

ATTENUATION OF STORMWATER CONTAMINANTS FROM HIGHWAY RUNOFF
WITHIN UNSATURATED LIMESTONE, DADE COUNTY, FLORIDA

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CONVERSION FACTORS

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

<u>Multiply</u>	<u>By</u>	<u>To obtain</u>
inch (in)	25.4	millimeter (mm)
	0.0254	meter (m)
foot (ft)	0.3048	meter (m)

National Geodetic Vertical Datum of 1929 (NGVD of 1929).--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level, is referred to as sea level in this report.

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ABSTRACT

Infiltration of stormwater in heavily urbanized parts of Dade County, Florida, constitutes a prime source of recharge to the unconfined Biscayne aquifer, the sole source of drinking water for southeast Florida. Pondered stormwater at the test site contained greater concentrations of lead, zinc, manganese, nitrogen (except nitrate), and phosphorus than that water which percolated through the unsaturated limestone. Attenuation of some stormwater contaminants in the surface soils and limestone is indicated at the test site adjacent to a busy roadway. Lead concentrations of 610 micrograms per gram and zinc concentrations of 91 micrograms per gram were found in the thin (about 1 inch) surface soils, nearly 20 times more than the concentrations of these metals at greater depth. In contrast, soil and rock samples at a control site remote from heavy traffic contained low concentrations of metals and showed little variation in concentration with depth.

INTRODUCTION

The Biscayne aquifer, a highly permeable, unconfined aquifer, is the sole source of drinking water for about 3 million people in southeast Florida. The Biscayne is composed of limestone, sandstone, and sand that range in age from Pliocene through Pleistocene. The upper part of the aquifer in much of the Miami area is the Miami Oolite, a limestone within which vertical permeability exceeds horizontal permeability (Parker and others, 1955, p. 102-103). The permeability is the result of solution of the limestone by percolating rainfall. The cavities that were formed are generally filled with calcareous and quartz sand. Because of the permeable character of the limestone and sand, the water within the aquifer is possibly vulnerable to increased constituent concentrations from several sources. An obvious and widespread potential source is the direct infiltration of stormwater from yards and lawns, highways, bridges, parking lots, sidewalks, shopping centers, and so forth in the urbanized Miami area.

Through the years, the aquifer has furnished dependable supplies of acceptable quality water to some of the largest public-supply well-field systems in the country despite the apparent potential for contamination from infiltrated stormwater. In many cases, the well fields originally in virtually undeveloped areas are now in densely developed areas. As urbanization continues to expand farther inland, recharge areas may become subject to surface materials that originated in the urban environment. Recharge to the aquifer occurs within the inland areas for much of southeast Florida; thus, deterioration of the water quality of the surface water or ground water within these areas could result in downgradient deterioration of the ground-water quality including the water of the major well-field areas.

In past years, local environmental agencies have recorded only rare instances of contamination or disease outbreaks caused by waterborne chemical and biological components. Nevertheless, these agencies must continuously appraise the water quality to advise local governing bodies on water-related matters of zoning and growth. A concern of local officials is: Why have there not been many more occurrences of chemical contamination in view of the rapid growth of the area and the vulnerability of the aquifer to direct infiltration of stormwater runoff from urban areas? One reason may be the capacity of the unsaturated limestone of the surficial aquifer to remove or reduce contaminants from stormwater by sorption, mechanical filtering, and biological activity during percolation to the water table.

Purpose and Scope

This study is the initial phase of an investigation to determine the capabilities of the types of geologic materials within the unsaturated zone of the Biscayne aquifer to attenuate contaminants primarily from stormwater runoff from a busy roadway. The specific objectives of this initial study are to determine the differences in the concentration of chemical constituents in water samples collected at various depths in the unsaturated zone immediately after rainfalls and in samples of the soil and the limestone, sandstone, and sand at selected depths in the unsaturated zone of the Miami Oolite. The chemical constituents analyzed were lead, zinc, iron, cadmium, chromium, nickel, mercury, manganese, nitrogen, and phosphorus.

Description of Sites

Two sites were selected in Miami for sampling the geologic materials and stormwater. The test site is in a commercial-residential area which receives stormwater runoff from a busy roadway; the control site, for comparison, is in a residential area remote from direct infiltration of highway stormwater runoff (fig. 1).

