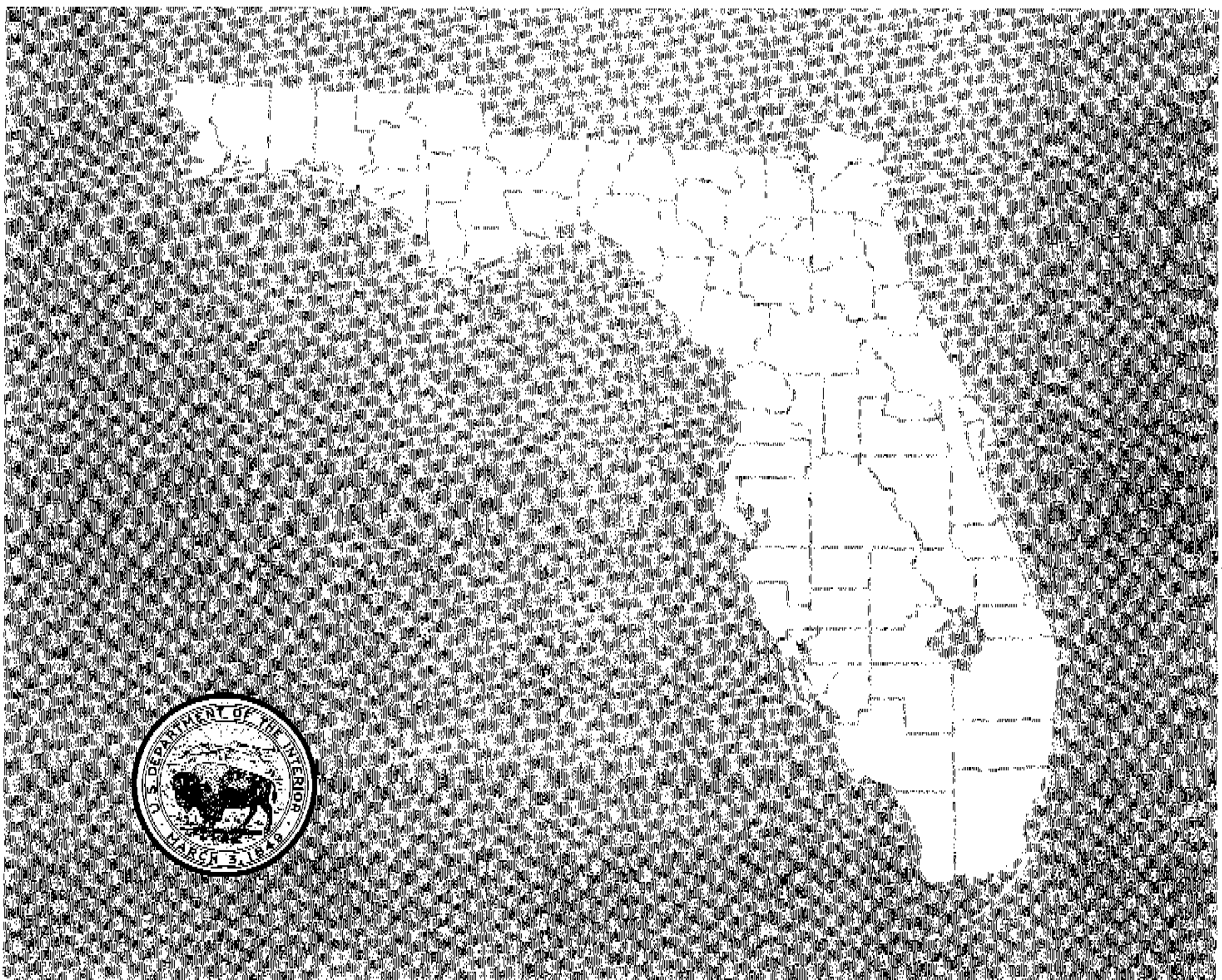
EFFECTS OF TWO STORMWATER MANAGEMENT METHODS ON THE QUALITY OF WATER IN THE UPPER BISCAYNE AQUIFER AT TWO COMMERCIAL AREAS IN DADE COUNTY, FLORIDA

U.S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS REPORT 88-4069

Prepared in cooperation with the

SOUTH FLORIDA WATER MANAGEMENT DISTRICT



ABBREVIATIONS AND CONVERSION FACTORS

For use of readers who prefer to use metric (International System) units, conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
acre	0.4047	hectare (ha)

ADDITIONAL ABBREVIATIONS

µg/L = micrograms per liter
mg/L = milligrams per liter
µS/cm = microsiemens per centimeter
ANOVA = analysis of variance
COD = chemical oxygen demand
Kjel-N = Kjeldahl nitrogen
NH_4-N = ammonia nitrogen
NO_3-N = nitrate
ortho-P = orthophosphate
Pt-Co = platinum-cobalt
p-values = probability values
TOC = total organic carbon
tot-P = total phosphorus

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Tallahassee, Florida

1988

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ABSTRACT

This study is part of a continued effort to assess the effects of urban stormwater recharge on the water quality of the Biscayne aquifer in southeast Florida. In this report, the water-quality effects on shallow ground water resulting from stormwater disposal by exfiltration trench and grassy swale were investigated at two small commercial areas in Dade County, Florida. One study area (airport) was located near the Miami International Airport and had a drainage area of about 10 acres overlying a sandy soil; the other study area (free zone) was located at the Miami International Free Trade Zone and had a drainage area of about 20 acres overlying limestone. The monitoring design for each study area consisted of seven sites and included water-quality sampling of the stormwater in the catch basin of the exfiltration trench, ground water from two wells 1 foot from the trench (trench wells), two wells 20 feet from the trench, and ground water from two wells at the swale from April 1985 through May 1986. Eleven water-quality variables (target variables) commonly found in high levels in urban stormwater runoff were used as tracers to estimate possible changes in ground-water quality that may have been caused by stormwater recharge.

Comparison of the distribution of target variables indicated that the concentrations tended to be greater in the stormwater in the exfiltration trench than in water from the two wells 1 foot from the trench at both study areas. The concentration difference for several target variables was statistically significant at the 5-percent level. Lead, for example, had median concentrations of 23 and 4 micrograms per liter, respectively, in stormwater and water from the two trench wells at the airport study area, and 38 and 2 micrograms per liter, respectively, in stormwater and ground water at the free zone. Similar reductions in concentrations between stormwater and water from the two trench wells were indicated for zinc at both study areas and also for nitrogen, phosphorus, and organic content at the free zone. This trend suggested that the exfiltration trench at both study areas may function as a partial trap for some chemical substances present in stormwater.

A comparison of the distribution of the 11 target variables and major ionic composition in water from the two trench wells and the two wells 20 feet from the trench did not indicate a notable horizontal stratification at either study area. A vertical difference between 10 and 15 feet, however, was indicated at the free zone with major ions in greater concentrations at 15 feet. The vertical variability in ground water near the trench at the free zone may have been the result of stormwater dilution in the upper (10-foot) zone.

The ground-water quality at the swale was quite dissimilar to that near the exfiltration trench at both the airport and free zone study areas. Data indicated that the ground-water environment at both swales was anaerobic as evidenced by abundant ammonia nitrogen and iron and trace levels of sulfate. Anaerobic conditions at the swale may have been the result of poor drainage and high organic content of soils. Significant biochemical cycling in the ground water at the swales precluded any assessment of quality effects that may result from stormwater infiltration.

INTRODUCTION

Water-quality management of urban stormwater by some method of detention or retention prior to discharge to State waters is required by the State of Florida under rules of the Florida Department of Environmental Regulation (FDER) (Florida Department of Environmental Regulation, 1982). The FDER has delegated the responsibility of stormwater management in the south Florida area to the South Florida Water Management District (SFWMD). The general protocol used by SFWMD for the management of stormwater runoff from a developed project is detention of either the first inch of or the total runoff from a 3-year, 1-hour rainfall event, whichever is greater (Cullum, 1984, p. 4).

Some of the management methods commonly used to abate stormwater transport of potential pollutants to State waters are surface detention or retention basins, or grassy swales (Yousef and others, 1985, p. 3). The subsurface exfiltration trench (French drain) is another method of stormwater management commonly used in south Florida. Exfiltration trenches in south Florida are usually constructed near or beneath the water table to induce artificial recharge (exfiltration) of stormwater. Some exfiltration trenches are designed to accept (retain) all stormwater from a drainage basin with no outflow other than recharge; others are designed to detain the first inch of stormwater before overflow begins by means of a discharge pipe.

Implicit in this management philosophy is that detention of stormwater will improve its quality; however, the degree of water-quality improvement achieved by the various detention methods and the ultimate environmental benefit to State receiving waters is not well documented (Yousef and others, 1985, p. 3). Literature is beginning to accrue on stormwater management and surface-water quality. Yet, little is known regarding the effects of stormwater recharge on the quality of shallow aquifers.

Potential contamination of the shallow Biscayne aquifer is particularly important because it is the major source of drinking water in southeast Florida. Because of concerns about the lack of scientific information on the possible effects on the quality of the shallow Biscayne aquifer resulting from current stormwater management practices, the South Florida Water Management District and the U.S. Geological Survey entered into a cooperative hydrologic study of two small commercial areas in Dade County. Both study areas included exfiltration trench and swale methods of stormwater disposal. One study area was located where the lithology is predominantly sand and the other area where the lithology is predominantly limestone.

This report describes the quality of stormwater and ground water at the two study areas and generally assesses, where possible, the effects of stormwater disposal on the shallow ground water. Data for the study were collected from April 1985 through May 1986. The experimental design of this study was limited in some aspects and the results do not represent a thorough documentation of stormwater effects on shallow ground water. The results of this study are only intended to supplement ongoing SFWMD studies of stormwater management.

