MUNICIPAL SOLID-WASTE DISPOSAL AND GROUND-WATER QUALITY IN A COASTAL ENVIRONMENT, WEST-CENTRAL FLORIDA

By Mario Fernandez, Jr.

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CONTENTS

ILLUSTRATIONS

TABLES

ABBREVIATIONS AND CONVERSION FACTORS

Factors for converting inch-pound units to International System of Units (SI) and abbreviations of units

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
ton, short	0.9072	metric ton (t)
micromho (umho/cm at 25°C)	1.00	microsiemen (uS/cm at 25°C)

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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. NGVD of 1929 is referred to as sea level in the text of this report.

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GLOSSARY

This glossary presents simplified definitions of technical terms used in this report. For additional terms relating to the subjects see Langbein and Iseri (1960); U.S. Department of Health, Education, and Welfare (1970a; 1970b); Brunner and Keller (1972); and Lohman (1972).

Anaerobic digestion: Bacterial digestion of organic materials in the cells that occurs under oxygen-free conditions.
Aquifer: A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield water to wells and springs.
Artesian: Ground water that is under sufficient hydrostatic pressure to rise above the zone of saturation. Synonymous with confined.
Cell: The volume of compacted solid waste enclosed by natural soil or cover material in a landfill.
Chemical oxygen demand (COD): The amount of oxygen required to chemically oxidize organic and inorganic materials in leachate.
Cluster: The location of three or more wells of different depths within about 5 feet of each other; usually referred to as a well cluster.
Confined aquifer: An aquifer containing confined ground water.
Confined ground water: Water in an aquifer under pressure significantly greater than atmospheric. The aquifer's upper limit is the bottom of a bed of distinctly lower hydraulic conductivity than the material in which the confined water occurs.
Gradient: Change in elevation per unit distance.
Head: The elevation relative to some datum, generally sea level, of the upper surface of water that occurs in a well that penetrates an aquifer, also called static head.
Hydraulic conductivity: The property or capacity of a porous rock, sediment, or soil for transmitting a fluid.
Hydraulic gradient: Change of hydraulic head per unit distance.
Hydrogeology: Relating to ground water and geology.
Landfill: A well-planned, carefully designed, and properly located operation that is based on engineering methods and techniques, applied knowledge of hydrology and geology, and operated in a manner that protects and maintains the quality of our environment.
Leachate: A liquid emanating from a waste-disposal cell that contains dissolved, suspended, or microbial contaminants from the solid waste.
Porosity, effective: Refers to amount of interconnected pore space available for fluid transmission. It is expressed as a percentage of the total volume occupied by the interconnected interstices.
Potentiometric surface: As related to the confining aquifer, it is the level to which water will rise in tightly cased wells.
Solid waste: Synonymous with refuse.
Surficial (unconfined) aquifer: An aquifer in which the upper surface of the saturated zone, the water table, is at atmospheric pressure and is free to rise and fall.
Transmissive: Relates to rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient.
Water table: The upper surface of the zone of saturation.
Well cluster: See cluster.

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ABSTRACT

Two landfilling methods for disposal of municipal solid waste are used in the coastal environment of Florida: the trench method, also called "cut and cover," and the area method. A high water table along the coast causes problems when refuse in trenches is in contact with ground water. The saturated waste creates a point source of degraded water quality.

When water flows through solid waste, leachate is produced that contains dissolved and finely suspended inorganic and organic matter. Concentrations of chloride and ammonia nitrogen and chemical oxygen demanding substances are greater for old leachate (5 years or older) than for new leachate (24 hours to 1 week) as a result of anaerobic digestion of refuse. The quantities of contaminants produced vary, and contaminants may reoccur over a period of time. The rate of migration for leachate-laden ground water varies depending on the hydraulic gradient of the water table and the physical properties of the soil. In a Pinellas County landfill, the rate of horizontal migration is about 1.2 feet per year.

In the coastal area of west-central Florida, two basic hydrogeologic conditions occur: (1) permeable sand overlying clay and limestone and (2) permeable sand overlying limestone. The saturated portion of the overlying sand composes the surficial aquifer. In places, layers of clay separate the surficial aquifer from the limestone, or Floridan (artesian) aquifer, the principal source of water in the area.