The test site (fig. 1) is near a roadside immediately adjacent to LeJeune Road, one of the heaviest traveled, 2-lane roadways in the Coral Gables-Miami area (18,000 cars per day) and in use for about 50 years. The site is located in a swale and receives runoff from the road surface and a large lawn area. Temporary ponding occurs after heavy rainfall. The site is in one of the low parts of the swale where the accumulation of runoff contaminants is thought to be maximum. The land-surface altitude of the swale at the test site is about 12 feet, and the thickness of the unsaturated zone is about 10 to 11 feet.

The control site (fig. 1) is in the highest part and near the center of an undeveloped park where the land-surface altitude is more than 15 feet. The general area is overgrown with various grasses and weeds. The site is 300 feet from the nearest roadway, is 1 to 2 feet higher than the roadway, and therefore, receives no stormwater runoff although the site is probably affected by dust fallout from vehicular traffic. The thickness of the unsaturated zone is 14 to 15 feet. At highest ground-water level conditions, the unsaturated zone is reduced to a thickness of about 10 feet.

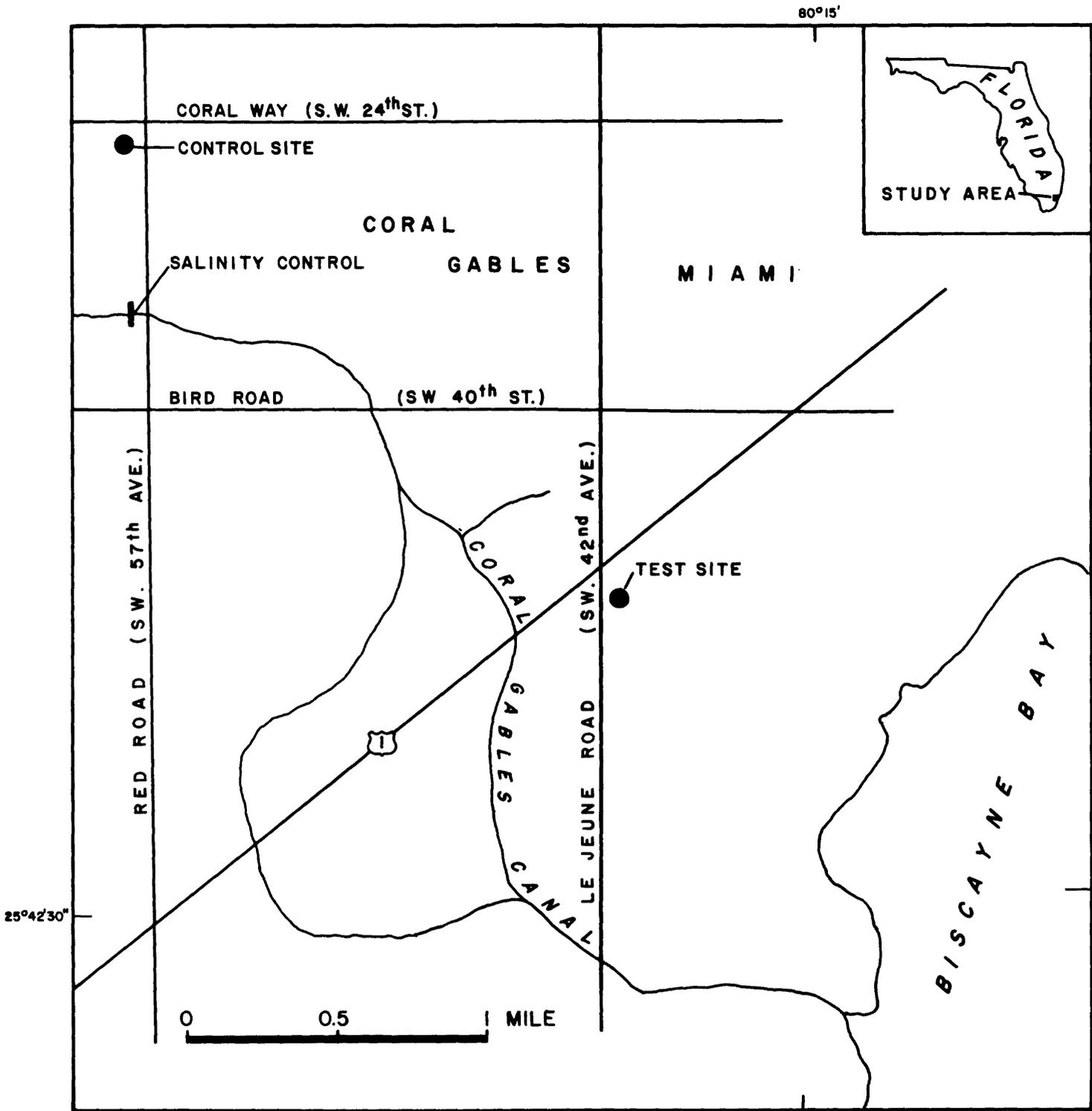


Figure 1.--Location of test sites in the Coral Gables-Miami area, Florida.

METHODS

Soil and rock samples were collected from both sites. Each site was cored without the use of circulating water, using a 2-inch diameter drilling spoon. The lithologic material was collected at 1-foot intervals through the first 4 feet and then at 2-foot intervals through the entire unsaturated section to the depth of the water table. Samples were pulverized with a porcelain mortar and pestle, passed through a 2-mm nylon screen, and shipped to the U.S. Geological Survey Central Laboratory, in Doraville, Ga., for chemical analysis.

Water samples from the unsaturated zone and stormwater were collected at the test site only. A lysimeter, which consisted of a standard 2-micron porous ceramic cup at the end of a hollow polyvinyl chloride (PVC) cylinder, 2 inches in diameter, was used to collect water in the unsaturated zone (fig. 2). Lysimeters were installed at 1-foot intervals from 1 to 4 feet below land surface and at 6 and 8 feet below land surface. The ceramic cup was packed with a slurry of glass beads and sealed above and below with bentonite powder. The seal prevents water from moving vertically into the ceramic cup insuring that the water collected in the lysimeter has moved laterally through the unsaturated material.