DESCRIPTION OF THE TWO STUDY AREAS

One study area was located at an airport employees' parking lot, east of the Miami International Airport in east-central Dade County (fig. 1). This area is referred to as the airport throughout the report. The second study area is located west of the airport at the Miami International Free Trade Zone, a commercial complex of warehouses and businesses for transshipping international products. This area is referred to as the free zone throughout the report. A description of the monitoring sites at both study areas is listed in table 1.

Table 1.—Description of monitoring sites at the airport and free zone study areas

Site number		Source	Location	Well depth, in feet
Airport	Free Zone			
1	8	Stormwater	Exfiltration trench catch basin.	--
2	9	Ground water	Well 1 foot from exfiltration trench perimeter	10
3	10	Ground water	Well 1 foot from exfiltration trench perimeter	15
4	11	Ground water	Well 20 feet from exfiltration trench perimeter	10
5	12	Ground water	Well 20 feet from exfiltration trench perimeter	15
6	13	Ground water	Well in grassy swale	10
7	14	Ground water	Well in grassy swale	15

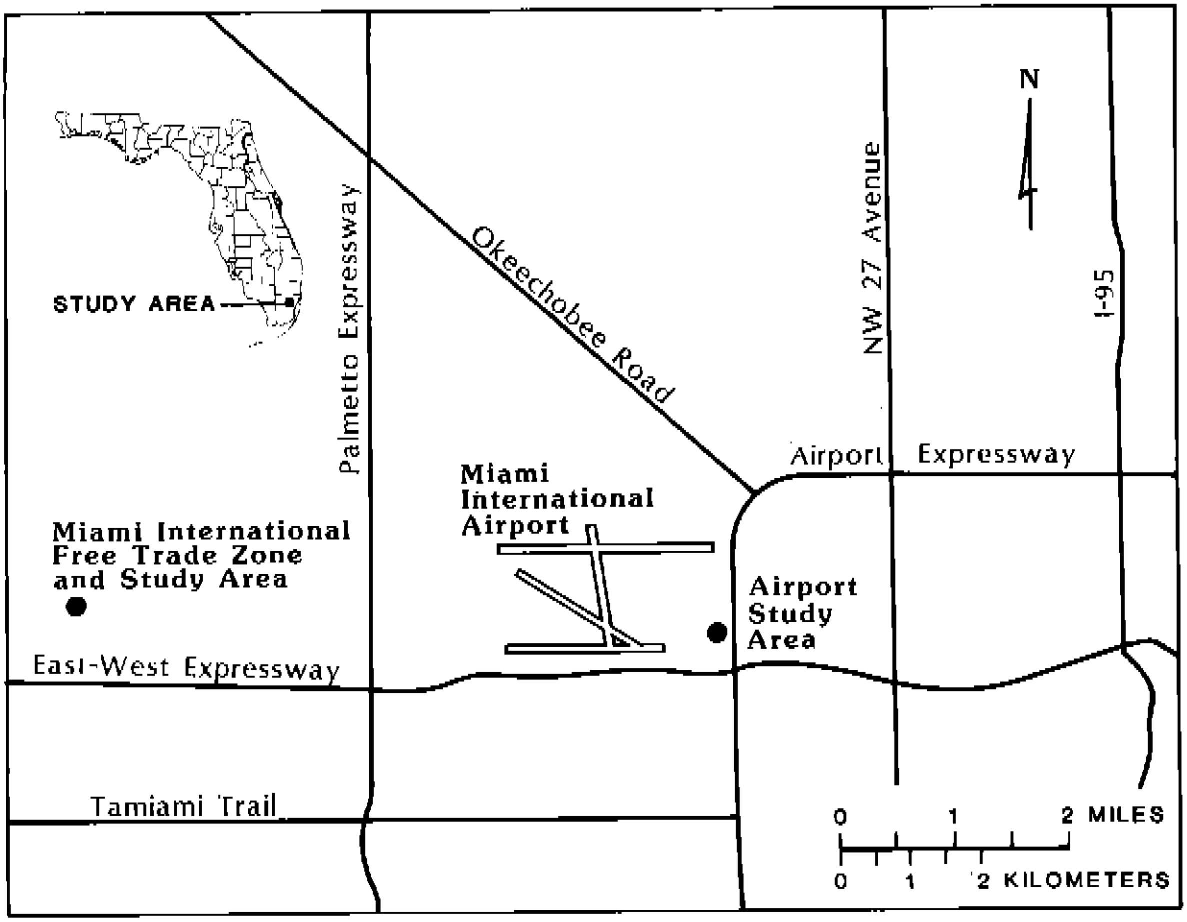

Figure 1.—Locations of the two study areas in east-central Dade County.

The airport study area receives drainage from a 10-acre, asphalt-covered parking lot with its exfiltration trench network in a predominantly sandy soil (fig. 2a). This network is designed for stormwater retention with no outflow pipe. The contributing area of the parking lot discharging stormwater to the exfiltration-trench catch basin (site 1) was estimated to be about 8 acres. The contributing area of stormwater to the swale where ground-water monitoring sites 6 and 7 were located was about 2 acres that included parts of the parking lot east of the exfiltration trench monitoring site and N.W. 14th Street. The capacity of the parking lot was about 1,000 vehicles.

The free zone study area receives drainage from a 20-acre, asphalt-covered parking lot with its exfiltration trench network in predominantly limestone rock (fig. 2b). The exfiltration trench network outflow is to the Northline Canal adjacent to N.W. 25th Street. The contributing area of stormwater to the exfiltration trench catch basin (site 8) was estimated to be about 10 acres of the southern part of the parking lot. The contributing area of stormwater to the swale where ground-water monitoring sites 13 and 14 were located was estimated to be about 10 acres of the northern half of the parking lot. The capacity of the parking lot was several hundred vehicles.

GENERAL DESCRIPTION OF STORMWATER MANAGEMENT METHODS

Exfiltration-Trench Disposal System

A schematic section of a typical exfiltration trench is shown in figure 3. The catch basin is the point of entry of stormwater into the system. The exfiltration trench may be a single unit or connected to other catch basins to form a drainage network. The catch basin of the exfiltration trench functions as an initial sediment trap. A perforated pipe, generally 36 inches in diameter, that extends longitudinally within the trench from the catch basin, functions as an exfiltration

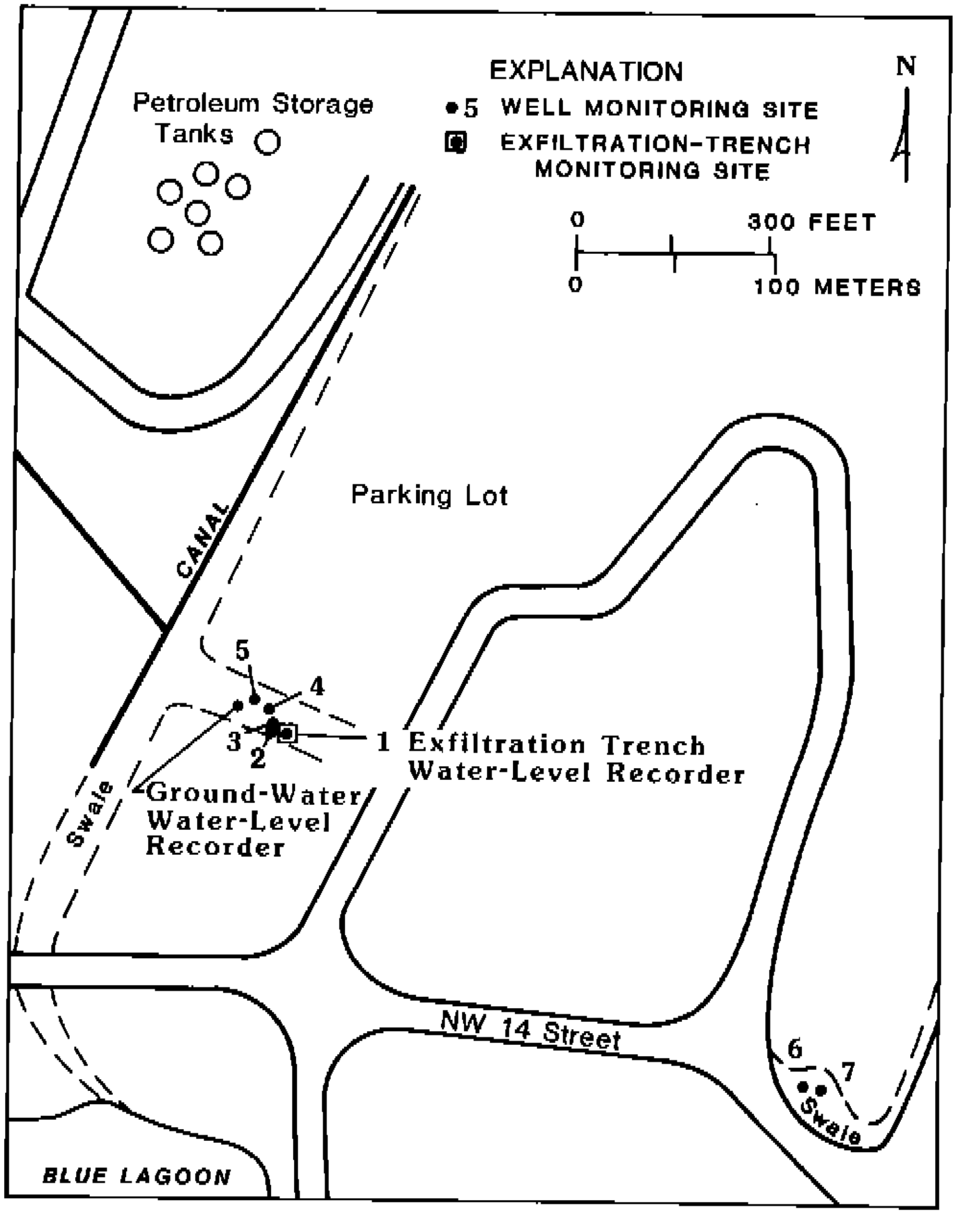

Figure 2a. – Study area near Miami International Airport.