Factors in landfill site selection are divided into two broad groups: visible and hidden. The visible factors include (1) land development; (2) surface drainage; (3) soil types; (4) swamps, streams, and lakes; (5) sinkholes; and (6) nearby individual and public-supply wells. Hidden factors are those that cannot be observed directly, such as: thickness and permeability of surficial sand, silt, and clay; depth to top of limestone; and sinkhole connection--either directly or indirectly with the underlying limestone aquifer.

After a prospective landfill site has been identified based on available information, additional information needed for a final site selection would include: the drilling of test holes around and within the site to determine the hydrogeologic properties; collection of corings from test holes for soil analysis; and installation of observation wells for water-level measurements and water-quality monitoring. Water levels measured in wells can be used to develop water-level contour maps and determine direction of ground-water movement. Monitoring the ground water of a landfill serves to: (1) establish ground-water quality before landfill operations begin and (2) determine changes in water quality and movement of altered ground water over a period of time by comparing sequential results.

Introduction of refuse into a ground-water system creates degradation. However, with careful site selection and a well-planned monitoring system, the negative impact upon surrounding areas can be minimized.

INTRODUCTION

The modern landfill that utilizes the procedures of daily or periodic covering of the refuse was developed during the 1930's in Fresno, Calif. (American Public Works Association, 1966). The customary method of handling wastes at landfills at that time was burning.

As population increased and cities expanded, problems arose with locating landfills close to the cities. Landfills needed to be reasonably close to centers of population to make them economically feasible (short hauling time) and, yet, sufficiently far away so that nuisances and odors would not be bothersome. The selection of landfill locations was made primarily based on economics with little thought given to environmental effects, especially effects on ground-water resources. Solid waste, which is synonymous with refuse, encompasses categories from garbage to sewage treatment residue. A list of categories, composition, and source is presented in table 1.

The greatest generator of municipal solid waste is the American middle-class family (J. Thompson, U.S. Environmental Protection Agency, oral commun., 1980). In Florida, generation of solid waste between 1975 and 1980 averaged approximately 4.5 pounds per day per person, or about 7.8 million tons per year. This amount is expected to increase by about 2 percent per year for the next 10 years, or by about 160,000 tons per year (J. Reese, Florida Department of Environmental Regulation, oral commun., 1980).

In 1975, the estimated daily tonnage of solid waste for Pinellas, Hillsborough, Manatee, and Pasco Counties in coastal west-central Florida was 3,757 tons per day. Of this amount, 2,742 tons, or about 73 percent, was paper and yard trash. Food accounted for only 10 percent of the total solid waste generated (Tampa Bay Regional Planning Council, 1975). The two most populous counties in the coastal area of west-central Florida, Hillsborough and Pinellas Counties, generate about 3,200 tons of solid waste each day.

This report explains how landfills can affect ground-water resources in a coastal environment. The report defines solid waste and briefly describes the four common methods for its disposal. The landfill method used in coastal west-central Florida is described in detail. It also presents hydrologic and geologic factors to be considered when locating landfills in a coastal environment and describes how to plan a water-quality monitoring program at a landfill site. Examples from other studies of the impact of landfills on ground water in coastal areas of west-central Florida are included.

The report was prepared for public officials, planners, and operational personnel who are interested in municipal solid-waste disposal. It is also intended for laymen concerned with problems of disposing of solid waste in an environmentally safe manner.

