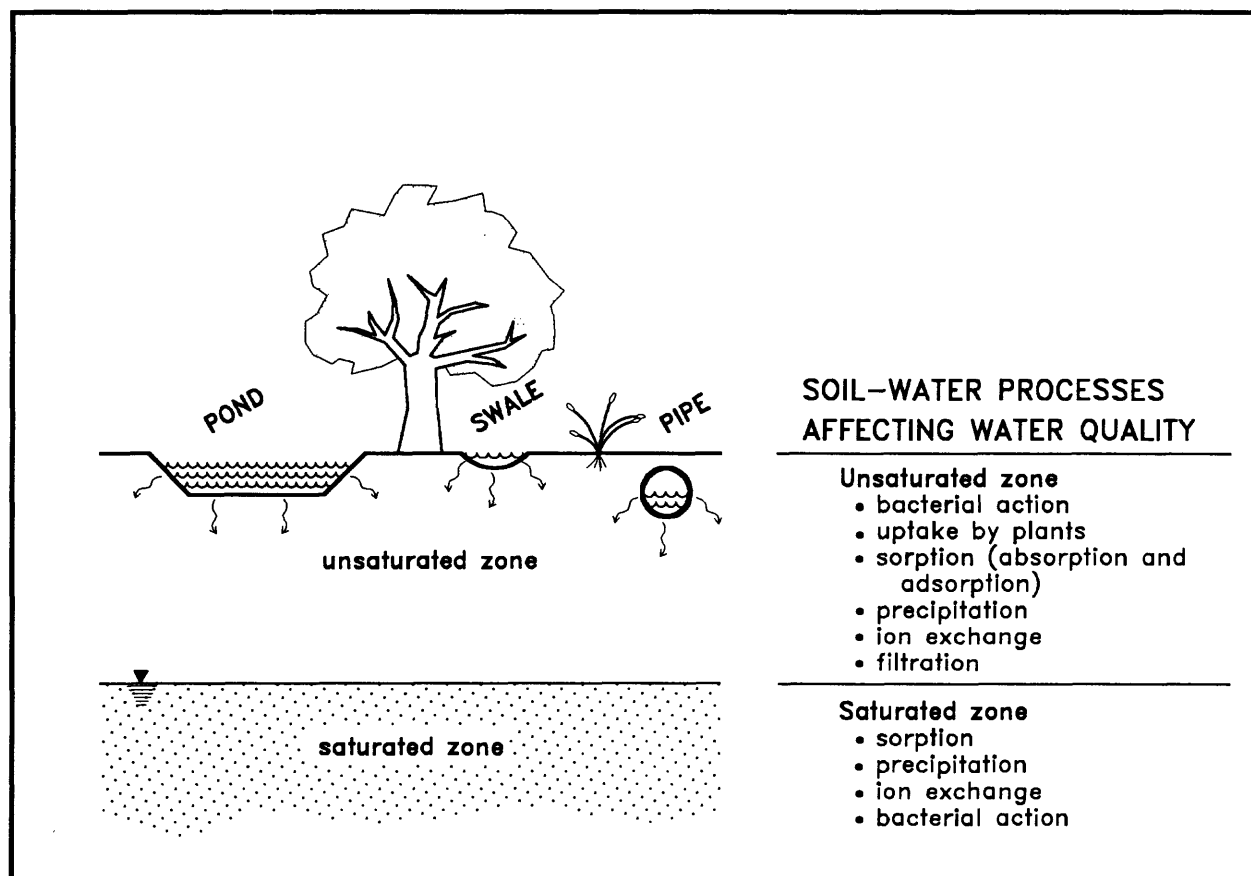


Figure 1.—Ground-water movement and processes affecting water quality.

Although many of the same processes occurring in the unsaturated zone also occur in the saturated zone (sorption, ion exchange, and precipitation), most of the attenuation of loads occurs in the unsaturated zone. One reason for the attenuation is because organic material at the soil surface traps many constituents. Also, oxygen is available in the unsaturated zone for redox reactions (removing constituents from solution by precipitation) and for bacterial activity. Plant roots may take in nutrients in the unsaturated zone, thus reducing the load to the saturated zone. Percolating water may be in contact with the soil longer in the unsaturated zone, as the storage requirements of the unsaturated soil are satisfied, than in the saturated zone, where the hydraulic conductivity (and thus flow rate) increases. Differences in constituent concentrations between the unsaturated zone and the saturated zone also may be caused by dilution, as the infiltrating water enters the saturated zone.

One unknown that concerns the routing of runoff to the subsurface environment is whether the soils will eventually clog, decreasing or eliminating their ability to convey water and remove constituents. This would occur more rapidly in a wastewater treatment operation that uses land spreading, because of the nutrient-rich water associated with secondary treated wastewater. Maintenance of structures used for treatment of runoff is an important factor to the life of the structure, and to the protection of ground-water resources. Removal of sediments after a number of years facilitates infiltration, and prevents the potential release of metals and nutrients from the sediments under changing environmental conditions. Additionally, the maintenance of aerobic conditions in ponds also protects receiving ground-water quality by reducing the concentrations of soluble species that may exfiltrate out of the pond.

## STUDY AREAS

The FDOT structures selected for this study are located in central Florida, a rapidly developing metropolitan area. Traffic in the area has increased dramatically since the early 1970's because of the growing population, and the number of vehicles far exceeds the design capacity of many roads, thus creating an ever increasing source of undesirable constituents in runoff from the road surfaces.

The five structures selected for study (fig. 2), are located near Orlando and Longwood, Fla., and include one exfiltration pipe, two ponds (one detention and one retention), and two swales. A brief description of each study location follows.

An exfiltration pipe located under the street and sidewalk area of a downtown Orlando street (Washington Street) was selected for study (figs. 3 and 4), in part because the pipe was a prototype design for the city. The pipe was designed to provide storage for the first 0.50 inch of runoff from a 1-acre street and parking lot drainage area (Harper and others, 1982).

At the time of the study, the pipe had been in operation for about 5 years. A new parking garage had been built adjacent to the study site and was completed a few months before this study began. An exfiltration system was installed beneath the new parking lot to handle stormwater runoff from the parking garage and lot. The design included an overflow feature such that when the system beneath the parking lot reached a certain storage volume, water would overflow a weir and discharge into the Washington Street exfiltration pipe. Overflow was not observed during the time of the study.

The street is curbed, and runoff enters the pipe from the curb through a drop inlet at one end of the pipe. Sampling sites around the pipe included four wells tapping the saturated zone of the surficial aquifer system, and three lysimeters at varying depths in the unsaturated zone (fig. 3 and table 1), installed in March 1984. Photographs of the street are shown in figure 5. Traffic on the street is light to moderate.

The detention pond in this study, located west of the city of Orlando on Silver Star Road was the subject of an earlier highway runoff study that reported on constituent-load changes through the system (Martin and Smoot, 1986). The quality of the water in the surficial aquifer system near the pond is the subject of the present study. The wetland adjacent to, and receiving outflow from, the pond was the subject of a concurrent study. Locations of the seven wells tapping the surficial aquifer in the vicinity of the pond and wetlands are shown in figure 6. A photograph of the study area is shown in figure 7. The total drainage area is 41.6 acres, of which 33 percent is roadway. The average daily traffic count in 1984 was 22,000 vehicles per day.



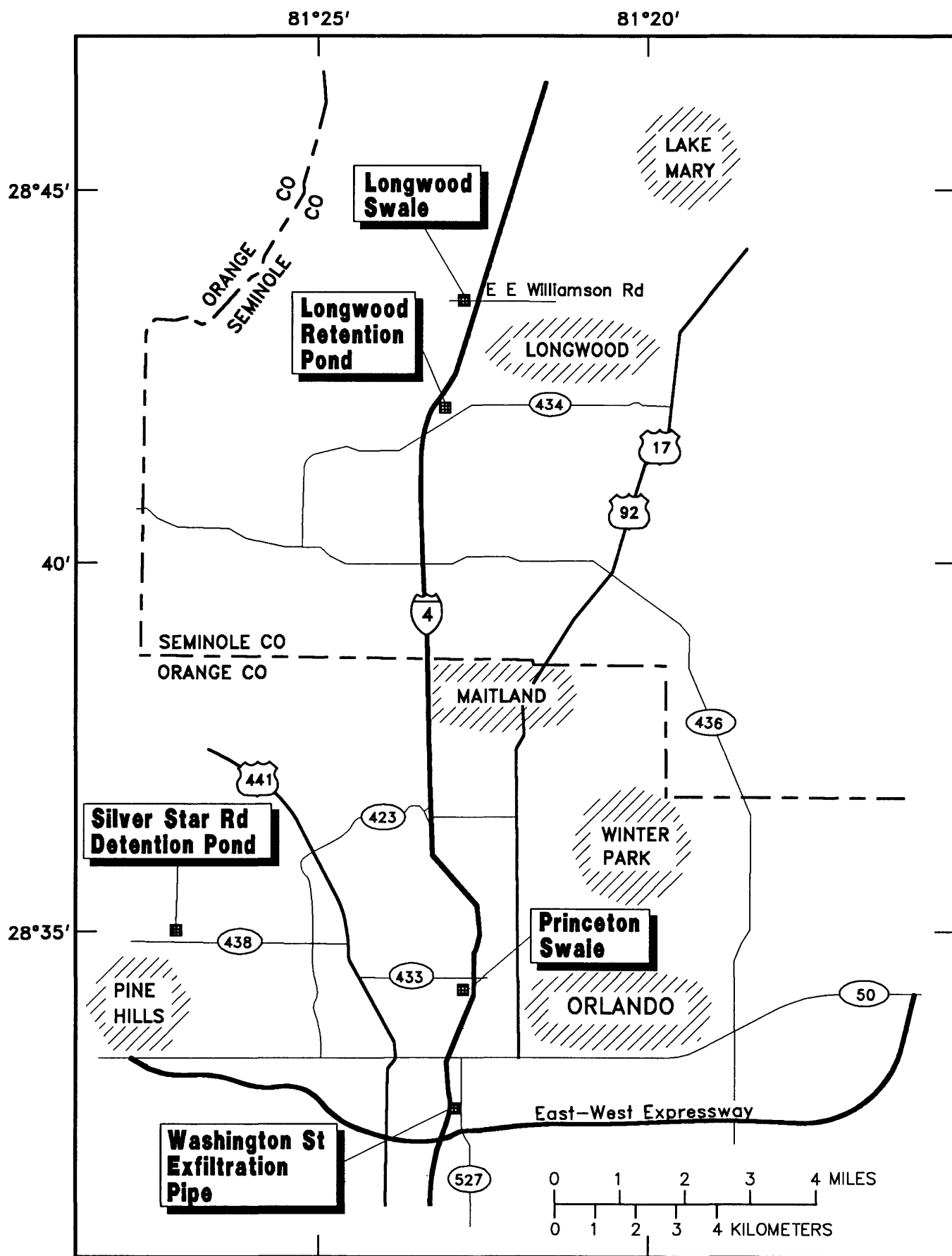
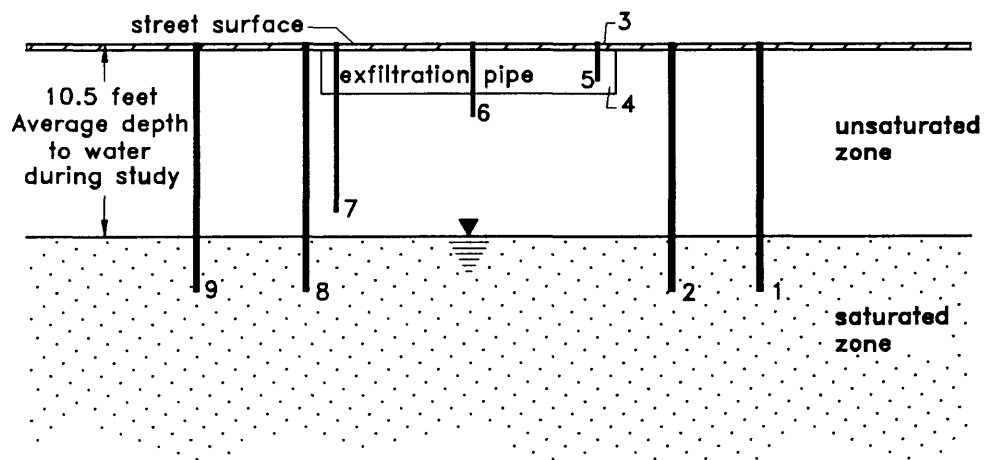
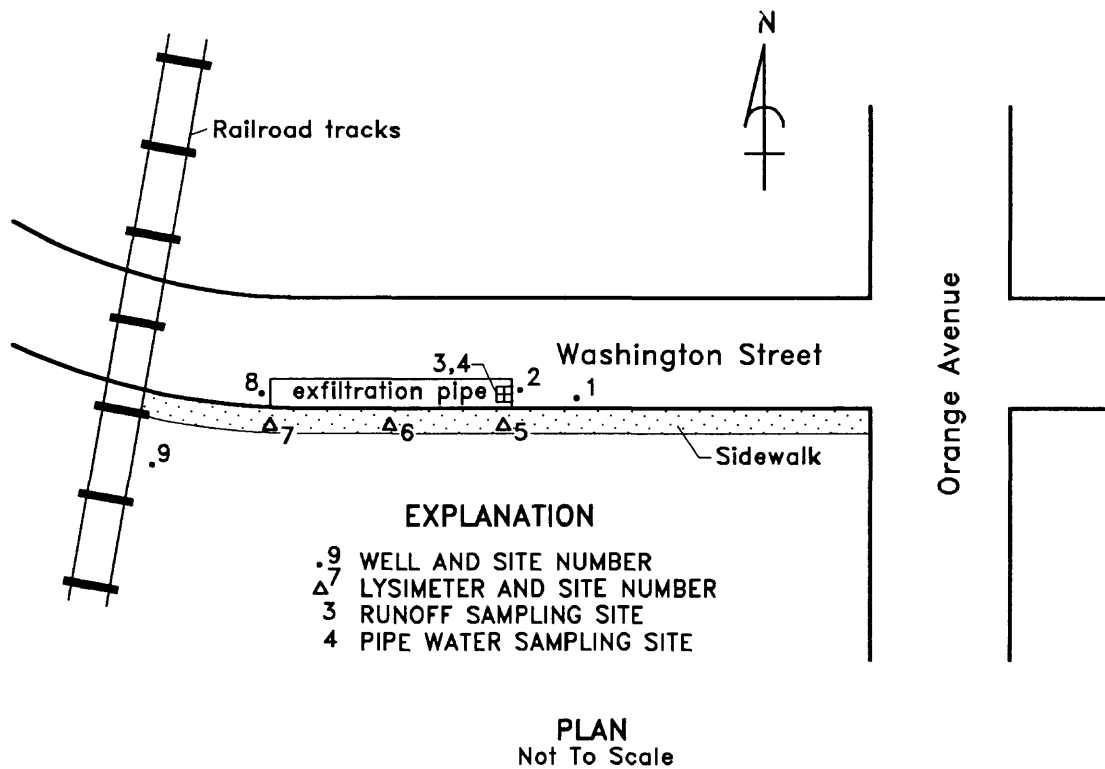


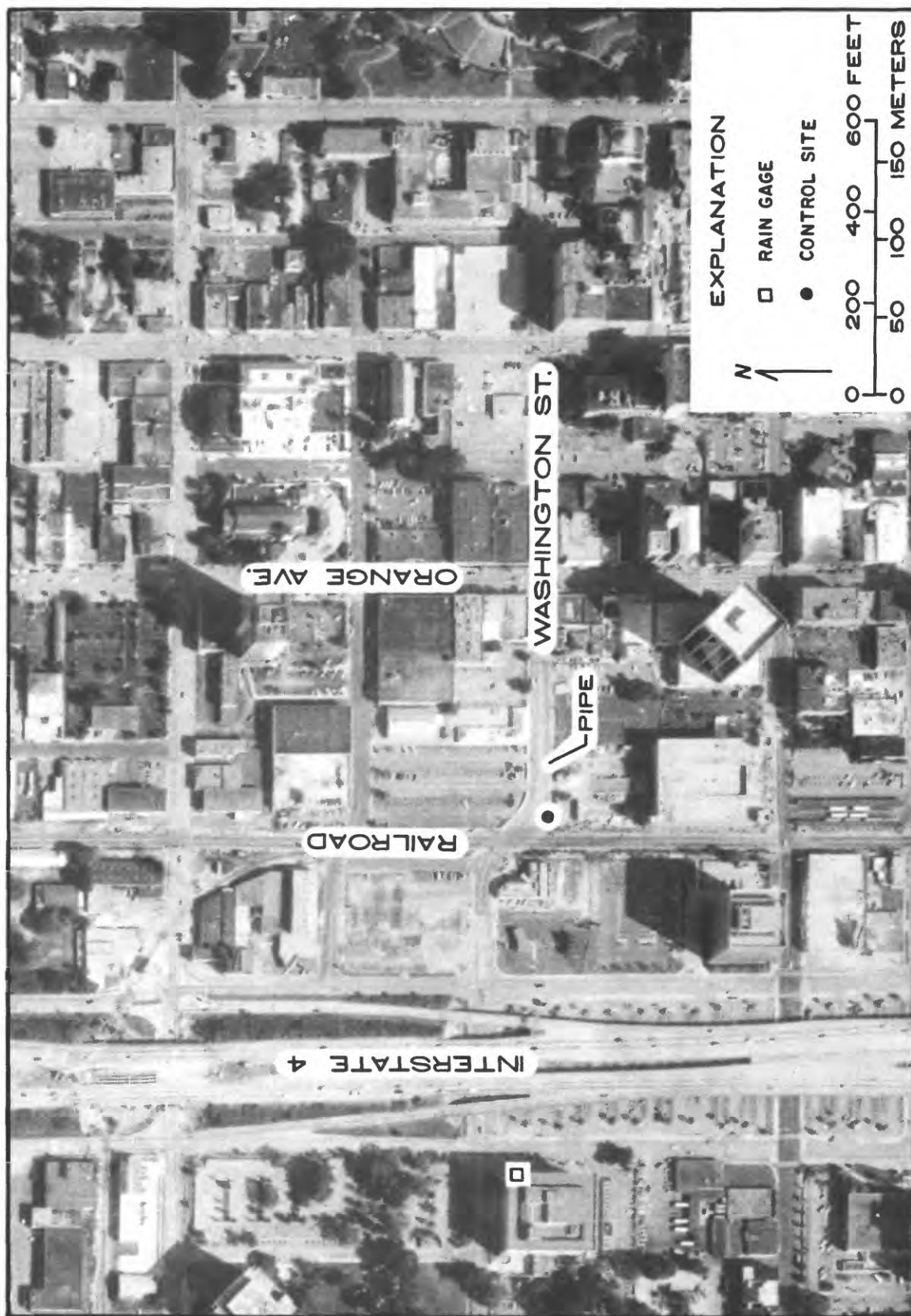
Figure 2.--Location of study areas.



All wells are 18 feet deep.  
Screened interval at 15 to 18 feet below land surface.

**PROFILE**  
Not To Scale

Figure 3.—Exfiltration pipe and sampling sites.



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Figure 4.--Aerial photograph of downtown Orlando showing the Washington Street exfiltration study area.

Table 1.--Sampling sites and type of data collected at each study area

| Site No.                                   | Site name                                | Type of data collected  |
|--|--|---|
| <u>Washington Street exfiltration pipe</u> |  |   |
| 1  | Well 10 feet east of exfiltration pipe   | Water quality of the surficial aquifer system                                     |
| 2  | Well 2 feet east of exfiltration pipe    | Do.   |
| 3  | Stormwater to exfiltration pipe          | Runoff water quality  |
| 4  | Exfiltration pipe                        | Runoff water quality, constituent concentrations in sediment                      |
| 5  | 3-foot depth lysimeter, east end of pipe | Unsaturated zone water quality  |
| 6  | 5-foot depth lysimeter, middle of pipe   | Do.   |
| 7  | 8-foot depth lysimeter, west end of pipe | Do.   |
| 8  | Well 2 feet west of exfiltration pipe    | Water quality of the surficial aquifer system                                     |
| 9  | Background well                          | Water quality of the surficial aquifer system (control)                           |
| <u>Silver Star Road detention pond</u>     |  |   |
| 1  | Well number 1                            | Water quality of the surficial aquifer system                                     |
| 2  | do. 2                                    | Do.   |
| 3  | do. 3                                    | Do.   |
| 4  | do. 4                                    | Do.   |
| 5  | do. 5                                    | Do.   |
| 7  | do. 7                                    | Do.   |
| 8  | do. 8                                    | Do.   |
| <u>Longwood retention pond</u>             |  |   |
| 1  | Well number 1                            | Water quality of the surficial aquifer system                                     |
| 2  | do. 2                                    | Do.   |
| 3  | do. 3                                    | Do.   |
| 4  | do. 4                                    | Do.   |
| 5  | do. 5                                    | Do.   |
| 6  | do. 6                                    | Do.   |
| 7  | do. 7                                    | Do.   |
| 8  | do. 8                                    | Intermediate aquifer water quality<br>Grain size analysis                         |
| 9  | Background well                          | Water quality of the surficial aquifer system                                     |
| 10   | South inlet, highway runoff              | Standing water and runoff water quality<br>Constituent concentrations in sediment |
| 11   | North inlet, parking lot runoff          | Standing water quality<br>Constituent concentrations in sediment                  |
| 12   | East inlet, parking lot runoff           | Standing water quality<br>Constituent concentrations in sediment                  |
| <u>Princeton and Interstate 4 swale</u>    |  |   |
| 1  | Well number 2                            | Water quality of the surficial aquifer system                                     |
| 2  | do. 4                                    | Do.   |
| 3  | do. 5                                    | Do.   |
| 4  | do. 6                                    | Do.   |
| 5  | do. 8                                    | Do.   |
| 6  | do. 9                                    | Do.   |
| 7  | do. 10                                   | Do.   |
| 8  | do. 11                                   | Do.   |
| 9  | Background well                          | Do.   |
| 10   | Sediment site west of well 4             | Constituent concentrations in sediment  |
| 11   | do. near well 2                          | Do.   |
| 12   | Stormwater to swale                      | Runoff water quality  |
| <u>Longwood and Interstate 4 swale</u>     |  |   |
| 1  | Well number 1                            | Water quality of the surficial aquifer system                                     |
| 2  | do. 2                                    | Do.   |
| 3  | do. 3                                    | Do.   |
| 4  | do. 4                                    | Do.   |
| 5  | Background well                          | Water quality of the surficial aquifer system (control)                           |
| 6  | Sediment site (near well 3)              | Constituent concentrations in sediment  |
| 7  | Sediment site (near background well)     | Do.   |



**YEAR OF PHOTOGRAPHY: 1984**

Figure 5.—Washington Street exfiltration pipe study area looking east (top) and west (bottom).

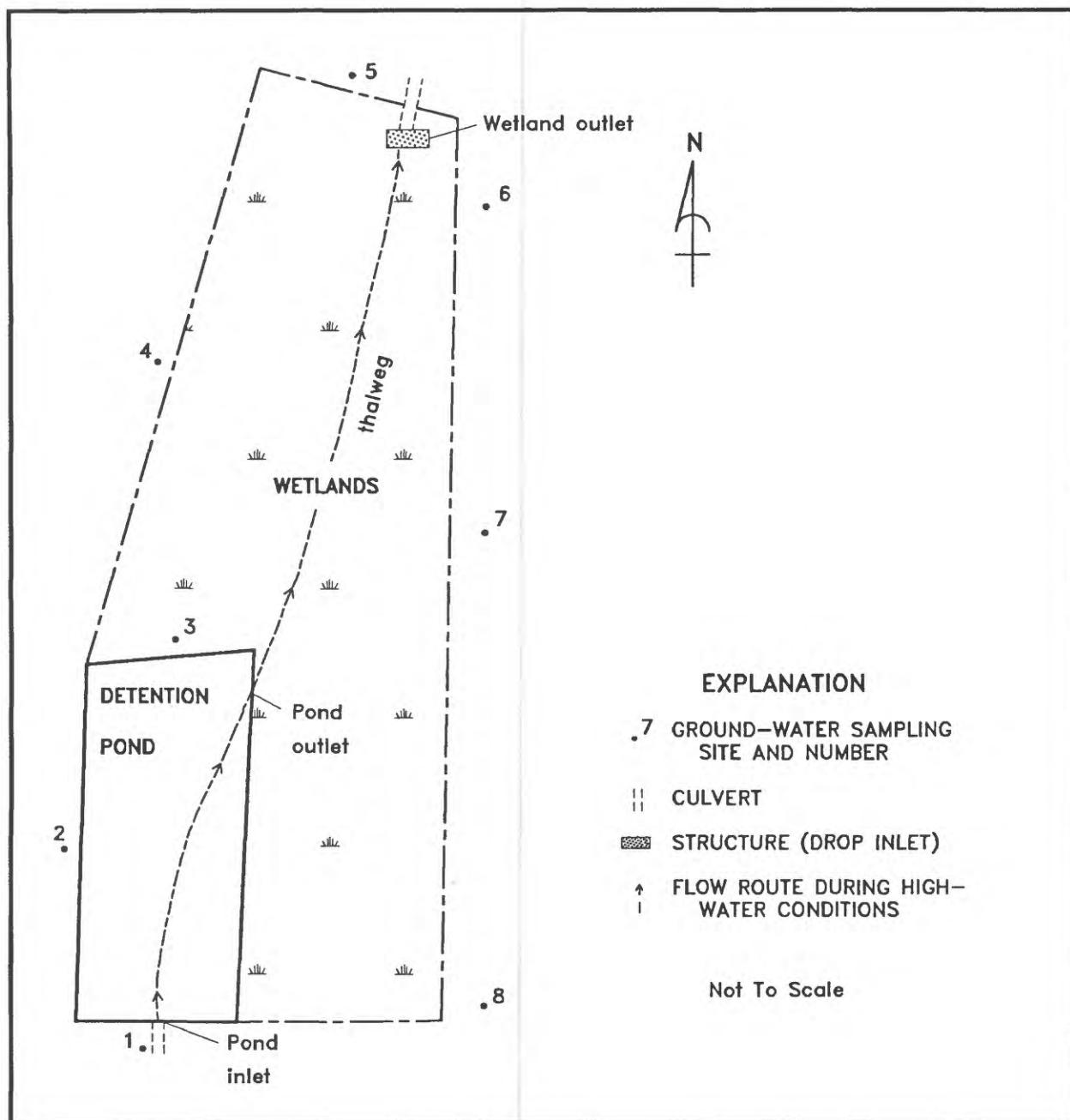


Figure 6.--Silver Star Road detention pond and sampling sites.



**YEAR OF PHOTOGRAPHY: 1985**

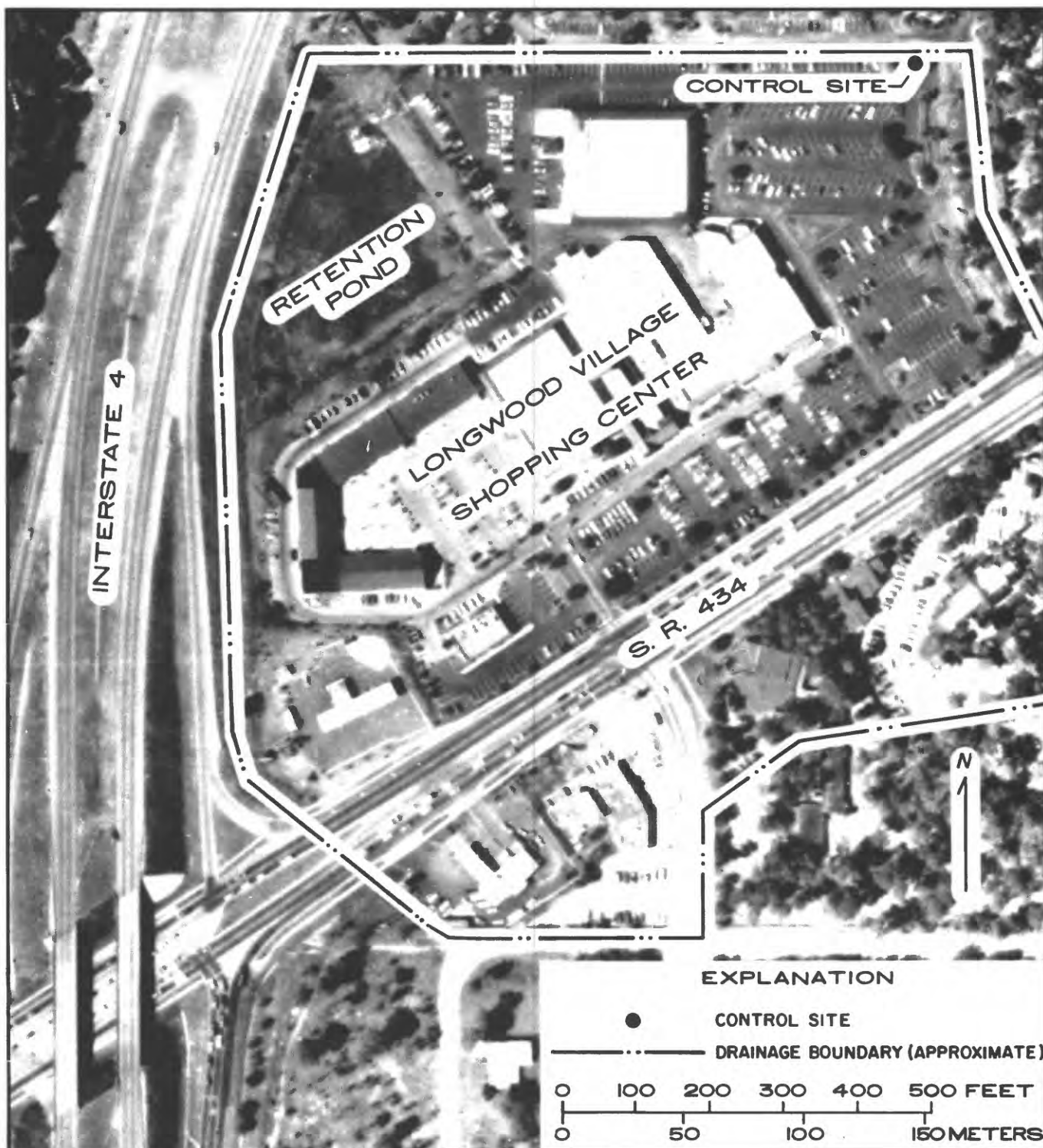
Figure 7.--Silver Star Road detention pond study area, looking north.

A retention pond near Longwood, Fla., in southwest Seminole County was selected for study. The pond is located at the northeast corner of the intersection of Interstate 4 and State Road (SR) 434, behind a shopping center (figs. 8 and 9). The pond is normally dry, but generally fills rapidly during rainstorms from three culverts, the largest of which is from SR 434. The pond drains quickly and often is dry between storms even during the wet summer months. There is no outlet for this pond, and it seems from topographic maps of the area that it may be the location of a relict sinkhole. The pond has a total drainage area of 57.9 acres and receives runoff from SR 434 (3.1 acres), the parking lot of the shopping center (7.4 acres), and a gas station (0.75 acre). The section of SR 434

that drains to this pond is heavily traveled with a traffic count in 1985 of 40,910 vehicles per day; the traffic count on Interstate 4 eastbound at SR 434 is lower--30,307 vehicles per day. During a large part of the day, the traffic on SR 434 is very slow moving or stopped at traffic lights, thus producing a "worst case" scenario for automobile-related constituents to be deposited on road surfaces. Because the pond is often dry, it was possible to install observation wells directly in the pond. The study area and sampling sites are shown in figure 10.

One of the two swale study areas is located along Interstate 4 just north of Orlando, at the Princeton Street westbound Interstate 4 acceleration ramp, and it receives runoff from 0.4 acre of highway (fig. 11). Runoff enters the swale





AERIAL PHOTOMAP COURTESY OF CITY OF ALTAMONTE SPRINGS, FLORIDA.  
 AERIAL PHOTOGRAPHS TAKEN MARCH 29, 1985 BY KUCERA AND ASSOCIATES, INC.

Figure 8.--Aerial photograph of the Longwood retention pond study area.





**YEAR OF PHOTOGRAPHY: 1986**

Figure 9.—Longwood retention pond study area, looking north-northwest (top), and east (bottom).