(recharge) conduit for the stormwater and provides a secondary sediment trap. A coarse rock aggregate between the pipe and the trench wall prevents side wall collapse and plugging of pipe perforations and serves as a conveyance to distribute exfiltrated stormwater to the trench walls.

The trench is about 5 to 6 feet in width with the base typically 2.5 feet beneath the water table. A polyfilter is used along the periphery of the trench to deter filling in of the voids in the coarse aggregate by fine soils during reverse flow conditions that result from high ground-water levels. The

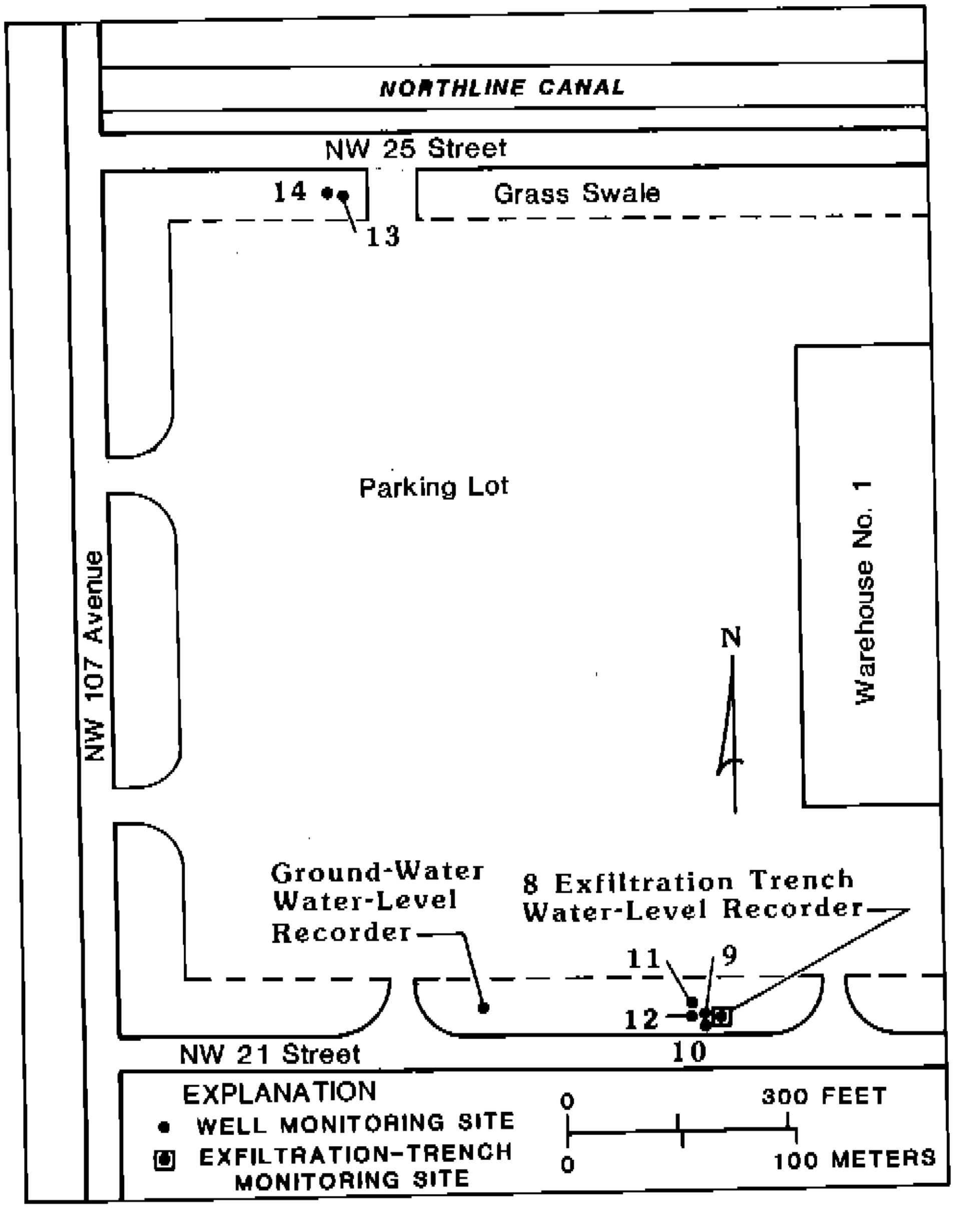

Figure 2b. – Study area at the Miami International Free Trade Zone.

polyfilter also filters fine materials suspended in stormwater to prevent clogging of native soil, which would reduce its infiltration capacity. A 6-inch thickness of filter material, such as pea gravel, is used over the coarse rock and covered with builder's felt to prevent vertical infiltration of silts and sediment and to prevent subsidence. The trench area is then backfilled with native soil. A positive overflow pipe sometimes drains to a canal or lake. Specific design specifications for exfiltration trenches may be found in the U.S. Department of Transportation's "Design Guidelines Manual" (Hannon, 1980).

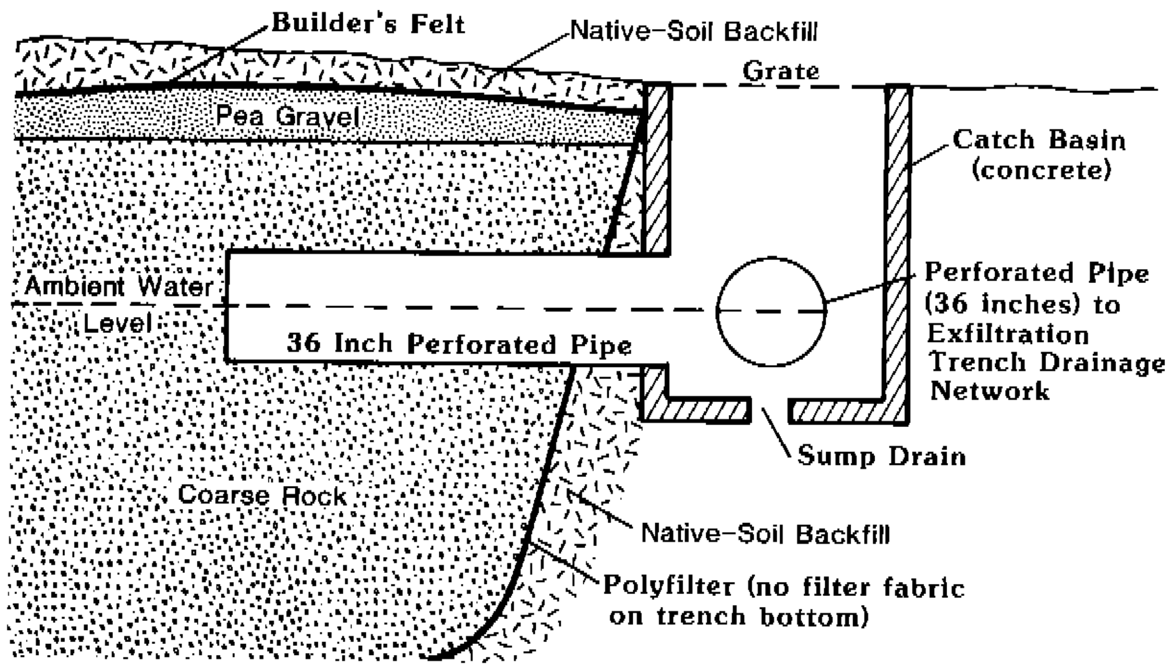

Figure 3. – Schematic section of a typical exfiltration trench.

Swale Disposal System

Swales are shallow, depressed areas with shallow-sided slopes that are generally vegetated, and are used to drain and infiltrate stormwater runoff. Swales were first used to reduce peak discharges by functioning as equalization basins, and through the concept of pooling water, were more recently designed to reduce velocities and increase rates of sedimentation and infiltration (Wanielista and others, 1987, p. 1). Currently in Florida, swales are intended for water-quality control and are usually designed to detain the stormwater runoff from the 3-year frequency, 1-hour duration rainfall event (Wanielista and others, 1987, p. 1).

DATA COLLECTION

The monitoring wells at both study areas were drilled using ambient ground water for drilling fluids. Polyvinyl casing was seated in the borehole and the annular space grouted, leaving the bottom of the well open. The wells were finished at ground level. At each study area, a cluster of two wells (trench wells) was placed about 1 foot outside the trench perimeter at depths of 10 feet (approximately the bottom of the trench) and 15 feet and a second cluster of two wells, at depths of 10 feet and 15 feet, was placed about 20 feet from the exfiltration trench. This well configuration was used to estimate horizontal and vertical variation of water quality within the immediate zone of stormwater exfiltration. Two water-level recorders were installed in each study area, one in the catch basin to measure the water levels in the exfiltration trench and one outside the trench to measure ground-water levels. An automatic recording rain gage installed at each site was used in conjunction with the water-level recorders to measure the amount of rainfall for sampling events, the storm duration, and the duration of antecedent dry-day periods. A summary of hydrologic conditions during storm sampling is given in table 2.

Table 2. – Summary of hydrologic conditions for the storm sampling at the airport and free zone study areas

[Trench water level is average water level in exfiltration trench monitoring wells (sites 2–5 and 9–12); swale water level is average water level in swale monitoring wells (sites 6–7 and 13–14)]

Date	Rain-fall, in inches	Time of rainfall, in hours	Time sampled, in hours	Antecedent dry days	Monitoring well water levels, in feet above sea level	
					Trench	Swale
			Airport			
05/25/85	1.73	1515–1700	1700–1810	27	2.46	2.44
06/12/85	.24	1330–1335	1700–1900	18	2.45	2.44
[1]02/19/86	.87	1900–2300	1100–1300	11	2.62	2.62
04/13/86	.49	0400–0700	0900–1200	12	2.71	2.70
05/05/86	.50	0430–1410	1700–1930	22	2.70	2.69
			Free zone			
04/29/85	0.50	1130–1145	2100–2200	14	–	–
05/25/85	1.50	1400–1500	1500	27	2.54	2.55
02/18/86	.85	0700–0900	0900–1100	11	2.82	2.83
04/13/86	.50	0445–0800	0500–0800	12	2.87	2.88
05/04/86	.50	1200–1300	1400–1800	21	2.61	2.60

[1]Storm began February 18 at 1900 and ended February 19 at 2300, sampling was on February 19.