As water moves through the porous ceramic of the cup, the quality of the water may be affected by the processes of filtering, sorption, and desorption. The effect of lysimeters altering the concentrations of trace metals, major ions, and nutrients in water samples has been studied by several researchers. Johnson and others (1981) suggest that the lysimeters do not alter the concentrations of trace metals or major ions. Hansen and Harris (1975) examined the effect of lysimeters on nitrates and phosphates at concentrations that were comparable to those observed in this investigation and concluded that lysimeters may introduce bias into nutrient data because of sorption or desorption. Hansen and Harris (1975) suggest that potential bias is increased when the "sorptive capacity of the ceramic cup is significantly greater than that of the adjacent soil," as may be the case at the test site.

ATTENUATION OF STORMWATER CONTAMINANTS

Soil and Geologic Material

The unsaturated zone at the test site is characterized by oolitic limestone that is iron stained and contains a large quantity of partly cemented, quartz sand. The surface geologic material is a tan to gray limestone and a 1-inch veneer of black organic soil. Separating the surficial material from the underlying limestone and filling irregularities in the limestone surface is an iron-stained layer of fine to medium quartz sand. A description of the material in the unsaturated zone at this site is given in table 1.

The control site is underlain by 15 feet or more of white- to cream-colored oolitic limestone and sandstone. Surface material, 1-foot thick, is cream-colored quartz sand containing flecks of organic material. Beneath the surface material are thin layers of the hard and dense sandstone, but most of the unsaturated zone is soft, partly cemented, calcareous sand (table 1). This site differs strikingly from the test site in the absence of the dark-stained, surface organic materials and the iron-stained limestone.