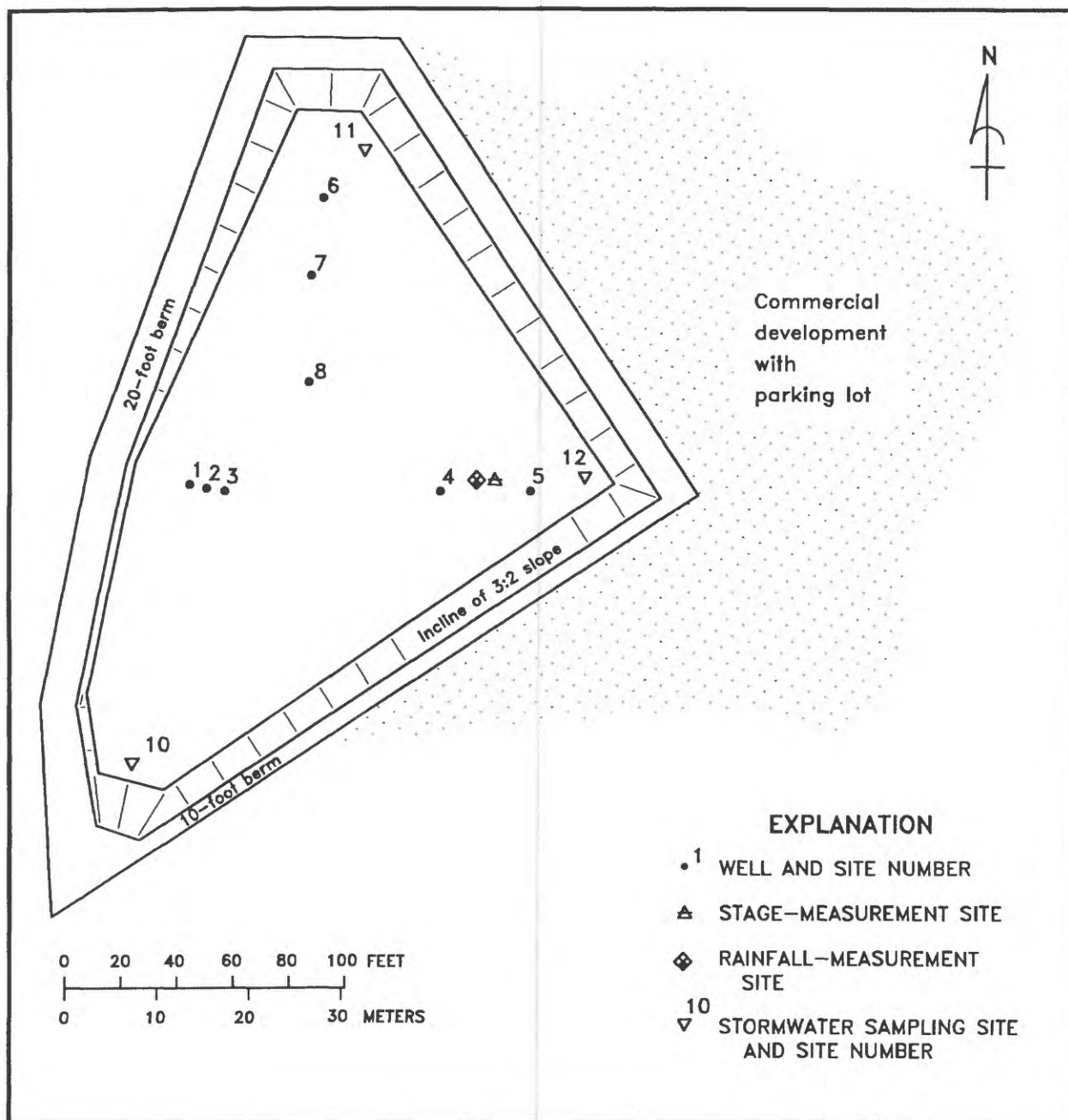
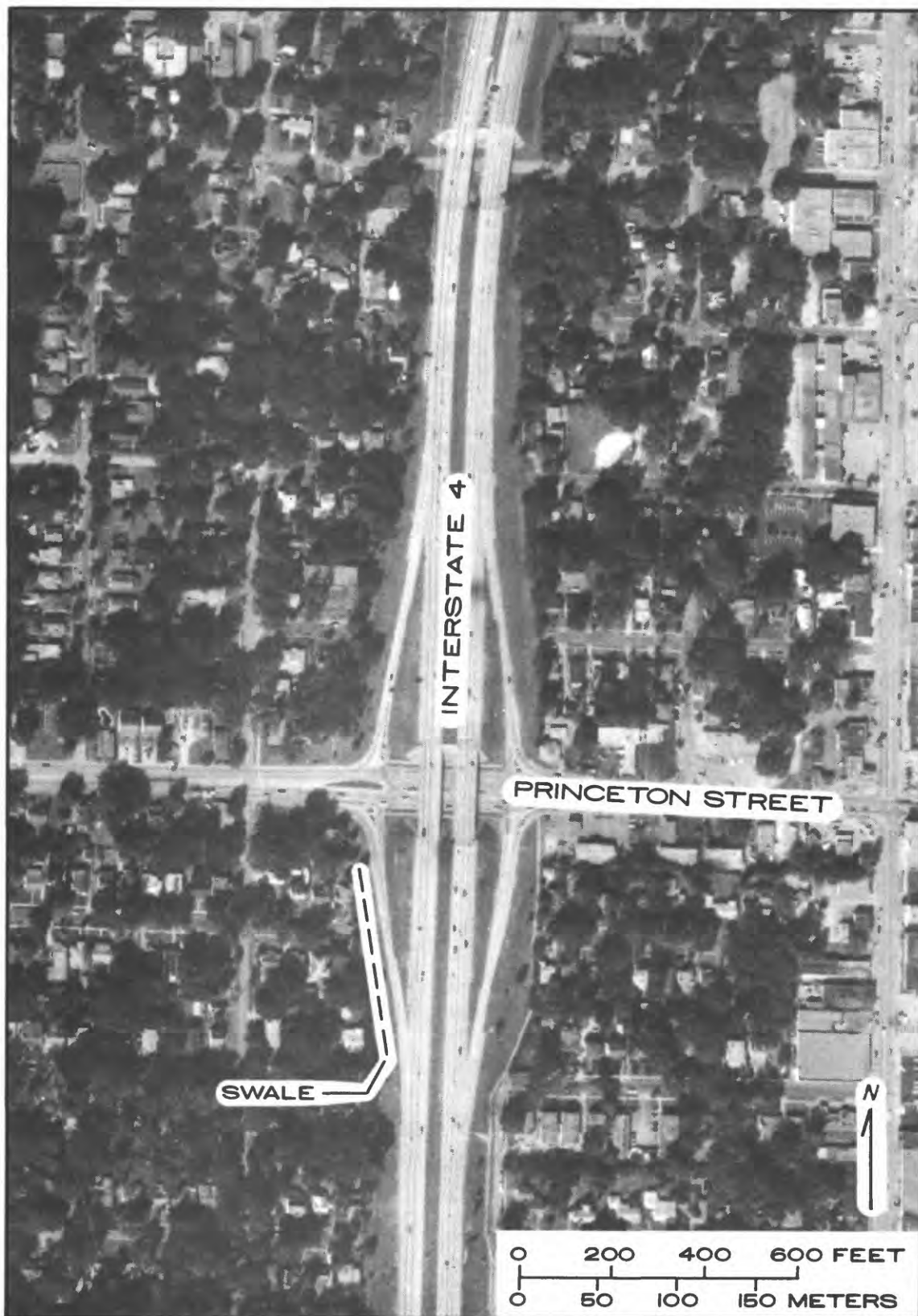


Figure 10.—Longwood retention pond and sampling sites.



AERIAL PHOTOMAP BY CONTINENTAL AERIAL SURVEYS, INC.,  
FROM AERIAL PHOTOGRAPHS TAKEN NOVEMBER 1983

Figure 11.--Aerial photograph of the Princeton Street and Interstate 4  
swale study area.

through a 24-inch culvert at the north end of the swale. The section of highway which drains to the swale (westbound lanes) had a traffic count of 54,066 vehicles per day in 1983, which is in the top five segments of highest traffic count throughout downtown Orlando. In addition to the runoff from Interstate 4, a small amount of overland flow from the adjacent acceleration ramp, and from a small area of nearby residential brick streets also drain into the swale, but the largest

contribution of runoff comes from the highway. Observation wells were installed in the surficial aquifer system in March 1984, and were located longitudinally along approximately 200 feet of the swale in areas of highest infiltration (fig. 12). The configuration of the swale is shown in figure 13.

The second swale study area also was along the Interstate-4 corridor, but was in Seminole County, north of Longwood, Fla., approximately

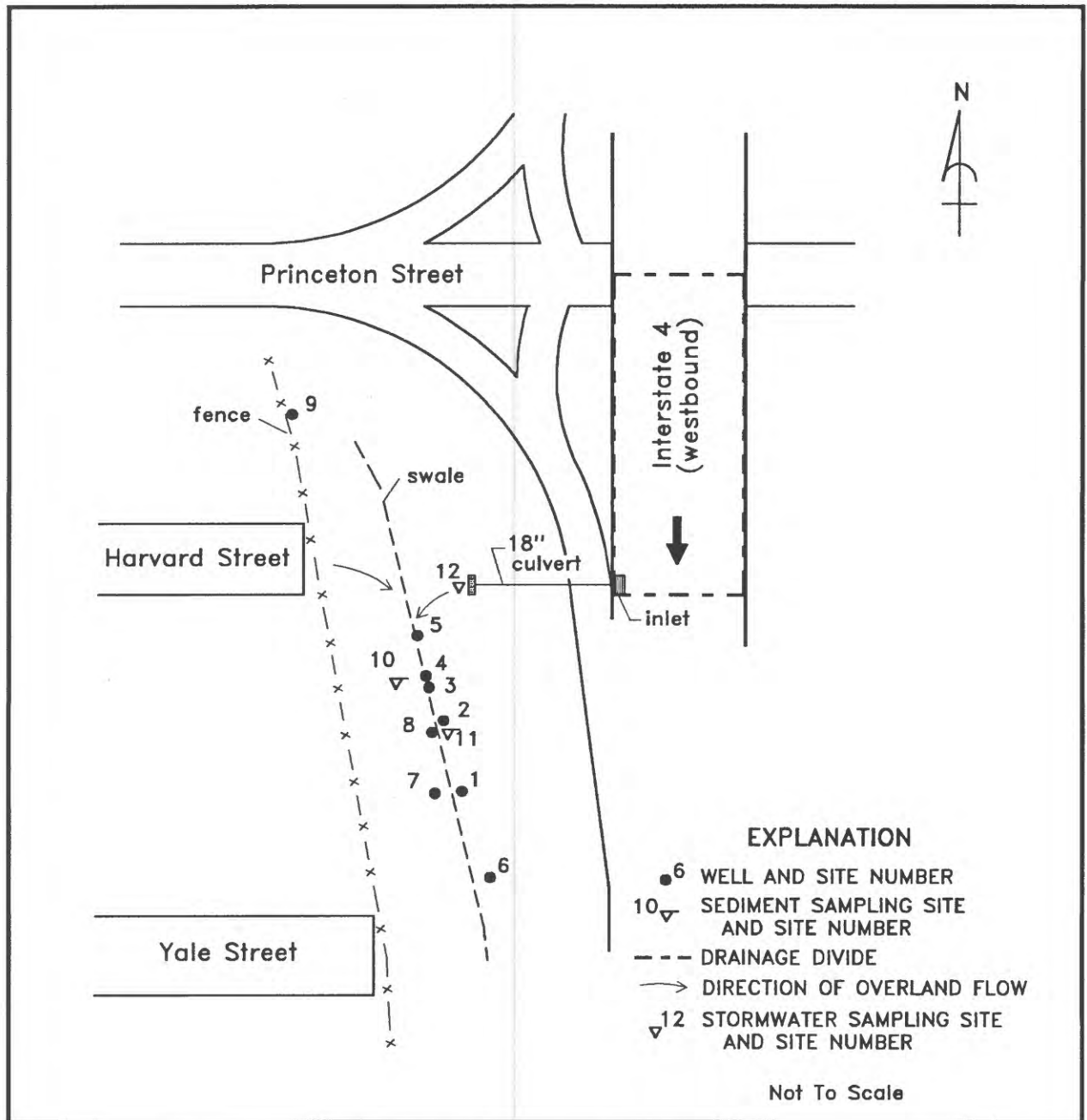


Figure 12.--Princeton Street and Interstate 4 swale and sampling sites.



**YEAR OF PHOTOGRAPHY: 1984**

Figure 13.—Princeton Street and Interstate 4 swale, looking south (top), and north (bottom).

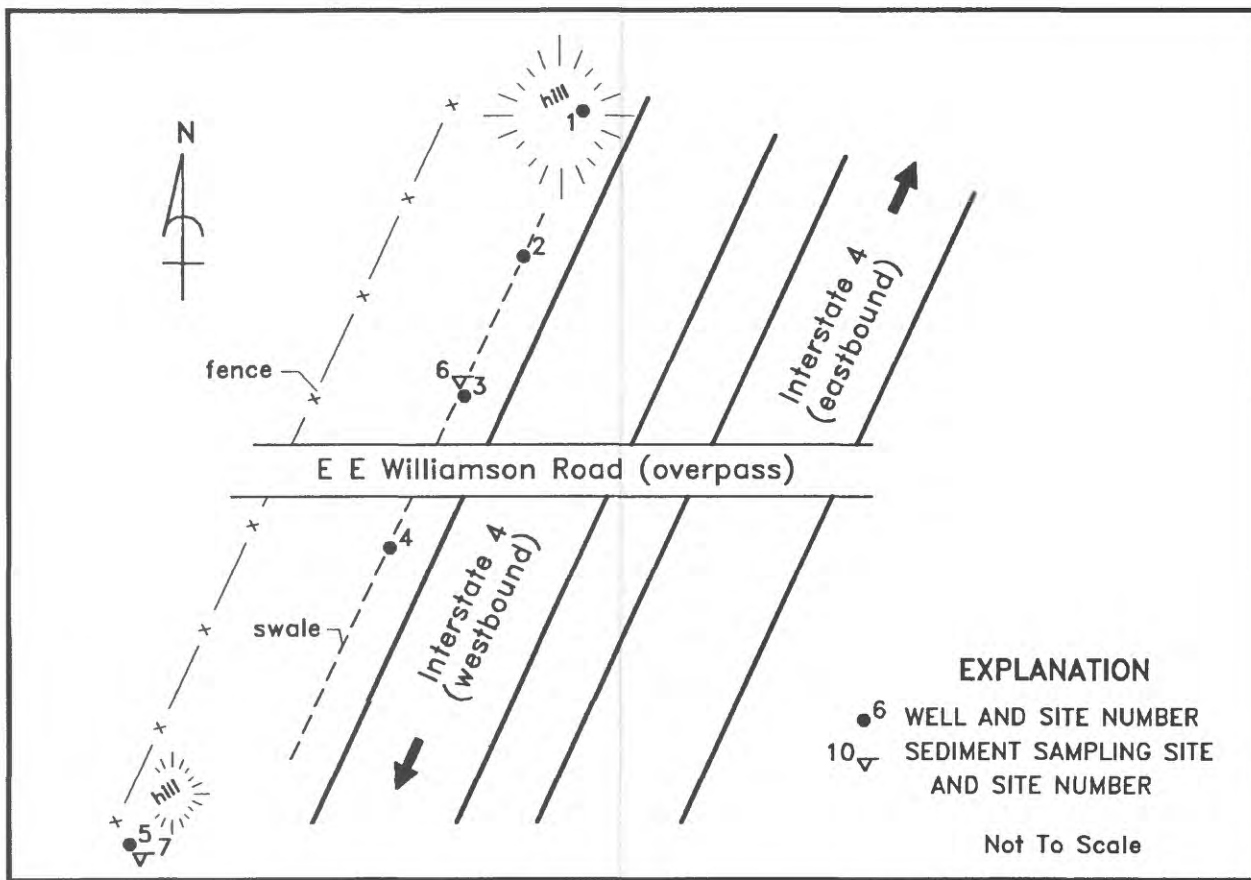


Figure 14.--Longwood and Interstate 4 swale and sampling sites.

midway between two Interstate exits (Longwood and Lake Mary). The average daily traffic was 23,800 vehicles per day in 1985. The drainage area to this swale is approximately 8.8 acres. Surface runoff enters the swale by overland flow from the shoulders of the highway. Approximately 2 acres of the drainage area are road surface and shoulder; the remainder is the grassed surface of the swale. To provide upgradient and downgradient sampling sites, observation wells in the surficial aquifer system were installed along the length of the swale (0.6 mile) in areas that were thought to differ in amounts of infiltrating water (fig. 14). A photograph of the swale is shown in figure 15.

## SAMPLING AND LABORATORY PROCEDURES

### General Sampling Methods

Several wells were installed at each study area to sample water quality and to determine the ground-water gradient. Wells were located upgradient and downgradient of each structure. Polyvinyl chloride casing and screen were used to construct the wells in augered boreholes.

At each study area, one control well was installed for sampling. The control well was located near the structure location, but far enough away to presumably be out of the zone of





**YEAR OF PHOTOGRAPHY: 1986**

Figure 15.--Longwood and Interstate 4 swale, looking north (top), and south (bottom), at the E. E. Williamson overpass.

influence of the structure. It was decided that a control well at each study area would better represent ambient ground-water quality than would a control well in a remote, pristine environment, totally removed from urban influences.

Sampling sites and types of samples collected (ground water, runoff, and sediment) are listed in table 1 for all study areas.

Ground-water samples were collected seasonally, usually one day after a rainstorm. Antecedent conditions varied for specific sampling times. Rainfall data were collected at two locations: the Longwood retention pond and a location near the exfiltration study area in downtown Orlando. Data from the downtown rainfall gaging site also were applicable to the nearby Princeton Street swale location.

Because of the scope of the study, it was not possible to do rigorous, intensive sampling at each site with time to study the effects on ground-water quality from individual rainfalls that generated runoff. In the monitoring of the surficial aquifer system, it cannot be determined with absolute certainty when a volume of water from a particular rainstorm reaches the saturated zone. Water entering the soil from a rainstorm will move downward toward the saturated zone, but soil storage requirements must be satisfied before the water can reach the saturated zone. A rise in the water table may be due to water previously held in soil storage in the unsaturated zone that has just recently been displaced by water infiltrating downward from the most recent storm. Thus, water travels down from the surface in a layered fashion, with recent storms pushing the older water from previous storms downward toward the saturated zone.

In general, the samples collected for this study do not represent any one storm, but probably reflect a general quality of ground water from infiltration of several storms. Because the movement of ground water in the unsaturated zone is, with few exceptions, vertical, water in the saturated zone should be a mixture of waters that have infiltrated from the surface, and not primarily water from off-site (upgradient).

Sediment samples were collected at all sites. At the Silver Star Road detention pond, bed sediment samples were collected with an Eckman dredge. At the Longwood retention pond, samples were collected during a dry period from

the pond bottom, and included only the top 1 inch of soil. The samples from the Longwood retention pond were analyzed for priority pollutants in addition to inorganic constituents and nutrients. Additionally, core samples were collected during the drilling of a 65-foot deep borehole in the middle of the Longwood pond to determine local geology. Sediment samples collected at the two swale study areas were from two depths—one from the upper 2 inches, and one from 4 to 6 inches below the land surface. Samples at each swale were collected at two sites that varied in distance from the highway. These samples were collected to verify, for these swales, what has been reported in other stormwater studies—that concentrations of constituents in soils decrease with depth and with distance from the road surface.

Data from the five study areas were compiled into a data base for analysis. Data analysis included three steps: (1) plot and observe the range and median values of selected constituents at each study area, (2) statistically analyze data by using analysis of variance techniques, and (3) compare measured water-quality data to State drinking water quality standards (Florida Department of Environmental Regulation, 1982).

### Analytical Methods

Ground-water samples for inorganic constituents were collected as follows:

1. Wells were pumped until specific conductance of the discharge water stabilized, and a minimum of two casing volumes was removed.
2. Water samples were processed at the time of collection using standard U.S. Geological Survey procedures (Fishman and Friedman, 1985). Samples for dissolved constituents 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 National Laboratories in Doraville, Ga., and in Arvada, Colo. Samples for nutrients were treated with mercuric chloride and shipped, packed in ice, to the laboratory in Ocala, Fla. The analytical procedures used by the laboratories are described in Wershaw and others (1983) and Fishman and Friedman (1985).



Ground-water samples were collected at four of the five study areas and analyzed for organic constituents using a Flame Ionization Detection (FID) scan. The FID scan is useful as a screening tool to detect the presence of organics (methylene-chloride extractable compounds only) in water samples, but it is not a quantitative technique. Collection of ground-water samples for FID scan analysis requires special handling and materials (glass bottle, Teflon<sup>1</sup> tubing, and stopper). Samples were shipped to the U.S. Geological Survey laboratory in Ocala, Fla., for analysis.

Sediment samples collected at all study areas were analyzed for inorganic constituent concentrations by U.S. Geological Survey laboratories in both Georgia and Colorado, but analysis of organic constituent concentrations in sediments was done only in the Colorado laboratory. Sediment distribution and clay mineralogy analysis of samples was done by the Geology Department of the University of South Florida. Some sediment distribution analysis was done by the author at the University of Central Florida for sediments from the exfiltration pipe study area.

#### Quality Assurance

Although the analytical laboratory of the U.S. Geological Survey maintains its own quality assurance program, several samples were included as part of this study as a test of the data collection. In March 1986, a blank (deionized water) sample was processed in the field in the same manner as ground-water samples. Results of this sampling are shown in table 2. The blank sample ideally should be very low in constituent concentrations. Values of pH varied significantly between laboratory and field measurements, however, the pH of deionized water is difficult to measure because of the limitations of the measurement probes in low ionic-strength water. Most constituent concentrations were at or below laboratory detection limits. Organic nitrogen was higher than expected, but this may be due to error introduced during digestion of the sample in a predominately nitrogen atmosphere.

<sup>1</sup>Use of trade names in this paper is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 2. — *Chemical analysis of a blank sample, March 26, 1986*

[Values in parentheses are reruns of the sample. Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter]

| Constituent or physical property                         | Concentration |
|--|---------------|
| Turbidity (NTU)  |               |
| pH (pH units):   | 0.40          |
| Laboratory   | 5             |
| Field  | 8.4           |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) |               |
| Laboratory   | 1             |
| Field  | 12            |
| Nitrogen, as N:  |               |
| Nitrate  | .01           |
| Ammonia plus organic,                                    | .62           |
| Nitrite plus nitrate                                     | .02           |
| Nitrite  | .01           |
| Ammonia  | .03           |
| Organic  | .59           |
| Orthophosphorus, as P                                    | .01           |
| Phosphorus, as P   | .02           |
| Carbon, total organic                                    | .10           |
| Calcium  | < 1           |
| Magnesium  | < 1           |
| Sodium   | < 1           |
| Potassium  | < .1          |
| Chloride   | < .2          |
| Sulfate  | .4            |
| Alkalinity, total  | < 3           |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | < 1           |
| Cobalt ( $\mu\text{g}/\text{L}$ )                        | 1 (< 1)       |
| Copper ( $\mu\text{g}/\text{L}$ )                        | < 1           |
| Iron ( $\mu\text{g}/\text{L}$ )                          | < 10          |
| Lead ( $\mu\text{g}/\text{L}$ )                          | < 1           |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | 6 (< 1)       |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 10 (< 10)     |

Two replicate samples also were collected during the study (table 3). The only discrepancy in these samples is in the Kjeldahl nitrogen (ammonia plus organic) concentrations; almost all of the difference can be attributed to the organic nitrogen fraction, and again may be due to sample digestion in a nitrogen atmosphere.

### BACKGROUND WATER QUALITY

The quality of ground water near a runoff detention structure will be influenced by the surrounding urban environment in addition to

the infiltrating street runoff. Ground-water quality in an urbanized area would be expected to differ from the quality of ground water in a natural environment, such as a forest. Comparing the water quality near a structure to a pristine environment control site would be of interest, but may not indicate what influence the structure (exfiltrating street runoff) alone is having on the subsurface environment, independent of other urban factors. Therefore, control wells were installed at all study areas but one (Silver Star Road). The purpose of the control well is to determine ambient water quality in the saturated

Table 3.—*Results of replicate sampling*

[Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter]

| Constituent or<br>physical property                      | Longwood Pond<br>well 8<br>July 10, 1986 |          | Princeton Street swale<br>well 6<br>September 9, 1986 |          |
|--|--|----------|---|----------|
|  | Sample 1                                 | Sample 2 | Sample 1  | Sample 2 |
| Turbidity (NTU)  | 26                                       | 28       | 3   | 2.7      |
| Color (Pt-Co units)                                      | 5  | <5       | <5  | <5       |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | 74                                       | 74       | 138   | 138      |
| Field pH (pH units)                                      | 5.6                                      | 5.6      | 6   | 6        |
| Lab pH (pH units)  | 6  | 6        | 6.4   | 6.4      |
| Nitrogen species, as N:                                  |  |          |   |          |
| Ammonia  | .05                                      | .03      | .03   | .03      |
| Nitrite  | .01                                      | .06      | < .01   | < .01    |
| Ammonia plus organic                                     | .94                                      | .22      | < .20   | .22      |
| Nitrite plus nitrate                                     | .7                                       | .7       | .21   | .22      |
| Phosphorus, as P   | .01                                      | .01      | .08   | .09      |
| Orthophosphorus, as P                                    | .01                                      | .01      | .08   | .08      |
| Total organic carbon                                     | <.01                                     | <.01     | 1.3   | 1        |
| Calcium  | 7  | 7        | 13  | 13       |
| Magnesium  | 1.7                                      | 1.7      | 2.4   | 2.5      |
| Sodium   | 2.2                                      | 2.2      | 6.3   | 6.2      |
| Potassium  | .5                                       | .5       | 1.8   | 1.8      |
| Chloride   | 2.6                                      | 2.7      | 14  | 14       |
| Sulfate  | 7.2                                      | 7.1      | 24  | 23       |
| Alkalinity   | 18                                       | 18       | 15  | 15       |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | <1                                       | <1       | <1  | <1       |
| Copper ( $\mu\text{g}/\text{L}$ )                        | 1  | 1        | 2   | 6        |
| Iron ( $\mu\text{g}/\text{L}$ )                          | 240                                      | 240      | 640   | 640      |
| Lead ( $\mu\text{g}/\text{L}$ )                          | <5                                       | <5       | <5  | <5       |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | <1                                       | <1       | 2   | 5        |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 25                                       | 21       | 18  | 19       |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | <10                                      | 20       | <10   | <10      |

zone in the particular area of land use in which the structure is located, but located far enough away to be unaffected by the structure.

The importance of a control well located near the structure itself is illustrated by the Stiff diagrams (Hem, 1985) of ionic composition (fig. 16). In figure 16, the median values of major ions in ground water in 11 wells in the Ocala National Forest, located about 50 miles north of Orlando, were plotted at the same scale with the control sampling site at each structure location. The variability in composition between the Ocala

ground water and the control sites is apparent, as are the differences in ground water among control sites.

Comparison of other water-quality measurements at control sites to values in the Ocala National Forest surficial aquifer system ground water illustrates further the desirability of a control sampling site at each study location. Median concentrations of nutrients, ions, and metals, and values of selected physical measurements are listed in table 4 for ground water from control sites at four of the five study locations and

Table 4.--Median concentrations of nutrients, major ions, and minor elements for 13 wells in the surficial aquifer system in the Ocala National Forest, and the control sites at the Washington Street exfiltration study area, two swale study areas, and the Longwood retention pond study area

[Concentrations are dissolved, in milligrams per liter, unless otherwise noted. If number of samples = 1, then the median listed is the value for that sample. If number of samples = 2, then the median equals the mean. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter; -- denotes no sample or value]

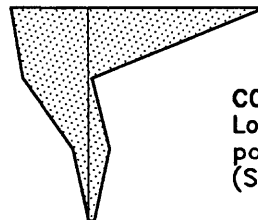
| Constituent or Physical property                         | Ocala National Forest |                  | Washington Street exfiltration pipe |        | Longwood pond  |        | Longwood swale |        | Princeton swale |        |
|--|-----------------------|------------------|-------------------------------------|--------|----------------|--------|----------------|--------|-----------------|--------|
|  | No. of samples        | Median           | No. of samples                      | Median | No. of samples | Median | No. of samples | Median | No. of samples  | Median |
| Turbidity (NTU)  | --                    | --               | 3                                   | 2.65   | 2              | 500    | 2              | 454    | 2               | 4.85   |
| Color (Pt-Co units)                                      | --                    | --               | 3                                   | <5     | 2              | <5     | 2              | <5     | 2               | <5     |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | 11                    | 27               | 3                                   | 345    | 2              | 258    | 2              | 89     | 2               | 155    |
| Field pH (pH units)                                      | 11                    | 4.7              | 3                                   | 6.5    | 2              | 6.7    | 2              | 5.6    | 2               | 6.8    |
| Lab pH (pH units)  | 11                    | 5                | 3                                   | 6.7    | 2              | 7.6    | 2              | 6.7    | 2               | 6.8    |
| Nitrogen species, as N:                                  |                       |                  |                                     |        |                |        |                |        |                 |        |
| Ammonia  | 11                    | <sup>1</sup> .01 | 3                                   | .02    | 2              | .09    | 2              | .05    | 2               | .02    |
| Nitrite  | 11                    | <sup>1</sup> .01 | 3                                   | .01    | 2              | .63    | 2              | .01    | 2               | .01    |
| Ammonia plus organic                                     | --                    | --               | 3                                   | .44    | 2              | 1.17   | 2              | .76    | 2               | .16    |
| Nitrite plus nitrate                                     | 11                    | <sup>1</sup> .01 | 3                                   | .4     | 2              | 1.9    | 2              | .67    | 2               | .09    |
| Phosphorus, as P   |                       |                  |                                     |        |                |        |                |        |                 |        |
| Orthophosphorus, as P                                    | 11                    | <sup>1</sup> .01 | 3                                   | .03    | 2              | .51    | 2              | .23    | 2               | .02    |
| Total organic carbon                                     | --                    | --               | 3                                   | 2.7    | 2              | 1.15   | 2              | 1.3    | 2               | 1.35   |
| Calcium  | 11                    | .4               | 3                                   | 50     | 2              | 24.5   | 2              | 6.6    | 2               | 11     |
| Magnesium  | 11                    | .5               | 3                                   | 2.5    | 2              | 12.5   | 2              | 4.25   | 2               | 2.65   |
| Sodium   | 11                    | 2.1              | 3                                   | 7.7    | 2              | 5.85   | 2              | 1.95   | 2               | 8.25   |
| Potassium  | 11                    | .1               | 3                                   | 4.45   | 2              | .9     | 2              | .55    | 2               | 2.3    |
| Chloride   | 11                    | .4               | 3                                   | 4.6    | 2              | 11     | 2              | 4.6    | 2               | 14.5   |
| Sulfate  | 10                    | .62              | 3                                   | 46     | 2              | 2.35   | 2              | 7.1    | 2               | 19.5   |
| Alkalinity   | 5                     | .82              | 3                                   | 76     | 2              | 135    | 2              | 27.5   | 2               | 17.5   |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      |                       |                  |                                     |        |                |        |                |        |                 |        |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | --                    | --               | 1                                   | <10    | 2              | <10    | 2              | 90     | 2               | <10    |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | 14                    | <sup>1</sup> <1  | 1                                   | <1     | 2              | <1     | 2              | <1.5   | 2               | <1     |
| Copper ( $\mu\text{g}/\text{L}$ )                        | 14                    | <sup>1</sup> 2.5 | 3                                   | <10    | 2              | 1.5    | 2              | 2      | 2               | 3.5    |
| Iron ( $\mu\text{g}/\text{L}$ )                          | 14                    | <sup>1</sup> 40  | 3                                   | 3      | 2              | 10.5   | 2              | 90     | 2               | 1,140  |
| Lead ( $\mu\text{g}/\text{L}$ )                          | 13                    | <sup>1</sup> <1  | 3                                   | <10    | 2              | <5     | 2              | <5     | 2               | <5     |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | 11                    | <sup>1</sup> <1  | 1                                   | <1     | 2              | <2.5   | 2              | 3      | 2               | 6      |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 14                    | <sup>1</sup> 10  | 3                                   | 15     | 2              | <3.5   | 2              | 24     | 2               | 20.5   |

<sup>1</sup>Concentrations are for total, not dissolved, constituent.

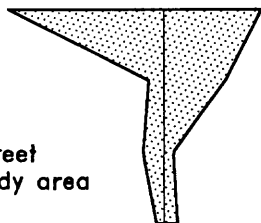
**SURFICIAL AQUIFER  
SYSTEM**  
Ocala National Forest  
11 wells



**CONTROL WELL**  
Longwood retention  
pond  
(Site 9)



**CONTROL WELL**  
Washington Street  
Exfiltration study area  
(Site 9)



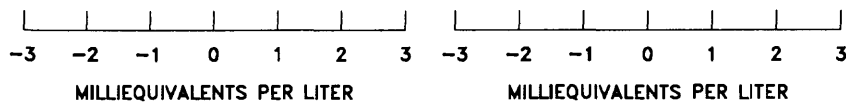
**WELL -  
65 FEET DEEP**  
Longwood retention  
pond  
(Site 8)



**CONTROL WELL**  
Princeton swale  
(Site 9)



**CONTROL WELL**  
Longwood swale  
(Site 5)



### EXPLANATION

|           |   |              |
|-----------|---|--------------|
| Calcium   | — | Bicarbonate  |
| Magnesium | — | Sulfate      |
| Sodium    | — | Chloride     |
| Potassium | — | Nitrate as N |

Figure 16.--Ionic composition of ground water at control sites and surficial aquifer wells in the Ocala National Forest. (Median values used.)

for Ocala National forest surficial aquifer system water. With few exceptions, the ground water at the control sites was dissimilar to the Ocala ground water, as was shown by figure 16. Additionally, the median values vary among control sites at the study areas listed, indicating local influences on ground-water quality.