Water-quality sampling at the seven monitoring sites at each study area (table 1) was conducted during five storms (table 2) and one nonstorm period (April 8–9, 1986), from April 1985 through May 1986. The chemical and physical variables measured included those commonly associated with urban runoff. Some sampling for major ionic composition was also done at each monitor site at the airport and free zone study areas. The U.S. Geological Survey National Water Quality Laboratory, in Lakewood, Colo., and the U.S. Geological Survey Water-Quality Service Unit, in Ocala, Fla., provided analytical services for this study. The analytical methods used by the laboratories are described by Skougstad and others (1985).

Monitoring wells were purged using reinforced Tygon[1] hose lowered to the bottom of the well. At least three casing volumes of water were removed with a centrifugal pump prior to sample collection. A Teflon tube attached to a peristaltic pump was used to collect water samples. Stormwater samples were collected using grab-sampling techniques.

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

DATA ANALYSIS

The primary focus of the data analysis was to assess the general water-quality distribution within the shallow ground water in each study area. The major inorganic ions were used to estimate background variability. The occurrence and distribution of selected target water-quality variables were then used to assess possible cause and effect relations between stormwater recharge and the shallow ground water.

Target Variables

Eleven water-quality variables, referred to as target variables in this report, were used as tracers in the attempt to measure possible effects of stormwater in the two study areas. The target variables were selected because they are commonly found in urban stormwater, are environmentally significant, and most are determined with acceptable analytical precision. The 11 target variables comprised 3 general water-quality categories:

1. Kjeldahl nitrogen (Kjel-N), ammonia nitrogen (NH_4-N), nitrate (NO_3-N), orthophosphate (ortho-P), and total phosphorus (tot-P) were used as indicators of primary nutrient material. Concentrations of these variables at levels above natural conditions are commonly associated with man's activities.
2. Iron, lead, and zinc were used as indicators of the magnitude of trace metals. Concentrations of lead and zinc in stormwater above ambient levels often are the result of man's activities and are commonly detected in commercial and industrial urban runoff. Undesirable concentrations of iron are common in urban runoff, but significant quantities are also naturally present in shallow ground water of the Biscayne aquifer.
3. Chemical oxygen demand (COD), total organic carbon (TOC), and color were used as indicators of oxygen demanding material and general organic content. Oxygen demanding material, primarily organic, is often found in urban runoff. Natural organic material is common, however, in water from the Biscayne aquifer.

Statistical Methods

The primary statistical method used was nonparametric analysis of variance (ANOVA). Nonparametric ANOVA procedures use ranks of data (lowest = rank 1, to greatest = rank n). Two-way ANOVA was used to examine water-quality variance by location and depth and one-way ANOVA was used to examine water-quality variance between stormwater and nearby ground water. The null hypothesis used for ANOVA throughout the report was that mean ranks were equal ("no difference"). ANOVA results are summarized by p-values that represent the probability that differences in mean ranks were due to chance. That is, a smaller p-value infers a lower probability that the mean ranks are equal. A p-value equal to or less than 0.05 was used as a basis for rejection of the null hypothesis of equal mean ranks. Similar applications of nonparametric ANOVA in the assessment of water-quality data are described in Helsel (1983) and Helsel and Ragone (1984).

EFFECTS OF STORMWATER MANAGEMENT METHODS ON WATER QUALITY

Airport Study Area

The following discussion of results for this study area is arranged to describe the general geochemical setting, the occurrence and distribution of selected target variables, and the possible effects of stormwater recharge on the quality of shallow ground water. All hydrological and chemical data used for this description and assessment may be obtained in the U.S. Geological Survey Office in Miami, Florida.

Major Inorganic Ions

The predominant water type of samples collected at the seven monitoring sites at the airport study area was calcium bicarbonate. Calcium and bicarbonate accounted for greater than 70 percent, respectively, of the cation and anion milliequivalents. The range in median concentration of dissolved solids (sum of constituents) was 276 (site 2) to 323 mg/L (milligrams per liter) (site 7) among the six ground-water sites and was 316 mg/L in the single stormwater sample (site 1) (table 3). The dissolved solids was about 10 percent greater in ground water at the swale (sites 6

Table 3.—Summary of major inorganic ions at the airport study area

[Dissolved concentrations in milligrams per liter]

Site	Source	Location	Depth, in feet	Major ion	Number of samples	Mean	Standard deviation	Range		Median
1	Stormwater	Exfiltration trench catch basin.	--	Calcium	1	90	--	90		90
				Magnesium	1	5.8	--	5.8		5.8
				Sodium	1	26	--	26		26
				Potassium	1	2.2	--	2.2		2.2
				Chloride	1	41	--	41		41
				Sulfate	1	11	--	11		11
				Bicarbonate	1	280	--	280		280
				Solids, sum of constituents	1	316	--	316		316
2	Ground water	Well 1 foot from exfiltration trench perimeter.	10	Calcium	3	83	4.93	77	86	85
				Magnesium	3	5.3	.17	5.2	5.5	5.2
				Sodium	3	24	.58	24	25	24
				Potassium	3	2.0	.15	1.8	2.1	2.0
				Chloride	3	37	1.15	36	38	38
				Sulfate	3	10	.98	8.3	11	11
				Bicarbonate	3	240	26.46	220	270	230
				Solids, sum of constituents	3	282	14.25	271	298	276
3	Ground water	Well 1 foot from exfiltration trench perimeter.	15	Calcium	3	81	1.15	80	82	82
				Magnesium	3	5.8	.10	5.7	5.9	5.8
				Sodium	3	28	1.15	27	29	27
				Potassium	3	1.8	0	1.8	1.8	1.8
				Chloride	3	41	1.00	40	42	41
				Sulfate	3	8.9	.55	8.5	9.5	8.6
				Bicarbonate	3	243	28.87	210	260	260
				Solids, sum of constituents	3	288	16.58	268	298	297
4	Ground water	Well 20 feet from exfiltration trench perimeter.	10	Calcium	3	84	1.73	82	85	85
				Magnesium	3	5.4	.08	5.4	5.5	5.4
				Sodium	3	25	1.73	24	27	24
				Potassium	3	1.9	.06	1.8	1.9	1.9
				Chloride	3	38	3.21	36	42	37
				Sulfate	3	9.7	.36	9.3	10	9.8
				Bicarbonate	3	260	10.00	250	270	260
				Solids, sum of constituents	3	294	5.14	288	297	297
5	Ground water	Well 20 feet from exfiltration trench perimeter.	15	Calcium	3	84	2.52	81	86	84
				Magnesium	3	5.3	.12	5.2	5.4	5.4
				Sodium	3	25	1.73	24	27	24
				Potassium	3	1.8	.06	1.8	1.9	1.8
				Chloride	3	39	3.06	36	42	38
				Sulfate	3	10	.72	9.6	11	10
				Bicarbonate	3	257	23.09	230	270	270
				Solids, sum of constituents	3	283	10.08	281	301	286
6	Ground water	Well in grassy swale.	10	Calcium	3	96	1.00	95	97	96
				Magnesium	3	5.7	.10	5.6	5.8	5.7
				Sodium	3	23	0	23	23	23
				Potassium	3	1.7	.06	1.7	1.8	1.7
				Chloride	3	35	1.00	34	36	35
				Sulfate	3	.2	.23	.1	.5	.1
				Bicarbonate	3	327	28.87	310	360	310
				Solids, sum of constituents	3	325	14.20	317	341	317
7	Ground water	Well in grassy swale.	15	Calcium	1	98	--	98		98
				Magnesium	1	5.6	--	5.6		5.6
				Sodium	1	23	--	23		23
				Potassium	1	1.7	--	1.7		1.7
				Chloride	1	34	--	34		34
				Sulfate	1	1.0	--	1.0		1.0
				Bicarbonate	1	320	--	320		320
				Solids, sum of constituents	1	323	--	323		323

and 7) than in ground water near the exfiltration trench (sites 2–5). In contrast, little variation in the concentrations of dissolved solids was indicated among samples collected from the four monitor wells (sites 2–5) near the exfiltration trench.

Differences in concentrations of individual ions were indicated among the six ground-water monitoring sites. Particularly notable was the difference in sulfate concentrations in ground water between the four sites (sites 2–5) near the exfiltration trench and the two swale sites (sites 6 and 7). Median concentrations of sulfate in ground water from the trench wells (sites 2 and 3) and from the wells 20 feet from the trench (sites 4 and 5) ranged from 8.6 to 11 mg/L, whereas median sulfate in ground water from the swale wells (sites 6 and 7) ranged from 0.1 to 1.0 mg/L. Median concentrations of calcium and bicarbonate were slightly greater and sodium and chloride were slightly less in ground water at the swale than in ground water near the exfiltration trench.

The distribution of the concentrations of major ions among the ground-water monitoring sites were examined using a two-way nonparametric ANOVA. The purpose of the ANOVA was to determine the probability level that the apparent differences in ion concentrations in ground water by monitoring location and by depth were statistically significant or were primarily attributed to background variability. Analytical data for the first ANOVA were arranged to examine the concentration variance among the general three monitoring locations. That is, the major ion data collected at the ground-water monitoring sites were pooled into three subgroups: the two trench wells (sites 2 and 3); the two wells 20 feet from the trench (sites 4 and 5); and the two wells in the swale (sites 6 and 7). Results of this ANOVA inferred that all of the seven major ions and the dissolved solids were significantly different by subgroup at the 5-percent significance level (table 4). By depth, only magnesium inferred a significant effect.