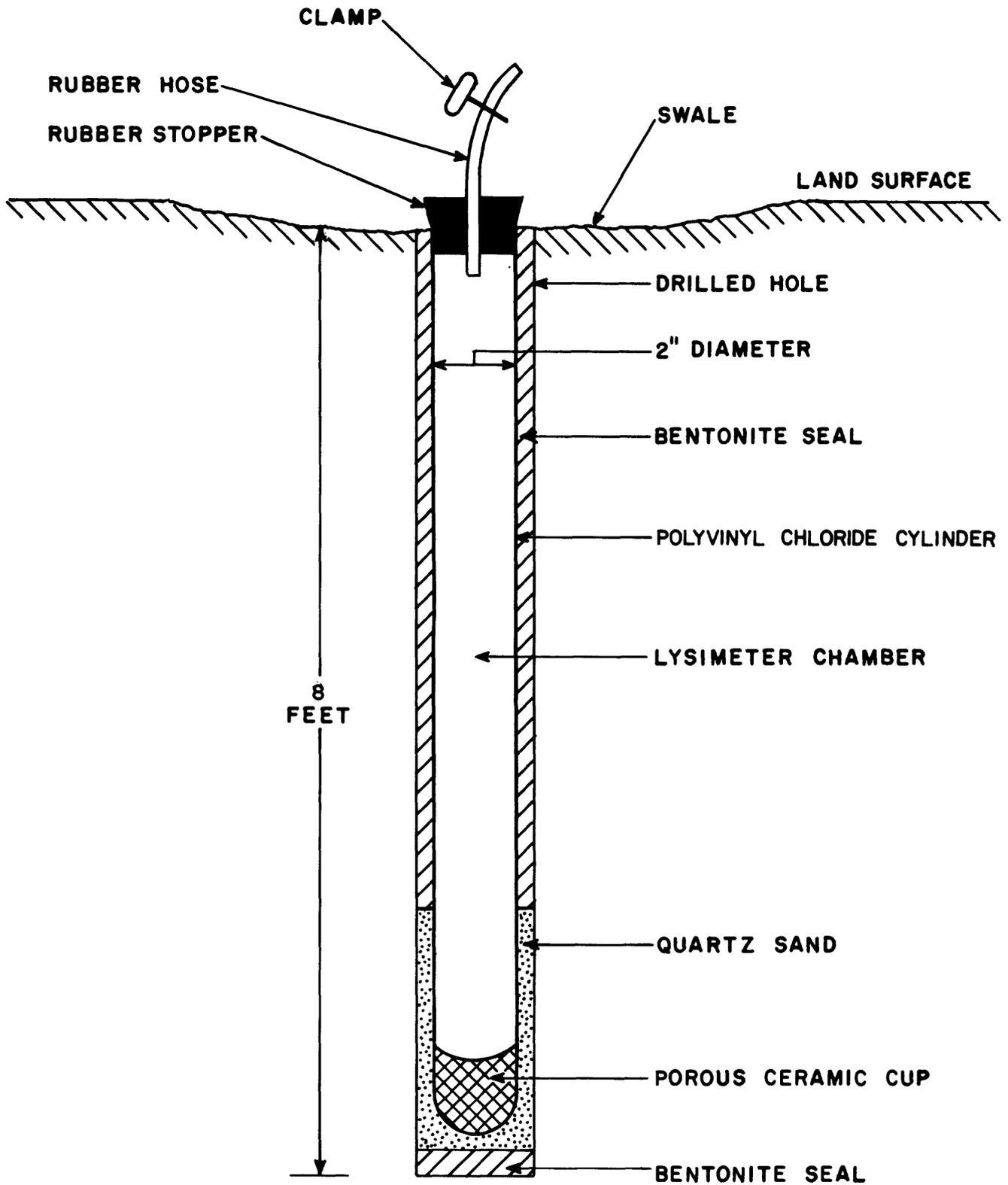


Figure 2.--An installed lysimeter.

Table 1.--Lithologic logs of test holes at the test and control sites

Depth below land surface (feet)	Lithologic description
Test site	
0 - 1	Limestone, tan to gray, oolitic, coated with carbonaceous material, much organic content of dark-gray color.
1 - 2	Sand, tan to brown, iron-stained, quartz, fine to medium, angular and subrounded, and tan to cream oolitic limestone.
2 - 3	Limestone, cream colored, oolitic, good porosity, many oolites dissolved out, iron-stained.
3 - 4	Limestone, cream, oolitic as above but low porosity.
4 - 6	Limestone, iron-stained, oolitic, silty, and sandstone, iron-stained, quartz, fine-grained, hard.
6 - 8	Limestone, tan to yellow, iron-stained, low porosity, and sandstone, iron-stained, quartz, fine-grained, hard.
8 - 10	Silt, tan to yellow, clayey, sandy, calcareous, low permeability.
Control site	
0 - 1	Sand, highly organic, quartz, subrounded, medium to coarse, and fragments of cream, oolitic limestone.
1 - 2	Limestone, white to cream, oolitic, slightly organic.
2 - 3	Limestone, white to cream, oolitic, moderate to good porosity; contains medium quartz grains, clear and frosted.
3 - 4	Limestone, white to cream, very oolitic, soft, moderate porosity.
4 - 6	Limestone as above, but fewer oolites, and quartz sand with carbonate cement, low porosity.
6 - 8	Sandstone, white, rounded quartz grains, carbonate cement, fair porosity.
8 - 10	Sandstone, cream to light tan, coarse to medium, rounded, good porosity, calcareous, and sandy limestone, cream, quartz.
10 - 12	Sandstone as above, slightly darker in color and more loose quartz sand.
12 - 14	Sandstone, more tan than above, slight iron-staining, quartz, good permeability and porosity, and much angular and rounded quartz sand.