## STORMWATER RUNOFF QUALITY

The main purpose of this study was to determine whether constituent concentrations were elevated in areas around highway-runoff detention structures. Earlier research has

identified constituents that are of concern, and has made available much information on the concentrations that might be expected in runoff from roads. Therefore, the collection of runoff samples was not a major effort of this study. However, several runoff samples were collected to compare to values cited in the literature.

Table 5 lists mean water-quality values from a report on highway runoff (Kobriger and others, 1981), median values and flow-weighted concentrations in runoff from one sampled storm at Washington Street, values obtained for one runoff sample from two study areas, and median values

Table 5.--Concentrations of nutrients and minor elements in stormwater runoff, values from available literature, Washington Street, Longwood retention pond, Princeton Street and Interstate 4 swale, and median values at Silver Star Road pond inlet

[Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter. -- denotes no value available]

| Constituent or physical measure                          | Nation-wide average value | Washington Street <sup>2</sup> , 09-27-84 | Longwood Pond, 07-22-86 | Princeton and Interstate 4 swale, 07-22-86 | Silver Star Road Pond inlet (Median) |
|--|---------------------------|---|-------------------------|--|--------------------------------------|
| Turbidity (NTU)  | --                        | 1.9/3.42                                  | 3.5                     | 1  | --                                   |
| Color (Pt-Co units)                                      | --                        | 40/68                                     | 50                      | 10   | 40                                   |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | --                        | 115/189                                   | 143                     | 115  | 145                                  |
| pH-field (standard units)                                | --                        | --  | 6.8                     | 6.8  | 7.2                                  |
| pH-lab (standard units)                                  | --                        | --  | 7.0                     | 6.7  | 7.2                                  |
| Nitrogen, as N:  |                           |   |                         |  |                                      |
| Ammonia, total   | --                        | .04/.04                                   | .47                     | .4   | .08                                  |
| Ammonia  | --                        | --  | .44                     | .38  | .06                                  |
| Nitrite, total   | --                        | .02/.06                                   | .06                     | .08  | .01                                  |
| Nitrite  | --                        | --  | .05                     | .08  | .01                                  |
| Ammonia plus organic, total                              | 2.9                       | 1.1/1.5                                   | 3.1                     | 1.1  | 1.1                                  |
| Ammonia plus organic                                     | --                        | --  | 2.1                     | .98  | .7                                   |
| Nitrite plus nitrate, total                              | --                        | .11/.31                                   | 1.6                     | 1.2  | .1                                   |
| Nitrite plus nitrate                                     | --                        | --  | 1.5                     | 1.2  | .1                                   |
| Phosphorus, total, as P                                  | --                        | .22/.25                                   | 1.2                     | .2   | .14                                  |
| Phosphorus, as P   | --                        | --  | .88                     | .16  | .05                                  |
| Orthophosphorus, total, as P                             | .8                        | .09/.13                                   | .58                     | .14  | .06                                  |
| Orthophosphorus, as P                                    | --                        | --  | .49                     | .11  | .02                                  |
| Total organic carbon                                     | 41                        | 13/44                                     | 55                      | 25   | 15                                   |
| Calcium  | --                        | --  | 18                      | 17   | 32                                   |
| Magnesium  | --                        | --  | .99                     | .44  | 1.45                                 |
| Sodium   | --                        | --  | 5.6                     | 1.8  | 3.2                                  |
| Potassium  | --                        | --  | 2.7                     | 1.4  | 1.6                                  |
| Chloride   | 386                       | --  | 4.9                     | 1.4  | 5.3                                  |
| Sulfate  | --                        | --  | 23                      | 19   | 7.8                                  |
| Alkalinity   | --                        | --  | 63                      | 26   | 92                                   |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | --                        | --  | 60                      | 70   | --                                   |
| Cadmium ( $\mu\text{g}/\text{L}$ )                       | 40                        | --  | 1                       | 1  | <1                                   |
| Chromium ( $\mu\text{g}/\text{L}$ ), total               | 40                        | --  | 12                      | 4  | 3                                    |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | --                        | --  | <1                      | <1   | <10                                  |
| Copper ( $\mu\text{g}/\text{L}$ ), total                 | 100                       | --  | 48                      | 23   | 10                                   |
| Copper ( $\mu\text{g}/\text{L}$ )                        | --                        | --  | 12                      | 8  | <10                                  |
| Iron ( $\mu\text{g}/\text{L}$ ), total                   | 10,300                    | --  | 2,100                   | 269  | --                                   |
| Iron ( $\mu\text{g}/\text{L}$ )                          | --                        | --  | 56                      | 28   | --                                   |
| Lead ( $\mu\text{g}/\text{L}$ ), total                   | 960                       | 200/160                                   | 150                     | 46   | 34                                   |
| Lead ( $\mu\text{g}/\text{L}$ )                          | --                        | --  | 6                       | 6  | 7                                    |
| Nickel ( $\mu\text{g}/\text{L}$ ), total                 | 20                        | --  | 10                      | 4  | --                                   |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | --                        | --  | 3                       | 3  | --                                   |
| Zinc ( $\mu\text{g}/\text{L}$ ), total                   | 410                       | 180/195                                   | 290                     | 209  | 60                                   |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | --                        | --  | 59                      | 150  | 20                                   |

<sup>1</sup>Kobriger and others (1981, table 33, p. 89).

<sup>2</sup>Median value and flow-weighted concentration of all samples collected during one storm.

of inlet concentrations at the Silver Star Road detention pond (from an earlier study of the pond). The mean values reported by Kobriger and others (1981) are computed from samples collected during a study from 1977 through 1978, from six highway sites. Three sites were located in Milwaukee, Wisc., and one site was located in each of the following cities: Harrisburg, Pa.; Denver, Colo.; and Nashville, Tenn.

In general, only small differences in water quality are evident among the runoff samples from the study locations listed in table 5. Comparison of average constituent concentrations in the report by Kobriger and others (1981) to those for local study areas indicates that local values are lower, particularly for chloride, iron, and lead. The chloride concentrations reported by Kobriger and others (1981) may be due to deicing of roads with salt in colder climates. Lead concentrations were as high as 910  $\mu\text{g/L}$  (micrograms per liter) at the inlet of the Silver Star Road detention pond site, which is still below the average (960  $\mu\text{g/L}$ ) reported by Kobriger and others (1981). The difference in lead concentrations may be a function of the number of vehicles that use leaded gasoline, which may have been much higher during the time of the national study than for the present study. Additionally, there are few industrial sources of lead in Orlando. Although the constituent concentrations for this study generally are lower than those reported by Kobriger and others (1981), they still represent a potential for contaminating ground water by increasing concentrations above natural conditions.

Five runoff samples were collected across a storm hydrograph for one storm (0.11-inch rainfall) at the Washington Street study area. A statistical summary of the storm runoff data collected at Washington Street and that collected at the inlet to the Silver Star Road detention pond during a 2-year period (1982 through 1984) by Martin and Smoot (1986) is presented in table 6 for comparison.

The drainage basins and associated land uses differ between the Washington Street and Silver Star Road study areas, which may partly explain the higher values at the Washington Street location for selected water-quality measurements. Maximum color and total organic carbon, and median lead and zinc were higher in runoff samples at Washington Street. These results are of interest because the Washington Street data

represent only one storm and one antecedent condition, whereas the Silver Star Road summary represents 12 storms varying in rainfall volume, intensity, and antecedent condition.

## **EFFECTS OF HIGHWAY-RUNOFF DETENTION METHODS ON GROUND WATER**

### **Exfiltration System**

Water from sites at the Washington Street exfiltration study area was sampled during 1984–85. The sites represent street runoff, water standing in the pipe after several storms, and water in the unsaturated and saturated zones. Vacuum lysimeters made of Teflon material were used for sampling water in the unsaturated zone. Teflon material was used because of its relative inertness. A study by Zimmerman and others (1978) showed that Teflon lysimeters consistently recovered 98 to 106 percent of the test standards used for all nutrients. Teflon lysimeters may be left in the sediment for long periods of time without clogging and do not alter nutrient concentrations as do some ceramic cup lysimeters (Hansen and Harris, 1975). Lysimeters were located adjacent to the exfiltration pipe at varying depths corresponding to points of interest relative to the pipe (fig. 17). The objective was to examine changes in quality of water with depth.

One of the primary difficulties in sampling water in the unsaturated zone is the uncertainty of when water collected in the lysimeter actually passed by the lysimeter, because of the many variables involved. Some of these variables include the percentage of saturation of the soil, which has an effect on the rate of movement of water, and the silica flour used as a packing around the lysimeter's porous section. Silica flour is used to maintain hydraulic conductivity between the lysimeter and the surrounding soil, so that a sample may be uniformly drawn into the lysimeter. However, because of its fine grain size, the silica-packing functions like a sponge, and holds water. For this reason, it is necessary to evacuate as much water as possible from the silica and the lysimeter before actual samples of recently exfiltrated pipe water are collected. Thus, if it is desired to collect a sample of water after exfiltrating from the pipe, water in the lysimeter must be evacuated and discarded just before the exfiltrated water moves past the

Table 6. — *Statistical summary of stormwater data at Washington Street and Silver Star Road study areas*

[Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter; -- denotes no sample or value]

| Constituent or physical measure                             | Washington Street storm<br>09-27-84 (5 samples) |        |         | No. of samples | Silver Star Road pond inlet<br>08-20-82 through 06-13-84 |        |         |
|---|---|--------|---------|----------------|--|--------|---------|
|   | Maximum   | Median | Minimum |                | Maximum  | Median | Minimum |
| Turbidity (NTU)   | 6.8   | 1.9    | 1.5     | --             | --   | --     | --      |
| Color (Pt-Co units)   | 160   | 40     | 20      | 7              | 80   | 40     | 10      |
| Specific conductance<br>( $\mu\text{S}/\text{cm}$ at 25 °C) | 370   | 115    | 74      | 61             | 302  | 145    | 35      |
| Solids, total   | 648   | 148    | 72      | --             | --   | --     | --      |
| Solids, dissolved   | 384   | 99     | 57      | --             | --   | --     | --      |
| Nitrogen, total, as N:                                      |   |        |         |                |  |        |         |
| Ammonia   | .08   | .04    | .02     | 44             | .56  | .08    | .01     |
| Nitrite   | .16   | .02    | .01     | 44             | .05  | .01    | < .01   |
| Ammonia plus organic  | 3.4   | 1.1    | .53     | 45             | 3.2  | 1.1    | .4      |
| Nitrite plus nitrate  | .63   | .11    | .09     | 44             | .6   | .10    | < .01   |
| Phosphorus, total, as P                                     | .34   | .22    | .14     | 44             | .52  | .14    | .02     |
| Orthophosphorus,<br>total, as P                             | .30   | .09    | .06     | 44             | .33  | .06    | .01     |
| Carbon,   |   |        |         |                |  |        |         |
| total organic   | 120   | 13     | 7       | 46             | 28   | 15     | 1.8     |
| total inorganic   | 20  | 16     | 10      | --             | --   | --     | --      |
| Lead, total ( $\mu\text{g}/\text{L}$ )                      | 300   | 200    | 33      | 48             | 910  | 34     | 7       |
| Zinc, total ( $\mu\text{g}/\text{L}$ )                      | 350   | 180    | 70      | 50             | 530  | 60     | 10      |

lysimeters, and this evacuated water should be discarded. For this study, when a rainstorm was anticipated, each lysimeter was evacuated prior to the storm. Frequently three or more samples were collected from each lysimeter in succession, representing water percolating through the unsaturated zone for 12 to 18 hours during and after a storm.

#### Water-Quality Variations

To determine the variability in water quality, ranges and median values of selected constituents and specific conductance at individual sampling sites were computed (table 7) and plotted. Summary statistics in table 7 are listed in the order of progression through the system, beginning with the pipe (site 4) and ending in the saturated zone (sites 1, 2, and 3). Water-quality values for stormwater entering the pipe were listed in table 5 and for the control well, in table 4. In general, water-quality values vary more and

are higher in the unsaturated zone than in the saturated zone. Examples include specific conductance, nitrate plus nitrite nitrogen, calcium, alkalinity, and zinc. Plots of the data illustrate this more clearly.

Specific conductance varied considerably in water from the unsaturated zone (fig. 18), particularly in the most shallow lysimeter (3-foot). During most storms, the exfiltration pipe would not fill to capacity, and was frequently less than half-full, because of the rapid exfiltration from the pipe and the relatively large storage volume of the pipe relative to the volume of storm runoff. It is possible that exfiltrated stormwater frequently did not pass by the first lysimeter at the 3-foot depth, adjacent to the pipe center line. Thus, the water being drawn into the lysimeter for a sample may have resided, tightly bound in the soil matrix in the unsaturated zone from earlier storms. It may be that major ions in this water held in the soil becomes more concentrated because of evaporation losses.

The range and median specific conductance of water decreased with depth in the unsaturated zone. The 5-foot lysimeter, located adjacent to the pipe bottom, may not have been in the receiving zone of pipe exfiltrate as frequently as the 8-foot lysimeter, located 2 feet below the bottom of the trench (fig. 3). This may explain the greater variability in specific conductance at this location than at the 8-foot depth.

Other constituents that varied with sampling location at the exfiltration pipe study area are shown in figures 19 and 20. Most of the phosphorus (fig. 19) was in the orthophosphorus form. With the exception of well site 8 (2 feet west of the pipe), all values were equal to or less than 0.2 mg/L (milligrams per liter). Dissolved phosphorus was consistently highest at well site 8. Schiner and German (1983) reported total phosphorus in supply wells in the Orlando area

ranged from 0.01 to 0.30 mg/L, with a median value of 0.07 mg/L. There are no drinking water standards for phosphorus, but Hem (1985) reports that concentrations present in natural water generally are less than a few milligrams per liter.

Most of the nitrogen at all sampling sites was in the form of nitrate nitrogen, but organic nitrogen was the dominant species in the pipe water. Nitrate plus nitrite nitrogen were plotted (fig. 19) to show the variability in the 3-foot and 5-foot lysimeters, and the surprisingly high values in the control well (three samples). If the high values in the control well are representative of a background ground-water quality, the data from this study would seem to indicate that the stormwater is diluting nitrate in the ground water around the pipe.

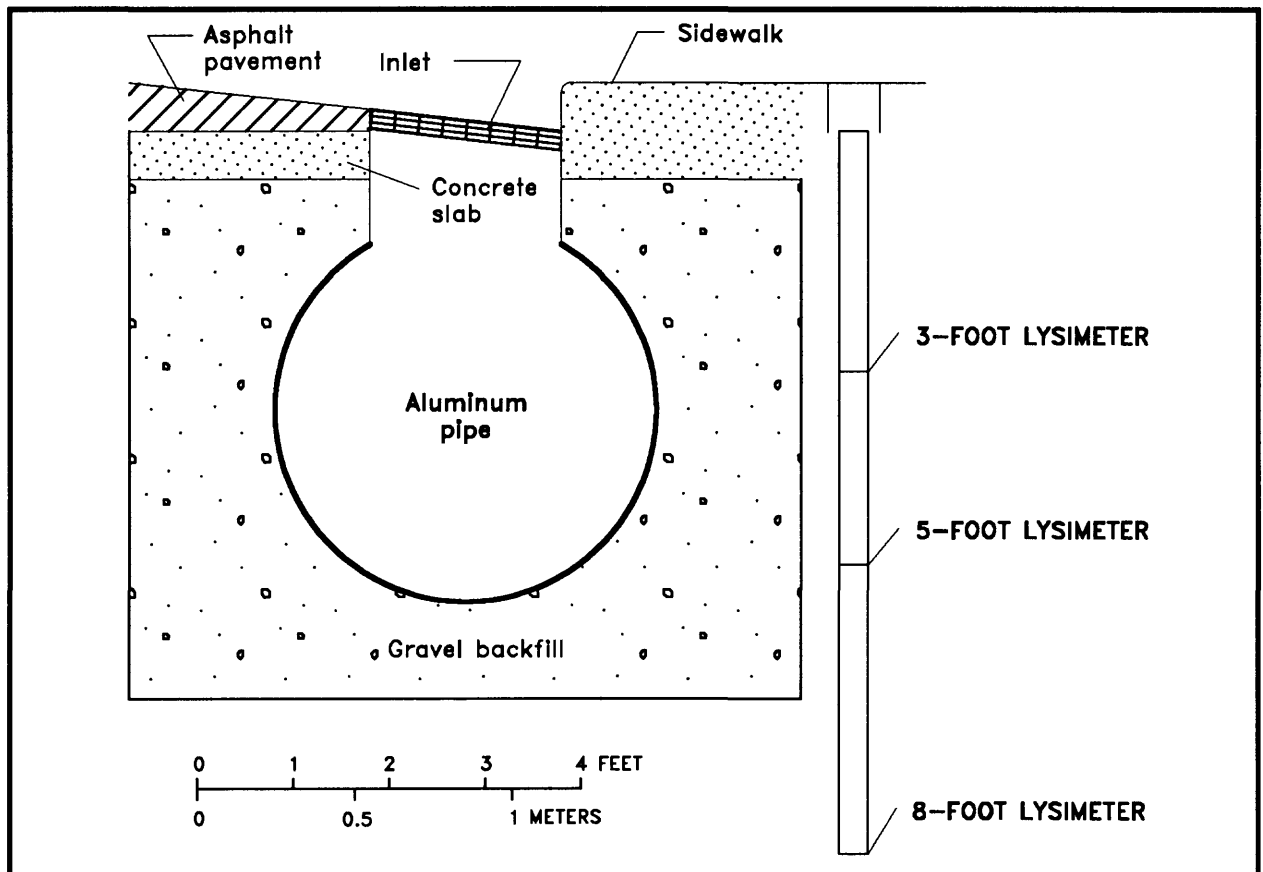


Figure 17.--Cross-sectional view of Washington Street exfiltration pipe showing relative locations of lysimeters.



Table 7. --Statistical summary of water-quality data for Washington Street sampling sites

[Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter; -- denotes no sample or value.]

| Constituent or physical measure                          | Site 4 (exfiltration pipe) |            |        | Site 5 (lysimeter 3 feet deep) |            |        | Site 6 (lysimeter 5 feet deep) |            |        | Site 7 (lysimeter 8 feet deep) |            |        |
|--|----------------------------|------------|--------|--------------------------------|------------|--------|--------------------------------|------------|--------|--------------------------------|------------|--------|
|  | Number of samples          | Range      | Median | Number of samples              | Range      | Median | Number of samples              | Range      | Median | Number of samples              | Range      | Median |
| Turbidity (NTU)  | 6                          | 0.50 - 11  | 3.6    | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Color (Pt-Co units)                                      | 6                          | 5 - 85     | 22.5   | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | 6                          | 72 - 164   | 108    | 30                             | 145 - 675  | 490    | 31                             | 126 - 500  | 320    | 24                             | 136 - 380  | 245    |
| Field pH (pH units)                                      | 1                          | 7.1 - 7.7  | 7.5    | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Lab pH (pH units)  | 5                          | 7.1 - 7.7  | 7.5    | 2                              | 7.9 - 8.1  | --     | 2                              | 7.8 - 7.9  | --     | 2                              | 7.6        | --     |
| Nitrogen species, as N                                   |                            |            |        |                                |            |        |                                |            |        |                                |            |        |
| Ammonia  | 5                          | .04 - .12  | .07    | 4                              | <.01 - .02 | <.01   | 9                              | <.01 - .03 | <.01   | 9                              | <.01 - .04 | <.01   |
| Nitrite  | 5                          | <.01 - .09 | .01    | 4                              | <.01 - .05 | <.01   | 9                              | <.01 - .04 | <.01   | 9                              | <.01 - .05 | <.01   |
| Ammonia plus organic                                     | 5                          | .19 - 1.6  | .41    | 4                              | .20 - 4.5  | 4.1    | 9                              | .1 - 1.7   | .5     | 9                              | .3 - 3.3   | .3     |
| Nitrite plus nitrate                                     | 5                          | .25 - .82  | .44    | 4                              | .84 - 9.4  | 4.15   | 9                              | .64 - 10   | 6.7    | 9                              | .50 - 1.7  | .83    |
| Phosphorus, as P   | 5                          | .05 - .18  | .06    | 2                              | .17 - .21  | --     | 2                              | .13 - .21  | --     | 3                              | .19 - .20  | .20    |
| Orthophosphorus, as P                                    | 5                          | .02 - .16  | .05    | 4                              | .16 - .23  | .19    | 9                              | .14 - .19  | .16    | 9                              | .17 - .21  | .19    |
| Total organic carbon                                     | 5                          | 7 - 43     | 18     | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Calcium  | 5                          | 10 - 19    | 13     | 14                             | 50 - 79    | 71     | 14                             | 44 - 76    | 70.5   | 15                             | 26 - 59    | 51     |
| Magnesium  | 5                          | .19 - .94  | .29    | 14                             | 1.1 - 1.7  | 1.6    | 14                             | .89 - 1.8  | 1.6    | 15                             | .59 - 1.7  | 1.1    |
| Sodium   | 5                          | 1.1 - 9.2  | 5.1    | 1                              | 9.1 - 18   | 16     | 1                              | 2.7 - 5.9  | 4.6    | 1                              | 1.8 - 11   | 7.5    |
| Potassium  | 5                          | 2.4 - 14   | 8.7    | 1                              | 22         | --     | 1                              | 5.6        | --     | 1                              | 4.8        | --     |
| Chloride   | 5                          | 5 - 8.3    | 2.3    | 1                              | 3.2        | --     | 1                              | 2.6        | --     | 1                              | 4.2        | --     |
| Sulfate  | 5                          | 5.6 - 15   | 9.9    | 1                              | 40         | --     | 1                              | 18         | --     | 1                              | 8.1        | --     |
| Alkalinity   | 5                          | 21 - 83    | 48     | 1                              | 187        | --     | 1                              | 129        | --     | 1                              | 74         | --     |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | 2                          | 120 - 170  | --     | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | 2                          | <.1 - <.10 | --     | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Copper ( $\mu\text{g}/\text{L}$ )                        | 4                          | 4 - 20     | <.10   | 16                             | 6 - 80     | <.10   | 16                             | 7 - 26     | <.10   | 17                             | 9 - 90     | <.10   |
| Iron ( $\mu\text{g}/\text{L}$ )                          | 5                          | 14 - 72    | 21     | 13                             | 4 - 71     | 10     | 13                             | <.3 - 18   | 6      | 14                             | 3 - 21     | 12     |
| Lead ( $\mu\text{g}/\text{L}$ )                          | 5                          | <.1 - <.10 | <.10   | 18                             | 1 - 30     | <.10   | 17                             | 1 - 20     | <.10   | 17                             | 2 - 20     | <.10   |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | 2                          | 3 - 4      | --     | --                             | --         | --     | --                             | --         | --     | --                             | --         | --     |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 5                          | 13 - 30    | 27     | 18                             | 8 - 94     | 30     | 17                             | 30 - 100   | 42     | 17                             | 30 - 80    | 50     |

| Constituent or physical measure                          | Site 1 (well 10 feet east) |             |        | Site 2 (well 2 feet east) |             |        | Site 8 (well 2 feet west) |             |        |
|--|----------------------------|-------------|--------|---------------------------|-------------|--------|---------------------------|-------------|--------|
|  | No. of samples             | Range       | Median | No. of samples            | Range       | Median | No. of samples            | Range       | Median |
| Turbidity (NTU)  | 6                          | 0.60 - 9.4  | 2.4    | 6                         | 0.5 - 13    | 2.5    | 5                         | 0.8 - 48    | 2.8    |
| Color (Pt-Co units)                                      | 6                          | <.5 - 5     | <.5    | 6                         | <.5 - 5     | <.5    | 5                         | <.5 - 5     | <.5    |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | 7                          | 185 - 250   | 210    | 7                         | 195 - 200   | 270    | 7                         | 168 - 224   | 172    |
| Field pH (pH units)                                      | 2                          | 6.8 - 7.1   | --     | 2                         | 6.9 - 7.2   | --     | 2                         | 6.2 - 7.1   | --     |
| Lab pH (pH units)  | 7                          | 6.9 - 7.3   | 6.9    | 7                         | 6.9 - 7.4   | 7      | 7                         | 6.1 - 6.9   | 6.2    |
| Nitrogen species, as N                                   |                            |             |        |                           |             |        |                           |             |        |
| Ammonia  | 7                          | .02 - .03   | .02    | 7                         | .02 - .04   | .02    | 6                         | .01 - .03   | .02    |
| Nitrite  | 7                          | <.01 - <.01 | <.01   | 7                         | <.01 - <.10 | <.01   | 6                         | <.01 - <.01 | <.01   |
| Ammonia plus organic                                     | 7                          | .06 - .25   | .14    | 7                         | .05 - .42   | .17    | 6                         | .08 - .38   | .19    |
| Nitrite plus nitrate                                     | 7                          | .20 - .72   | .40    | 7                         | .12 - 1.2   | .40    | 6                         | 1 - 1.3     | 1.2    |
| Phosphorus, as P   | 7                          | .12 - .18   | .15    | 7                         | .28 - .49   | .32    | 6                         | .04 - .09   | .06    |
| Orthophosphorus, as P                                    | 7                          | .09 - .15   | .14    | 7                         | .28 - .47   | .31    | 6                         | .04 - .06   | .05    |
| Total organic carbon                                     | 6                          | 3 - 5       | 3.2    | 6                         | 3 - 5.5     | 3.8    | 5                         | 1.5 - 8     | 2.1    |
| Calcium  | 7                          | 28 - 38     | 33     | 7                         | 30 - 49     | 39     | 7                         | 18 - 33     | 21     |
| Magnesium  | 7                          | .54 - .96   | .73    | 7                         | .84 - 2     | 1.2    | 7                         | 1.2 - 1.8   | 1.7    |
| Sodium   | 7                          | 2.6 - 8     | 5.1    | 7                         | 2.5 - 10    | 5.6    | 7                         | 3.3 - 11    | 10     |
| Potassium  | 6                          | 5.1 - 7.6   | 5.8    | 6                         | 3.1 - 6.8   | 5.6    | 6                         | 2.3 - 10    | 3.2    |
| Chloride   | 6                          | .7 - 20     | 9.2    | 6                         | .9 - 17     | 10     | 6                         | 1.1 - 12    | 5      |
| Sulfate  | 6                          | 13 - 17     | 13.5   | 6                         | 12 - 16     | 13     | 6                         | 31 - 40     | 31.5   |
| Alkalinity   | 6                          | 64 - 84     | 74     | 6                         | 58 - 109    | 94.5   | 6                         | 26 - 59     | 37     |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | 2                          | <.10 - 20   | --     | 2                         | 40 - 80     | --     | 2                         | <.10 - 40   | --     |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | 2                          | <.1 - <.10  | <.10   | 2                         | <.1 - 10    | <.10   | 2                         | <.1 - 10    | <.10   |
| Copper ( $\mu\text{g}/\text{L}$ )                        | 6                          | 1 - <.10    | <.10   | 6                         | 2 - 10      | 4      | 6                         | <.1 - 10    | <.10   |
| Iron ( $\mu\text{g}/\text{L}$ )                          | 7                          | <.3 - 7     | <.3    | 7                         | <.3 - 8     | 4      | 7                         | <.3 - 21    | 3      |
| Lead ( $\mu\text{g}/\text{L}$ )                          | 7                          | <.1 - <.10  | <.10   | 7                         | <.1 - 10    | <.10   | 7                         | <.1 - 10    | <.10   |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | 2                          | <.1 - 1     | --     | 2                         | 2 - 3       | --     | 2                         | <.1 - 1     | --     |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 7                          | <.3 - 69    | 18     | 7                         | 5 - 35      | 22     | 7                         | 5 - 58      | 16     |

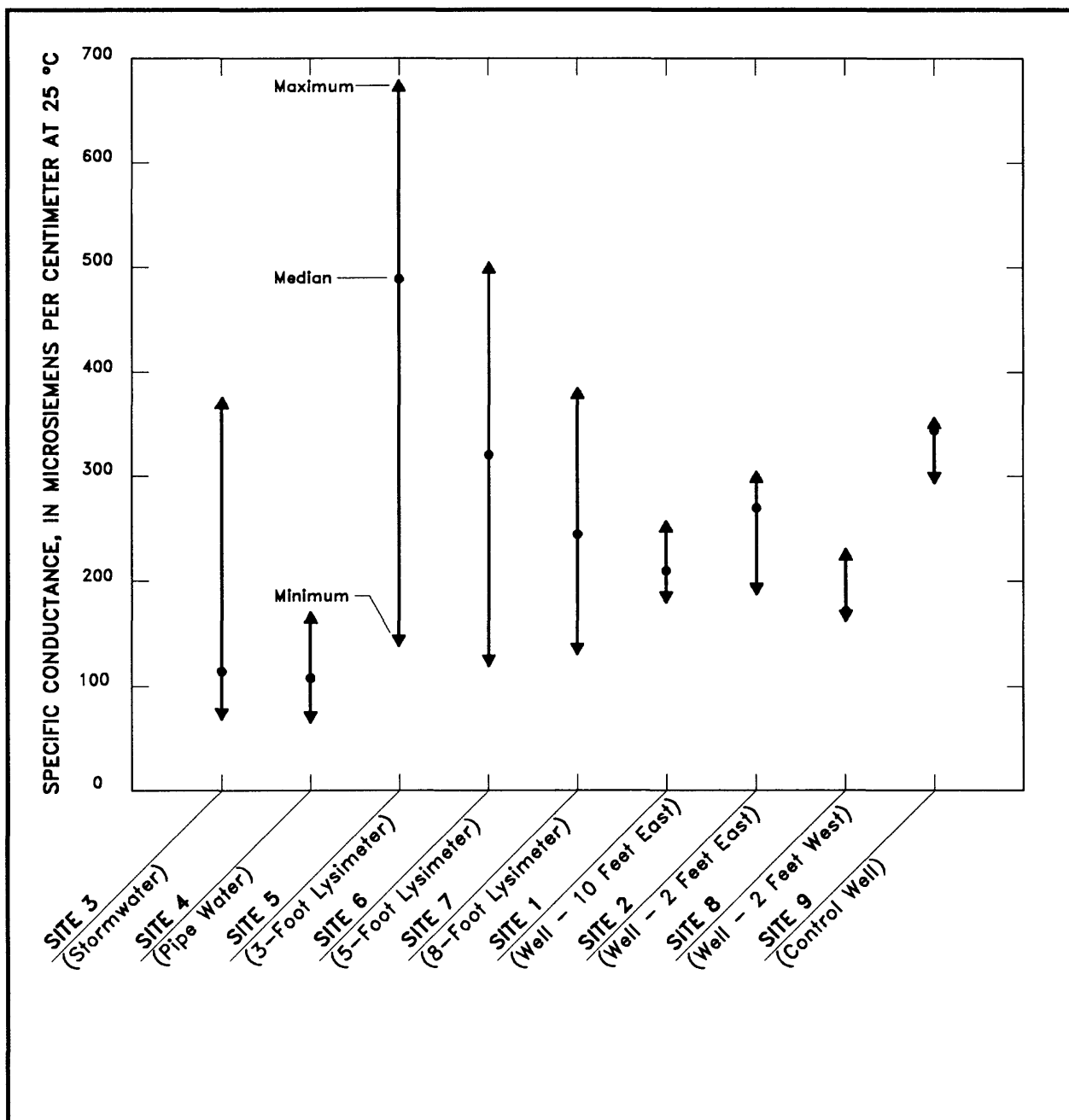


Figure 18.--Specific conductance at sampling sites at the Washington Street exfiltration study area.