A second ANOVA was used to examine the concentration variance of the two ground-water subgroups near the exfiltration trench. Results inferred that there were no significant differences in concentrations of major ions between the trench well subgroup (sites 2 and 3) and the subgroup comprising the two wells 20 feet from the exfiltration trench (sites 4 and 5).

Thus, the results of the two ANOVA inferred that the concentration of major ions in samples from the four monitoring wells near the exfiltration trench (sites 2–5) were generally similar, but the concentrations of the major ions in ground water near the exfiltration trench and in the ground water at the swale were statistically different. Most of the major ion differences in ground water between the swale and near the trench were slight except for sulfate. The low concentrations of sulfate in the samples of ground water at the swale (sites 6 and 7), however, suggested biochemical cycling. The possibility of sulfate reduction as a result of anaerobic decomposition of organic matter was generally supported by a significant increase in ammonia nitrogen and iron and is discussed in the following section.

Table 4.—Significance probabilities (p-values) associated with the null hypothesis that the mean ranks of major ions grouped by selected sites and depths at the airport study area are equal

Major ion	ANOVA 1 Trench wells (sites 2 and 3), wells near trench (sites 4 and 5), and swale wells (sites 6 and 7).		ANOVA 2 Trench wells (sites 2 and 3) and wells near trench (sites 4 and 5).	
	Subgroup	Depth	Subgroup	Depth
Calcium	[1]0.0063	0.5560	0.4227	0.4227
Magnesium	[1].0046	[1].0457	.1496	.1243
Sodium	[1].0006	.1047	.2427	.1118
Potassium	[1].0139	.0805	1.000	.0892
Chloride	[1].0117	.3296	.6385	.0892
Sulfate	[1].0013	.4632	.3202	.2291
Bicarbonate	[1].0057	.8832	.2547	.9407
Ion sum	[1].0121	.6865	.5885	.7338

[1]Statistically significant difference at the 5-percent level.

Target Variables

Median color levels at the airport study area ranged from about 30 Pt-Co (platinum-cobalt) units in stormwater from the exfiltration trench (site 1) and in water from the four monitoring wells near the exfiltration trench (sites 2–5) to about 60 Pt-Co units in water from the two monitoring wells at the swale (sites 6 and 7) (table 5). Ammonia concentrations were notably greater in ground water at the swale (sites 6 and 7) than in either the stormwater at the exfiltration trench (site 1) or the ground water near the exfiltration trench (sites 2–5). Median concentrations of ammonia ranged from above 1 mg/L at the swale (sites 6 and 7) to less than 0.15 mg/L near the trench (sites 2–5). Median concentrations of iron were also greater in ground water at the swale (sites 6 and 7), although individual samples of stormwater at the exfiltration trench (site 1) and of water from the 10-foot deep trench well (site 2) had concentrations exceeding 3,000 μg/L (micrograms per liter). Median concentrations of lead and zinc were greater in the stormwater from the exfiltration trench (site 1) than in the ground water of the airport study area. No distribution pattern was indicated for concentrations of phosphorus, chemical oxygen demand, or organic carbon.

Table 5.—Summary of target variables at the airport study area

[Concentrations in milligrams per liter, except as indicated. Pt-Co units, platinum-cobalt units; μg/L, micrograms per liter]

Site	Source	Location	Depth, in feet	Target variable	Number of samples	Mean	Standard deviation	Range		Median
1	Stormwater	Exfiltration trench catch basin.	--	Color (Pt-Co units)	4	40	22	20	70	30
				Nitrogen, total Kjeldahl	4	1.37	1.51	.27	3.60	.80
				Nitrogen, total ammonia	4	.71	1.27	.07	2.61	.08
				Nitrogen, total nitrate	4	.14	.17	.01	.38	.08
				Phosphorus, total orthophosphate	4	.03	.02	.01	.06	.02
				Phosphorus, total	4	.09	.11	.01	.24	.06
				Iron, total recoverable, μg/L	4	3,840	7,440	100	15,000	130
				Lead, total recoverable, μg/L	4	21	11	7	31	23
				Zinc, total recoverable, μg/L	4	60	22	40	90	55
				Chemical oxygen demand	4	45	35	12	93	38
				Carbon, total organic	4	17	7	8	26	18
2	Ground water	Well 1 foot from exfiltration trench perimeter.	10	Color (Pt-Co units)	6	30	11	20	50	30
				Nitrogen, total Kjeldahl	6	.68	.08	.58	.83	.68
				Nitrogen, total ammonia	6	.06	.05	.02	.15	.03
				Nitrogen, total nitrate	6	.14	.11	.01	.29	.14
				Phosphorus, total orthophosphate	6	.02	.01	.01	.03	.01
				Phosphorus, total	6	.03	.01	.01	.04	.02
				Iron, total recoverable, μg/L	6	850	1,240	90	3,200	185
				Lead, total recoverable, μg/L	6	5	4	2	13	4
				Zinc, total recoverable, μg/L	6	28	17	10	60	25
				Chemical oxygen demand	6	28	9	18	41	27
				Carbon, total organic	6	17	4	12	24	15

Table 5.—Summary of target variables at the airport study area—Continued

Site	Source	Location	Depth, in feet	Target variable	Number of samples	Mean	Standard deviation	Range (low)	Range (high)	Median
3	Ground water	Well 1 foot from exfiltration trench perimeter.	15	Color (Pt-Co units)	6	30	11	20	50	30
				Nitrogen, total Kjeldahl	6	.74	.11	.60	.87	.75
				Nitrogen, total ammonia	6	.05	.04	.02	.11	.03
				Nitrogen, total nitrate	6	.10	.08	.01	.18	.08
				Phosphorus, total orthophosphate	6	.01	.01	.01	.03	.01
				Phosphorus, total	6	.02	.01	.01	.04	.02
				Iron, total recoverable, µg/L	6	393	163	250	700	340
				Lead, total recoverable, µg/L	6	6	6		17	4
				Zinc, total recoverable, µg/L	6	22	12	10	40	20
				Chemical oxygen demand	5	28	14	7	48	29
				Carbon, total organic	6	17	6	10	26	16
4	Ground water	Well 20 feet from exfiltration trench perimeter.	10	Color (Pt-Co units)	6	35	11	20	50	35
				Nitrogen, total Kjeldahl	6	.84	.20	.60	1.20	.80
				Nitrogen, total ammonia	6	.11	.05	.06	.19	.09
				Nitrogen, total nitrate	6	.12	.11	.01	.27	.10
				Phosphorus, total orthophosphate	6	.02	.02	.01	.05	.01
				Phosphorus, total	6	.03	.01	.01	.04	.02
				Iron, total recoverable, µg/L	6	323	305	70	910	250
				Lead, total recoverable, µg/L	6	12	14		36	8
				Zinc, total recoverable, µg/L	6	37	39	10	110	20
				Chemical oxygen demand	6	40	17	29	72	32
				Carbon, total organic	6	18	4	12	22	17
5	Ground water	Well 20 feet from exfiltration trench perimeter.	15	Color (Pt-Co units)	6	30	8	20	40	30
				Nitrogen, total Kjeldahl	6	.70	.09	.58	.79	.70
				Nitrogen, total ammonia	6	.05	.05	.01	.15	.02
				Nitrogen, total nitrate	6	.15	.12	.01	.28	.18
				Phosphorus, total orthophosphate	6	.01	.01	.01	.03	.01
				Phosphorus, total	6	.03	.01	.01	.05	.03
				Iron, total recoverable, µg/L	6	306	319	40	870	190
				Lead, total recoverable, µg/L	6	5	5		14	3
				Zinc, total recoverable, µg/L	6	25	5	20	30	25
				Chemical oxygen demand	6	34	8	26	48	32
				Carbon, total organic	6	14	4	10	20	14
6	Ground water	Well in grassy swale.	10	Color (Pt-Co units)	5	60	16	35	75	60
				Nitrogen, total Kjeldahl	5	2.92	.08	2.80	3.00	2.90
				Nitrogen, total ammonia	5	2.24	.15	2.10	2.50	2.20
				Nitrogen, total nitrate	5	.01	.00	.01	.02	.01
				Phosphorus, total orthophosphate	5	.02	.01	.01	.03	.01
				Phosphorus, total	5	.03	.02	.01	.06	.03
				Iron, total recoverable, µg/L	5	2,520	545	2,100	3,400	2,200
				Lead, total recoverable, µg/L	5	4	4	1	12	2
				Zinc, total recoverable, µg/L	5	32	16	20	60	30
				Chemical oxygen demand	5	31	10	20	46	32
				Carbon, total organic	5	18	2	15	21	18

Table 5.—Summary of target variables at the airport study area—Continued

Site	Source	Location	Depth, in feet	Target variable	Number of samples	Mean	Standard deviation	Range		Median
7	Ground water	Well in grassy swale.	15	Color (Pt-Co units)	6	50	32	20	100	55
				Nitrogen, total Kjeldahl	6	1.92	.86	.80	3.00	1.95
				Nitrogen, total ammonia	6	1.24	.81	.31	2.10	1.27
				Nitrogen, total nitrate	6	.44	.64	.01	1.70	.20
				Phosphorus, total orthophosphate	6	.03	.02	.02	.08	.02
				Phosphorus, total	6	.04	.02	.01	.08	.04
				Iron, total recoverable, μg/L	6	1,260	908	150	2,200	1,400
				Lead, total recoverable, μg/L	6	9	8		23	7
				Zinc, total recoverable, μg/L	6	30	21	10	70	25
				Chemical oxygen demand	6	35	15	19	58	30
				Carbon, total organic	6	15	2	12	18	14

Similar to the statistical analyses of the major-ion data, a two-way nonparametric ANOVA for the target variables by selected monitoring location and depth were made. The first ANOVA was designed to examine the probability level that the apparent concentration differences among the three ground-water monitoring locations (subgroups) were statistically significant or the result of background variability. Results inferred that color, Kjeldahl nitrogen, ammonia nitrogen, and iron were significantly different at the 5-percent level (table 6). The levels of these four target variables were all notably greater in ground water for the swale subgroup (sites 6 and 7). A significant depth effect was also inferred for ammonia nitrogen. The average concentration of ammonia nitrogen was 0.72 mg/L in samples collected at 10 feet and 0.45 mg/L in samples from 15 feet.