Chemical analyses of metals in the soil and rock at selected depths at the test site (table 2) and the control site (table 3) are nearly identical below the 2-foot level. In the first foot of material, there is marked difference in lead and zinc concentrations between the two sites. The test site has concentrations of lead (610 ug/g) and zinc (91 ug/g) in this upper foot that are nearly 20 times higher than those concentrations at the control site (30 and 5 ug/g, respectively). The soil and weathered oolitic limestone, which contain organic material from decayed vegetation, appear to be effective in adsorbing and filtering lead and zinc from stormwater, as indicated by the marked reduction in concentrations with depth within the upper foot.

The comparison of iron concentrations at the two sites probably should not be made because of the erratic occurrence of iron within the earth materials of southeast Florida. Parker and others (1955, p. 73) indicated that the occurrence of iron in ground water in southeast Florida is nonuniform, and concentrations differ within short vertical and horizontal distances. The iron-stained limestone throughout the unsaturated zone at the test site (table 1) is visual evidence of the relatively high iron concentrations shown in table 2.

Although based on very limited data, the greater concentrations of lead and zinc near the surface at the test site suggest that the surficial materials (sand, organic material, and limestone) are effective in attenuating and accumulating these metals by sorption and filtering. The low concentration of metals in the upper part of the section at the control site suggests that this site has not been affected by such traffic-generated constituents as lead and zinc. Concentrations of the other metals analyzed, except iron, show minimal concentrations throughout the sections at both sites.

Concentrations of phosphorus and nitrogen are greater at the test site than at the control site, and at both sites they are generally greater within the upper 2 or 3 feet of the unsaturated zone. This distribution again suggests a tendency toward filtering and sorption at the shallow depth. Kjeldahl nitrogen is markedly higher at the test site at each corresponding depth analyzed than at the control site.

Unsaturated Limestone

The relative quality of the stormwater runoff, as a function of percolation depth, was estimated at the test site from samples that were collected from standing water and lysimeters following three rainstorms on March 23, March 25, and April 11, 1982. The storms produced sufficient rainfall (0.37, 1.01, and 0.68 inches, respectively) to cause ponding and subsequent infiltration and percolation to a depth of at least 4 feet. Water samples from the lysimeters were collected 20 to 24 hours after the storms. The results of the chemical analyses are given in table 4. For the lysimeter analyses, it should be noted that these data may not precisely duplicate the quality of the actual percolation because of sample contact with the lysimeters.

The first storm on March 23, 1982, represents the first flush of dust, fallout, and debris from the surrounding area into the swale after a 16-day dry period. The second storm occurred on March 25, 2 days after the first. There was a 2-week dry period between the second storm and the third storm sampled which occurred on April 11.

Table 2.---Concentrations of chemical constituents determined in rock and soil samples at the test site

[Concentrations are in micrograms per gram, except for nitrogen and phosphorus which are in milligrams per kilogram]

Depth below land surface (feet)	Cad- mium	Chro- mium	Iron	Lead	Manga- nese	Mer- cury	Nickel	Zinc	Kjeldahl nitrogen	Nitrate + nitrite nitrogen	Total phos- phorus
0 - 1	2	9	640	610	25	0.01	10	91	3,920	44	570
1 - 2	2	9	210	30	10	.01	10	12	7,000	4.0	100
2 - 3	2	5	97	30	6	.01	10	4	9,210	2.3	47
3 - 4	3	5	190	40	8	.01	20	5	1,350	2.0	48
4 - 6	3	5	170	40	8	.01	20	6	882	2.0	86
6 - 8	3	8	830	40	10	.01	20	4	916	2.0	150