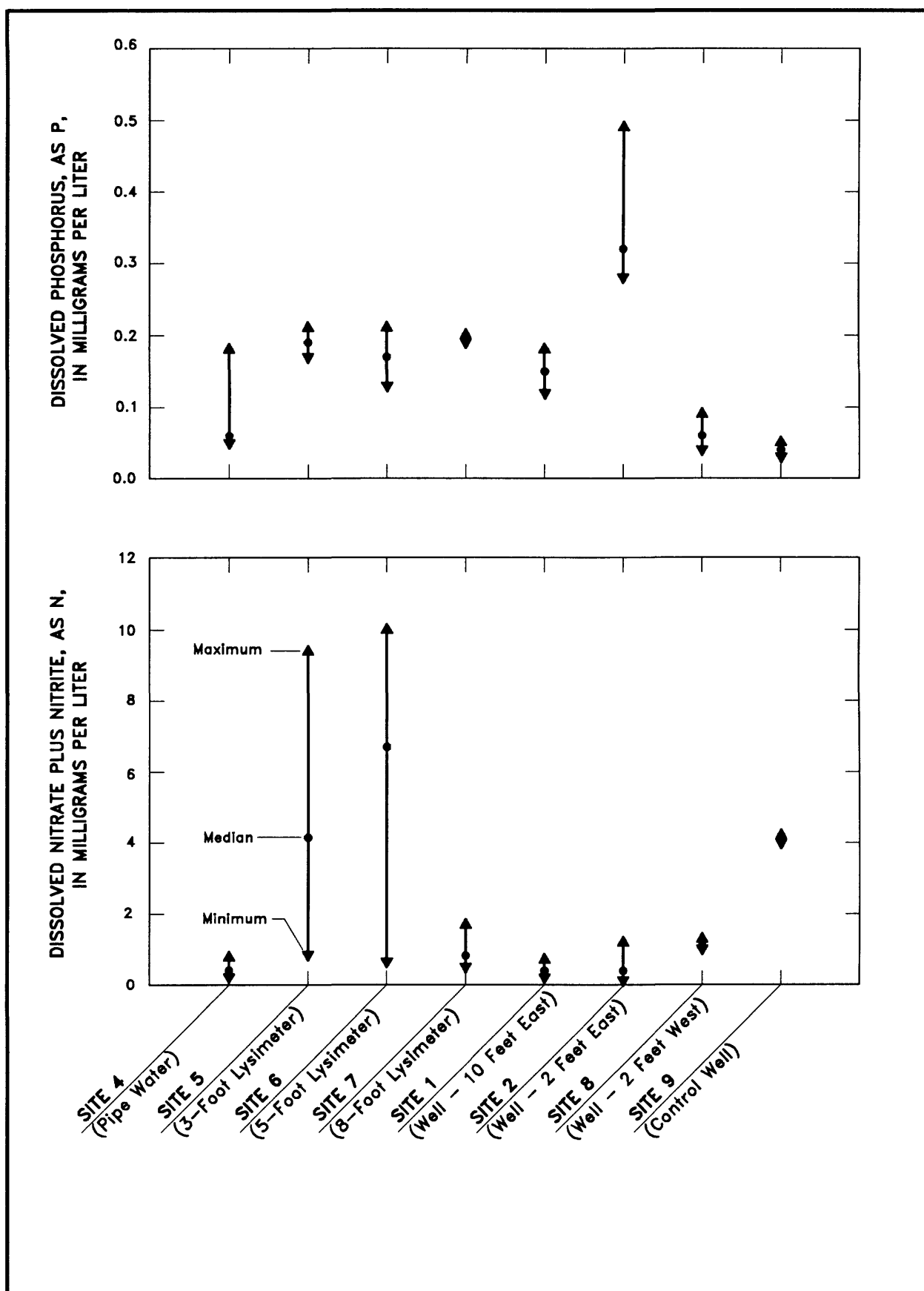


Figure 19.--Dissolved nitrate plus nitrite nitrogen and dissolved phosphorus at sampling sites at the Washington Street exfiltration study area.

Concentrations of dissolved copper at the sampling sites in the exfiltration study area are shown in figure 20. Dissolved copper in most samples was below detection limits (1 or 10  $\mu\text{g/L}$ ). The maximum values shown for the 3-foot and 8-foot lysimeters occurred in August 1985. Dissolved zinc (fig. 20) fluctuated through a wide range in all ground-water samples, with the exception of the control site. Median values for dissolved zinc, however, were highest in the unsaturated zone. Median values in ground water in the vicinity of the pipe and downgradient of the pipe were not appreciably higher than in the control well, and were lower than in the pipe water.

Stiff diagrams (Hem, 1985, p. 175) and Piper diagrams (Hem, 1985, p. 178) were compiled for sampling sites at the Washington Street study area (figs. 21 and 22). These diagrams are useful for analysis of major ionic composition of the sampled waters, and can indicate basic differences in water quality that may be a result of the influence of street runoff. Median values of ions were used for the plots except for the lysimeters, which were sampled only once for major ions. The most obvious difference in ionic composition indicated by figure 21 is the magnitude of the calcium and bicarbonate in water from the unsaturated zone (sites 5 and 6) compared to water in the saturated zone (sites 1, 2, and 8). Calcium and bicarbonate seem to increase after initially exfiltrating from the pipe into the soil (note the magnitude of these ions in the pipe water), but decrease with vertical movement through the subsurface system. Site 7 is the exception to this general observation, as it resembles saturated zone samples in ionic composition. One possible reason for the difference between the upper unsaturated zone and the saturated zone may be the material used as backfill around the pipe, which may have concrete rubble (high in calcium bicarbonate) or other nonnative materials. Runoff from road surfaces generally is alkaline from contact with pavement materials. Much of the calcium and bicarbonate in waters at this study location probably originated from leaching of lime materials in concrete used for the sidewalk and curbs. Soils 12 feet below land surface (depth at which well screens were placed) may be relatively undisturbed compared to the area directly around the pipe (where lysimeters were placed).

The ionic composition of water at different locations around the pipe also can be compared graphically using a Piper diagram (fig. 22). This figure indicates that water at the different sampling sites basically is similar, with the exception of sites 7 and 9 (control well and 8-foot lysimeter), which have a greater percentage of sulfate than the other sites.

### Statistical Comparisons

Statistical procedures were used to further evaluate the effects of infiltration of street runoff on the receiving ground water. The objective of using statistical methods was to determine if significant differences in water quality exist among sampling locations. Observed significant differences in water quality between stormwater entering the pipe or pipe water, and water in either the unsaturated or saturated zones would indicate either attenuation of constituents or increasing concentrations upon entering the subsurface system. Further comparisons of water quality among ground-water sampling sites and the control well site might indicate increasing constituent concentrations near the exfiltration pipe above what is "typical" for the location.

Dissolved concentrations of constituents in surface-water (runoff and pipe water) samples were used for comparison to concentrations from other locations. More significant differences probably would have been detected had total concentrations at surface-water sites been used for statistical tests. However, very little of the particulate fraction of constituents in runoff entering the exfiltration pipe will enter the unsaturated or saturated zones because of settling in the pipe and filtering through the rock backfill and filter fabric surrounding the pipe. Thus, the dissolved fraction of constituents in runoff and pipe water are most important when comparing concentrations among sampling locations.

Water-quality data frequently are not normally distributed. For this reason, data were converted to rank values before testing because statistical methods based on ranks do not require the assumption of normality (Helsel, 1983). The Statistical Analysis System (SAS) procedure General Linear Models (GLM) was used for analysis of variance (ANOVA), with the TUKEY option for multiple comparisons to detect where differences occurred (SAS Institute, Inc., 1982, p. 139-151).

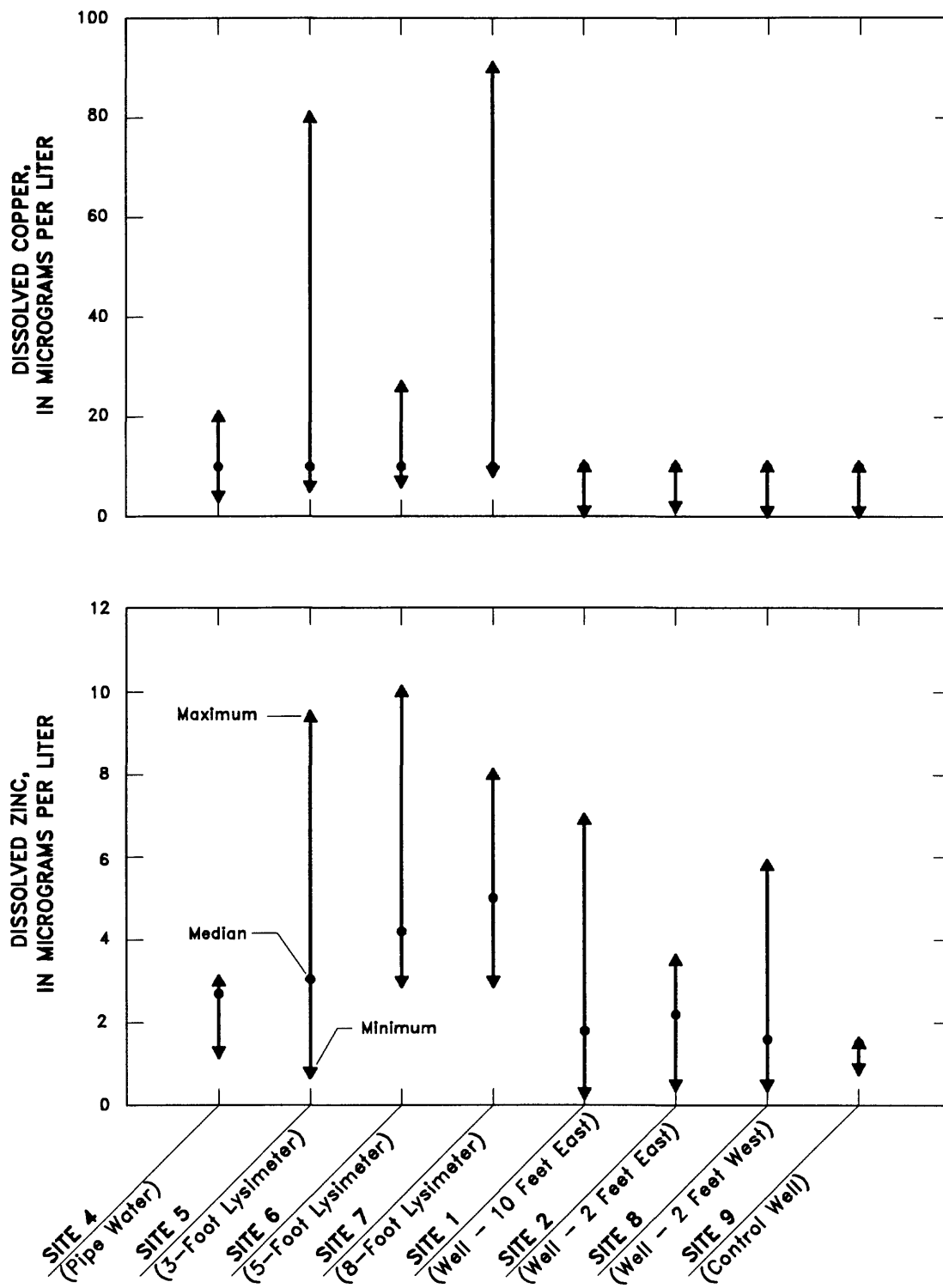
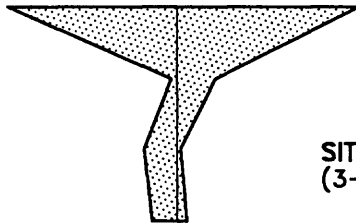


Figure 20.--Dissolved zinc and dissolved copper at sampling sites at the Washington Street exfiltration study area.

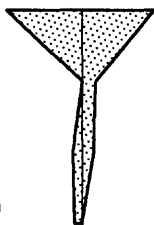
**SITE 4**  
(Pipe Water)



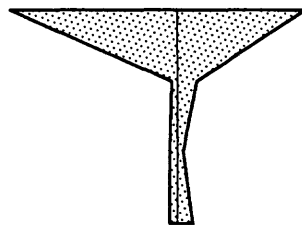
**SITE 5**  
(3-Foot Lysimeter)



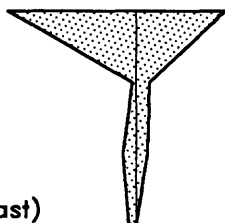
**SITE 1**  
(Well - 10 Feet East)



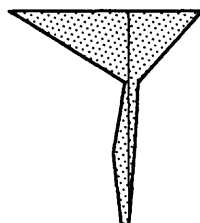
**SITE 6**  
(5-Foot Lysimeter)



**SITE 2**  
(Well - 2 Feet East)



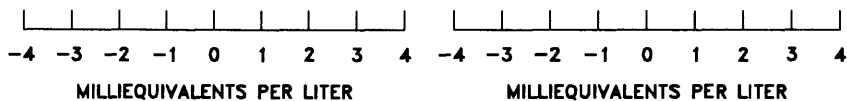
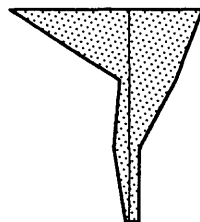
**SITE 7**  
(8-Foot Lysimeter)



**SITE 8**  
(Well - 2 Feet West)



**SITE 9**  
(Control Well)



### EXPLANATION

|           |   |              |
|-----------|---|--------------|
| Calcium   | — | Bicarbonate  |
| Magnesium | — | Sulfate      |
| Sodium    | — | Chloride     |
| Potassium | — | Nitrate as N |

Figure 21.—Ionic composition of water from sampling sites at the Washington Street exfiltration study area. (Median values used except for lysimeters.)

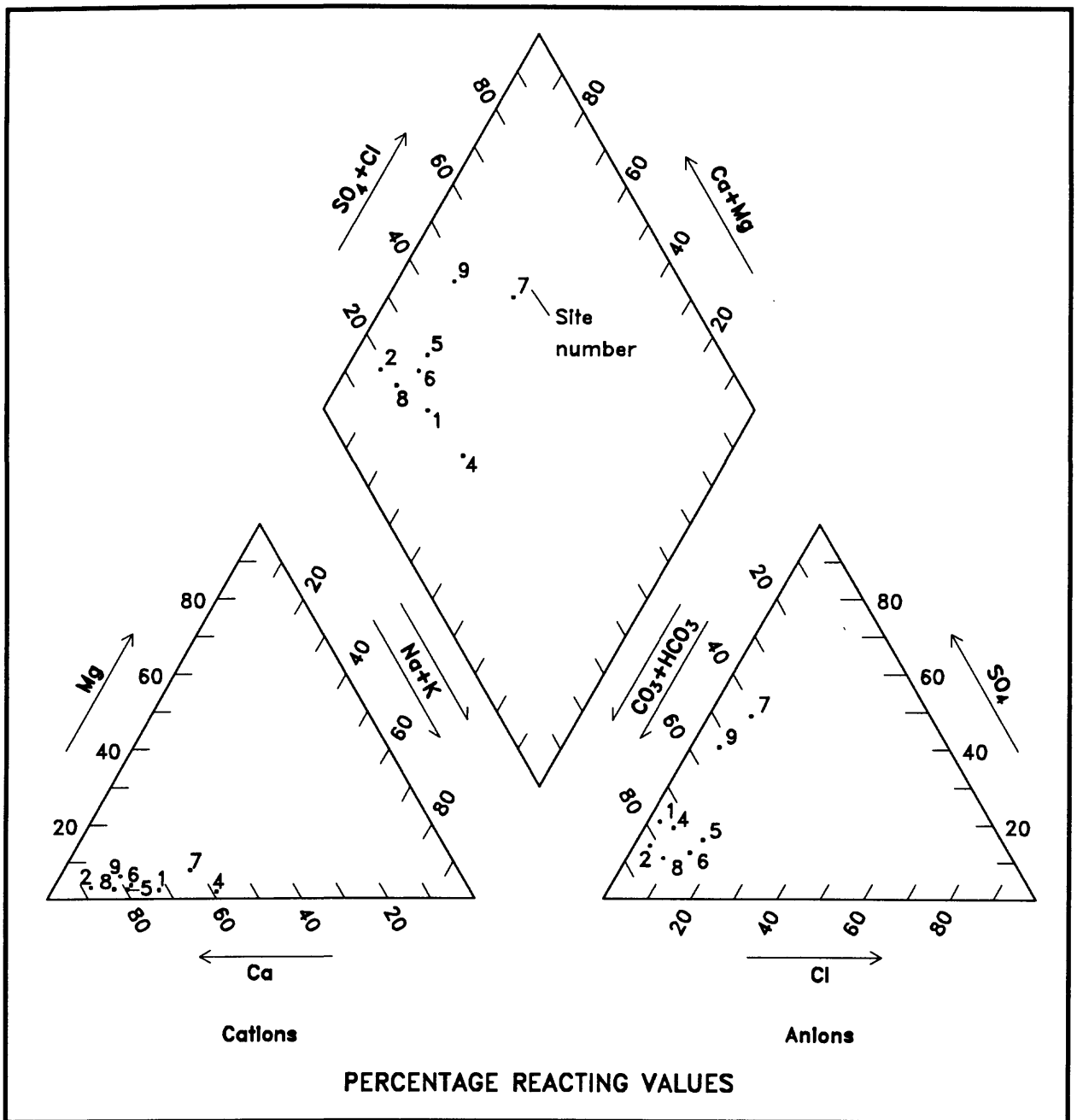


Figure 22.—Ionic composition of water from sampling sites at the Washington Street exfiltration study area. (Median values used.)

These statistical procedures test for significant differences among mean values of data that are grouped by sampling location. The first test, ANOVA, indicates whether the means of the data are significantly different among sampling locations, without identification of specific locations. The multiple comparison test is used when a significant difference is indicated by the ANOVA test, and identifies which locations differ, and the direction of the difference (for example, mean concentrations of a particular constituent might be higher in runoff and pipe water than in ground water).

To identify changes in water quality with sampling location, data were pooled into groups according to data "type" by sampling location. Data types at the exfiltration study area included surface waters (runoff and pipe water), unsaturated zone water, ground water around the structure, and ground water at the control well site. Included in the statistical testing were 26 water-quality variables. Results of ANOVA and multiple comparisons are listed in table 8.

Of the 26 water-quality measures, 14 were significantly different among the data types corresponding to sampling location (table 5). As was noted in figure 18, specific conductance values are significantly higher in water from the unsaturated zone than in incoming surface waters and water in the saturated zone. The difference in test results for laboratory and field pH is due to the inclusion of pH values for the unsaturated zone in the laboratory pH measurements, which biased the distribution of the laboratory values. Because of the small volume of water available for analysis, very few field pH measurements were made on water samples collected from the unsaturated zone. The mean pH of water in the unsaturated zone is higher than the mean pH of water in the saturated zone near the structure and at the control well site. Dissolved iron concentrations differed significantly with location. Dissolved iron concentrations are significantly higher in runoff and pipe water than in ground water and decrease with downward movement of water through the system, perhaps due to continuing precipitation of iron or complexation into nonsoluble species.

Zinc is the only metal other than iron for which significant differences among data types are indicated. Zinc is more soluble than other

metals, particularly lead, and commonly is found in higher concentrations than other metals in ground water. Mean zinc concentrations were highest in water from the unsaturated zone.

### Sediment Analysis

The distribution of particle sizes was determined for selected sites at the exfiltration study area. Material from the saturated and unsaturated zone, obtained during installation of wells and lysimeters, respectively, and accumulated sediment in the pipe were analyzed for size distribution (table 9). A study by Sartor and Boyd (1972, p. 146) found an association between the finer particle sizes in street sweepings and constituent concentrations. In their study, the less than 43- $\mu\text{m}$  fraction of street sweepings accounted for only 5.9 percent of the total solids, but it also accounted for 51.2 percent of the heavy metals, 73 percent of the pesticides, and 33 to 50 percent of the nutrients. Sartor and Boyd (1972) reported that 15.6 percent of total solids by weight were less than 104  $\mu\text{m}$  in size, which agrees with the value reported for 150  $\mu\text{m}$  or less for site 4, sediments accumulated in the pipe (table 9). The primary reason for the association of constituents with the finer particle sizes is the larger surface area (ratio of surface area to volume increases as diameter of particle decreases) available for adsorption. Horowitz (1984) cites numerous references in which researchers have determined that one of the most significant factors controlling sediment capacity for retaining trace metals is grain size. The small fractions of sediments in the < 74  $\mu\text{m}$  size at sites 1, 2, 5, and 6 indicate little silt or clay are available for adsorption, so it is not as likely to be the primary removal mechanism for constituent attenuation.

Sediment from street runoff settles in the exfiltration pipe and accumulates with time. The Washington Street exfiltration pipe had been in use for 5 years prior to this study, and sediments had never been removed from the pipe. The accumulation of sediments in an exfiltration pipe eventually will decrease the rate of exfiltration by clogging the holes in the pipe and the rock backfill around the pipe. Additionally, allowing sediments to collect for a long period of time may allow for resuspension of particulate matter, or dissolution of previously bound chemical



Table 8.—*Results of analysis of variance of rank data, grouped by data types, and multiple comparisons for the Washington Street exfiltration pipe study area*

[p-value, the probability that observed differences are due to chance rather than to the sampling location. Lysimeter data are included in the tests unless indicated with an asterisk (\*)]

Hypothesis being tested by analysis of variance: Means of the k data types are equal.

Alternate hypothesis: At least two of the data type means differ.

Data types are: S = runoff or pipe water; U = unsaturated zone; G = surficial aquifer system near the exfiltration pipe; and C = control well.

The less than (<) and greater than (>) symbols indicate the direction of the difference between the groups indicated in that column. For example, a ">" symbol for color under the S:G column means that color was significantly higher in runoff or pipe water than in water from the surficial aquifer system. If no symbol is shown, the test result indicated no significant difference.

| Dissolved constituent<br>or physical measure | Significant<br>difference | p-value | Multiple comparisons |     |     |     |     |     |
|--|---------------------------|---------|----------------------|-----|-----|-----|-----|-----|
|  |                           |         | S:U                  | S:G | S:C | U:G | U:C | G:C |
| Turbidity                                    | No *                      | 0.06    |                      |     |     |     |     |     |
| Color  | Yes *                     | .0001   |                      | >   | >   |     |     |     |
| Specific conductance                         | Yes                       | .0001   | <                    |     | <   | >   |     |     |
| pH—field                                     | No *                      | .3319   |                      |     |     |     |     |     |
| pH—lab                                       | Yes                       | .0001   |                      | >   |     | >   | >   |     |
| Ammonia                                      | Yes                       | .0001   | >                    | >   | >   | <   |     |     |
| Nitrite                                      | No                        | .3746   |                      |     |     |     |     |     |
| Ammonia and organic nitrogen                 | Yes                       | .0001   |                      | >   |     | >   |     | <   |
| Nitrite and nitrate nitrogen                 | Yes                       | .0001   | <                    |     | <   | >   |     | <   |
| Phosphorus                                   | Yes                       | .0049   |                      |     |     |     | >   | >   |
| Orthophosphorus                              | Yes                       | .0003   | <                    |     |     |     | >   | >   |
| Total organic carbon                         | Yes *                     | .0001   |                      | >   | >   |     |     |     |
| Calcium                                      | Yes                       | .0001   | <                    |     | <   | >   |     |     |
| Magnesium                                    | Yes                       | .0001   | <                    | <   | <   |     |     | <   |
| Sodium                                       | No                        | .6673   |                      |     |     |     |     |     |
| Potassium                                    | No                        | .5679   |                      |     |     |     |     |     |
| Chloride                                     | No                        | .4896   |                      |     |     |     |     |     |
| Sulfate                                      | Yes                       | .0098   |                      |     | <   |     |     |     |
| Alkalinity                                   | No                        | .0903   |                      |     |     |     |     |     |
| Aluminum                                     | No *                      | .0511   |                      |     |     |     |     |     |
| Chromium                                     | No *                      | .7290   |                      |     |     |     |     |     |
| Copper                                       | No                        | .1345   |                      |     |     |     |     |     |
| Iron   | Yes                       | .0001   | >                    | >   | >   | >   | >   |     |
| Lead   | No                        | .4262   |                      |     |     |     |     |     |
| Nickel                                       | No *                      | .0764   |                      |     |     |     |     |     |
| Zinc   | Yes                       | .0001   | <                    |     |     | >   | >   |     |

Table 9.—*Particle size distribution in sediments at the Washington Street exfiltration pipe study area*

[Sieve size indicated in parentheses]

| Site No.       | Percent (by weight) passing indicated sieve size |                         |                        |
|----------------|--|-------------------------|------------------------|
|                | 250 $\mu\text{m}$ (60)                           | 150 $\mu\text{m}$ (100) | 74 $\mu\text{m}$ (200) |
| 1              | 84   | 12                      | 2                      |
| 2              | 82   | 16                      | 2                      |
| <sup>1</sup> 4 | --   | 15                      | --                     |
| 5              | 54   | 17                      | 2                      |
| 6              | 74   | 29                      | 6                      |

<sup>1</sup>Sediment analyzed by University of South Florida, Department of Geology, Tampa, Florida.

constituents, which may then travel out of the pipe and enter the ground water. Sediment from the pipe was sampled twice to determine constituent concentrations (table 10). Sediment concentrations usually are much higher than concentrations in the water column, and are highly variable.

The predominant form of nitrogen in sediment from the exfiltration pipe is organic. Much of the nitrogen in the urban environment originates from nitrogen fixation from the atmosphere and from precipitation (Novotny and Chesters, 1980).

Metal concentrations in sediments reported by Galvin and Moore (1982) collected from a control structure (catchment) serving a detention basin in Bellevue, Wash., are listed in table 10. Mean metal concentrations in street dust from 12 stormwater studies nationwide reported by Bradford (1977) also are listed for comparison with concentrations in the exfiltration pipe sediment. Comparison of the values in sediments at the exfiltration pipe to the national averages for street dust showed that only cadmium is about the same as the national average. The other metals (chromium, copper, nickel, lead, and zinc) are less than 10 percent of the reported average concentrations. Generally, the constituent concentrations in sediments from the Washington Street exfiltration pipe are lower than concentrations in catchment sediments from Bellevue, Wash. Although the samples for this study were of sediment that had accumulated in the pipe for 5 years, the street is not a major highway, and not as heavily travelled as were those highways used in the 12 studies summarized by Bradford (1977), so lower concentrations would be expected.

## Ponds

### Silver Star Road Detention Pond

The Silver Star Road detention pond was chosen as a study area because prior research had been done and was continuing at that location. Originally, eight wells were installed for water-quality sampling, but one location (shown as site 6 in fig. 6) was destroyed. This was the first study area selected and instrumented, and a control well was not planned. However, well 4 is upgradient of the wetland and pond, and was used as a control well site. The general direction of ground-water flow at the site is east-northeast, across the pond and wetland and towards a drainage canal on the east and north sides of the study area. Well depths range from 8 to 12 feet. The depth to the water table below land surface ranged from 1 foot (at site 4) to 4.8 feet (site 5). Well screens are 3 feet in length, and the water table ranges from 3.6 to 9 feet above the well screen. Thus, ground-water samples were collected from depths that ranged from 3.6 to 12 feet below the water table. Sites 1, 2, and 3, adjacent to the pond, probably do not receive much recharge water from the pond because the native soils are very clayey.

### Longwood Retention Pond

The Longwood retention pond was chosen as a study area because it may represent a "worst case" situation; there is no surface outflow, and there is high traffic volume on SR 434. Sites 1, 2, and 3 were located near the point at which highway runoff enters the pond, and these wells range in depth from 15 feet (site 1) to 25 feet (site 3). The objective of the depth selection was to detect

possible vertical differences in water quality. Sites 4, 5, 6, and 7 (all at the same depth as site 1, 15 feet) were located in the pond to obtain areal coverage of ground water beneath the pond (fig. 10). Site 8, which is deeper than the other wells (65-feet deep), was used to determine the lithology of the sediments beneath the pond, to monitor the water quality of the intermediate aquifer, and to detect any downward movement of constituents.

Data from the control well site at the Longwood retention pond presented some interpretive problems. Although the well was constructed to sample background water quality of the surficial aquifer system, drill cuttings and water-level measurements indicate that water from the well may be from the intermediate aquifer system or the Upper Floridan aquifer. The control well is located in a small grassy area

at the edge of the parking lot (fig. 8), about 700 feet from the pond. The land surface at the control well is 78 feet above sea level, and the pond bottom is 47.2 feet above sea level. The bottom of the control well is 20 feet above sea level (fig. 23). Ground-water levels beneath the pond ranged from 36.3 feet to 46.1 feet above sea level. When the control well was drilled, the water level initially was 24 feet above sea level, but rose approximately 4 feet shortly thereafter, indicating that the aquifer was semiconfined. These water levels indicate a gradient from the pond toward the control site.

Clay was found at 26 feet above sea level during the drilling of the control well. Clay also was found when drilling the 71.5-foot deep borehole for site 8 (65-foot deep well in the pond), at 24 feet below sea level, or 50 feet below the clay layer found in the control well borehole

Table 10.— *Concentrations of selected constituents in sediments in the Washington Street exfiltration pipe and reported values from two other studies*

[Nutrient concentrations are in milligrams per kilogram; minor element concentrations are in micrograms per gram. -- denotes no sample or value]

| Constituent                         | August 30,<br>1984 | May 28,<br>1985 | Catchment<br>sediment, <sup>1</sup><br>Bellevue, Wash. | Street<br>dust <sup>2</sup><br>(mean) |
|-------------------------------------|--------------------|-----------------|--|---------------------------------------|
| <b>Nutrients:</b>                   |                    |                 |  |                                       |
| Nitrogen, total ammonia, as N       | 3.8                | 2.2             | --   | --                                    |
| Nitrogen, ammonia and organic, as N | 710                | 1,000           | --   | --                                    |
| Nitrogen, nitrate and nitrite, as N | 8                  | 2               | --   | --                                    |
| Phosphorus, as P                    | 390                | 110             | --   | --                                    |
| <b>Minor elements:</b>              |                    |                 |  |                                       |
| Aluminum                            | 550                | --              | --   | --                                    |
| Cadmium                             | 4                  | 2               | 1.4  | 4.2                                   |
| Chromium                            | 20                 | 9               | 20   | 225                                   |
| Cobalt                              | --                 | 10              | --   | --                                    |
| Copper                              | 7                  | 9               | 35   | 133                                   |
| Lead                                | 140                | 20              | 600  | 3,440                                 |
| Manganese                           | --                 | 23              | --   | --                                    |
| Mercury                             | .05                | .23             | .11  | --                                    |
| Nickel                              | 130                | --              | 20   | 48                                    |
| Zinc                                | 60                 | 100             | 310  | 520                                   |

<sup>1</sup>Galvin and Moore, 1982, p. 3-87.

<sup>2</sup>Galvin and Moore, 1982, p. 3-49, mean values for street dust from 12 commercial areas reported originally by Bradford, 1977.

(site 9). The occurrence of clay layers at different depths (26 feet above sea level, and 24 feet below sea level) indicates discontinuous confining layers are present in the study area.

Drill cuttings near the bottom of the control well contained iron and phosphatic rock pebbles, indicative of the Hawthorn Formation of the intermediate aquifer system. Tibbals (1977) reports that the top of the Floridan aquifer system in the study area ranges from 0 to 25 feet below sea level, or 25 to 50 feet below the bottom of the control well (fig. 23).

The Longwood retention pond apparently is a relict sinkhole that has been naturally plugged and stable for many years. According to Tibbals (1977), the pond area is shown as a high-rate recharge area. The area just southeast of the pond is characterized by karst topography with many small sinkhole lakes, which are typical of a high-rate recharge area underlain by

discontinuous confining layers. Clays probably occur in lenses in the unconsolidated sediments above the consolidated rock of the Floridan aquifer system. This is probably the case in the vicinity of the Longwood retention pond, as evidenced by the occurrence of clay at different altitudes at sites 8 and 9. Because of these discontinuous confining layers, a true water table (at atmospheric pressure) may not exist at the control well site, but only directly below and in the immediate vicinity of the pond because of the infiltration of runoff water.