Table 1.--The nature of solid waste

[Modified from American Public Works Association, 1966]

Category	Composition	Sources
Garbage	Wastes from preparation, cooking, and serving of food; market wastes from handling, storage, and sale of produce.	Households, restaurants, institutions, stores, markets.
Rubbish	Combustible: paper, cartons, boxes, barrels, wood, excelsior, tree branches, yard trimmings, wood furniture, bedding, dunnage.	
	Noncombustible: metals, tin cans, metal furniture, dirt, glass, crockery, minerals.	
Ashes	Residue from fires used for cooking and heating and from on-site incineration.	
Street refuse	Sweepings, dirt, leaves, catch basin dirt, contents of litter receptacles.	Streets, sidewalks, alleys, vacant lots.
Dead animals	Cats, dogs, horses, cows.	
Abandoned vehicles	Unwanted cars and trucks left on public property.	
Industrial	Food processing wastes, boiler house cinders, lumber scraps, metal scraps, shavings.	Factories, powerplants.
Demolition wastes	Lumber, pipes, brick, masonry, and other construction materials from razed buildings and other structures.	Demolition sites to be used for new buildings, renewal projects, expressways.
Construction wastes	Scrap lumber, pipe, other construction materials.	New construction, remodeling.
Special wastes	Hazardous solids and liquids; explosives, pathological wastes, radioactive materials.	Households, hotels, hospitals, institutions, stores, industry.
Sewage treatment residue	Solids from coarse screening and from grit chambers; septic tank sludge.	Sewage treatment plants; septic tanks.

METHODS OF SOLID-WASTE DISPOSAL

Four methods of solid-waste disposal are commonly used in the United States: (1) landfilling, (2) incineration, (3) composting, and (4) resource recovery. The methods and problems involved with each are as follows:

1. Landfilling -- Landfilling is the burial of refuse with daily cover to prevent disease spread. Drawbacks to landfilling include esthetics, scarcity of suitable land, and contamination of the ground-water resources. This method is the only solid-waste disposal method used in coastal west-central Florida at present (1981) and is discussed in detail in subsequent sections of this report.

2. Incineration -- Incineration is the reduction of solid wastes by burning. Objections to incineration involve disposal of the burned material and air and water pollution. Water-pollution problems originate from scrubbers used in smoke, fly-ash, and odor emission-control units. Scrubbers are used for gas cleaning in which the gas is passed through a spray chamber (usually water in incinerators) to remove particulates. Wastewater from scrubber units is generally ponded and subsequently treated and disposed of. Air-pollution problems result if scrubbers are not used. Incineration residue, a mixture of unburned refuse, ashes, and metals (tin cans, and so forth), may degrade the water quality if in contact with surface or ground water. Incineration is presently giving way to resource-recovery plants in Florida and elsewhere.

3. Composting -- Composting is defined as "the biochemical degradation of organic materials to sanitary, nuisance-free, humus-like material" (American Public Works Association, 1966). With added chemicals, compost can be used as a mechanism for slow release of fertilizer and as a soil conditioner. The main drawbacks to composting are that the compost must be transported to areas where it can be used and residual metals, glass, and other materials must be disposed of by other methods. Manual separation of ferrous and nonferrous metals prior to composting is an added expense.

4. Resource recovery -- Resource recovery includes recovery of recyclable material, such as glass, metals, and paper. Generation of energy, in the form of steam, is produced by incineration of the remaining refuse. The steam can be used for heating or to drive steam turbines in generating electricity. As natural resources are depleted and energy costs rise, resource recovery and incineration of solid wastes to generate steam will probably increase. Following are some plants already in operation:

   Chicago, Ill. ... 1,000 tons per day capacity with the steam being sold to a candy manufacturer.

   Sagus, Mass. .... 1,400 tons per day capacity with the steam purchased by General Electric.

   Baltimore, Md. .. 600 tons per day capacity with the steam sold to the city of Baltimore.

   A resource-recovery plant in metropolitan Dade County, Fla., will soon be operational. The plant will handle between 3,000 and 3,700 tons per day. Steam produced will be sold to Florida Power and Light for generating electrical power. Maximum power generation will be 77 megawatts (Tom Henderson, Dade County Public Works Department, oral commun., 1980).

Pinellas County, Fla., is building a resource-recovery plant to handle about 2,000 tons of solid waste per day. Heat from burning garbage will produce sufficient steam to drive a 50.9 megawatt turbine generator; enough power to supply more than 25,000 homes. The generated power will be sold to Florida Power Corporation (Donald Acenbrack, Pinellas County Department of Solid Waste Management, written commun., 1982).