Table 3.--Concentrations of chemical constituents determined in rock and soil samples at the control site

[Concentrations are in micrograms per gram, except for nitrogen and phosphorus which are in milligrams per kilogram]

Depth below land surface (feet)	Cad- mium	Chro- mium	Iron	Lead	Manga- nese	Mer- cury	Nickel	Zinc	Kjeldahl nitrogen	Nitrate + nitrite nitrogen	Total phos- phorus
0 - 1	2	6	270	30	29	0.01	10	5	2,860	5.8	92
1 - 2	2	4	41	40	9	.01	20	3	1,210	2.0	45
2 - 3	3	4	53	40	7	.01	20	4	645	2.0	59
3 - 4	3	5	41	30	7	.01	20	1	554	2.0	31
4 - 6	2	4	33	30	5	.01	10	6	269	2.0	34
6 - 8	2	3	38	30	6	.01	20	3	102	2.0	2
8 - 10	1	8	76	20	3	.01	10	6	526	2.0	26
10 - 12	1	4	180	10	2	.01	10	7	197	2.0	64
12 - 14	1	7	100	10	2	.01	10	6	284	2.0	23

Table 4. --Concentrations of chemical constituents determined in water samples for three storms at the test site

[Concentrations are in micrograms per liter, except for nutrients which are in milligrams per liter]

Constituents	Storm 1 0.37 inch (March 23, 1982)			Storm 2 1.01 inches (March 25, 1982)			Storm 3 0.68 inch (April 11, 1982)						
	1-foot lysimsim-	2-foot lysimsim-	eter eter	Ponded	2-foot lysimsim-	3-foot lysimsim-	eter eter	1-foot lysimsim-	2-foot lysimsim-	3-foot lysimsim-	eter eter	4-foot lysimsim-	eter eter
Metals													
Cadmium	1	1	1	1	1	1	1	3	3	3	3	3	3
Chromium	5	--	--	1	--	18	18	3	5	2	5	8	8
Iron	110	80	140	50	68	210	210	50	78	59	97	130	130
Lead	330	10	30	90	10	20	20	140	30	30	30	30	30
Manganese	21	2	3	7	2	2	2	14	3	3	3	3	3
Mercury	.8	.1	.1	.2	.1	.1	.1	.2	.2	.1	.1	.1	.1
Nickel	14	--	1	2	1	3	3	3	--	4	3	5	5
Zinc	420	15	27	50	16	73	73	80	12	23	12	12	12
Nutrients													
Ammonia nitrogen (as N)	.60	--	.03	.17	.06	.08	.08	.06	--	.03	.06	.10	.10
Nitrate nitrogen (as N)	1.2	--	19.0	.43	14.0	11.0	11.0	.08	--	2.2	3.5	2.9	2.9
Nitrite nitrogen (as N)	.18	--	.03	.04	.05	.05	.05	.08	--	.03	.02	.04	.04
Organic nitrogen (as N)	5.2	--	3.8	.75	2.0	2.0	2.0	1.8	--	1.5	1.4	1.6	1.6
Total nitrogen	7.2	--	22.9	1.39	16.1	13.1	13.1	2.0	--	3.8	5.0	4.6	4.6
Orthophosphate	1.0	--	.12	.24	.06	.30	.30	.97	--	.06	.08	.13	.13
Total phosphorus	1.2	--	.15	.25	.12	.30	.30	1.0	--	.07	.08	.13	.13

The ponded water during each storm had higher concentrations of lead, zinc, and manganese than the water that infiltrated and was collected in the lysimeters. The highest concentrations of these trace metals in ponded water occurred during the first storm, and the lowest concentrations occurred during the second storm. This indicates that the magnitude of these metals in stormwater runoff is likely related directly to the length of the antecedent dry period.

The distribution of the concentrations of lead and zinc in lysimeter samples at the test site was similar to that observed in the rock and soil samples; that is, the lead and zinc concentrations in the rock and soil samples collected within the 1-foot depth were much greater than those in deeper samples. This near-surface concentration profile is generally corroborated by the decrease in concentrations of lead and zinc between the standing water and lysimeter samples at the 1- to 2-foot depth. This decrease in concentration is particularly apparent for storm 1 when the lead and zinc, respectively, decreased from 330 ug/L and 420 ug/L in the ponding water, to 10 and 15 ug/L at the 1-foot level, and to 30 and 27 ug/L at the 2-foot level, respectively.