Results of a second ANOVA of target variables in ground water between the subgroup of trench wells (sites 2 and 3) and the subgroup of wells 20 feet from the exfiltration trench (sites 4 and 5) is also given in table 6. The resulting p-values inferred that none of the target variables in ground water near the exfiltration trench were significantly different at the 5 percent level either by subgroup location or depth.

Table 6.—Significance probabilities (p-values) associated with the null hypothesis that the mean ranks of target variables grouped by selected sites and depths at the airport study area are equal

Target variables	ANOVA 1: Trench wells (sites 2 and 3), wells near trench (sites 4 and 5), and swale wells (sites 6 and 7).		ANOVA 2: Trench wells (sites 2 and 3) and wells near trench (sites 4 and 5).		ANOVA 3: Exfiltration trench (site 1) and trench wells (sites 2 and 3).
	Subgroup	Depth	Subgroup	Depth	Subgroup
Color (Pt-Co units)	[1]0.0396	0.4103	0.9782	0.8273	0.9072
Nitrogen, total Kjeldahl	[1].0001	.2455	.4734	.6867	.4140
Nitrogen, total ammonia	[1].0001	[1].0164	.4307	.1037	.0992
Nitrogen, total nitrate	.7376	.1562	.8277	.8703	.9077
Phosphorus, total orthophosphate	.2562	.6851	.8312	.4318	.2769
Phosphorus, total	.1743	.5253	.6585	.9118	.5530
Iron, total recoverable	[1].0006	.4106	.2853	.6976	.3187
Lead, total recoverable	.9737	.9244	.8046	.4286	[1].0072
Zinc, total recoverable	.7481	.6563	.8023	.8238	[1].0047
Chemical oxygen demand	.3692	.9259	.1702	.9776	.4147
Carbon, total organic	.9360	.0546	.8011	.2818	.7282

[1]Statistically significant difference at the 5-percent level.

The magnitude of ammonia nitrogen and iron in ground water at the swale suggested the occurrence of anaerobic microbial decomposition. Anaerobic decay was also suggested by the low levels of sulfate discussed previously. Anaerobic conditions are common in poorly drained soils with porewater devoid of oxygen. In the anaerobic environment the dominant microbial community is one that can utilize sulfate and iron, in place of oxygen, as electron acceptors (Brock and others, 1984, p. 124). Thus, microbial oxidation of organic compounds in the anaerobic environment commonly results in the reduction, for example, of sulfate to sulfide and ferric iron to ferrous iron. Ammonia nitrogen is also a byproduct resulting from anaerobic decomposition of vegetative material containing organic nitrogen (proteins) (Brock and others, 1984, p. 124 and 424; Bailey and Ollis, 1986, p. 911). The greater color level in ground water at the swale was likely in part associated with ferric chelates.

A comparison of the concentrations of target variables in samples of stormwater from the exfiltration trench (site 1) and samples water from the trench wells (site 2 and 3), which were located 1 foot from the exfiltration trench perimeter, indicated slight differences (table 5). The most notable difference was the greater concentrations of lead and zinc in the stormwater. The target-variable data between the stormwater and the adjacent ground water were examined using a one-way nonparametric ANOVA, the purpose of which was to ascertain the probability that differences in concentrations between stormwater and ground water in the immediate area of recharge were statistically significant or the result of background variability. Results inferred that lead and zinc were significantly different at the 5-percent level (table 6).

Assessment of Stormwater Effects

Results of this limited data collection did not indicate that stormwater recharge from the exfiltration trench greatly affected the quality of shallow ground water near the trench. Results of ANOVA inferred that only the concentrations of lead and zinc were significantly different at the 5-percent level, with the greater concentrations in the stormwater. Assuming this sampling reconnaissance was generally representative of conditions over time, the lower concentrations of lead and zinc in ground water in the immediate area of recharge suggested the possibility that these trace metals in stormwater were partially removed or trapped within the exfiltration trench. Sedimentation, precipitation, or sorption within the trench system are possible processes that may have partially prevented the movement of lead and zinc into the adjacent ground water. However, far more rigorous experimentation and data collection would be required to confirm this conjecture.

There was no indication that the concentrations of major ions and target variables were significantly different within the ground-water zone monitored by the two wells 1 foot from the perimeter of the exfiltration trench and the two wells 20 feet from the trench. The absence of variation in ground-water quality in this zone suggested that stormwater recharge from the trench had not caused any notable chemical stratification.

Evidence of anaerobic biogeochemical cycling in the ground water at the swale generally precluded any conjecture on the probable effects caused by downward percolation of stormwater. The apparent anaerobic generation of such target variables as ammonia, iron, color, and the likely reduction of sulfate was probably the result of inadequate drainage of organic-rich swale soils.

Free Zone Study Area

As with the previous section, this discussion of monitoring results for the free zone is intended to describe selected water-quality conditions of the area along with a brief assessment of the effects of stormwater recharge on the chemical character of shallow ground water.

Major Inorganic Ions

The predominant water type at the free zone study area was calcium bicarbonate. Concentrations of calcium ranged from 76 percent of the total cation milliequivalents in samples of stormwater from the exfiltration trench (site 8) to about 84 percent in water samples collected from the four wells near the trench (sites 9–12). Bicarbonate concentrations ranged from 74 percent in stormwater (site 8) to about 86 percent in ground water at the swale (sites 13 and 14). The range in dissolved solids (sum of constituents) ranged from a median concentration of 102 mg/L in stormwater (site 8) to almost 700 mg/L in ground water at the swale (sites 13 and 14) (table 7). Concentrations of most major ions were about twofold greater in ground water near the exfiltration trench (sites 9–12) than in the stormwater collected in the trench (site 8). Similarly, the concentrations of major ions, except sulfate, in water from the two monitoring wells in the swale (sites 13 and 14) were about twofold greater than in ground water near the exfiltration trench (sites 9–12). The low levels of sulfate in ground water at the swale, which ranged in median concentration from 3.1 mg/L (site 13) to 1.6 mg/L (site 14), suggested anaerobic decomposition.

Table 7. – Summary of major ions at the free zone study area

[Concentrations in milligrams per liter]

Site	Source	Location	Depth, in feet	Major ion	Number of samples	Mean	Standard deviation	Range		Median
8	Stormwater	Exfiltration trench catch basin.	--	Calcium	2	31	2.8	29	33	31
				Magnesium	2	1.2	.2	1.1	1.4	1.2
				Sodium	2	4.4	.6	4.0	4.8	4.4
				Potassium	2	2.5	1.8	1.2	3.8	2.5
				Chloride	2	8.4	5.0	4.8	12	8.4
				Sulfate	2	13	7.6	7.2	18	13
				Bicarbonate	2	84	1.4	83	85	84
				Solids, sum of constituents	2	102	18.8	89	116	102
9	Ground water	Well 1 foot from exfiltration trench perimeter.	10	Calcium	3	96	4.0	92	100	96
				Magnesium	3	3.7	.2	3.6	3.9	3.7
				Sodium	3	14	.6	14	15	14
				Potassium	3	1.6	.1	1.5	1.6	1.6
				Chloride	3	23	.6	23	24	23
				Sulfate	3	25	1.5	24	27	26
				Bicarbonate	3	270	0	270	270	270
				Solids, sum of constituents	3	300	2.3	297	302	300
10	Ground water	Well 1 foot from exfiltration trench perimeter.	15	Calcium	3	99	1.7	97	100	100
				Magnesium	3	4.0	.1	4.0	4.1	4.0
				Sodium	3	15.7	.6	15	16	16.0
				Potassium	3	1.3	.1	1.2	1.4	1.3
				Chloride	3	26	1.7	24	27	27
				Sulfate	3	24	1.0	23	25	24
				Bicarbonate	3	283	11	280	300	300
				Solids, sum of constituents	3	317	11	304	323	322
11	Ground water	Well 20 feet from exfiltration trench perimeter.	10	Calcium	3	96	1.5	94	97	96
				Magnesium	3	3.8	.3	3.6	4.1	3.7
				Sodium	3	15	.6	14	15	15
				Potassium	3	1.6	0	1.6	1.6	1.6
				Chloride	3	23	.6	23	24	23
				Sulfate	3	25	.6	25	26	25
				Bicarbonate	3	267	5.8	260	270	270
				Solids, sum of constituents	3	298	4.9	292	302	299
12	Ground water	Well 20 feet from exfiltration trench perimeter.	15	Calcium	3	103	5.8	100	110	100
				Magnesium	3	4.2	.3	3.9	4.5	4.1
				Sodium	3	16	1.0	15	17	16
				Potassium	3	1.4	.3	1.1	1.6	1.5
				Chloride	3	25.7	1.2	25	27	25
				Sulfate	3	24	3.5	22	28	22
				Bicarbonate	3	290	17	280	310	280
				Solids, sum of constituents	3	320	14	310	336	313
13	Ground water	Well in grassy swale.	10	Calcium	3	207	5.8	200	210	210
				Magnesium	3	13	0	13	13	13
				Sodium	3	42	.6	42	43	42
				Potassium	3	5.0	.3	4.7	5.3	5.1
				Chloride	3	64	1.0	63	65	64
				Sulfate	3	2.8	2.5	.1	5.1	3.1
				Bicarbonate	3	727	5.8	720	730	730
				Solids, sum of constituents	3	697	5.80	693	703	694

Table 7.—Summary of major ions at the free zone study area—Continued

[Concentrations in milligrams per liter]