Some drawbacks to resource recovery include (1) economic value of the recovered product; (2) requirement of sufficient land to handle the accumulation of solid waste during down time; and (3) the cost-benefit ratio of establishing and operating the plant.

LANDFILLS

Modern type landfills have been in use about 50 years, a relatively short time considering how long man has been discarding solid waste. There are two landfilling methods commonly used: the trench method and the area method.

The trench method, also called "cut and cover," is a method whereby solid waste is deposited in "V"-shaped or flat-bottomed excavations. The excavated earth is placed to the side of the trench and is subsequently used as daily cover material for the cells (fig. 1). One problem in using this method in a coastal environment in Florida is the high water table. During the process of filling, trenches must be dewatered continuously by pumping water into nearby fields, canals, or retention basins. This method may also cause water-quality problems because the refuse in trenches is in contact with ground water, creating a source for water-quality degradation.

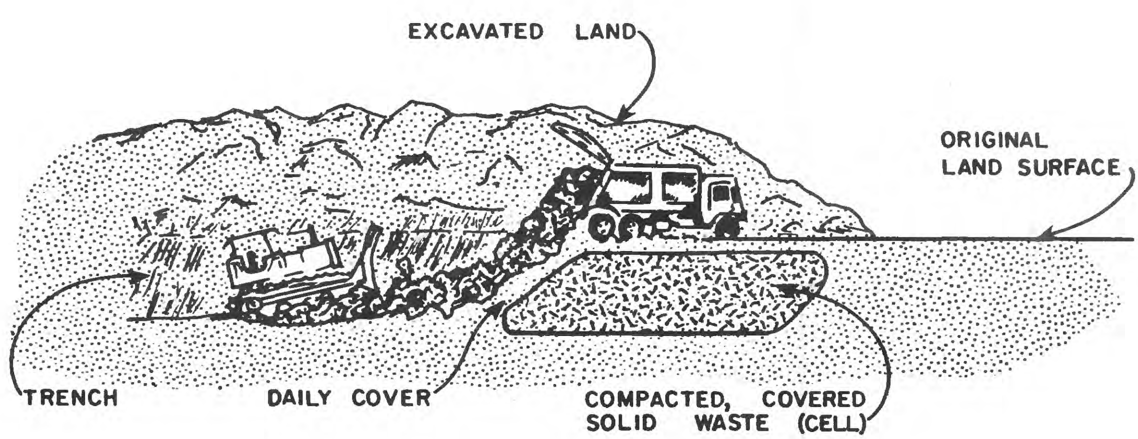


Figure 1.--Trench method of landfilling.

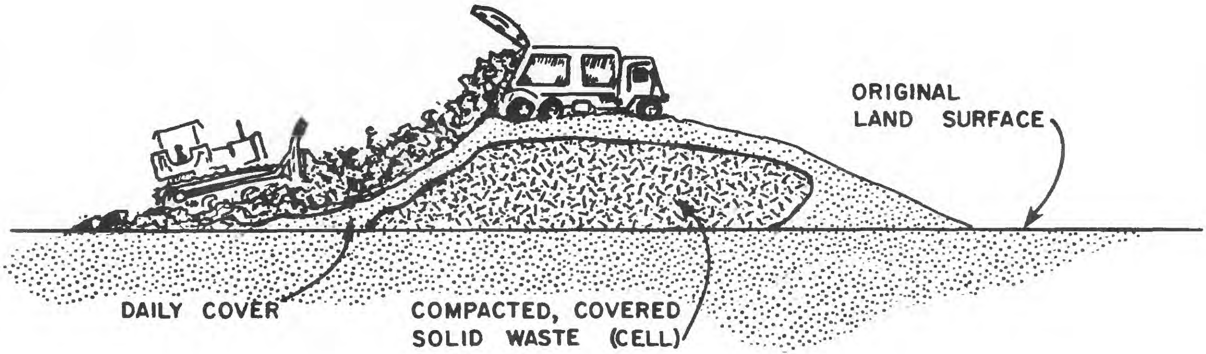


Figure 2.--Area method of landfilling.