Nitrogen specie and phosphorus concentrations in the ponded water and percolation also showed some trends during the three storms (table 4). The highest concentrations in ponded stormwater occurred for the first storm, and concentrations decreased greatly for the second storm but increased again for the third storm. Similar to some of the metals, the relative concentration of nitrogen species and phosphorus is also probably a function of the length of the dry period before each storm.

Concentrations of nitrate nitrogen in the samples collected in the lysimeters were higher by an order of magnitude than those in the ponded stormwater. A probable cause for these higher nitrate concentrations in the unsaturated zone is the nitrification of the nitrogenous materials contained in the upper soil and rock column. Interestingly, the rock and soil samples at 1 to 2 feet and 2 to 3 feet below land surface (table 2) indicate a higher Kjeldhal nitrogen concentration than is present at the 0- to 1-foot depth. Profile concentrations of nitrate in the unsaturated zone did, however, decrease with each subsequent storm.

SUMMARY

1. The contaminant attenuation capacity of near-surface unsaturated limestone in Dade County, Florida, was investigated in March and April 1982.
2. Two sites were selected for study: A test site near a busy two-lane roadway; and a control site, for comparison, in a residential area remote from direct stormwater runoff from roadways.
3. Lithologic samples at multiple depths from the surface to the water table were collected at both sites for description of geologic materials and chemical analysis.
4. Lysimeters were installed at depths of 1, 2, 3, 4, 6, and 8 feet below land surface at the test site to capture percolating stormwater.

5. Three storms were sampled in 1982: March 23, after a 16-day dry period; March 25; and April 11, after a 2-week dry period.
6. The stormwater at the test site had greater concentrations of lead, manganese, zinc, ammonia, and phosphorus than those concentrations in water collected at depth from the lysimeters. Concentrations of these constituents in the ponded water generally varied among the storms as a function of the length of antecedent dry conditions.
7. Nitrate, as a function of depth, showed a trend of increasing concentrations at the test site with the stormwater having lower concentrations than the water in the lysimeters. This is probably due to the flushing of decomposing organic material which is undergoing ammonification and nitrification within the unsaturated zone.
8. Chemical analysis of the lithologic material showed that the upper 1 foot of material at the test site contained higher concentrations of lead, manganese, and zinc than those determined at depth.
9. The surface material at the test site appears to be effective in attenuating traffic-generated chemical constituents washing from the roadway, thus, inhibiting these constituents from reaching the water table.

SELECTED REFERENCES

- Hansen, E. A., and Harris, A. R., 1975, Validity of soil-water samples collected with porous ceramic cups: Soil Science Society American Proceedings, v. 39, p. 528-536.
- Hardee, Jack, Miller, R. A., and Mattraw, H. C., Jr., 1978, Stormwater-runoff data for a highway area, Broward County, Florida: U.S. Geological Survey Open-File Report 78-612, 166 p.
- Johnson, T. K., Cartwright, Keros, and Schuller, R. M., 1981, Monitoring of leachate migration in the unsaturated zone in the vicinity of sanitary landfills: Ground-Water Monitoring Review, v. 1, no. 3, p. 55-63.
- Klein, Howard, and Hull, J. E., 1978, Biscayne aquifer, southeast Florida: U.S. Geological Survey Water-Resources Investigations 78-107, 52 p.
- Miller, R. A., Mattraw, H. C., Jr., and Hardee, Jack, 1979, Stormwater runoff data for a commercial area, Broward County, Florida: U.S. Geological Survey Open-File Report 79-982, 120 p.
- Parker, G. G., Ferguson, G. E., and Love, S. K., and others, 1955, Water resources of southeastern Florida: U.S. Geological Survey Water-Supply Paper 1255, 955 p.
- U.S. Department of Agriculture, Soil Conservation Service, 1958, Soil survey (detailed reconnaissance) of Dade County, Florida: Series 1947, no. 4, 1 p.
- 1975, Soil taxonomy - a basic system of soil classification for making and interpreting soil surveys: Agriculture Handbook no. 436, 34 p.