Site	Source	Location	Depth, in feet	Major ion	Number of samples	Mean	Standard deviation	Range		Median
14	Ground water	Well in grassy swale.	15	Calcium	3	210	10	200	220	210
				Magnesium	3	13	.8	13	14	13
				Sodium	3	43	.6	42	43	43
				Potassium	3	5.0	.4	4.5	5.2	5.2
				Chloride	3	64	1.0	63	65	64
				Sulfate	3	1.4	1.2	.1	2.5	1.6
				Bicarbonate	3	713	21	690	730	720
				Solids, sum of constituents	3	693	1.2	692	694	693

The concentrations of major ions in ground water were examined using two-way nonparametric ANOVA. Analytical data for the first ANOVA was arranged to examine the significance probabilities that no statistical difference existed among the three ground-water subgroups comprised of trench wells (sites 9 and 10), wells 20 feet from the trench (sites 11 and 12), and swale wells (sites 13 and 14). Results inferred that all seven major ions were significantly different among subgroups and all major ions, except sulfate, were significantly different between depths (table 8). A second ANOVA of the two subgroups comprised of trench wells (sites 9 and 10) and wells 20 feet from the trench (sites 11 and 12) indicated no significance between major-ion concentrations, but a significant depth effect remained. Based on median concentrations, individual ions, except sulfate, were about 5 to 10 percent greater in water from the two 15-foot wells (sites 10 and 12), with the dissolved solids ranging from 299 mg/L in samples collected at 10 feet (sites 9 and 11) to 318 mg/L at 15 feet (sites 10 and 12).

Table 8.—Significance probabilities (p-values) associated with the null hypothesis that the mean ranks of major ions grouped by selected sites and depths at the free zone study area are equal

Major ion	ANOVA 1 Trench wells (sites 9 and 10), wells near trench (sites 11 and 12), and swale wells (sites 13 and 14).		ANOVA 2 Trench wells (sites 9 and 10) and wells near trench (sites 11 and 12).	
	Subgroup	Depth	Subgroup	Depth
Calcium	[1]0.0001	[1]0.0098	0.6680	[1]0.0121
Magnesium	[1].0001	[1].0179	.5247	[1].0334
Sodium	[1].0001	[1].0052	.5108	[1].0088
Potassium	[1].0001	[1].0128	.2347	[1].0113
Chloride	[1].0001	[1].0025	1.000	[1].0019
Sulfate	[1].0004	.1166	.9396	.1756
Bicarbonate	[1].0001	[1].0007	.4946	[1].0002
Ion sum	[1].0001	[1].0039	1.000	[1].0011

[1]Statistically significant difference at the 5-percent level.

Target Variables

Based on median concentrations, nitrate nitrogen, phosphorus, lead, zinc, and chemical oxygen demand were greater in stormwater in the exfiltration trench (site 8) than in the ground water of the study area (table 9). Median concentrations of Kjedahl nitrogen, ammonia nitrogen, and iron, however, were notably greater in ground water at the swale (sites 13 and 14).

Table 9.—Summary of target variables at the free zone study area

[Concentrations in milligrams per liter, except as indicated. Pt-Co units, platinum-cobalt units; µg/L, micrograms per liter]

Site	Source	Location	Depth, in feet	Target variable	Number of samples	Mean	Standard deviation	Range		Median
8	Stormwater	Exfiltration trench catch basin.	--	Color (Pt-Co units)	5	55	30	25	100	60
				Nitrogen, total Kjeldahl	5	3.80	1.44	2.10	5.40	3.80
				Nitrogen, total ammonia	5	.66	0.59	.17	1.60	.34
				Nitrogen, total nitrate	5	2.34	2.66	.61	7.0	1.30
				Phosphorus, total orthophosphate	5	.09	.06	.05	.19	.06
				Phosphorus, total	5	.20	.07	.12	.29	.22
				Iron, total recoverable, µg/L	5	4,760	8,530	620	20,000	830
				Lead, total recoverable, µg/L	5	3,220	7,140	10	16,000	38
				Zinc, total recoverable, µg/L	5	960	1,920	70	4,400	130
				Chemical oxygen demand	5	154	85	39	290	170
				Carbon, total organic	5	29	11	20	46	24
9	Ground water	Well 1 foot from exfiltration trench perimeter.	10	Color (Pt-Co units)	6	39	7	30	50	40
				Nitrogen, total Kjeldahl	6	.79	.06	.72	.88	.80
				Nitrogen, total ammonia	6	.13	.02	.12	.16	.13
				Nitrogen, total nitrate	6	.14	.06	.01	.14	.01
				Phosphorus, total orthophosphate	6	.01	0	.01	.01	.01
				Phosphorus, total	6	.01	.01	.01	.02	.01
				Iron, total recoverable, µg/L	6	835	415	360	1,600	775
				Lead, total recoverable, µg/L	6	6	7		19	2
				Zinc, total recoverable, µg/L	6	21	16	5	50	20
				Chemical oxygen demand	6	21	9	7	30	21
				Carbon, total organic	6	15	3.2	11	18	16
10	Ground water	Well 1 foot from exfiltration trench perimeter.	15	Color (Pt-Co units)	6	40	9	30	50	40
				Nitrogen, total Kjeldahl	6	.93	.15	.80	1.20	.90
				Nitrogen, total ammonia	6	.12	.02	.10	.14	.13
				Nitrogen, total nitrate	6	.01	.01	.01	.02	.01
				Phosphorus, total orthophosphate	6	.01	0	.01	.01	.01
				Phosphorus, total	6	.01	.01	.01	.02	.01
				Iron, total recoverable, µg/L	6	1,110	541	780	2,200	935
				Lead, total recoverable, µg/L	6	6	7		16	2
				Zinc, total recoverable, µg/L	6	30	11	20	50	30
				Chemical oxygen demand	6	25	8	20	41	22
				Carbon, total organic	6	16	2	14	18	16
11	Ground water	Well 20 feet from exfiltration trench perimeter.	10	Color (Pt-Co units)	6	40	6	30	50	40
				Nitrogen, total Kjeldahl	6	.82	.10	.70	.96	.79
				Nitrogen, total ammonia	6	.16	.03	.10	.19	.17
				Nitrogen, total nitrate	6	.04	.07	.01	.17	.01
				Phosphorus, total orthophosphate	6	.01	0	.01	.01	.01
				Phosphorus, total	6	.01	.01	.01	.02	.01
				Iron, total recoverable, µg/L	6	518	319	120	900	600
				Lead, total recoverable, µg/L	6	2	2		5	2
				Zinc, total recoverable, µg/L	6	14	9	5	30	10
				Chemical oxygen demand	6	30	11	17	46	28
				Carbon, total organic	6	16	2	13	19	15

Table 9.—Summary of target variables at the free zone study area—Continued

Site	Source	Location	Depth, in feet	Target variable	Number of samples	Mean	Standard deviation	Range		Median
11	Ground water	Well 20 feet from exfiltration trench perimeter.	10	Color (Pt-Co units)	6	40	6	30	50	40
				Nitrogen, total Kjeldahl	6	.82	.10	.70	.86	.78
				Nitrogen, total ammonia	6	.16	.03	.10	.19	.17
				Nitrogen, total nitrate	6	.04	.07	.01	.17	.01
				Phosphorus, total orthophosphate	6	.01	0	.01	.01	.01
				Phosphorus, total	6	.01	.01	.01	.02	.01
				Iron, total recoverable, μg/L	6	518	318	120	900	600
				Lead, total recoverable, μg/L	6	2	2		5	2
				Zinc, total recoverable, μg/L	6	14	9	5	30	10
				Chemical oxygen demand	6	30	11	17	46	28
				Carbon, total organic	6	16	2	13	19	15
12	Ground water	Well 20 feet from exfiltration trench perimeter.	15	Color (Pt-Co units)	6	40	8	30	50	40
				Nitrogen, total Kjeldahl	6	.89	.07	.78	.98	.90
				Nitrogen, total ammonia	6	.12	.03	.08	.16	.12
				Nitrogen, total nitrate	6	.02	.02	.01	.06	.01
				Phosphorus, total orthophosphate	6	.01	0	.01	.01	.01
				Phosphorus, total	6	.02	.01	.01	.03	.01
				Iron, total recoverable, μg/L	6	822	288	450	1,200	795
				Lead, total recoverable, μg/L	6	1	1		3	1
				Zinc, total recoverable, μg/L	6	21	11	5	40	20
				Chemical oxygen demand	6	40	35	16	110	26
				Carbon, total organic	6	17	3	14	22	17
13	Ground water	Well in grassy swale.	10	Color (Pt-Co units)	6	60	20	50	100	50
				Nitrogen, total Kjeldahl	6	5.22	2.78	1.50	7.40	6.50
				Nitrogen, total ammonia	6	4.09	2.37	.62	6.00	5.10
				Nitrogen, total nitrate	6	.12	.27	.01	.66	.01
				Phosphorus, total orthophosphate	6	.02	.02	.01	.07	.01
				Phosphorus, total	6	.04	.02	.01	.07	.04
				Iron, total recoverable, μg/L	6	4,380	2,270	860	7,500	4,500
				Lead, total recoverable, μg/L	6	4	5		11	2
				Zinc, total recoverable, μg/L	6	21	13	5	40	20
				Chemical oxygen demand	6	64	21	38	87	70
				Carbon, total organic	6	28	9	16	40	30
14	Ground water	Well in grassy swale.	15	Color (Pt-Co units)	6	60	21	40	100	50
				Nitrogen, total Kjeldahl	6	5.13	2.55	2.00	7.30	6.15
				Nitrogen, total ammonia	6	4.05	2.10	1.30	5.80	4.90
				Nitrogen, total nitrate	6	.03	.05	.01	.13	.01
				Phosphorus, total orthophosphate	6	.02	.01	.01	.04	.01
				Phosphorus, total	6	.05	.02	.03	.07	.06
				Iron, total recoverable, μg/L	6	5,370	1,520	3,500	7,400	5,200
				Lead, total recoverable, μg/L	6	3	2		5	3
				Zinc, total recoverable, μg/L	6	22	15	5	50	20
				Chemical oxygen demand	6	59	16	37	80	58
				Carbon, total organic	6	26	4	19	30	26

Similar to the statistical analyses of the major ion data, two-way nonparametric ANOVA for the target variables by selected monitoring locations (subgroups) were made. The analytical data for first ANOVA was arranged to examine the probability that the apparent concentration differences among the three ground-water monitoring locations were statistically significant. Results inferred that 8 of the 11 target variables were significantly different at the 5-percent level among subgroups and 3 target variables were significantly different between depths (table 10). The levels of the eight target variables that indicated significance were greater in ground water for the swale subgroup (sites 13 and 14), although differences in median color units and concentrations of orthophosphorus and total phosphorus among the three subgroups were slight. The other target variables, particularly ammonia nitrogen and iron, were notably greater at the swale. Concentrations of both ammonia nitrogen and iron also were inferred to have a significant depth effect. The median concentration of ammonia nitrogen was slightly greater in ground water from the 10-foot zone (0.17 mg/L) than the 15-foot zone (0.14 mg/L), whereas iron was less in ground water in the 10-foot zone (840 µg/L) than the 15-foot zone (1,050 µg/L).