Under normal conditions (no runoff routed to the pond), the gradient of the water table would be expected to be toward the relict sinkhole (the retention pond), and dewatering of the surficial aquifer system in the vicinity of this relict sinkhole might occur. However, the routing of highway and parking lot runoff to the relict sinkhole causes mounding of the ground water beneath

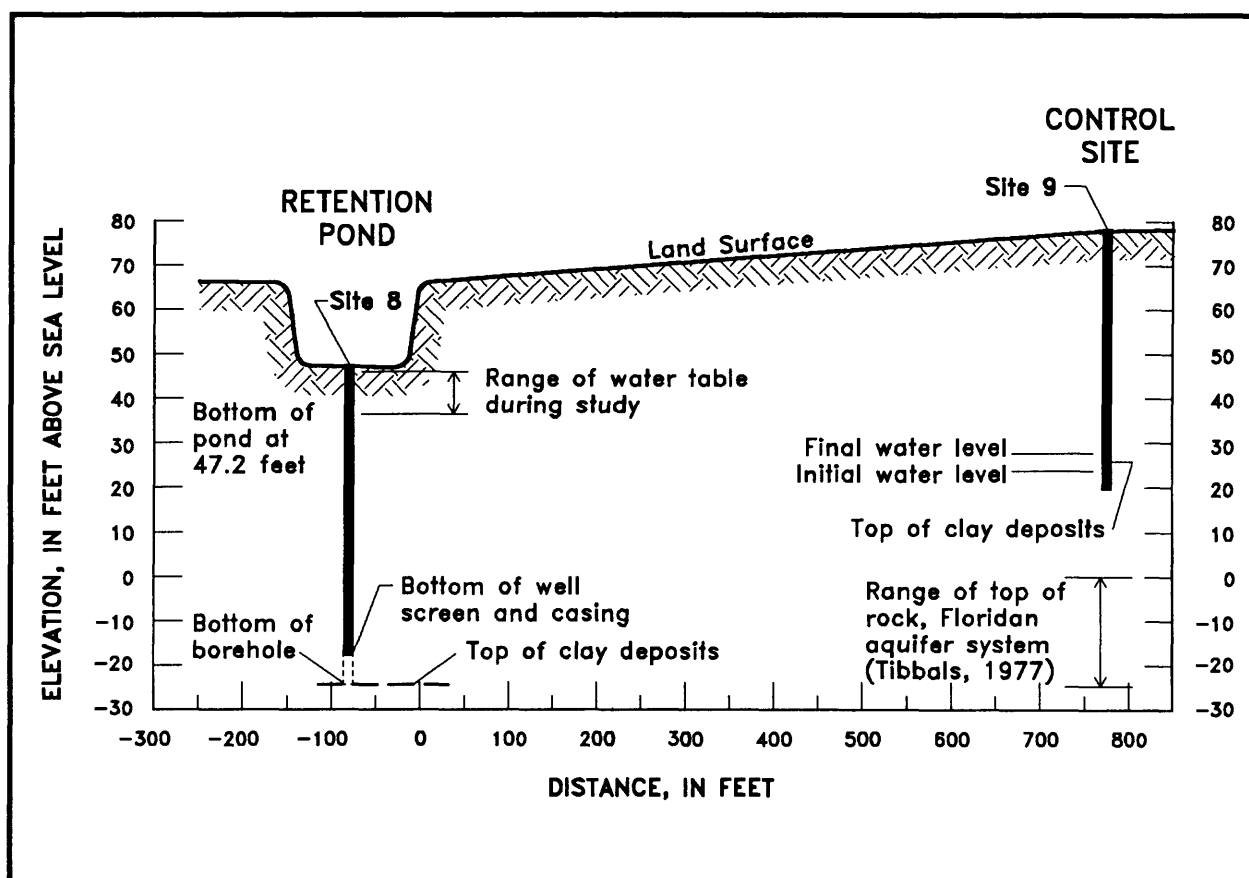


Figure 23.--Relation of control site to Longwood retention pond.

the pond, resulting in a gradient away from the pond. Water levels measured in the control well and in wells located in the pond during this study indicate that mounding occurs, even during the dry season. More observation wells would be needed to better define the ground-water system in this area. The potentiometric surface of the Floridan aquifer system in this vicinity is 30 feet above sea level (Tibbals, 1977), which is below the lowest measured water level beneath the pond, resulting in a downward gradient toward the Floridan aquifer system. The overall ground-water gradient in the surficial aquifer system in the area is to the west, so it is possible that ground water initially moves to the east, but eventually flowlines probably curve back to the west.

Quality of water from the control well site was used for comparison because the well is in the vicinity of the pond and is located in the first saturated zone in the subsurface system. The well may not be entirely independent of the mounding effects of water beneath the retention pond, and may also be more representative of the intermediate aquifer system. Comparison of water quality between the control well site and well sites in the pond may offer clues as to the original source of water sampled at the control well site.

The two ponds used in this ground-water study had one significant difference that could affect their impact on ground-water quality—the Silver Star Road pond detains water and has a surface outlet, whereas the Longwood pond is a retention pond, with no surface outlet. Water entering the Longwood pond must either evaporate or infiltrate. Soluble constituents must either migrate down to the underlying ground water or be removed from the water phase by chemical, physical, or biological interactions. The pond often is dry for a sufficiently long duration to allow vegetation to grow on the pond bottom.

Because the Longwood pond may have a more severe impact on ground-water quality, additional work was initiated at this study area to determine some characteristics of the pond, that include infiltration rates, and the response of the pond to rainfall. Stage in the Longwood pond was monitored to determine infiltration rates after storms, and rainfall was measured at the site. Stage responded quickly to rainfall, as might be expected from a drainage basin with a high percentage of impervious area. Infiltration rates

in the pond varied from 0.13 in/hr to 0.36 in/hr during summer months, and increased during winter months to as much as 0.60 in/hr. Green and Ampt (1911) described the rate of infiltration as a function of the hydraulic conductivity, capillary suction head, and depth from soil surface to wetting front. The higher infiltration rate during winter months probably is due to an increase in capillary suction head in the unsaturated zone as moisture content decreases. Even during summer months when rainfall occurred almost daily, the pond would frequently be dry in just a few days. During this study, the water table was always below the pond bottom, even when water in the pond was 2 feet or more deep (fig. 23). Thus, an unsaturated zone existed under the pond throughout the study.

The Longwood pond was surveyed during a dry period to obtain stage-volume information. From the pond stage data, rainfall data, and the stage-storage curve, response curves were plotted for the pond (fig. 24). The change in storage due to rainfall was computed from the stage-storage relation and stage data, and is shown as the middle plot in figure 24. Most of the rainfalls during the study were 1 inch or less, and storage volume changes were less than 1 acre-ft (acre-foot).

An attempt was made to estimate loads of selected constituents to the pond. First, a regression line was fitted to the data for the storage-rainfall relation. Then, using the equation that describes this relation, and rainfall for the period of August 1985 through July 1986, during which most of the well water-quality data were collected, the total volume of water that entered the pond was estimated. The rainfall for the period was 52.42 inches, which corresponded to a storage volume of 13.04 acre-ft. Using data from table 5, estimates of loads of selected constituents were obtained. The annual load of nitrogen is 166.5 pounds; phosphorus, 42.5 pounds; zinc, 10.3 pounds; lead, 5.3 pounds; and copper, 1.7 pounds. The estimated loads indicate the amount of material that is either retained in the pond sediments or may have moved into the surficial aquifer system beneath the pond.

### Water-Quality Variations

Data for pH, specific conductance, and selected constituents are shown in figures 25 through 29 for ground-water sampling sites at both pond study locations. These figures

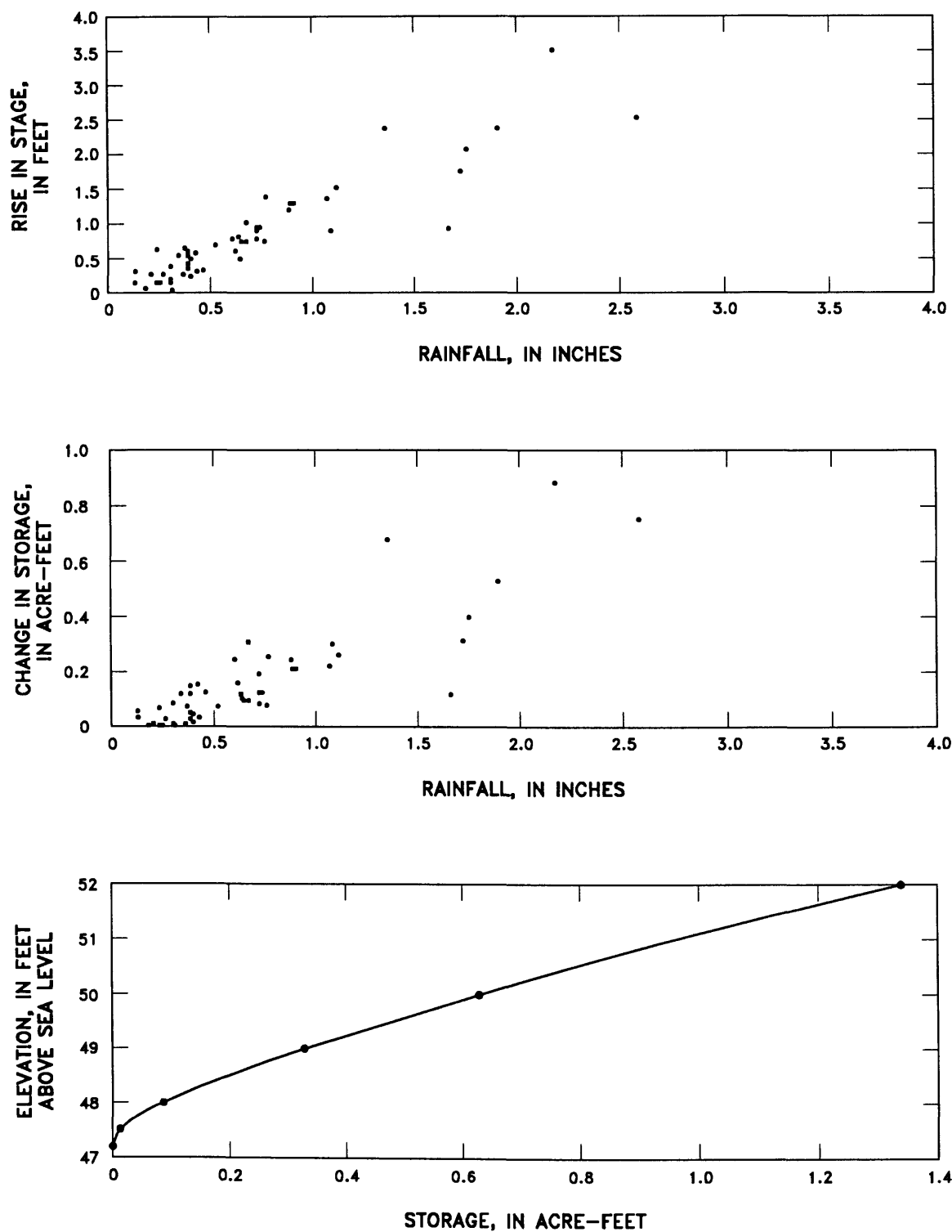


Figure 24.--Rainfall, stage, and volume relations at the Longwood retention pond.

illustrate the variability in data among sampling sites at the Longwood and Silver Star Road study areas, and between the two ponds.

Water-quality data for ground water at both ponds are summarized in table 11. All ground-water sites are included for the Silver Star Road pond, and all but the control well site at the Longwood pond. The sites at the Silver Star Road pond were combined because, although site 4 is used later for statistical comparisons, it was not originally located as a control well site, and may be located near enough to the wetland to be affected by the wetland. In general, ammonia, organic nitrogen, sodium, chloride, iron, and aluminum were present in higher concentrations in ground water at the Silver Star Road pond, and nitrate nitrogen, calcium, and alkalinity were higher in ground water at the Longwood pond. Ground water at the Silver Star pond also was more colored than the

Longwood pond ground water, possibly because of the proximity of the cypress wetlands that leach organic matter.

Specific conductance and pH are more variable in ground water at the Longwood pond (fig. 25). Only two samples were collected from each well at the Silver Star Road pond. In most cases the data from the two samples show little difference, although ground water at the Silver Star Road pond is more acidic than at Longwood. At the Longwood pond, the three sites displaying the most variation in specific conductance values are those located close to the inlet to the pond (sites 1, 2, and 3), in the path of incoming stormwater that initially has high dissolved solids concentrations. The two sites displaying the least variability at the Longwood pond are the deep well in the pond (site 8) and the control well (site 9), both of which may be in the intermediate aquifer.

Table 11.--Statistical summary of water-quality data for ground water at the Silver Star Road and Longwood pond study areas

[Control site for Longwood listed independently. Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter; -- denotes no sample or value]

| Constituent or physical property                         | Silver Star Road Pond |       |        |       |    | Longwood Pond      |       |        |  |                |
|--|-----------------------|-------|--------|-------|----|--------------------|-------|--------|--|----------------|
|  | Ground-water sites    |       |        |       |    | Ground-water sites |       |        |  |                |
|  | No. of samples        | Range | Median |       |    | No. of samples     | Range | Median |  | Control Median |
| Turbidity (NTU)  | 7                     | 5.5 - | 95     | 35    | 35 | 0.8 -              | 2,000 | 12     |  | 500            |
| Color (Pt-Co units)                                      | 7                     | 5 -   | 480    | 240   | 33 | <5 -               | 800   | <5     |  | 2.5            |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | 14                    | 105 - | 300    | 180   | 35 | 124 -              | 504   | 290    |  | 258            |
| Field pH   | 7                     | 5.3 - | 5.8    | 5.6   | 21 | 6.3 -              | 7.5   | 6.8    |  | 6.7            |
| Lab pH   | 14                    | 5.4 - | 7.3    | 5.9   | 34 | 6.7 -              | 8.2   | 7.5    |  | 7.6            |
| Nitrogen species, as N:                                  |                       |       |        |       |    |                    |       |        |  |                |
| Ammonia  | 14                    | .1 -  | 5.8    | .5    | 35 | .01 -              | .35   | .03    |  | .09            |
| Nitrite  | 14                    | .01 - | .02    | .01   | 35 | <.01 -             | 1.1   | <.01   |  | .05            |
| Ammonia plus organic                                     | 14                    | .33 - | 9.5    | 1.65  | 35 | .05 -              | 19    | .37    |  | 1.17           |
| Nitrate plus nitrite                                     | 14                    | .01 - | .1     | .06   | 35 | .01 -              | 3     | .33    |  | 1.90           |
| Phosphorus, as P   | 14                    | .02 - | 1.1    | .06   | 34 | .01 -              | .08   | .02    |  | .63            |
| Orthophosphorus, as P                                    | 14                    | .01 - | 1.1    | .04   | 35 | .01 -              | .06   | .01    |  | .51            |
| Total organic carbon                                     | 8                     | 11 -  | 60     | 28    | 35 | .1 -               | 34    | 1.8    |  | 1.15           |
| Calcium  | 14                    | 3.3 - | 23     | 11.55 | 35 | 21 -               | 100   | 51     |  | 24.5           |
| Magnesium  | 14                    | 1.3 - | 5.5    | 2.55  | 35 | .3 -               | 5.5   | 1.2    |  | 12.5           |
| Sodium   | 14                    | 3.4 - | 35     | 26    | 35 | 1 -                | 13    | 2.8    |  | 5.85           |
| Potassium  | 14                    | .3 -  | 2.6    | .9    | 35 | .3 -               | 7.7   | .9     |  | .9             |
| Chloride   | 14                    | 5.8 - | 74     | 29.5  | 35 | 1.1 -              | 14    | 2.7    |  | 11             |
| Sulfate  | 14                    | 3.2 - | 30     | 7.65  | 35 | 1.4 -              | 30    | 6.4    |  | 2.35           |
| Alkalinity, as $\text{CaCO}_3$                           | 14                    | 6 -   | 101    | 26.5  | 35 | 51 -               | 245   | 124    |  | 135            |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | 7                     | 50 -  | 500    | 200   | 32 | 10 -               | 90    | 15     |  | 10             |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | 13                    | <1 -  | 2      | <1    | 27 | <1 -               | 1     | <1     |  | <1             |
| Copper ( $\mu\text{g}/\text{L}$ )                        | 13                    | <1 -  | 5      | <1    | 35 | <1 -               | <10   | <1     |  | 1.5            |
| Iron ( $\mu\text{g}/\text{L}$ )                          | 7                     | 270 - | 5,100  | 1,700 | 34 | 3 -                | 1,300 | 19.5   |  | 10.5           |
| Lead ( $\mu\text{g}/\text{L}$ )                          | 14                    | <5 -  | 12     | <5    | 35 | <5 -               | <10   | <5     |  | <5             |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | 7                     | 2 -   | 85     | 3     | 28 | <1 -               | 3     | <1     |  | 2.5            |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 14                    | 5 -   | 220    | 35    | 40 | 3 -                | 140   | 20     |  | 3.5            |

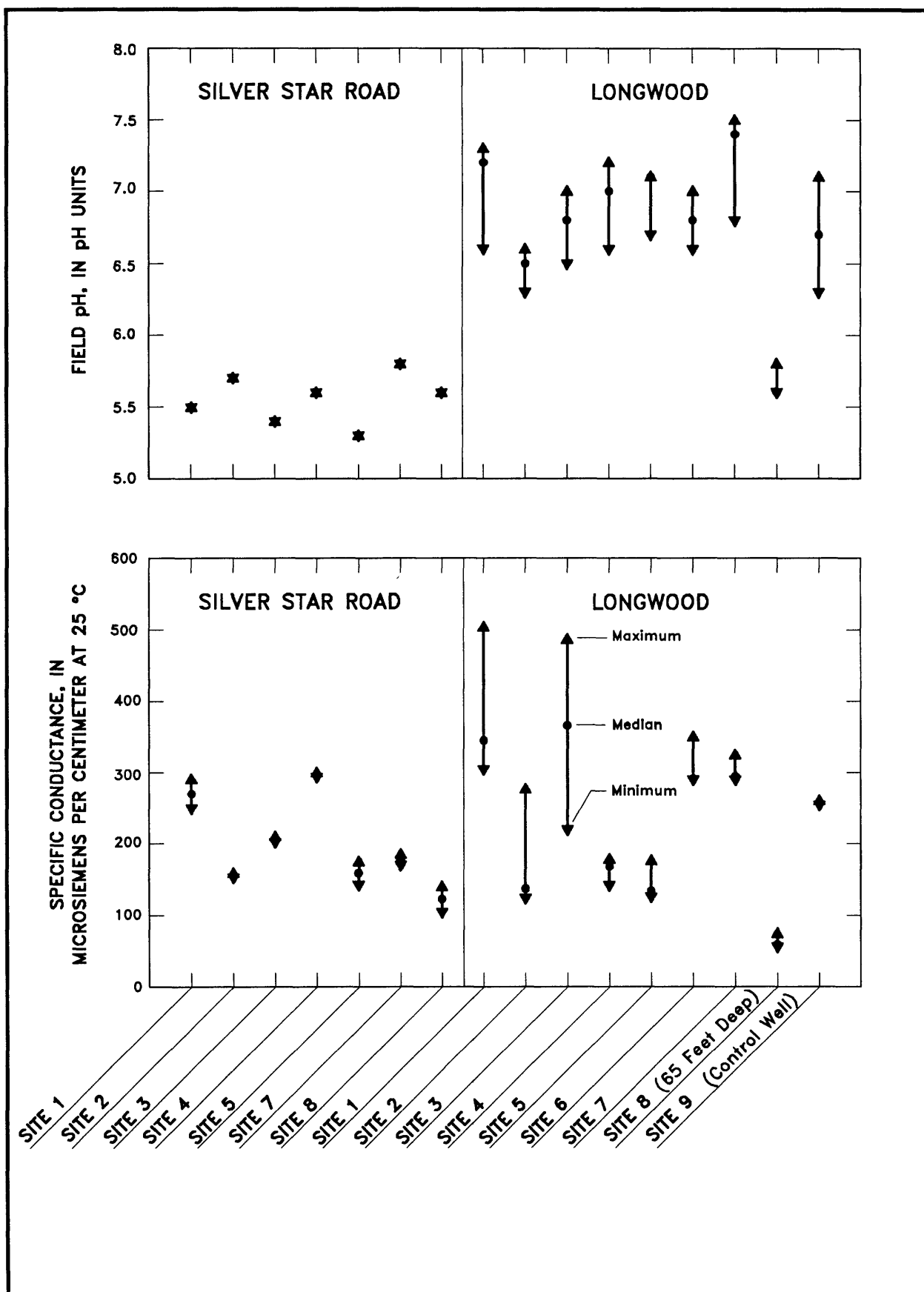


Figure 25.—Field pH and specific conductance at sampling sites at the Silver Star Road detention pond and the Longwood retention pond.



Selected nitrogen species are shown for both locations in figure 26. Again, the Longwood pond shows the greatest variability for both Kjeldahl (ammonia plus organic) nitrogen and nitrate plus nitrite nitrogen. Nitrogen in ground water at the Longwood pond primarily is in the organic form. The cause of the unusually high nitrate concentrations in the control well water is not apparent. Schiner and German (1983) reported only 0.29 mg/L maximum for nitrate nitrogen in supply wells in the Orlando area, but as much as 2.4 mg/L in drainage wells. The three maximum values of Kjeldahl nitrogen at the Longwood pond occurred at the same sampling time (March 1986), but not in all wells.

Dissolved orthophosphorus in ground water at both pond locations generally is present in low concentrations, and most of the phosphorus was in the orthophosphorus form (inorganic) (fig. 27). At the Longwood pond, phosphorus is highest in the water from the control well, but the cause for this is unknown. Although phosphatic pebbles were obtained from the control well, phosphorus is very insoluble, and the higher phosphorus in the water probably is not a result of dissolution of aquifer materials. The minimum and maximum values for dissolved orthophosphorus in water from site 2 (0.4 and 1.1 mg/L, respectively) at the Silver Star Road pond is higher than the second highest value obtained in drainage wells in Orlando (0.33 mg/L) (Schiner and German, 1983). This observation is of note because drainage wells receive stormwater directly, unlike ground water at the Silver Star Road study area, at which stormwater is detained, then filtered as it percolates down to the surficial aquifer system. Total organic carbon is more variable in ground water at the Silver Star Road study area than at the Longwood study area.

Aluminum in ground water is higher at the Silver Star Road pond than at the Longwood pond (50 to 500  $\mu\text{g/L}$  versus 10 to 90  $\mu\text{g/L}$ ) and more variable (fig. 28). Highest concentrations are in water from sites 7 and 8, in the area between the wetlands and the drainage canal. The soil materials around the pond are clayey, and this combined with a slightly acidic pH, may be the reason for higher soluble aluminum near the pond.

Dissolved zinc, in general, is more variable in ground water at the Longwood pond, and concentrations are higher in water beneath the

pond than in water from the control well. Zinc was highest in water from sites 1 and 8 at the Silver Star Road pond, closest to the highway. Median values in the Silver Star Road pond water are lower for dissolved and total zinc (20 and 60  $\mu\text{g/L}$ , respectively) (Martin and Smoot, 1986) than the median dissolved zinc in water at well sites 1 and 8. The maximum dissolved zinc concentration measured in the pond water at Silver Star Road was only 100  $\mu\text{g/L}$ , which is lower than the maximum measured values at well sites 1 and 8.

Dissolved iron concentrations (fig. 29) in ground water are significantly higher and more variable among sampling sites at the Silver Star Road pond. Snoeyink and Jenkins (1980, p. 379-382) define three "zones" for iron in ground water based on a  $\text{pe-pH}$  diagram that includes the interaction of iron with sulfide and bicarbonate. Two of these zones are characterized by low soluble iron concentrations, and a third, an intermediate zone between the other two, that is characterized by significantly higher dissolved iron concentrations. The solubility of iron in the intermediate zone is controlled by the mineral ferrous carbonate, which can have a much higher dissolved iron content than waters in equilibrium with ferrous hydroxide (upper zone) or ferrous sulfate (lower zone). The higher concentrations of dissolved iron at the Silver Star Road pond either are due to the location of the well intakes in this intermediate zone described by Snoeyink and Jenkins (1980), or possibly to iron in organic complexes.

Stiff and Piper diagrams are used to graphically show the water-quality variability in ground water at each pond, and for comparison between ponds. Stiff diagrams of median values of major ions in ground water at the Longwood retention pond (fig. 30) indicate that most of the ground water beneath the pond is a calcium bicarbonate type, with some variability with location. The Stiff diagram of water from the control well (site 9) looks very similar to the diagram of water from supply wells tapping the Floridan aquifer system (Schiner and German, 1983), with the exception of some magnesium replacing calcium. This supports the hypothesis that water in the control well is from the Upper Floridan aquifer. Rainfall values at Lake Hope, Maitland, Fla., a few miles south of the Longwood site, were plotted at the same scale to show the contribution of rainfall (very small) to the ionic makeup of the water.

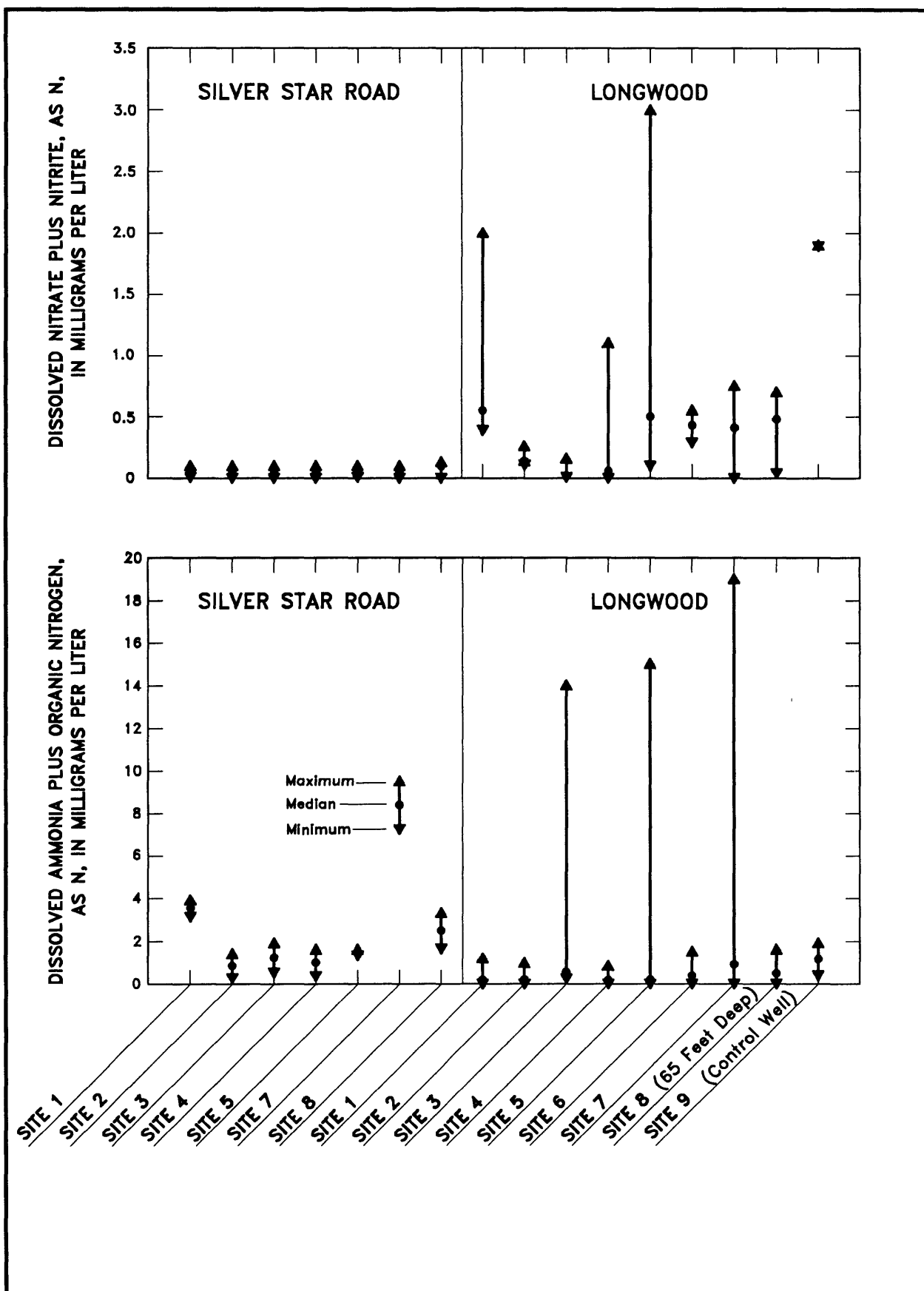


Figure 26.--Dissolved nitrate plus nitrite nitrogen, and dissolved ammonia plus organic nitrogen at sampling sites at the Silver Star Road detention pond and the Longwood retention pond.

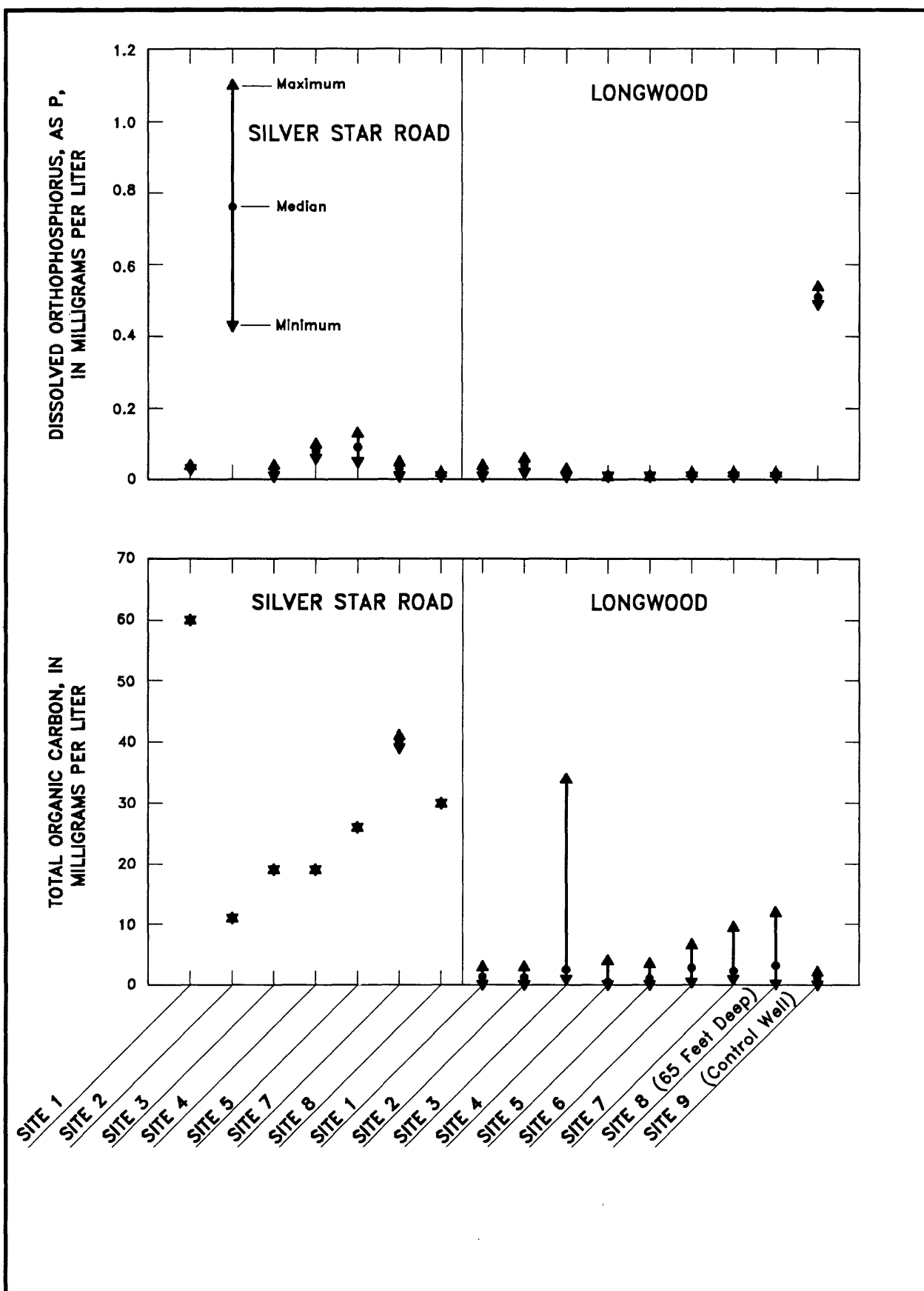


Figure 27.—Dissolved orthophosphorus and total organic carbon at sampling sites at the Silver Star Road detention pond and the Longwood retention pond.