The area method (fig. 2) is simply spreading, compacting, and covering refuse (cell) on natural land surfaces. This method is suitable for areas where the water table is high. In some areas, a natural seal, such as clay, is present or an artificial seal is installed to restrict the downward migration of pollutants to the ground water. In many areas, cover material must be hauled into such sites. In coastal west-central Florida, the costs of the material and hauling restrict use of the area method.

A common method of landfilling along the Gulf Coast is a combination of the trench and area methods (fig. 3). In this method of landfilling, called the high-rise method, operations are continued after trenches are filled by use of the area method. Solid-waste material in the trenches is compacted and covered and additional layers of solid waste are added to form mounds or fills that are higher than previous land-surface altitudes. This approach is used where sites suitable for landfills are limited or where land costs are high and operations at a site must be extended over long periods of time. Examples of the high-rise method of landfilling in coastal west-central Florida are Toytown landfill in Pinellas County, visible on the east side of Interstate 275 just south of County Road 686, and the Rocky Creek landfill in northwest Hillsborough County (fig. 4).

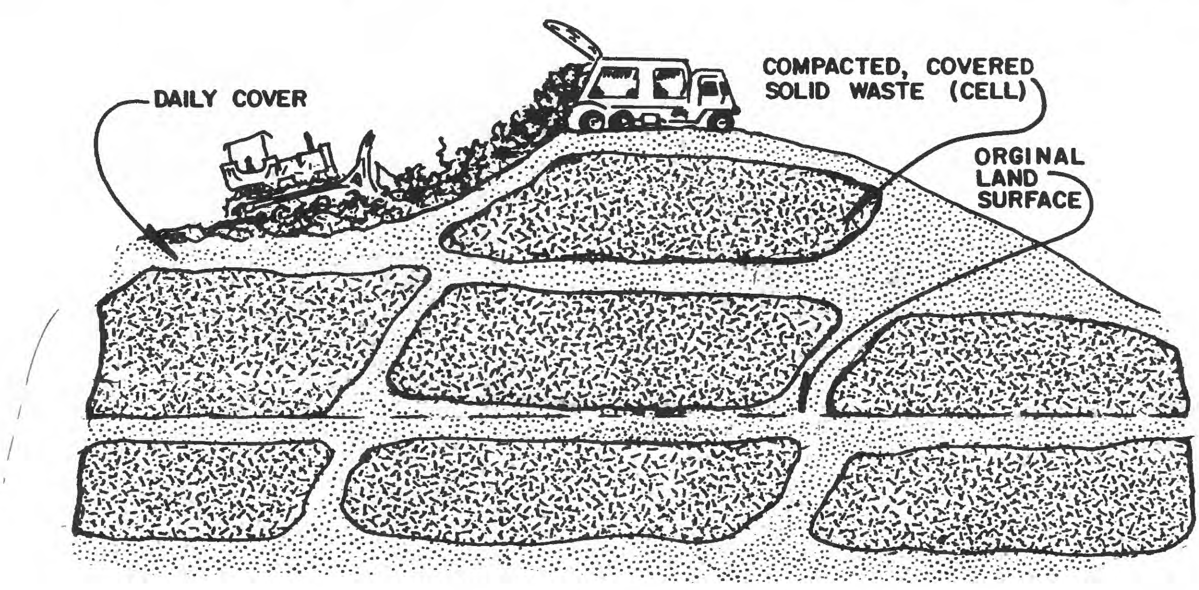


Figure 3.--High-rise method of landfilling.

A. Toytown landfill, Pinellas County.

B. Rocky Creek landfill, Hillsborough County.

Figure 4.--Examples of high-rise landfills in coastal west-central Florida.