Table 10. -- Significance probabilities (p-values) associated with the null hypothesis that the mean ranks of target variables grouped by selected sites and depths at the free zone study area are equal

Target variables	ANOVA 1 Trench wells (sites 9 and 10), wells near trench (sites 11 and 12), and swale wells (sites 13 and 14).		ANOVA 2 Trench wells (sites 9 and 10) and wells near trench (sites (sites 11 and 12).		ANOVA 3 Exfiltration trench (site 8) and trench wells (sites 9 and 10).
	Subgroup	Depth	Subgroup	Depth	Subgroup
Color (Pt-Co units)	[1]0.0002	0.8557	0.9107	0.9776	0.4368
Nitrogen, total Kjeldahl	[1].0001	[1].0285	.7776	[1].0127	[1].0001
Nitrogen, total ammonia	[1].0001	[1].0277	.2081	[1].0363	[1].0001
Nitrogen, total nitrate	.7143	.7773	.4804	.7496	[1].0001
Phosphorus, total orthophosphate	[1].0027	.6360	1.0000	1.0000	[1].0001
Phosphorus, total	[1].0001	.2021	.6025	.6025	[1].0001
Iron, total recoverable	[1].0001	[1].0294	.0902	[1].0429	.8801
Lead, total recoverable	.6059	.6186	.4060	.4875	[1].0013
Zinc, total recoverable	.2967	.1172	.1105	.0558	[1].0001
Chemical oxygen demand	[1].0001	.7255	.1462	.8000	[1].0003
Carbon, total organic	[1].0001	.3627	.5190	.3164	[1].0001

[1]Statistically significant difference at the 5-percent level.

Results of a second ANOVA to determine the significance probabilities between the mean ranks of target variables in ground water from the subgroups comprising the two trench wells (sites 9 and 10) and the two wells 20 feet from the trench (sites 11 and 12) is also given in table 10. The p-values inferred that none of the target variables near the exfiltration trench were significantly different at the 5 percent level by subgroup, but nitrogen, phosphorus, and iron had a significant depth effect. The differences in median concentrations by depth, however, were slight. The median ammonia and iron concentrations, respectively, were 0.15 mg/L and 695 µg/L in ground water from the 10-foot zone (sites 9 and 11) and 0.13 mg/L and 845 µg/L in ground water from the 15-foot zone (sites 10 and 12).

The apparent differences between the concentrations of target variables in stormwater in the exfiltration trench (site 8) and water from the two trench wells (sites 9 and 10) were examined using a one-way nonparametric ANOVA (table 10). Results inferred that 9 of the 11 target variables were significantly different at the 5-percent level. The median concentrations of all the target variables that inferred a significant difference were measurably greater in the stormwater.

Assessment of Stormwater Effects

The concentrations of several target variables were greater in stormwater from the exfiltration trench than in ground water from the two shallow wells located 1 foot from the trench. The general reduction in concentration suggested the possibility that some target variables in stormwater were partially removed (trapped) within the exfiltration trench prior to recharge. Many of the target variables, except perhaps nitrate and orthophosphorus, may have been strongly associated with particulate material and would have tended to settle under reduced velocity conditions in the exfiltration trench. Aerobic microbial activity could have accounted for reductions in concentrations of nitrate and phosphorus. This is conjecture, however, because analytical speciation of target variables was not within the scope of this reconnaissance.

It is noted that one sample collected on February 18, 1986, had concentrations that could be considered of environmental concern. This sample, which was associated with a 2-hour event of 0.85 inch of rainfall and 11 antecedent dry days (table 2), had a lead concentration of 16,000 μg/L and an iron concentration of 20,000 μg/L. The cause of these unusual concentrations was not determined.

Comparison of the concentrations of major ions and target variables in water between the trench wells and wells 20 feet from the trench indicated some vertical variation. Concentrations of most major ions, ammonia nitrogen, and iron in ground water from the 10-foot zone (sites 9 and 11) and ground water from the 15-foot zone (sites 10 and 12) were statistically different at the 5-percent level. Except for ammonia nitrogen, the concentrations were greater in the 15-foot zone. This vertical distribution may have resulted from dilution in the upper zone by stormwater recharge, but the effect on overall quality was considered minor.

The ground-water quality at the swale was quite dissimilar to that near the exfiltration trench. Stormwater recharge may have had an effect on the ground water beneath the swale; however, the scope of this reconnaissance was insufficient for any assessment. It appeared that the soil environment at the swale was anaerobic and the ground water also contained a much greater dissolved solids content than was present in ground water near the exfiltration trench. Such interrelated factors as poor drainage, limestone soil, and evapotranspiration could account for the relative increase in the concentrations of major ions, iron, and ammonia and the decrease in sulfate in the ground water at the swale.

SUMMARY

A water-quality reconnaissance study was conducted at two small commercial areas in Dade County, Florida, to assess the effects of two stormwater management methods (exfiltration trench and grassy swale) on the quality of water in the upper Biscayne aquifer. One study area was located near the Miami International Airport which covers an area of about 10 acres overlying a predominantly sandy soil, and the other study area was located at the Miami International Free Zone which covers an area of about 20 acres overlying limestone. The scope of the reconnaissance included the collection of water-quality and ancillary data on stormwater and shallow ground water at seven monitoring sites at each of the two study areas from April 1985 through May 1986.

Results of the study indicated that the predominant water type of the shallow ground water near the trench and in the swale at both the airport and free zone study areas was calcium bicarbonate. The median concentration of dissolved solids of water from the four monitoring wells near the exfiltration trench at the airport was 297 mg/L and 320 mg/L in water from the two wells in the swale. At the free zone, the median concentration of dissolved solids in water from the four monitoring wells near the trench was 303 mg/L and 694 mg/L in water from the two wells in the swale. Results of ANOVA inferred the difference in concentrations of dissolved solids between the ground water near the exfiltration trench and the swale at each study area was significantly different at the 5-percent level. Although overall concentrations of major ions were greater in ground water at both swales, sulfate concentrations were markedly less in ground water at swales than near the exfiltration trenches. Median concentration of sulfate in water from the four monitoring wells near the exfiltration trench and the two monitoring wells at

the swale, respectively, were 9.7 and 0.3 mg/L at the airport and 25 and 2.1 mg/L at the free zone.

The target variables that were used to assess the effect of stormwater recharge on the shallow ground water indicated considerable variability, but some distribution patterns were suggested at both study areas. The concentrations of the 11 target variables in trench stormwater and water from the two wells 1 foot from the trench were examined by using ANOVA. Results inferred that 2 of the 11 variables at the airport study area and 9 of the 11 target variables at the free zone were significantly different at the 5-percent level. Median concentrations of all the target variables that indicated significant differences were greater, some only slightly, in the stormwater in the trench than in water from the two adjacent trench wells. Lead and zinc were the only target variables that indicated a significant difference between stormwater and adjacent ground water at both the airport and free zone study areas. The distribution of these two trace metals suggested the possibility that the exfiltration trenches may function to some extent as traps for chemical substances present in stormwater. Lead, for example, had a median concentration of 23 μg/L in the trench stormwater and 4 μg/L in water from the two monitoring wells 1 foot from the trench at the airport study area, and 38 μg/L in the trench stormwater and 2 μg/L in the adjacent ground water at the free zone. Similarly, median concentrations of zinc in the stormwater and adjacent ground water at the airport and free zone, respectively, were 55 and 29 μg/L and 130 and 20 μg/L. At the free zone study area, several other target variables indicated a similar reduction in concentrations between samples of stormwater in the exfiltration trench and water from the trench wells.

A comparison of the distribution of major ions and target variables between the two monitoring wells 1 foot from the exfiltration trench and the two wells 20 feet from the trench did not indicate any notable differences that may have been attributable to trench recharge of stormwater at either study area. However, at the free zone, the concentrations of major ions and iron were slightly greater in ground water in the 15-foot zone than in the 10-foot zone. The vertical variability may have been the result of dilution by stormwater in the 10-foot zone.

The distribution of major ions and target variables in the ground water at both swales indicated the presence of anaerobic conditions. Analytical results for both the airport and free zone study areas indicated significantly greater concentrations of ammonia nitrogen, iron, and dissolved solids and significantly less sulfate in ground water at the swales than near the exfiltration trenches. It was conjectured that the anaerobic conditions at the two swales were the result of poor drainage and high organic content of soils. The evidence of rather significant biochemical cycling in the ground water at the swales resulting from anaerobic conditions precluded any assessment of the possible effects caused by downward percolation of stormwater. Any estimates of stormwater effects at the swales would require a far more rigorous experimental design than was used for this reconnaissance.

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