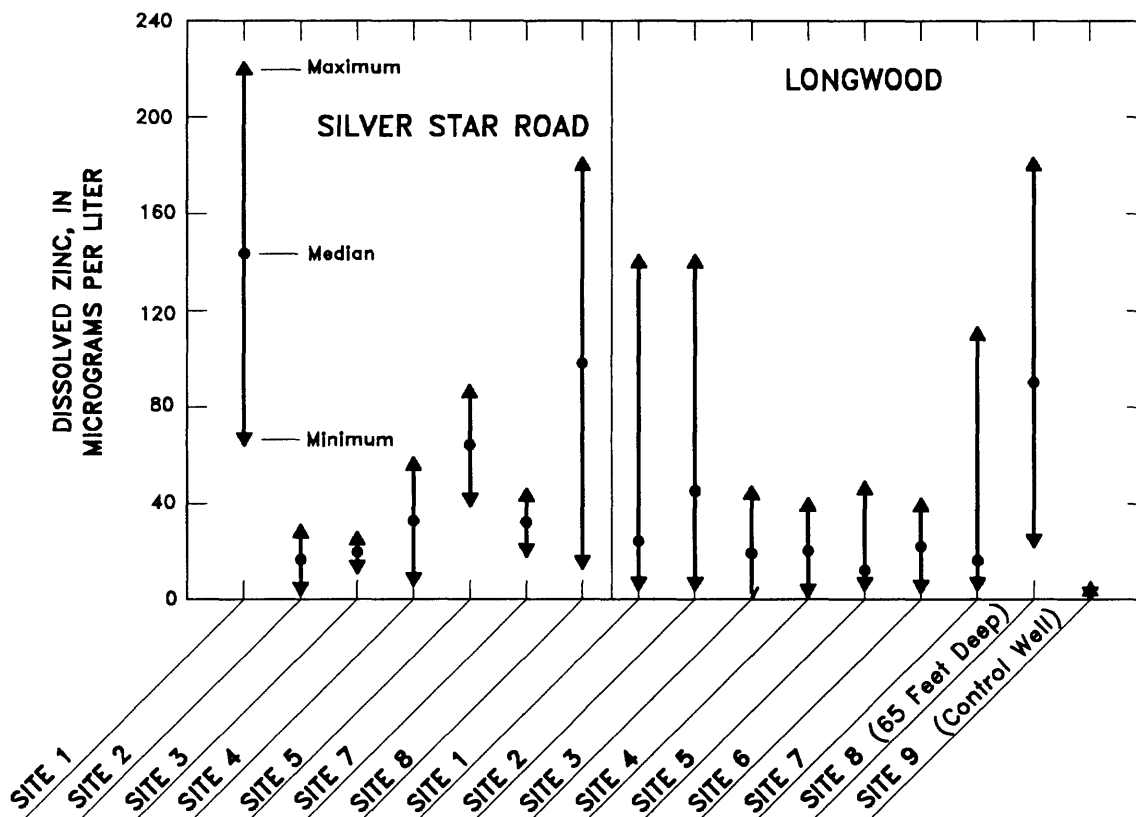
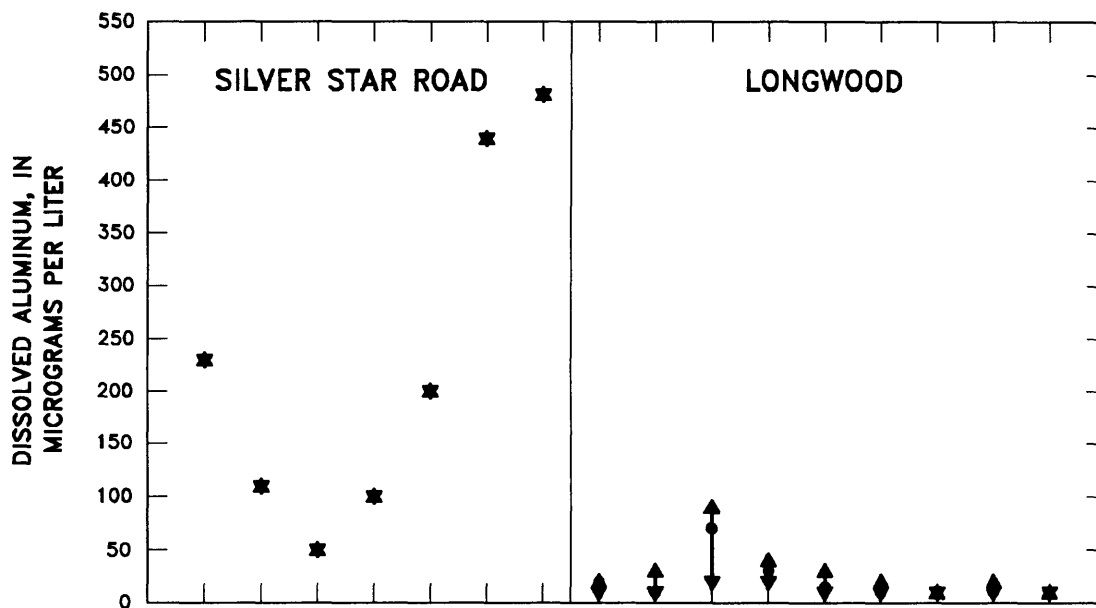


Figure 28.--Dissolved aluminum and dissolved zinc at sampling sites at the Silver Star Road detention pond and the Longwood retention pond.

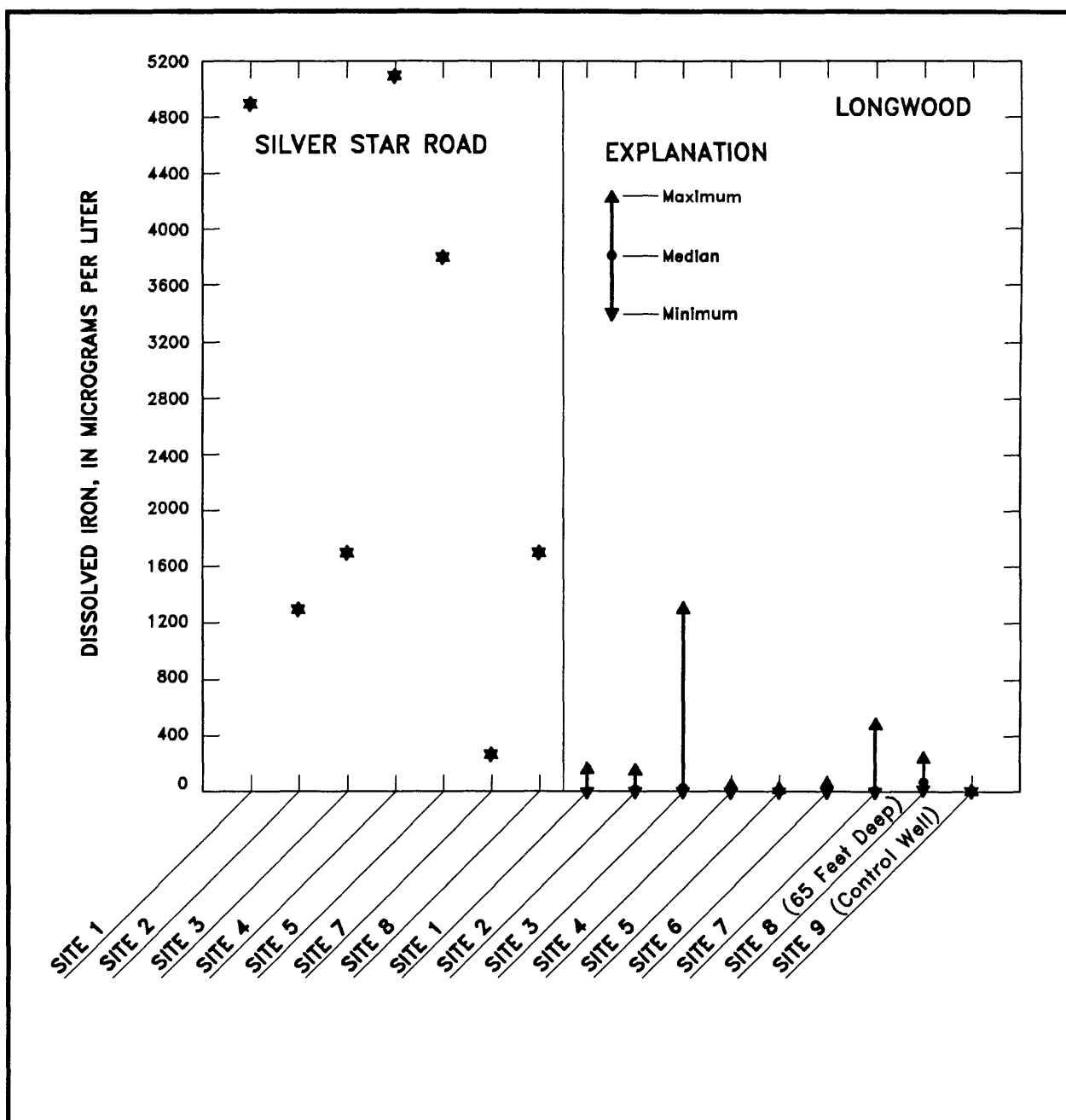


Figure 29.--Dissolved iron at sampling sites at the Silver Star Road detention pond and the Longwood retention pond.

**RAINFALL**  
Lake Hope, Maitland, Florida  
Mean of 19 samples

**FLORIDAN AQUIFER  
SYSTEM**  
Median values from  
65 supply wells in  
Orlando, Florida

**SITE 1**

**SITE 6**

**SITE 2**

**SITE 7**

**SITE 3**

**SITE 8**  
(65 Feet Deep)

**SITE 4**

**SITE 9**  
(Control Well)

**SITE 5**

**SITE 10**  
(Runoff)

-4 -3 -2 -1 0 1 2 3 4  
MILLIEQUIVALENTS PER LITER

-4 -3 -2 -1 0 1 2 3 4  
MILLIEQUIVALENTS PER LITER

#### EXPLANATION

|           |  |              |
|-----------|--|--------------|
| Calcium   |  | Bicarbonate  |
| Magnesium |  | Sulfate      |
| Sodium    |  | Chloride     |
| Potassium |  | Nitrate as N |

Figure 30.—Ionic composition of water from sites at the Longwood retention pond. (Median concentrations used except at rainfall site.)

In contrast to the calcium bicarbonate water at the Longwood pond, ground water at the Silver Star Road pond is predominately a sodium chloride type (fig. 31). Water quality of sites 7 and 8, between the wetland and the drainage canal, differ significantly from the water quality of ground water west and north of the pond (more calcium and bicarbonate, and less sodium and chloride), possibly reflecting the influence of exfiltrating water from the wetland.

Relative distributions of ions in ground water at both pond study areas are shown in figure 32. The variability in ionic composition at the Silver Star Road pond is evident from this figure, but no real pattern related to location is discernible. The ionic composition of ground water under the Longwood pond is much more uniform. The 65-foot deep well (site 8) in the pond and the control well (site 9) differ from sites in the pond, primarily with higher magnesium concentrations at both sites, and additionally, for site 8, sulfate.

#### Statistical Comparisons

*Among data types.*--The same procedure used for statistical analysis of water-quality data for the exfiltration pipe study area also was used for analysis of ground-water quality around the two study ponds. For the Silver Star Road detention pond, ground-water quality data were divided into two groups, one control group (consisting of well site 4 only) and one group comprised of well sites 1 to 3 and 5 to 8. Site 4 was used as a control because it is located in the most upgradient and distant location from the pond and wetland.

Twenty water-quality measures were used in the statistical testing (table 12). Significant differences occurred in specific conductance measurements, sodium, and chloride. The test results indicate that the mean values for these variables were significantly higher in the upgradient control well (site 4) than in ground water closer to the pond and wetland. Specific conductance plotted in figure 25 seems to be higher at site 4 (Silver Star pond) than at other locations in the vicinity of the pond and wetland. The lower values in ground water near the pond and wetlands may indicate some dilution by exfiltrating stormwater that has smaller concentrations of sodium, chloride, and other ions than what is in the surficial aquifer system.

The outcome of the statistical test for sodium and chloride probably was due to the calcium-bicarbonate water at sites 7 and 8.

Water-quality data were divided into four types for the Longwood study area. Data from one runoff sample and four pond water samples were grouped together as a surface-water type. Data from well sites 1 to 7, representing the water quality of the surficial aquifer system, comprised the second type. Data from site 8, representing the intermediate aquifer, is the third type, and data from the control well (site 9) is the fourth type or group.

Values for 25 physical measures and constituents were statistically tested, and of these, 14 were significantly different among the data types (table 13). The results shown in table 13 indicate where these differences occurred. Comparison of water quality of the surficial aquifer system beneath the pond to the quality of water at the control well site may indicate increasing concentrations below the pond due to infiltration of highway runoff.

Results of the TUKEY multiple comparison test indicate only phosphorus and orthophosphorus (which comprises the majority of the phosphorus) concentrations differed significantly between water in the surficial aquifer system beneath the pond and at the control well site. The mean concentrations of phosphorus and orthophosphorus are significantly higher at the control well site, which is not affected by highway runoff. This result may be related to other differences between the control site and the ground-water sites located in the pond (see the discussion in this report of the difference between the water levels of ground water beneath the pond and at the control site, and the difference in ionic composition).

Another indicator of possible effects on receiving ground water from highway-runoff infiltration would be the observation of significant changes in water quality with depth below the water table. Results of the TUKEY multiple comparison test between water quality of the surficial aquifer system (sites 1 to 7) and that of the intermediate aquifer water (site 8) indicate significant differences for specific conductance, pH, calcium, potassium, and alkalinity (all higher in the surficial aquifer system). Differences in values of these variables are probably related only to differences in aquifer materials. Water in the intermediate aquifer

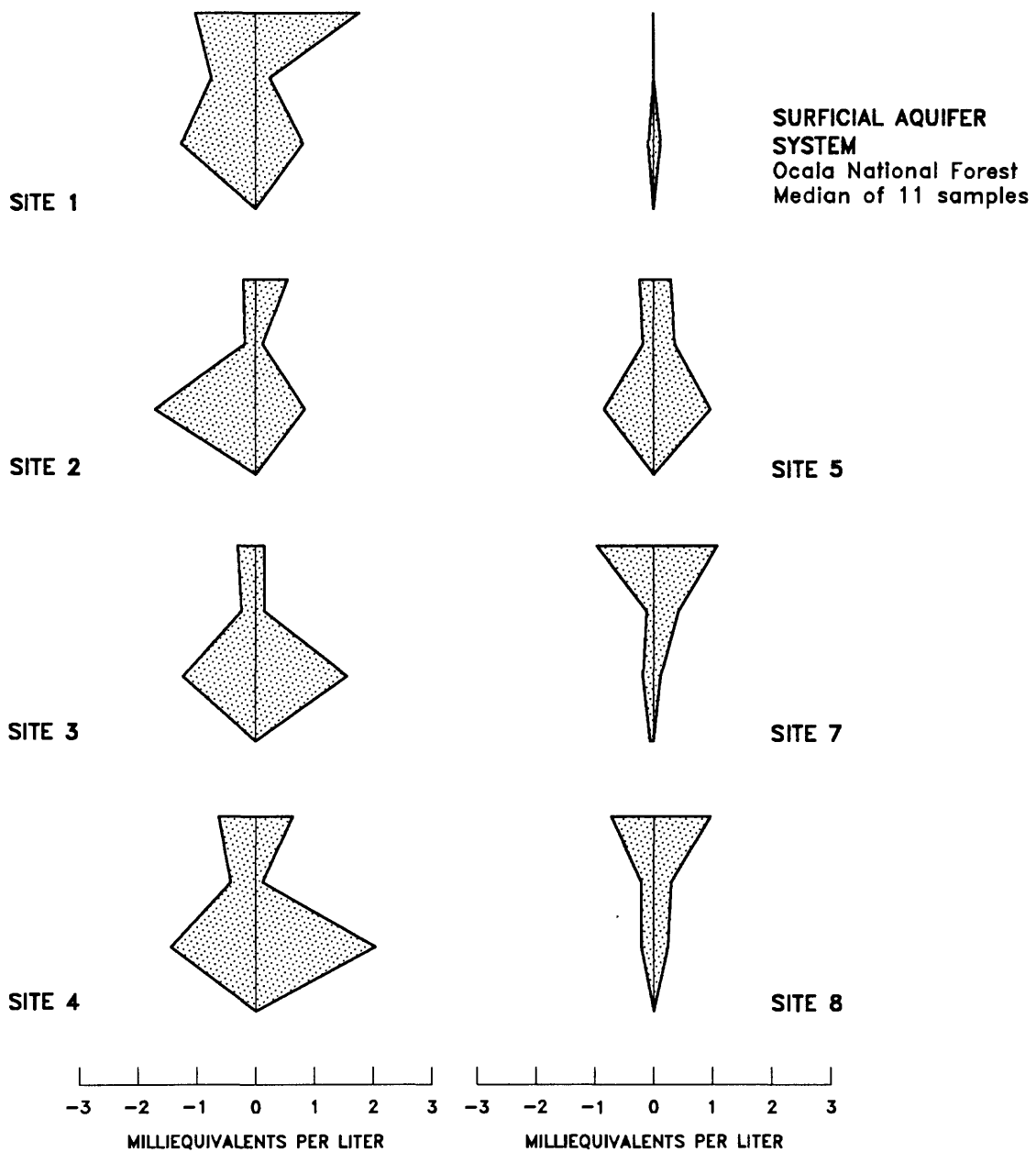


Figure 31.—Ionic composition of water from sites at the Silver Star Road detention pond. (Median values used.)



beneath the pond (site 8) may not originate from water directly above (in the pond). The time and distance needed for chemical changes to occur in water, between the surficial aquifer system 15 feet below the pond, and the intermediate aquifer 65 feet below the pond, which would modify the quality of water as indicated by these tests does not seem sufficient. Therefore, water from site 8

probably originated from somewhere other than the retention pond, and may have resided in the formation for many years.

The mean zinc concentration for the intermediate aquifer was significantly higher than the mean value for the surficial aquifer system, an unexpected test result. The maximum value of 180  $\mu\text{g/L}$  at site 8 (fig. 28) occurred twice.

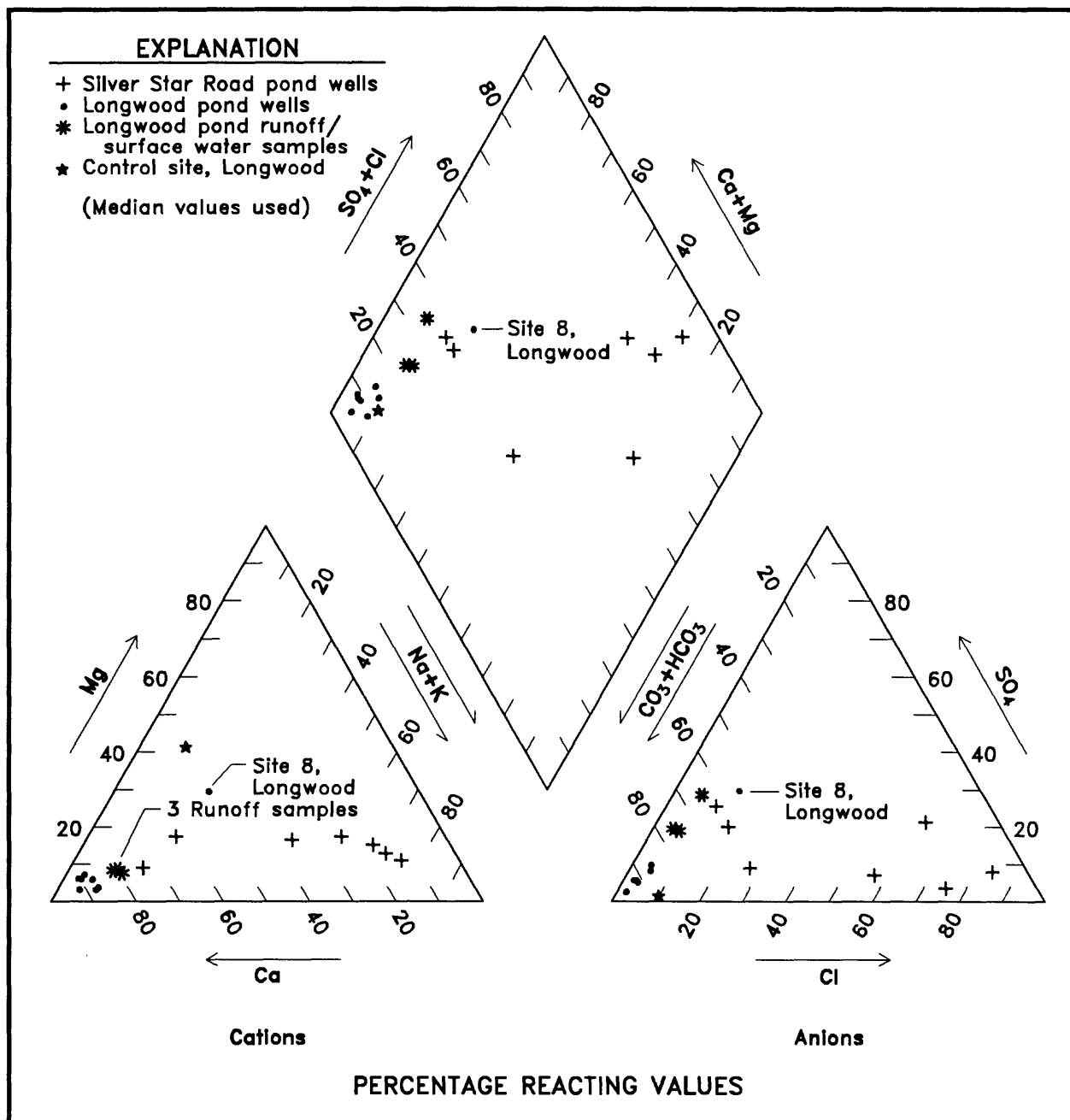


Figure 32.--Ionic composition of water from sampling sites at the Silver Star Road and Longwood pond study areas.

Table 12.—*Results of analysis of variance of rank data, grouped by data type, and multiple comparison test (TUKEY), Silver Star Road detention pond study area*

[p-value, the probability that observed differences are due to chance rather than to the sampling locations]

Hypothesis being tested by analysis of variance: Means of the two groups are equal.

Alternate hypothesis: One of the two group means differs.

Group G: Sites 1, 2, 3, 5, 7, 8.

Group C: Site 4 (control well).

An "x" in a column means that a significant difference was indicated between the means of the rank values of the groups indicated at the top of the column. For example, test results indicate that specific conductance (mean of rank values) was significantly higher in water from the control well site than in water from wells adjacent to the pond and wetland. If no symbol is shown, the test result indicated no significant difference.

| Dissolved constituent<br>or physical measure | Significant<br>difference | p-value | Multiple comparison test results |       |
|--|---------------------------|---------|----------------------------------|-------|
|  |                           |         | G > C                            | C > G |
| Specific conductance                         | Yes                       | 0.0212  |                                  | x     |
| pH—lab                                       | No                        | .5988   |                                  |       |
| Ammonia                                      | No                        | .2910   |                                  |       |
| Nitrite                                      | No                        | .5690   |                                  |       |
| Ammonia plus organic nitrogen                | No                        | .2494   |                                  |       |
| Nitrite plus nitrate nitrogen                | No                        | .8504   |                                  |       |
| Phosphorus                                   | No                        | .1493   |                                  |       |
| Orthophosphorus                              | No                        | .2870   |                                  |       |
| Total organic carbon                         | No                        | .4219   |                                  |       |
| Calcium                                      | No                        | .7302   |                                  |       |
| Magnesium                                    | No                        | .0808   |                                  |       |
| Sodium                                       | Yes                       | .0210   |                                  | x     |
| Potassium                                    | No                        | .8623   |                                  |       |
| Chloride                                     | Yes                       | .0210   |                                  | x     |
| Sulfate                                      | No                        | .1503   |                                  |       |
| Alkalinity                                   | No                        | .9315   |                                  |       |
| Chromium                                     | No                        | .3678   |                                  |       |
| Copper                                       | No                        | .2237   |                                  |       |
| Lead   | No                        | .1392   |                                  |       |
| Zinc   | No                        | .6317   |                                  |       |

However, this value is not high relative to State standards (5,000  $\mu\text{g/L}$ ) for drinking water (Florida Department of Environmental Regulation, 1982). The zinc concentrations at site 8 also were significantly higher than at the control well (site 9), but no significant difference was detected in mean concentrations between the group that included sites 1 to 7 (surficial aquifer system) and the control site. Because zinc is an ubiquitous element, the concentrations at site 8 probably are due to natural sources.

*Between study areas.*--A statistical test for differences in ground-water quality between the Silver Star Road pond area and the Longwood pond area also was used in data analysis. Any differences detected may be due to a number of factors, including land use, drainage area, traffic volume, and the design of the pond (wet or dry and detention or retention), which will affect the length of time water remains in the pond for sedimentation and biological and chemical processes to take place. Differences in water

Table 13.—*Results of analysis of variance of rank data, grouped by data type, and multiple comparison test (TUKEY), Longwood retention pond study area*

[p-value, the probability that observed differences are due to chance rather than to the sampling location]

Hypothesis being tested by analysis of variance: Means of the k data types are equal.

Alternate hypothesis: At least two of the data type means differ.

Data types are: S = runoff or water standing in pond; G = ground water under the pond, sites 1-7; D = ground water from site 8 (65-feet deep); C = ground water from site 9 (control well).

The less than (<) and greater than (>) symbols indicate the direction of the difference between the groups indicated at the top of the column. For example, a "<" symbol for specific conductance under the S:G column means that specific conductance was significantly lower in runoff or water standing in the pond than in water from the surficial aquifer system directly below the pond. If no symbol is shown, the test result indicated no significant difference.

| Dissolved constituent<br>or physical measure | Significant<br>difference | p-value | Multiple comparison test results |     |     |     |     |     |
|--|---------------------------|---------|----------------------------------|-----|-----|-----|-----|-----|
|  |                           |         | S:G                              | S:C | S:D | G:C | G:D | D:C |
| Turbidity                                    | No                        | 0.1073  |                                  |     |     |     |     |     |
| Color  | No                        | .0581   |                                  |     |     |     |     |     |
| Specific conductance                         | Yes                       | .0001   | <                                |     |     |     | >   |     |
| pH—field                                     | Yes                       | .0142   |                                  |     |     |     | >   |     |
| pH—lab                                       | Yes                       | .0003   |                                  |     |     |     | >   | <   |
| Ammonia                                      | No                        | .1938   |                                  |     |     |     |     |     |
| Nitrite                                      | Yes                       | .0087   | >                                |     |     |     |     |     |
| Ammonia plus organic nitrogen                | No                        | .4817   |                                  |     |     |     |     |     |
| Nitrite plus nitrate nitrogen                | No                        | .1704   |                                  |     |     |     |     |     |
| Phosphorus                                   | Yes                       | .0001   | >                                |     | >   | <   |     | <   |
| Orthophosphorus                              | Yes                       | .0001   | >                                |     | >   | <   |     | <   |
| Total organic carbon                         | No                        | .1689   |                                  |     |     |     |     |     |
| Calcium                                      | Yes                       | .0001   | <                                |     |     |     | >   |     |
| Magnesium                                    | Yes                       | .0294   |                                  | <   |     |     |     |     |
| Sodium                                       | Yes                       | .0470   |                                  | <   |     |     |     |     |
| Potassium                                    | Yes                       | .0211   |                                  |     | >   |     | >   |     |
| Chloride                                     | No                        | .0931   |                                  |     |     |     |     |     |
| Sulfate                                      | Yes                       | .0603   |                                  | >   |     |     |     |     |
| Alkalinity                                   | Yes                       | .0001   | <                                |     |     |     | >   | <   |
| Aluminum                                     | No                        | .0939   |                                  |     |     |     |     |     |
| Copper                                       | Yes                       | .0408   | >                                |     |     |     |     |     |
| Iron   | No                        | .1000   |                                  |     |     |     |     |     |
| Lead   | No                        | .2290   |                                  |     |     |     |     |     |
| Nickel                                       | No                        | .1704   |                                  |     |     |     |     |     |
| Zinc   | Yes                       | .0022   |                                  | >   |     |     | <   | >   |

quality may be related to aquifer materials, but in central Florida, most of the surficial aquifer system is fairly uniform throughout the area, and is comprised of quartz sand, with varying amounts of clay and shell (Lichtler, 1972). For statistical testing, ground-water data at sites 1 to 3 and 5 to 8 were pooled for the Silver Star Road pond, and at sites 1 to 7 for the Longwood pond.

Twenty-five constituents and physical measurements (the same as were listed in table 13) were tested. Chromium is not included in this

list because concentrations were always less than the laboratory detection limit of 1 µg/L (dissolved). Mean concentrations of ammonia and Kjeldahl nitrogen are significantly higher in ground water near the Silver Star Road pond than in ground water beneath the Longwood pond, but nitrate nitrogen is higher in ground water beneath the Longwood pond. This may be the result of a wet pond (Silver Star Road), which may have a reducing environment at the soil-water interface, compared to a dry pond

(Longwood), with an abundance of oxygen at the soil surface (oxidizing environment), which allows the oxidation of nitrogen to nitrate nitrogen. Also higher in ground water at the Silver Star Road pond than in ground water at the Longwood pond are mean concentrations of sodium and chloride (this also is indicated in the Piper and Stiff diagrams in figs. 30 and 32), total organic carbon, nickel, and aluminum. At the Longwood pond, only pH, nitrate nitrogen, and alkalinity values were significantly higher than in ground water at the Silver Star Road pond.

### Sediment Analysis

Sediment samples were collected at both pond study areas and analyzed for constituent concentrations. Nine locations in the pond at the Silver Star Road pond were sampled three times, for a total of 27 samples, and three locations were sampled once each at the Longwood pond. A statistical summary of the analyses is shown in table 14. Sediments serve as a reservoir for many constituents, retarding the migration of constituents to ground water. Values for most

constituents were higher in sediments in the Silver Star Road pond (table 14), with the exception of manganese.

At the Longwood pond, other sediment-related work also was completed, including the analysis of sediments from three locations for priority pollutants, sediment sizing and analysis of clay mineralogy for cores obtained during drilling of the 65-foot deep well (site 8). High concentrations (in the range of thousands of micrograms per kilogram) of several organic compounds were present in all three sediment samples. All the organic compounds were PAHs, specifically, fluoranthene, chrysene, benzo-A-pyrene, benzo-K-fluoranthene, benzo-A-anthracene, and other related compounds. Most of these compounds are petroleum or coal-tar derivatives (associated with pavement), and also are related to fossil fuel combustion (automobiles), which indicates that the most likely source of these compounds is the highway and parking lot runoff entering the pond. However, identification of these organic compounds in the sediment does not indicate their presence in the underlying ground water.

Table 14. — *Range of concentrations of selected constituents in bottom sediments at both detention and retention pond study areas*

[Concentrations are in micrograms per gram, unless otherwise noted. mg/kg, milligrams per kilogram; --, denotes no sample or value]

| Constituent                  | Silver Star Road<br>detention pond (9 sites) |    |        |       | Longwood<br>retention pond (3 sites) |    |        |        |
|------------------------------|--|----|--------|-------|--------------------------------------|----|--------|--------|
|                              | Range  |    | Median |       | Range                                |    | Median |        |
| Volatile solids (mg/kg)      | --   | -- | --     | --    | 13,300                               | -- | 55,400 | 32,300 |
| Nitrogen, as N               |  |    |        |       |                                      |    |        |        |
| Ammonia (mg/kg)              | 15   | -- | 230    | 92    | 6.6                                  | -- | 13     | 8.1    |
| Ammonia plus organic (mg/kg) | 470  | -- | 33,000 | 4,100 | 1,300                                | -- | 3,000  | 1,600  |
| Nitrite plus nitrate (mg/kg) | 2  | -- | 110    | 9     | --                                   | -- | --     | --     |
| Phosphorus, as P (mg/kg)     | 280  | -- | 1,800  | 1,100 | --                                   | -- | --     | --     |
| Cadmium                      | 1  | -- | 9      | 6     | 1                                    | -- | 1      | 1      |
| Chromium                     | 2  | -- | 240    | 20    | 3                                    | -- | 6      | 4      |
| Cobalt                       | 10   | -- | 10     | 10    | --                                   | -- | --     | --     |
| Copper                       | 1  | -- | 130    | 49    | 4                                    | -- | 18     | 13     |
| Lead                         | 10   | -- | 2,000  | 620   | 20                                   | -- | 470    | 200    |
| Manganese                    | 23   | -- | 35     | 29    | 60                                   | -- | 580    | 250    |
| Zinc                         | 1  | -- | 1,100  | 250   | 52                                   | -- | 120    | 100    |
| Iron                         | 1,800  | -- | 4,900  | 4,400 | 180                                  | -- | 1,300  | 830    |

FID scans of water samples from sites 1, 2, and 6 at the Longwood pond indicated possible concentrations of some organics in ground water at concentrations ranging from 1 to 5  $\mu\text{g/L}$  in water from site 1, and less than detection levels (1  $\mu\text{g/L}$ ) at sites 2 and 6. From this limited sampling, it seems that the organic compounds detected in the sediments have not yet migrated to the ground water.

Sediment cores were obtained during drilling of the deep well at the Longwood pond (site 8), and selected cores were analyzed for particle-size distribution and clay mineralogy by the Department of Geology, University of South Florida. The description of the sediment cores and sediment-size distribution information is listed in table 15. Three cores were analyzed for clay mineralogy: 0 to 1 foot, 5 to 6.5 feet, and 70 to 71.5 feet below land surface. The clays in the upper cores were predominately kaolinite (70 to 85 percent), and showed evidence of having been formed under acidic soil environments. The clays in the 70- to 71.5-foot deep core were predominately smectite (80 percent), a clay that has much greater adsorption properties and very low permeability. The cation exchange capacity of the upper 12 inches of soil was estimated to be only 1 milliequivalent per hundred grams of sample, but the smectite in the 70- to 71.5-foot sample raised the cation exchange capacity to 15 milliequivalents per hundred grams of sample. The small percentage of clays in the upper soils of the pond bottom probably do not account for much of the attenuation of constituents as water moves downward, but the high percentage of sand-sized particles allow rapid infiltration, which was observed during the study.

### Swales

Ground-water samples were collected for water-quality analysis from wells at the Princeton Street swale study area from June 1984 through April 1986. One runoff sample was collected in July 1986 (table 5). Water-quality samples were collected from wells at the swale study area north of Longwood, during the third year of the study (1986), but no runoff sample was obtained at this location. Sediment samples were collected at both swale areas, and one sample was collected at each swale for FID scan analysis.

Well depths at the Princeton Street swale study area vary from 13 feet (sites 1, 2, 3, and 5) to 24 feet (sites 6, 7, and 8). The well at site 4 is 19-foot deep, and at site 9 the well is 20-foot deep.

Drill cuttings indicated a thin (less than 1 foot) clay layer at the southern end of the swale, approximately 14 feet below land surface. However, clay was not found at the other sites (sites 3 and those north of site 3). Some water-quality differences between sites at different depths may be due to the presence of this clay layer.

All wells at the Longwood swale are 23 feet deep, except the control well, which is 34.5 feet deep. Mounding due to stormwater infiltration was evident from water-level measurements (fig. 33). The sampling depth below the water table varied among the wells. The greatest depth in the saturated zone that was sampled was at site 3, and sampling sites nearest the water table were sites 1 and the control site.

### Water-Quality Variations

Ranges in values of selected constituents and water-quality measures for sites at the Princeton Street and Longwood swale locations are shown in figures 34 through 36. One stormwater sample collected at the Princeton swale study area also is shown in the figures. Sites at Princeton are grouped by depth, thus sites 1, 2, 3, and 5 are listed before site 4 and sites 6 through 9.

A trend is not apparent in specific conductance of ground water in the more shallow wells at Princeton, but conductance apparently increases downgradient in the deeper wells (sites 8, 7, and 6) (fig. 34). Ground water below the swale tends to have lower specific conductance values than ground water upgradient at the control well site, probably because of the volume of water infiltrating at the swale compared to what infiltrates naturally at the control site. Although stormwater runoff may initially have high specific conductance values, after the initial "first flush" of water off road surfaces, specific conductance values tend to decrease and eventually approach values found in rainfall. This also may be the reason for the higher specific conductance values at site 1 at the Longwood swale. Site 1, which is halfway up a hillside that forms part of the swale (fig. 33), has the greatest depth to water of all the wells located in the swale (18 feet), and is not in a location where water would tend to pond, as it does at sites 2, 3, and 4. The control site (site 5) does not have similarly high conductance values, although it also does not receive infiltrating runoff and has a greater depth to water (33 feet) than site 1. Specific conductance values at sites 2 to 4 are similar to values at the control well site.

Table 15.—*Description of core samples and grain size analysis, Longwood retention pond, site 8*

[Analysis done by University of South Florida, Department of Geology, Tampa, Florida.  
-- denotes no data.]

Size categories:

Sand: 2–0.063 millimeters  
Silt: 63–3.9 micrometers  
Clay: < 3.9 micrometers

| Depth below<br>land surface | Description of sediments   | Percentage |      |      |
|-----------------------------|--|------------|------|------|
|                             |  | Sand       | Silt | Clay |
| 0 inch to 0.5 inch          | Brown silty sand, abundant leaf fragments.   | --         | --   | --   |
| 0.5 inch to 1 inches        | Clean sand.  | --         | --   | --   |
| 1 inch to 2 inches          | Organic peat, clayey, black.   | --         | --   | --   |
| 2 inches to 12 inches       | Sand, medium to fine, angular to subangular, light gray to gray, occasional orange stained horizons - contains clay layer at approximately 1/2 inch intervals.   | 88         | 3    | 9    |
| 5 feet to 6.5 feet          | Slightly clayey fine sand, very pale orange to very pale orange brown, faintly laminated with darker zones (more clay) approximately 1/4 inch thick.   | 89         | 3    | 8    |
| 10 feet to 10.33 feet       | Sand, medium to fine, subangular to subrounded, pale range gray, becoming slightly darker.   | --         | --   | --   |
| 10.33 feet to 10.83 feet    | Sand, medium to fine, light orange gray.   | 92         | 0    | 8    |
| 10.83 feet to 11.5 feet     | Sandy, muddy, mottled, medium gray to tan, clay content variable, faintly laminated.   | --         | --   | --   |
| 15 feet to 16.5 feet        | Sand, medium to fine, light brown to very light brown, mottled nonlaminated, but faintly laminated near bottom of interval.  | 95         | 2    | 3    |
| 16.5 feet to 70 feet        | Cores not analyzed - all seem to be same as 15 feet to 16.5 feet interval.   | --         | --   | --   |
| 70 feet to 71.5 feet        | Clay, sand, phosphatic, pale grayish green mottled with limonite zone and white blebs aluminum phosphate species. No internal primary depositional features apparent, dry core, dense and rocklike, slacks rapidly on wetting. | 68         | 3    | 29   |

The same pattern seen in specific conductance values at the Longwood swale also is evident for field pH values, although the range in values is greater at sites 2 to 5 (fig. 34). Ground water at both swales is acidic, sometimes reaching values below 4.5. Values of pH generally are lower in water from the deeper wells at the Princeton swale than in ground water at shallower depths, possibly indicating a more reducing environment below the clay layer.

Dissolved phosphorus values at both swales generally are low (<0.2 mg/L), but occasionally high values were found at site 1, Princeton Street, and site 5, Longwood (fig. 35). Although higher dissolved phosphorus was measured at site 1 (Princeton Street swale), the median value was

not much different from medians at other sites. The high concentrations measured in ground water at the control site (0.42 to 1.5  $\mu\text{g/L}$ ), Longwood swale, may have originated from fertilizer leaching from an adjacent abandoned orange grove.

The predominate form of nitrogen in ground water at the Princeton Street swale study area is nitrate nitrogen (table 16). Nitrite nitrogen frequently was below detection limits, so most of the nitrate plus nitrite is nitrate nitrogen. Nitrate is the main form in which nitrogen occurs in ground water (Freeze and Cherry, 1979). Nitrate values are more variable at sites at the Princeton Street swale than at individual sites at the Longwood swale, although the highest nitrate

values were measured at site 2 at the Longwood swale. With the exception of site 2, the majority of nitrogen in ground water at the Longwood swale is in the Kjeldahl form, and of this, organic nitrogen is dominant. Although not shown, Kjeldahl nitrogen concentrations are similar at all sites at the Longwood swale (including site 2).

Dissolved zinc in ground water at the swale study areas generally is less than  $100\text{ }\mu\text{g/L}$  (fig. 36). Zinc values are slightly more variable in ground water beneath the swale than at the control site at Princeton Street.

Higher and more variable zinc values were measured at site 1 than at other sites at the Longwood swale. This pattern, seen in specific conductance and pH values, also occurs in dissolved iron values (fig. 36). Dissolved iron concentrations under the Longwood swale vary more ( $180$  to  $1,500\text{ }\mu\text{g/L}$ ) and median values are higher than all dissolved iron concentrations at the control well site ( $40$  to  $140\text{ }\mu\text{g/L}$ ). Whereas

iron values also are more variable in ground water under the Princeton Street swale than at the control well site of that swale, iron tends to be much lower in ground water beneath the swale. These dissolved iron concentrations are much higher than what is allowed ( $300\text{ }\mu\text{g/L}$ ) by drinking water standards (Florida Department of Environmental Regulation, 1982), but iron commonly is present at higher concentrations in water in the surficial aquifer system than in water in the Floridan aquifer system. The iron in highway runoff (in the suspended form, which dissolves after entering the swale or pond) may be contributing to these high values, but it also may be a natural occurrence.

From these figures no clear trend is apparent in constituent concentrations or physical measures in the ground water near these swales. Occasionally, higher concentrations were measured in samples from the control wells (phosphorus at the Longwood swale and iron at the Princeton Street swale).

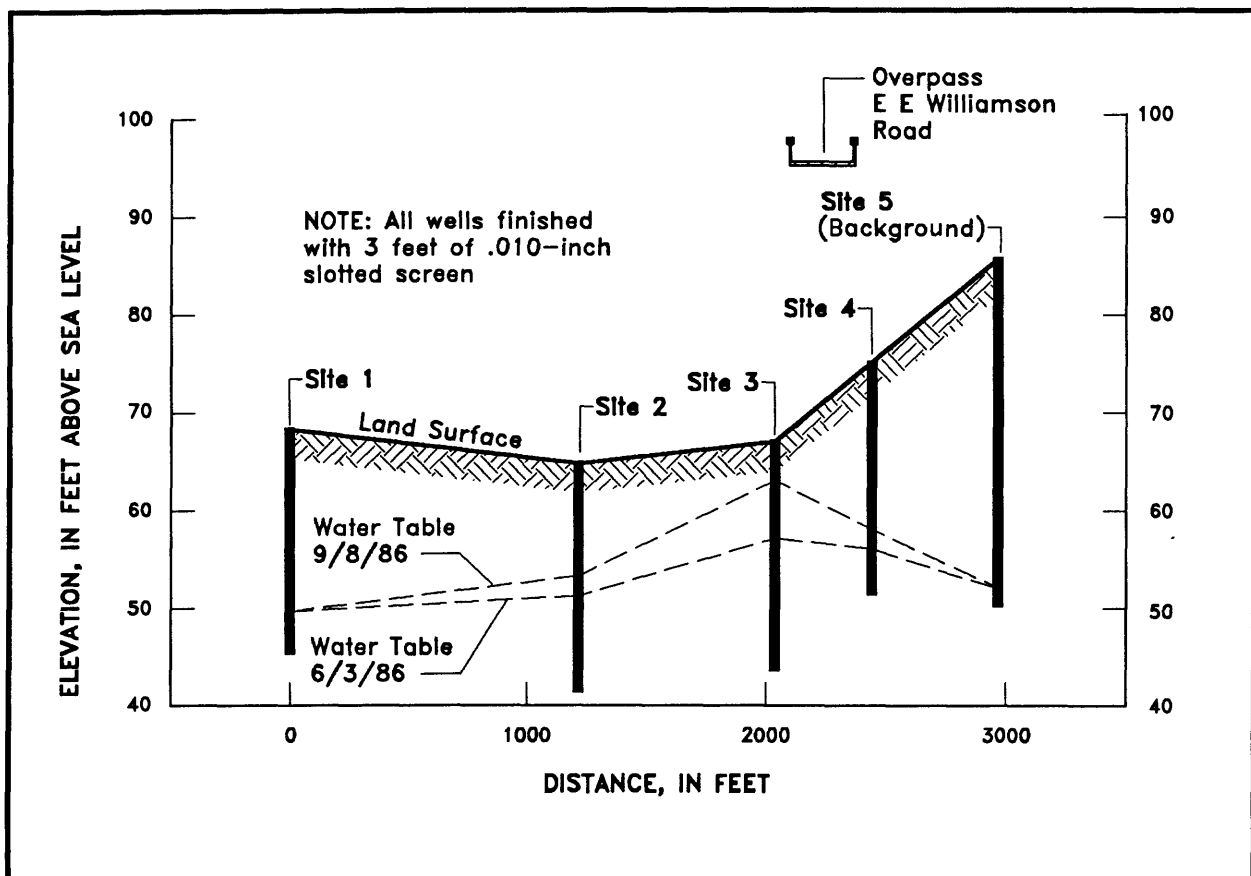


Figure 33.--Longitudinal section of Longwood swale.

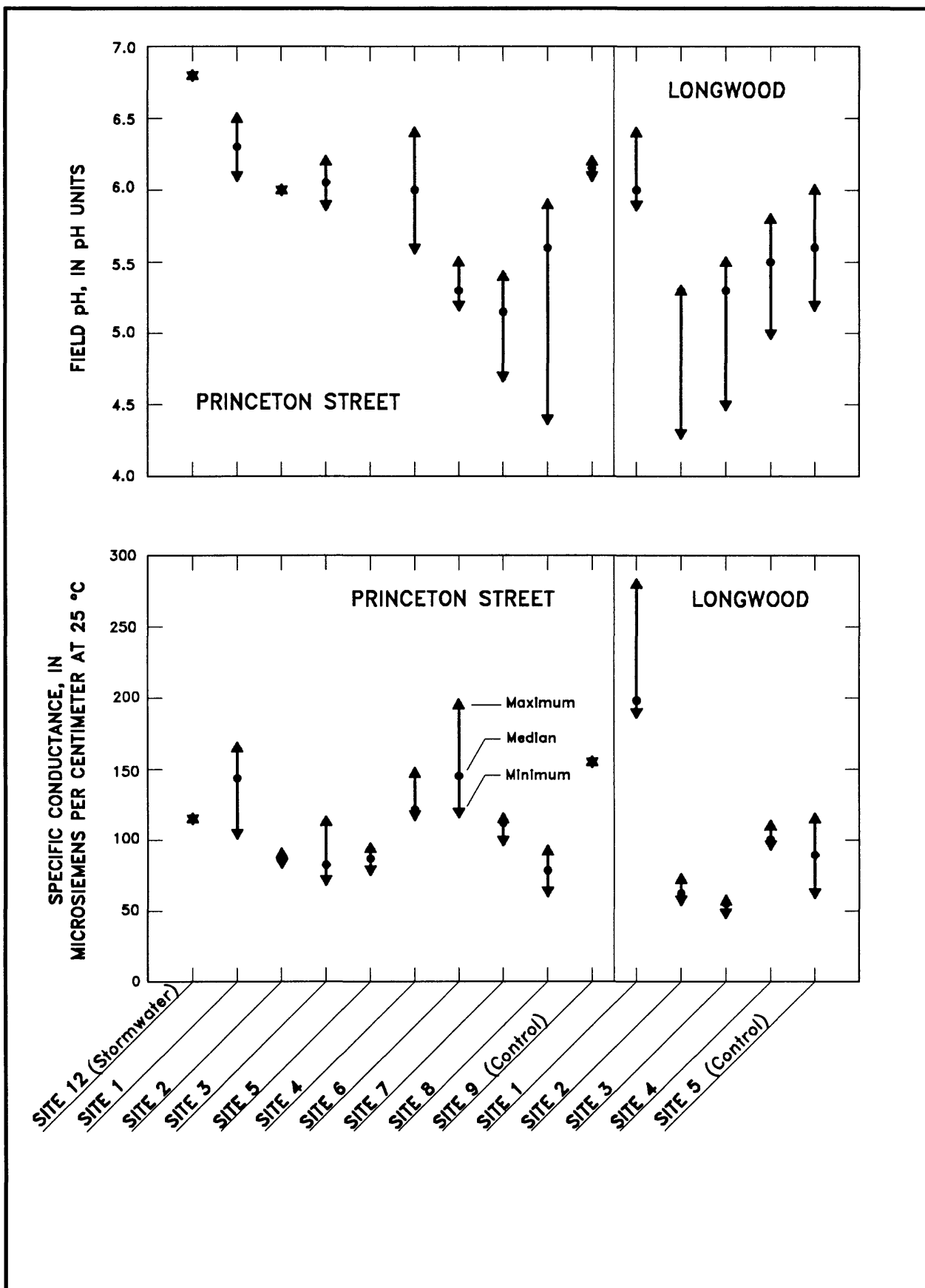


Figure 34.—Field pH and specific conductance at sampling sites at the two swale study areas.



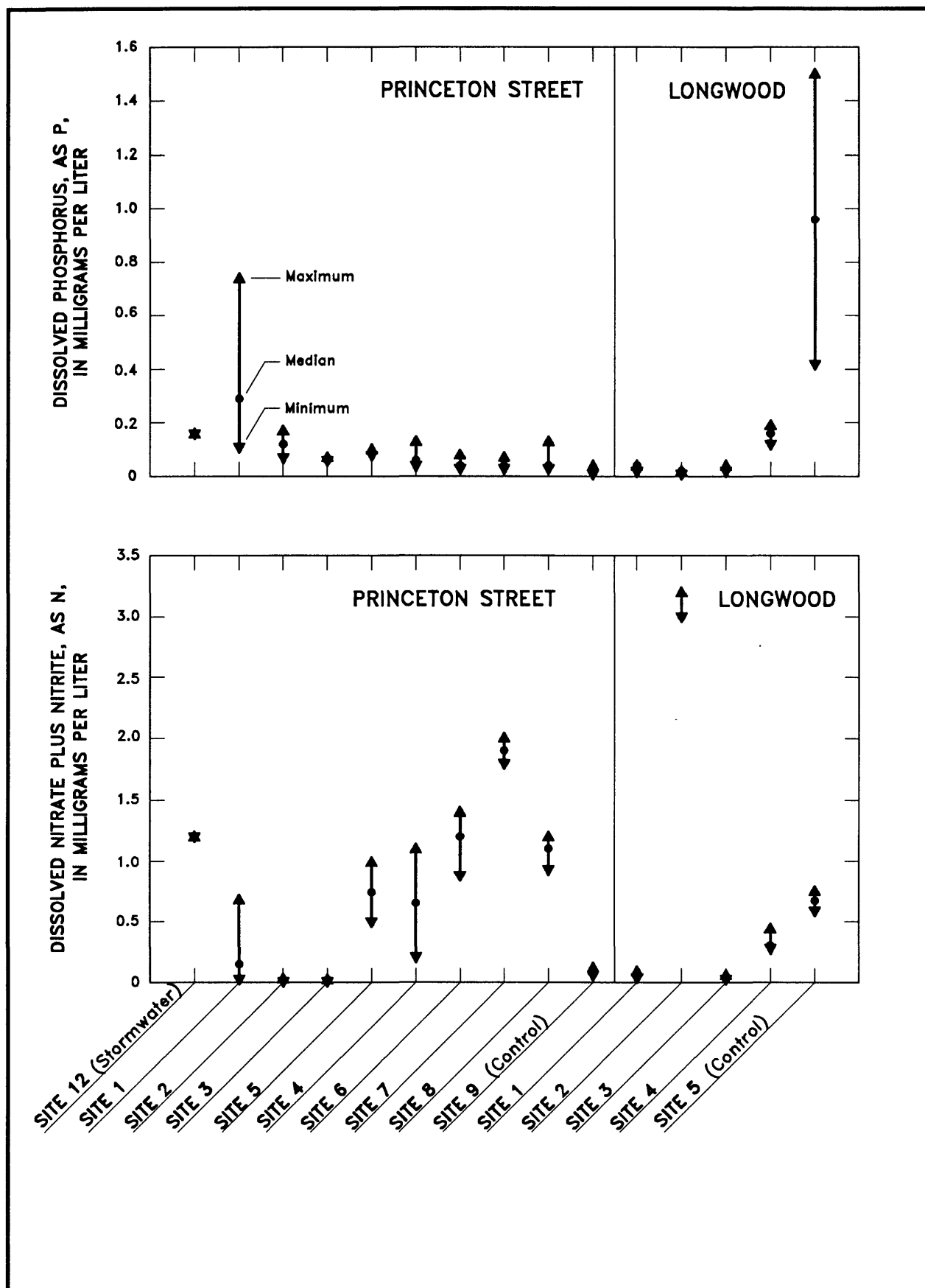


Figure 35.--Dissolved nitrate plus nitrite nitrogen and dissolved phosphorus at sampling sites at the two swale study areas.

Table 16. — *Statistical summary of concentrations of selected constituents in ground water at Princeton Street and Longwood swale study areas*

[Control sites are not included. Concentrations are dissolved, in milligrams per liter, unless otherwise noted. NTU, nephelometric turbidity units; Pt-Co units, Platinum-Cobalt units;  $\mu\text{S}/\text{cm}$  at 25 °C, microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter]

| Constituent or physical property                         | Princeton Street swale |       |   |      |        | Longwood swale     |       |   |       |        |
|--|------------------------|-------|---|------|--------|--------------------|-------|---|-------|--------|
|  | Ground-water sites     |       |   |      |        | Ground-water sites |       |   |       |        |
|  | No. of samples         | Range |   |      | Median | No. of samples     | Range |   |       | Median |
| Turbidity (NTU)  | 38                     | 0.2   | — | 370  | 4      | 12                 | 0.5   | — | 150   | 3.05   |
| Color (Pt-Co units)                                      | 37                     | < 5   | — | 10   | < 5    | 12                 | < 5   | — | 10    | < 5    |
| Specific conductance ( $\mu\text{S}/\text{cm}$ at 25 °C) | 40                     | 64    | — | 195  | 113    | 12                 | 49    | — | 280   | 84     |
| Field pH (pH units)                                      | 22                     | 4.4   | — | 6.5  | 5.6    | 12                 | 4.3   | — | 6.4   | 5.4    |
| Lab pH (pH units)  | 39                     | 4.9   | — | 6.7  | 5.8    | 11                 | 5.1   | — | 6.8   | 5.9    |
| Nitrogen species, as N:                                  |                        |       |   |      |        |                    |       |   |       |        |
| Ammonia  | 39                     | .01   | — | .14  | .02    | 12                 | .01   | — | .34   | .03    |
| Nitrite  | 40                     | < .01 | — | .07  | < .01  | 12                 | < .01 | — | .01   | < .01  |
| Ammonia plus organic                                     | 39                     | .05   | — | .70  | .15    | 12                 | .12   | — | .53   | .20    |
| Nitrite plus nitrate                                     | 40                     | < .01 | — | 2    | .98    | 12                 | .03   | — | 3.2   | .18    |
| Phosphorus, as P   | 40                     | .03   | — | .74  | .06    | 12                 | .01   | — | .19   | .03    |
| Orthophosphorus, as P                                    | 40                     | .01   | — | .39  | .03    | 12                 | .01   | — | .18   | .02    |
| Total organic carbon                                     | 39                     | < .1  | — | 11   | 1.10   | 12                 | .1    | — | 6.5   | .5     |
| Calcium  | 40                     | .37   | — | 18   | 5.15   | 12                 | .98   | — | 35    | 3.05   |
| Magnesium  | 40                     | .47   | — | 2.7  | 1.75   | 12                 | .97   | — | 6.4   | 3.25   |
| Sodium   | 40                     | 1.5   | — | 29   | 9.2    | 12                 | 2     | — | 5.3   | 2.75   |
| Potassium  | 39                     | .2    | — | 3.4  | .9     | 12                 | .2    | — | 2.8   | .7     |
| Chloride   | 39                     | 1.8   | — | 29   | 14     | 12                 | 3.4   | — | 11    | 7.25   |
| Sulfate  | 39                     | .7    | — | 32   | 18     | 12                 | 1.1   | — | 16    | 8.6    |
| Alkalinity, as $\text{CaCO}_3$                           | 39                     | 1     | — | 23   | 8      | 12                 | 3     | — | 115   | 6      |
| Aluminum ( $\mu\text{g}/\text{L}$ )                      | 27                     | < 10  | — | 160  | 20     | 12                 | < 10  | — | 100   | 30     |
| Chromium ( $\mu\text{g}/\text{L}$ )                      | 35                     | < 1   | — | 30   | < 1    | 12                 | < 1   | — | 2     | < 1    |
| Copper ( $\mu\text{g}/\text{L}$ )                        | 36                     | < 1   | — | 8    | 2      | 12                 | < 1   | — | 9     | < 2.5  |
| Iron ( $\mu\text{g}/\text{L}$ )                          | 40                     | 3     | — | 980  | 22     | 12                 | 180   | — | 1,500 | 815    |
| Lead ( $\mu\text{g}/\text{L}$ )                          | 40                     | < 1   | — | < 10 | < 1    | 12                 | 2     | — | < 5   | < 5    |
| Nickel ( $\mu\text{g}/\text{L}$ )                        | 35                     | < 1   | — | 6    | < 1    | 12                 | < 1   | — | 7     | 2      |
| Zinc ( $\mu\text{g}/\text{L}$ )                          | 40                     | 4     | — | 740  | 19     | 12                 | 10    | — | 170   | 34.5   |

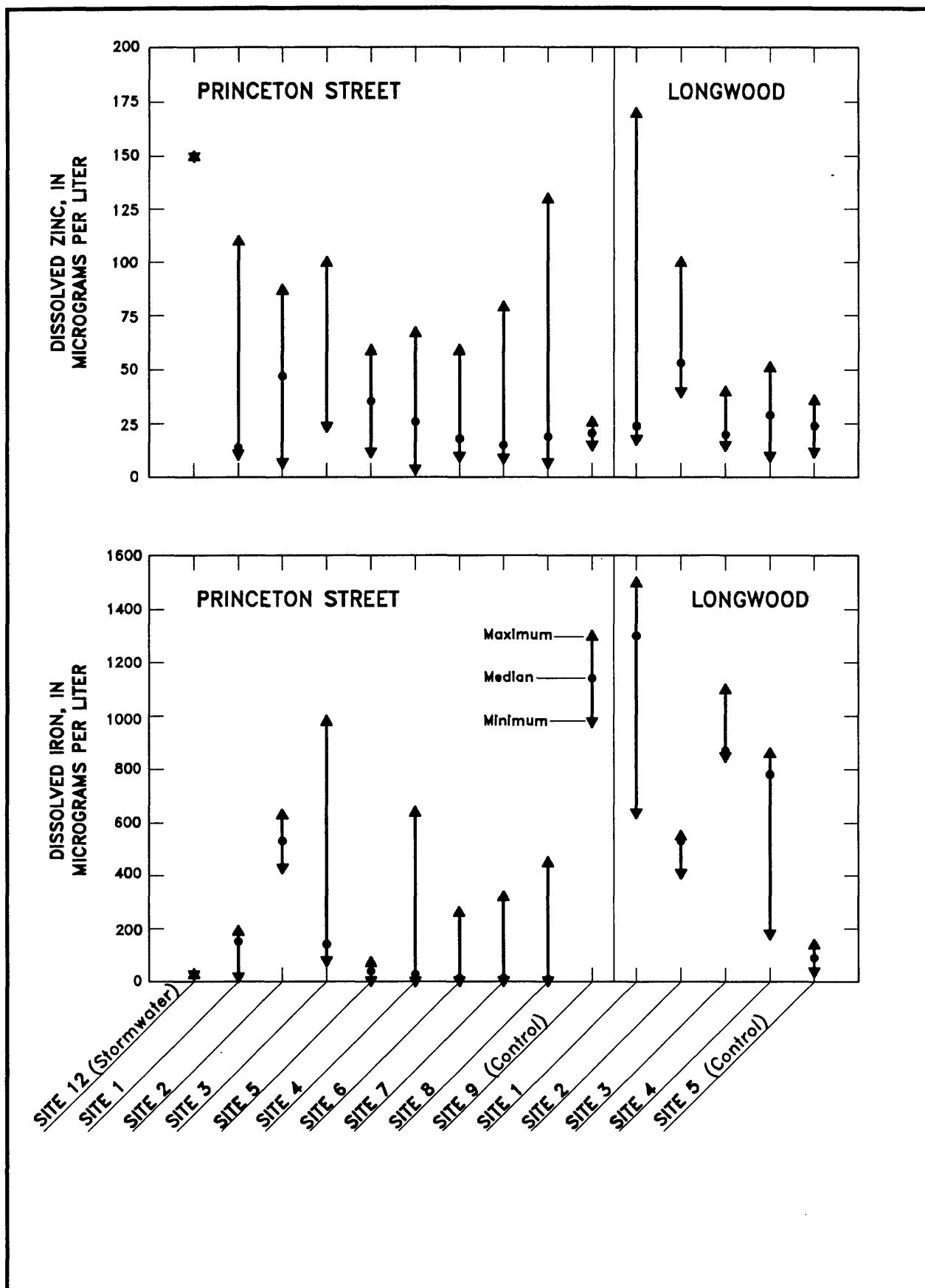


Figure 36.—Dissolved Iron and dissolved zinc at sampling sites at the two swale study areas.

Concentrations of major ions in ground water at both swales also were measured, and these may more reliably indicate changes in water quality than other constituents because of their conservative nature. Stiff diagrams are shown for both swale study areas in figures 37 and 38.

Major ions in ground water at the Princeton Street swale are shown in figure 37. Sites 1 to 3 and site 5 are all the same depth, and all have similar distributions of ions in water samples from the sites. Site 4 is slightly deeper, but the ionic composition of water is also similar to that of the other shallow wells, and all of these resemble the diagram for stormwater (site 12). Water from sites 8, 7, and 6 (moving downgradient) have higher sodium chloride concentrations than water from the shallower wells, and may be indicating the difference in water quality above and below the observed clay layer at this swale. The pattern displayed by the ionic composition of water from site 1 differs from that shown for water from site 7, although they are almost in the same location in the swale. This also is true for sites 2 and 8. This ionic difference may be a result of differing well depths (sites 1 and 2, 13 feet, and sites 7 and 8, 24 feet). This difference was not detected between ground water from sites 3 and 4, possibly because no clay was found during drilling at these sites. The ionic composition of ground water from shallower depths (sites 1 to 5) is more similar to the ionic composition of the incoming runoff (site 12), which is a calcium bicarbonate water. However, ground water from greater depths (sites 6 to 8) seems to be a sodium chloride type. Water from the control well site seems to be more evenly distributed ionically (roughly equal parts calcium and sodium cations, and bicarbonate and sulfate anions).

The distribution of major ions in ground water beneath the Longwood swale (fig. 38) is dissimilar among sampling sites. Concentrations of ions in rainfall at Lake Hope, Maitland, Fla., were plotted to show the type of distribution commonly found in rainwater--primarily calcium carbonate with some sodium and chloride. However, the concentrations in rainwater are much lower than what is typical of ground water.

The wells at the Longwood swale differ from each other in the depth of screened interval below the water table. At site 1, the screen is 2 feet below the water table, but at site 3, the water level is only 4 feet below land surface, and the

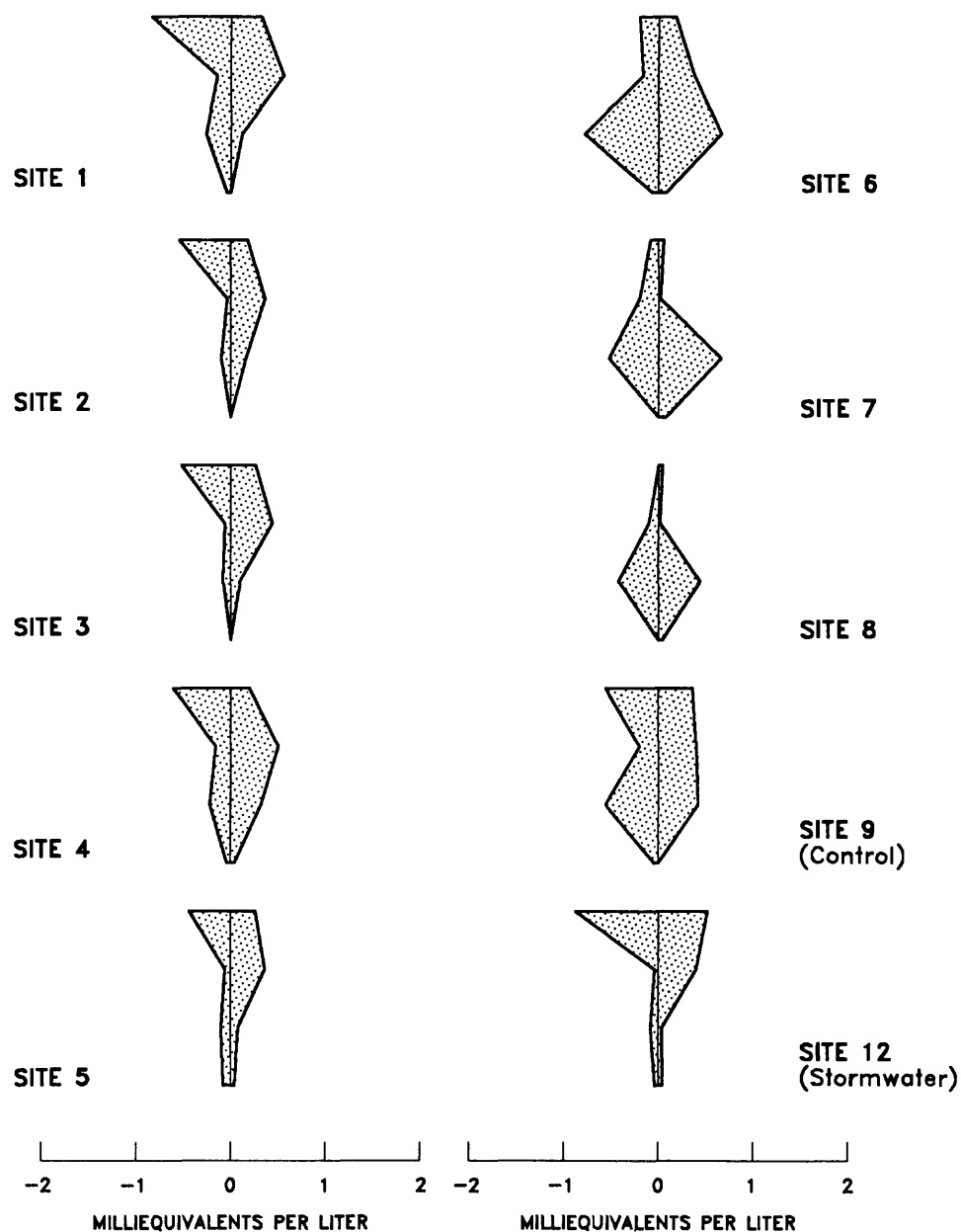
screened interval is 13 feet below the water table (fig. 33). The screened interval at site 2 is 8 feet below the water table, and the depth of the screened interval at site 4 is similar to that at site 1 (3 feet below the water table). Some differences in water quality might be attributable to depth in the surficial aquifer system. The Stiff diagram for water from site 3, the deepest well in reference to the water table, resembles the Stiff diagrams for water from sites at the Princeton Street swale that also tapped greater depths in the aquifer (sites 6 to 8). The high nitrate nitrogen concentrations measured at site 2 of the Longwood swale makes a noticeable contribution to the Stiff diagram. All the Stiff diagrams for ground water beneath the swale seem to significantly differ from the diagram for water from the control well site.

The quality of ground water below the Princeton Street and Longwood swales is summarized in table 16. This summary includes all ground-water sampling sites near each swale, excluding the control well sites. Only a few isolated values are high and were discussed previously in this report. Most metals, with the noticeable exception of iron, are present in low concentrations beneath the swales.

In August 1986 ground-water samples were collected at each swale study area for FID scan analysis. Site 3 was sampled at the Longwood swale, and site 5 at the Princeton Street swale. The water sample from the Longwood swale contained detectable concentrations of organic compounds estimated in the 1 to 20  $\mu\text{g/L}$  range and, based on the scan, these compounds are probably PAHs. The water sample from the Princeton Street swale did not contain detectable concentrations of organic compounds.

### Statistical Comparisons

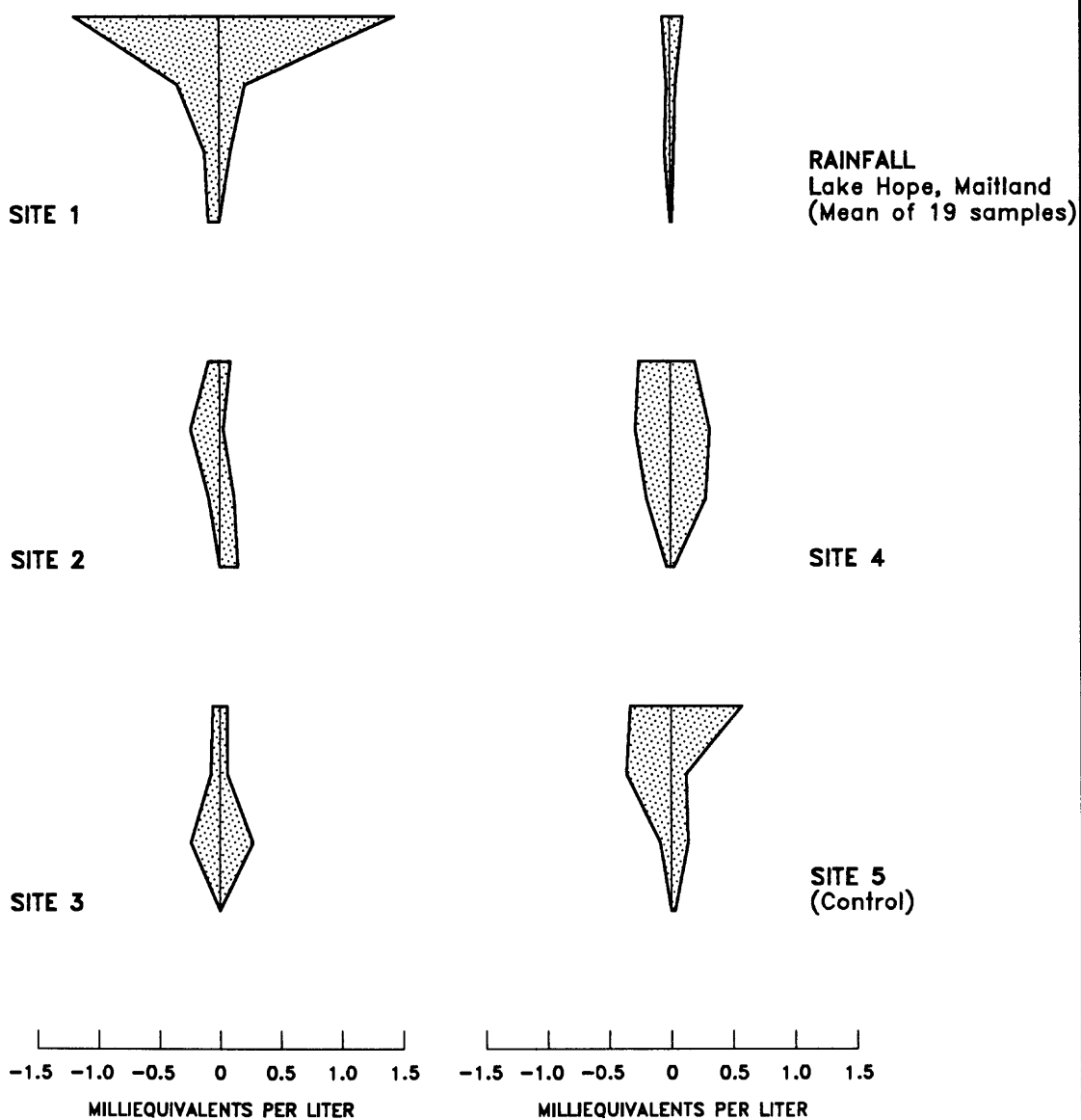
*Among data types.*--Statistical techniques were again utilized to detect any significant differences among sampling locations (denoted as data types for analysis). Analysis of variance methods were used to detect significant differences among data types, then TUKEY's multiple comparison technique was used to determine where differences occurred. As before, values of selected water-quality variables were converted to rank values before statistical testing proceeded. As expected, the statistical test results generally verified what was observed about the data from the figures already presented.



#### EXPLANATION

|           |   |              |
|-----------|---|--------------|
| Calcium   | — | Bicarbonate  |
| Magnesium | — | Sulfate      |
| Sodium    | — | Chloride     |
| Potassium | — | Nitrate as N |

Figure 37.—Ionic composition of water from sampling sites at the Princeton Street and Interstate 4 swale. (Median values used except for stormwater.)



#### EXPLANATION

|           |   |              |
|-----------|---|--------------|
| Calcium   | — | Bicarbonate  |
| Magnesium | — | Sulfate      |
| Sodium    | — | Chloride     |
| Potassium | — | Nitrate as N |

Figure 38.--Ionic composition of water from sampling sites at the Longwood swale. (Median values used except for rainfall.)

At the Longwood swale study area, only two data types were available for testing--ground water beneath the swale and ground water from the control well site. Data for sites 1 to 4 were pooled and compared to data for site 5 (control well). Results of the ANOVA test and TUKEY's test are listed in table 17. Mean concentrations of 4 of the 26 water-quality variables are significantly different between ground water near the swale and ground water from the control well site: phosphorus, orthophosphorus, sodium, and iron. The difference in phosphorus has already been noted in figure 35 as has the difference in iron (fig. 36). Mean sodium concentrations in water from sites 3 and 4 (5 and 4 mg/L, respectively) are twice the mean sodium concentration of water from the control well (2.0 mg/L); this difference probably led to the significant test result for sodium between the two groups (ground water below the swale and water from the control well).

At the Princeton Street swale study area, ground water at the swale was treated as one data type and compared to ground water at the control site, and runoff entering the swale. Water-quality data for sites 1 to 8 were pooled for the analysis. In some isolated cases, the ANOVA test sometimes indicated significant differences although the TUKEY test procedure did not (table 18). This situation occurred for laboratory pH and alkalinity values at this study area, but did not occur during statistical testing at any of the other four study areas. The reason for this result is the difference between the two tests (ANOVA and TUKEY) in how they control the error rate (which is a maximum of alpha, the test significance level). This is discussed in the SAS reference, and will not be covered here (refer to SAS Institute, Inc., 1982, p. 170-171).

There were no significant differences in mean concentrations among locations, with a few exceptions. The mean nitrite nitrogen concentration is significantly higher in runoff than in ground water (beneath the swale and at the control well site), an expected result because nitrite is converted to nitrate very rapidly, and usually is present in very low concentrations in ground water. The concentration of magnesium is higher in runoff than the mean concentration in ground water at the control site, but no difference was indicated between magnesium in ground water beneath the swale and from the control

well site. Of the metals, only mean iron concentrations are significantly different among the data types, and are higher in ground water at the control site than in ground water beneath the swale, also indicated in figure 36.

**Between study areas.**--A t-test was used to statistically test data at both swale study areas to determine if there are significant differences between ground water quality beneath the two swales. As with the ground water near the ponds, it is recognized that many factors may be responsible for any significant differences that may be detected. Rank data for 25 water-quality variables were tested. Chromium (dissolved) was not included because earlier analyses (at Princeton Street swale) had a higher detection level (10  $\mu\text{g/L}$ ), and could not be compared to values obtained at the Longwood swale (detection level of 1  $\mu\text{g/L}$ ). Ground-water quality data at each swale study area were pooled, excluding data from the control well site at each. At the Princeton Street swale, this included sites 1 to 8, and at the Longwood swale, sites 1 to 4.

Mean concentrations of 6 of the 25 water-quality variables were significantly higher in ground water at the Princeton Street swale study area. These dissolved constituents are: Kjeldahl nitrogen, phosphorus, orthophosphorus, sodium, chloride, and sulfate. Some of these differences may be due to the amount of traffic on the highway at the Princeton Street swale area and the culvert flow (compared to overland flow at the Longwood swale). Only dissolved iron was higher in ground water beneath the Longwood swale than beneath the Princeton Street swale.

### Sediment Analysis

Sediment samples were collected at both swale study areas, at two locations and at two depths at each location. The locations of the sediment sampling sites are shown in figure 12 (Princeton swale) and figure 14 (Longwood swale). At each of these sampling sites, sediment from the top 2 inches of soil, and 4 to 6 inches below the land surface was collected for analysis of nutrients and metals. Generally, constituent concentrations in sediments are lowest at the sampling site furthest from the highway, and concentrations decrease from the top 2 inches to the 4- to 6-inch interval (table 19). There are some exceptions to this, notably the phosphorus

Table 17. – *Results of analysis of variance of rank data, grouped by data type, and multiple comparison test (TUKEY), Longwood swale study area*

[p-value, the probability that observed differences are due to chance rather than to the sampling location]

Hypothesis being tested by analysis of variance: Means of the two groups are equal.

Alternate hypothesis: One of the two group means differ.

Group G: Sites 1-4.

Group C: Site 5.

An "x" in a column means that a significant difference was indicated between the means of the rank values of the groups indicated at the top of the column. For example, the mean of the ranks of dissolved phosphorus concentrations were significantly greater in water from the control site (site 5) than in water from the surficial aquifer system beneath the swale (sites 1-4). If no symbol is shown, the test result indicated no significant difference.

| Dissolved constituent<br>or physical measure | Significant<br>difference | p-value         | Multiple comparison test results |       |
|--|---------------------------|-----------------|----------------------------------|-------|
|  |                           |                 | G > C                            | C > G |
| Turbidity                                    | No                        | 0.1508          |                                  |       |
| Color  | No                        | .9235           |                                  |       |
| Specific conductance                         | No                        | .7305           |                                  |       |
| pH – field                                   | No                        | .7950           |                                  |       |
| pH – lab                                     | No                        | .1146           |                                  |       |
| Ammonia                                      | No                        | .5268           |                                  |       |
| Nitrite                                      | <sup>1</sup> --           | <sup>1</sup> -- |                                  |       |
| Ammonia and organic nitrogen                 | No                        | .0862           |                                  |       |
| Nitrite and nitrate nitrogen                 | No                        | .2898           |                                  |       |
| Phosphorus                                   | Yes                       | .0187           |                                  | x     |
| Orthophosphorus                              | Yes                       | .0137           |                                  | x     |
| Total organic carbon                         | No                        | .9292           |                                  |       |
| Calcium                                      | No                        | .6034           |                                  |       |
| Magnesium                                    | No                        | .7305           |                                  |       |
| Sodium                                       | Yes                       | .0498           | x                                |       |
| Potassium                                    | No                        | .8626           |                                  |       |
| Chloride                                     | No                        | .4869           |                                  |       |
| Sulfate                                      | No                        | .8634           |                                  |       |
| Alkalinity                                   | No                        | .2859           |                                  |       |
| Aluminum                                     | No                        | .6001           |                                  |       |
| Chromium                                     | No                        | .1383           |                                  |       |
| Copper                                       | No                        | .5884           |                                  |       |
| Iron   | Yes                       | .0212           | x                                |       |
| Lead   | No                        | .5424           |                                  |       |
| Nickel                                       | No                        | .5283           |                                  |       |
| Zinc   | No                        | .3835           |                                  |       |

<sup>1</sup>All values were less than, or equal to, the detection limit for dissolved nitrite.



Table 18. — *Results of analysis of variance of rank data, grouped by data type, and multiple comparison test (TUKEY), Princeton Street swale study area*

[p-value, the probability that observed differences are due to chance rather than to the sampling location]

Hypothesis being tested by analysis of variance: Means of the k data types are equal.

Alternate hypothesis: At least two of the data type means differ.

Data types are:

S: runoff to swale

G: sites 1-8

C: site 9

The less than (<) and greater than (>) symbols indicate the direction of the difference between the groups indicated in that column. For example, a "<" symbol for nitrite under the G:S column means that the mean of the ranks of dissolved nitrite concentrations was significantly lower in water from the surficial aquifer system (sites 1-8) than in runoff to the swale. If no symbol is shown, the test result indicated no significant difference.

| Dissolved constituent<br>or physical measure | Significant<br>difference | p-value            | Multiple comparison test results |     |     |
|--|---------------------------|--------------------|----------------------------------|-----|-----|
|  |                           |                    | G:S                              | G:C | S:C |
| Turbidity                                    | No                        | 0.4543             |                                  |     |     |
| Color  | No                        | .1648              |                                  |     |     |
| Specific conductance                         | No                        | .1288              |                                  |     |     |
| pH – field                                   | No                        | .0676              |                                  |     |     |
| pH – lab                                     | Yes                       | <sup>1</sup> .0259 |                                  |     |     |
| Ammonia                                      | No                        | .1433              |                                  |     |     |
| Nitrite                                      | Yes                       | .0002              | <                                |     | >   |
| Ammonia plus organic nitrogen                | No                        | .2189              |                                  |     |     |
| Nitrite plus nitrate nitrogen                | No                        | .2196              |                                  |     |     |
| Phosphorus                                   | No                        | .0752              |                                  |     |     |
| Orthophosphorus                              | No                        | .2926              |                                  |     |     |
| Total organic carbon                         | No                        | .2356              |                                  |     |     |
| Calcium                                      | No                        | .1766              |                                  |     |     |
| Magnesium                                    | Yes                       | .0367              |                                  |     | <   |
| Sodium                                       | No                        | .3061              |                                  |     |     |
| Potassium                                    | No                        | .0792              |                                  |     |     |
| Chloride                                     | No                        | .2423              |                                  |     |     |
| Sulfate                                      | No                        | .8472              |                                  |     |     |
| Alkalinity                                   | Yes                       | <sup>1</sup> .0234 |                                  |     |     |
| Aluminum                                     | No                        | .2092              |                                  |     |     |
| Chromium                                     | No                        | .5079              |                                  |     |     |
| Copper                                       | No                        | .8113              |                                  |     |     |
| Iron   | Yes                       | .0599              |                                  | <   |     |
| Lead   | No                        | .7344              |                                  |     |     |
| Nickel                                       | No                        | .0512              |                                  |     |     |
| Zinc   | No                        | .2783              |                                  |     |     |

<sup>1</sup>Although ANOVA results indicate a significant difference among data types, TUKEY's multiple comparison test resulted in no significant differences between any two data types, at a significance of 0.05.

Table 19. — *Values of selected nutrients and minor elements in sediments at two swale study areas*

[Nutrients are in milligrams per kilogram; minor elements are in micrograms per gram. Sample interval, in inches below land surface, indicated in parentheses]

| Constituents                         | Princeton Street swale |       |         |       | Longwood swale |       |        |       |
|--------------------------------------|------------------------|-------|---------|-------|----------------|-------|--------|-------|
|                                      | Site 11                |       | Site 12 |       | Site 6         |       | Site 7 |       |
|                                      | (0-2)                  | (4-6) | (0-2)   | (4-6) | (0-2)          | (4-6) | (0-2)  | (4-6) |
| <b>Nutrients:</b>                    |                        |       |         |       |                |       |        |       |
| Nitrogen, ammonia, as N              | 31                     | 8.5   | 6.6     | 6.3   | 21             | 9.7   | 6.7    | 4.4   |
| Nitrogen, ammonia plus organic, as N | 2,600                  | 1,900 | 1,200   | 310   | 5,700          | 1,000 | 900    | 220   |
| Nitrogen, nitrite plus nitrate, as N | < 4                    | < 4   | < 4     | < 4   | 33             | 9     | < 4    | < 4   |
| Phosphorus, as P                     | 1,100                  | 260   | 650     | 1,100 | 300            | 290   | 45     | 190   |
| <b>Minor elements:</b>               |                        |       |         |       |                |       |        |       |
| Cadmium                              | 1                      | < 1   | < 1     | < 1   | 1              | 1     | < 1    | < 1   |
| Chromium                             | 90                     | 90    | 40      | 30    | 130            | 90    | 20     | 20    |
| Cobalt                               | < 10                   | < 10  | < 10    | < 10  | < 10           | < 10  | < 10   | < 10  |
| Copper                               | 90                     | 110   | 50      | 20    | 120            | 150   | 30     | 40    |
| Iron                                 | 660                    | 590   | 330     | 410   | 1,800          | 1,900 | 130    | 370   |
| Lead                                 | 440                    | 130   | 130     | 10    | 450            | 40    | 40     | < 10  |
| Zinc                                 | 120                    | 40    | 40      | < 10  | 130            | 20    | 10     | < 10  |

concentration in the 4- to 6-inch sample at site 12, Princeton Street swale, and the same interval at site 7, Longwood swale. Phosphorus concentrations in the sediments do not show the same rate of reduction with depth as organic nitrogen (most of the nitrogen in the sediments is organic).

Concentrations of metals in sediments at the two swales are similar with the exception of iron, which is almost three times higher in the sediment near the road (site 6) at the Longwood swale than at site 11, Princeton Street swale (1,800  $\mu\text{g/g}$  (micrograms per gram) compared to 660  $\mu\text{g/g}$ , respectively). Concentrations of lead in these sediments are much higher than zinc, the reverse of the pattern observed in the ground water. For example, at site 11, Princeton Street swale, the concentration of lead in the top 2 inches of soil is 440  $\mu\text{g/g}$ , but zinc is only 120  $\mu\text{g/g}$ . These numbers are very close to the concentrations measured in the top 2 inches at site 6, Longwood swale--450  $\mu\text{g/g}$  lead and 130  $\mu\text{g/g}$

zinc. This may be because of the low solubility of lead relative to that of zinc.

The results from this limited sampling of sediments at both swales agree with results from other research--that constituent concentrations decrease with distance from the highway and with depth in the soils. Lagerwerff and Specht (1970) sampled soil and vegetation at four heavily traveled highway sites, as a function of depth and distance from the roadway, and reported that cadmium, nickel, lead, and zinc all decreased with distance from the road and with depth in the soil profile. Concentrations reported in the top 5 centimeters (or roughly 2 inches, as in this study), for two roadway sites in Maryland were about the same or slightly higher than those found for the two swales in this study. The other two roadways studied by Lagerwerff and Specht (1970) had lower concentrations in the top 5 centimeters (8 meters, or 26 feet, from the road) than those found for this study.

## COMPARISON AMONG DETENTION METHODS

One of the primary purposes of this study was to determine the effect on receiving ground-water quality caused by three runoff-detention methods. The three methods, also referred to here as structures, are exfiltration pipes, detention or retention ponds, and swales. Study areas included one exfiltration pipe, two ponds, and two swales. From the data collected at the five locations for the three structure types, it was desired to determine whether any one of the three methods of runoff detention affected ground water more than the other two.

The depth to the water-table varied among locations. The largest water table fluctuation (1.1 feet to 10.9 feet below land surface) occurred at the Longwood retention pond. Water-table fluctuations at the other sites were 2 to 5 feet during the study. The water table at the Silver Star Road detention pond was nearest the land surface of all the study locations, ranging from 0.8 feet to 2.3 feet below land surface. The larger depths to the water table at the other sites (over 10 feet) provided a thicker unsaturated zone through which soil processes might act to attenuate constituents before reaching the receiving ground water. Soils at all locations are similar.

Removal of constituents by settling occurs in all of the structures, but the greatest amount of settling probably occurs in ponds. Vegetative uptake and bacterial action in ponds and swales also contribute to the reduction of constituents. Of the three structures studied, exfiltration pipes probably provide the least amount of preliminary treatment (settling) of runoff prior to entering the subsurface system.

The effect on ground-water quality that any of these structures might have depends on numerous variables, such as the age of the structure, soil type, drainage basin area and percent impervious surface area relative to the structure size, traffic volume, age of the roadway, and other factors. A comparison of the quality of ground water based on structure type is by its nature a rough estimate, and the other factors involved should be considered when interpreting the results.

## Statistical Comparisons

Ground-water quality data for each structure type (pond, swale, pipe) were pooled, excluding control sites, unsaturated zone sites, and site 8 (intermediate aquifer) at the Longwood pond. The same statistical methods used earlier (analysis of variance and multiple comparisons, based on rank values) were again used. The statistical tests were used to detect possible higher values of some constituents in ground water near a particular structure type.

The analysis of variance test resulted in significant differences in mean concentrations among the three structure types for most of the 26 water-quality variables tested. Those variables not significantly different among the structure types are nitrite nitrogen, nickel, aluminum, chromium, copper, lead, and zinc (table 20). Only differences that were significant at the 0.05 level of confidence are discussed here.

Of the physical measurements, turbidity and color are significantly higher in ground water in the vicinity of the ponds, and specific conductance and pH are lowest beneath the swales.

Nitrogen species dominance differs by structure type. Mean concentrations of Kjeldahl nitrogen are significantly higher in ground water near ponds than beneath swales, and nitrite plus nitrate nitrogen is significantly higher in ground water beneath swales and near the exfiltration pipe than near ponds. Although the multiple comparison results indicate that nitrite plus nitrate nitrogen concentrations are lowest in ground water near ponds, the median concentration in ground water beneath the Longwood pond (0.33 mg/L) is five times greater than in ground water near the Silver Star Road pond (0.06 mg/L); this median concentration in ground water beneath the Longwood pond is similar to those concentrations found in ground water near the swales and exfiltration pipe. Although Kjeldahl nitrogen is the predominant species of nitrogen in ground water at both ponds, it is only slightly greater than the nitrite plus nitrate fraction at the Longwood pond. The low nitrite plus nitrate nitrogen concentration in ground water near the Silver Star Road pond may be due to the low concentrations in

Table 20. — *Results of analysis of variance of rank data and multiple comparison test (TUKEY) for data grouped by structure*

[Control well sites are not included]

An "x" in a column means that a significant difference was indicated between the means of the rank values of the groups indicated at the top of the column. For example, the mean of the ranks of turbidity measurements were significantly greater in water from the surficial aquifer system in the vicinity of ponds than beneath swales. A blank denotes no significant difference was indicated ]

| Constituent or physical property | Significant differences in mean concentrations between ground water at structures (based on rank values) |                |              |              |               |               |
|----------------------------------|--|----------------|--------------|--------------|---------------|---------------|
|                                  | Pond > Swales  | Swales > Ponds | Ponds > Pipe | Pipe > Ponds | Swales > Pipe | Pipe > Swales |
| Turbidity                        | x  |                | x            |              |               |               |
| Color                            | x  |                | x            |              |               |               |
| Specific conductance             | x  |                |              |              |               | x             |
| Field pH                         | x  |                |              |              |               | x             |
| Lab pH                           | x  |                |              |              |               | x             |
| Nitrogen species:                |  |                |              |              |               |               |
| Ammonia                          | x  |                | x            |              |               |               |
| Nitrite                          |  |                |              |              |               |               |
| Ammonia plus organic             | x  |                | x            |              |               |               |
| Nitrite plus nitrate             |  | x              |              | x            |               |               |
| Phosphorus                       |  | x              |              | x            |               | x             |
| Orthophosphorus                  |  | x              |              | x            |               | x             |
| Total organic carbon             | x  |                |              |              |               | x             |
| Calcium                          | x  |                |              |              |               | x             |
| Magnesium                        |  |                |              |              | x             |               |
| Sodium                           |  | x              |              | x            |               |               |
| Potassium                        |  |                |              |              |               | x             |
| Chloride                         |  | x              |              | x            | x             |               |
| Sulfate                          |  |                |              |              |               | x             |
| Alkalinity                       | x  |                |              |              |               | x             |
| Aluminum                         |  |                |              |              |               |               |
| Chromium                         |  |                |              |              |               |               |
| Copper                           |  |                |              |              |               |               |
| Iron                             |  |                | x            |              | x             |               |
| Lead                             |  |                |              |              |               |               |
| Nickel                           |  |                |              |              |               |               |
| Zinc                             |  |                |              |              |               |               |
| Totals                           | 10   | 5              | 5            | 5            | 3             | 10            |

stormwater entering the pond (median dissolved concentration is 0.10 mg/L) and to anaerobic conditions in the pond.

Phosphorus and orthophosphorus concentrations are significantly higher in ground water near the exfiltration pipe than in ground water near swales, and concentrations are greater near swales than near ponds. The low phosphorus concentrations in ground water near the Silver Star Road pond is due in part to the low concentrations in stormwater entering the pond. Phosphorus concentrations in stormwater entering the Longwood pond are higher than at the Silver Star Road pond, so the low concentrations in ground water beneath the Longwood pond may be due to vegetative or biological uptake of phosphorus in the pond before infiltration.

Calcium is the predominant major ion in ground water near ponds and the exfiltration pipe. Sodium is significantly higher in ground water near the swales and the exfiltration pipe than near the ponds, and potassium is highest (significant difference) in ground water near the exfiltration pipe. Of the anions measured, chloride is highest and alkalinity is lowest in ground water below the swales. Sulfate is highest in ground water at the exfiltration pipe. The significance of these results is, at present, unknown.

Iron is the only metal that was significantly different in ground water among the three structure types. Iron in ground water near the exfiltration pipe is lower than in ground water near the other two structure types. High iron concentrations were measured in ground water at the Longwood swale (median is 815  $\mu\text{g/L}$ ) and the Silver Star Road pond (median is 1,700  $\mu\text{g/L}$ ). The iron concentrations probably are due to the surrounding native soils and are not a result of structure type. Other metals, such as chromium and copper, frequently were less than detection levels (1  $\mu\text{g/L}$ ), with the exception of one value of 30  $\mu\text{g/L}$  in water from a well at the Princeton swale. Lead also was typically less than detection levels.

Significant differences in ground-water quality data were detected most frequently between swales and the other structure types. These statistical results imply that generally, values of water-quality variables tend to be lowest beneath swales. The predominant form of nitrogen in ground water near swales and the exfiltration pipe is nitrate nitrogen, whereas organic nitrogen

predominates in ground water near the detention and retention ponds. However, organic nitrogen is only slightly higher than nitrate nitrogen in ground water beneath the Longwood pond.

Highest phosphorus and orthophosphorus concentrations were detected in ground water near the exfiltration pipe, and lowest values were detected in ground water beneath the Longwood pond. The uptake of phosphorus at the Longwood pond may be the reason for the lower concentrations found in ground water beneath the pond, and the higher concentrations found in the unsaturated and saturated zones at the Washington Street study area may be due to the dissolution of phosphorus to the dissolved state as the stormwater exfiltrates, or to nonnative backfill in the vicinity of the pipe. Highest chloride, but lowest alkalinity values were detected in ground water beneath swales. Potassium and sulfate concentrations are highest in ground water near the exfiltration pipe.

The significant difference in iron concentrations in ground water at different structure locations likely is due to native materials and not to infiltration of highway runoff. Other metals measured in ground water near structures do not seem to be a problem because nearly all concentrations are below the detection level of the analytical laboratory tests.

### **Comparison to State Water-Quality Standards**

Constituent concentrations obtained from this study were compared to Florida Department of Environmental Regulation drinking water standards (Florida Department of Environmental Regulation, 1982). Although standards for drinking water are not available for all the constituents in this study, and do not actually apply to the surficial aquifer system, they are more applicable than surface-water standards (Class III, recreation, propagation and management of fish and wildlife) that take into account the effect of water quality on fish. With a few exceptions, most notably iron, constituent concentrations in ground water near the structures studied are well within the drinking water standards.

The limit for nitrate nitrogen in drinking water is 10 mg/L; this value was exceeded in only one sample collected from the unsaturated zone at the Washington Street study area (exfiltration

pipe). Drinking water standards indicate a minimum pH value of 6.5 must be maintained for a water supply, with no set maximum. The pH values in ground water near the Longwood pond and the exfiltration pipe were within this standard, but the pH in ground water beneath the swales and near the Silver Star Road pond were frequently more acidic than 6.5. Chloride and sulfate concentrations were always less than 75 mg/L, well below the standard of 250 mg/L.

Chromium and lead each have limits in drinking water supplies of 50  $\mu\text{g/L}$ . The maximum chromium concentration measured in this study was 30  $\mu\text{g/L}$ , in ground water from site 6, Princeton Street swale, and the maximum lead value was also 30  $\mu\text{g/L}$ , measured in water at site 5, in the unsaturated zone at the Washington Street exfiltration pipe. The standard for copper, 1,000  $\mu\text{g/L}$ , was never exceeded in any sample. The highest copper values detected were in the unsaturated zone at Washington Street: 80  $\mu\text{g/L}$  (site 5) and 90  $\mu\text{g/L}$  (site 7). The standard for zinc in drinking water is 1,000  $\mu\text{g/L}$ , and this value was never exceeded in samples from this study. The maximum zinc concentration measured was 220  $\mu\text{g/L}$ , site 1, Silver Star Road pond. No standards are available for nickel in drinking water, but the standard for Class III waters is 100  $\mu\text{g/L}$ , and the maximum value measured during the study was 85  $\mu\text{g/L}$  (site 5, Silver Star Road pond). Nickel concentrations at other study areas were always less than 10  $\mu\text{g/L}$ .

The standard for iron in drinking water is 300  $\mu\text{g/L}$ , which commonly was exceeded in ground water near structures in this study. Iron concentrations in ground water are highest at the Silver Star Road pond, but these high values probably are not due primarily to the effects of highway runoff, particularly in view of the low concentrations of other constituents detected during the study.

## SUMMARY AND CONCLUSIONS

Ground-water quality was sampled at five study areas representing three highway-runoff detention methods to detect any effects from infiltrating runoff. All five study locations were in central Florida and included one exfiltration pipe, two ponds, and two swales. Water-quality variables measured primarily were inorganic constituents, but water from selected wells were sampled for qualitative analysis of organic compounds. Sediment samples were collected at

all sites, and nutrient and metal concentrations in the sediments were measured. Priority pollutants were measured in sediments from one pond study area.

At each study area, a control well site was established for comparative purposes. Variability in the quality of ground water was analyzed statistically at each study area, between study areas for similar structures, and among unlike structures. Values of water quality variables obtained from the study were compared to drinking water standards.

Data were compared by structure type to determine any discernible differences between the different runoff-detention methods. Analysis of variance of ranks of pooled ground-water quality data (grouped by type of structure) excluded control sites and unsaturated zone sites. Significant differences were indicated for most water-quality variables at a significance level of 0.05.

Turbidity and color are significantly higher in ground water near ponds, and specific conductance and pH are lower in ground water below swales than near ponds or near the exfiltration pipe. Nitrate nitrogen, the most mobile of the nitrogen species in ground water, is significantly higher in ground water beneath the swales and the exfiltration pipe than near the ponds, and Kjeldahl nitrogen is highest near the ponds. Phosphorus (and orthophosphorus) concentrations are significantly higher in ground water near the exfiltration pipe than beneath swales and near ponds.

Concentrations of major ions in ground water differ among all three structure types and include calcium, sodium, potassium, chloride, and alkalinity (bicarbonate ion). Of the metals, only iron is significantly higher in ground water beneath swales and near ponds than near the exfiltration pipe, most likely because of the high iron concentrations measured in ground water at the Silver Star Road pond and the Longwood swale. Chromium, copper, and lead frequently were below detection levels, and no significant differences were detected in concentrations of any other metals, including zinc.

Values of water-quality variables measured in ground water for this study, with very few exceptions, were within drinking water standards. At both swale locations and at the Silver Star Road detention pond, the pH of ground water

frequently was lower than the minimum standard for drinking water (6.5), and the standard for iron, 300  $\mu\text{g/L}$ , was frequently exceeded, particularly in ground water at the Longwood swale and Silver Star Road pond. However, the high iron values are not completely attributable to highway runoff.

Results of this study indicate that natural processes occurring in soils do much to attenuate constituents prior to reaching the receiving ground water. Results from sampling unsaturated-zone water near the exfiltration pipe indicate that higher concentrations are present above the water table than in the saturated zone; this indicates a need to monitor the unsaturated zone at other locations to detect any migration of constituents from infiltrating runoff early enough for remedial measures. Where land is available, retention ponds are useful for attenuation of constituents through

physical, chemical, and biological processes prior to entering the subsurface system. Swales and exfiltration pipes do not provide as much pretreatment (settling) as a retention pond. However, the distance to water, and type of soils available are two critical factors to the success of a runoff detention structure in the attenuation of loads to ground-water resources.

Organic compounds detected in sediments at the Longwood retention pond indicate a potential problem that is a relatively new area of research in runoff studies. The detection of organic compounds in water from the unsaturated and saturated zones is difficult, particularly in the case of volatile organic compounds, but these may present a much greater potential problem to ground-water resources than the inorganic constituents that have been the focus of this and many earlier runoff studies.

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