CONSIDERATIONS IN LOCATING LANDFILL SITES

The criteria for site selection of landfills should be based on hydrologic and geologic considerations. Stewart and Duerr (1973) described site selection as follows:

> "The disposal of solid waste in west-central Florida is an involved process: selecting sites for landfills only on the basis of hydrologic and geologic criteria will insure minimal pollution of the water resources, particularly because of the limestone terrane. Undoubtedly, any site selected will have some undesirable features. However, modifying one or more of these features might make the site acceptable insofar as protection of the water resources is concerned.
>
> "Factors in landfill site selection are divided into two broad groups, visible and hidden. The visible factors are those that are familiar to many people, particularly planners, designers, and operational personnel who are directly involved in the solid-waste field. These factors include: (a) land development; (b) surface drainage and topography; (c) soil types; (d) swamps, streams, and lakes, including their drainage areas; (e) sinkholes; and (f) nearby individual and public-supply wells.
>
> "The hidden factors are those that cannot be observed directly and require personnel experienced in hydrology and geology to obtain the specialized types of information needed to make a site evaluation for a landfill operation. The hidden factors include: (a) type, thickness, and permeability of surficial sand, silt, and clay; (b) depth to top of limestone; (c) depth to and thickness of relatively impermeable clay zones; (d) depth o water table and direction of shallow ground-water flow, (e) depth to ter level in artesian aquifer and direction of ground-water flow; (f) tering capacity of clays; and (g) sinkholes connected either directly ndirectly with the underlying limestone aquifer."

Prospective Landfill Sites

Two areas that have hydrologic and geologic conditions favorable for landfills are shown in figure 5. Both areas are well drained, have deep water tables and relatively thick and extensive underlying clay layers, and are remote from urban development and areas of large ground-water withdrawals.

Unfavorable Landfill Sites

Several hydrologic and geologic factors in coastal west-central Florida, considered to be unfavorable for disposal of solid waste, include (Stewart and Duerr):

1. Poorly-drained, swampy sites.
2. Sites containing sinkholes.
3. Areas where the Floridan aquifer is at or within a few feet of land surface.

A. Site is on a well-drained, wooded area having a thick sand cover and a deep water table. The area is undeveloped and water drains naturally from the site.

B. Site has a thick cover of sand and clay, a deep water table, and nearby highways. It is in a rural area outside a large city, and surface drainage does not discharge into a potable body of water. Some overburden has been removed for road beds (Stewart and Duerr, 1973).

Figure 5.--Examples of sites that are favorable for landfill operations.

4. Sites near lakes and springs.
5. Sites near streams.
6. Low-lying, flood-prone areas.
7. Limestone quarries and sand and phosphate pits where limestone has been exposed.
8. Sites near public water-supply well fields.

Figure 6 shows sites that have one or more unfavorable features. For each proposed landfill site, in addition to geologic and hydrologic information, political, economic, and esthetic factors need to be evaluated to decide whether to develop the site or reject it.

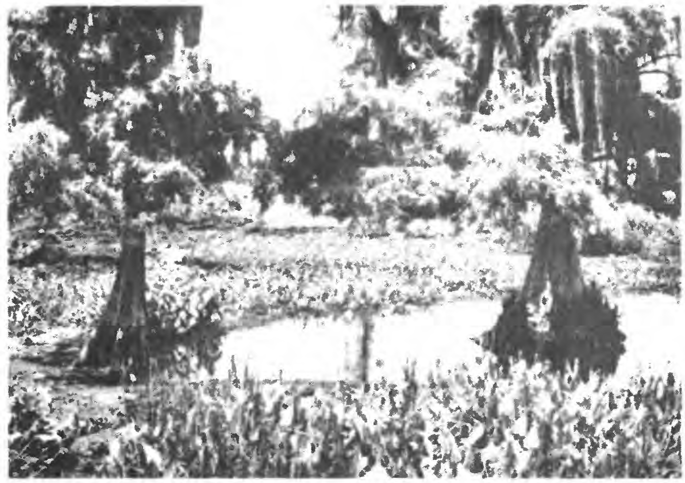
LEACHATE

When rain, surface water, or ground water flows through solid waste, it produces leachate that may have high concentrations of dissolved organic and inorganic matter. The dissolved matter can be simple inorganic salts leached from the waste materials or complex organic compounds that are produced by microbial decomposition of organic waste and released as a liquid.

The occurrence of leachate in ground water can be determined by analyzing water samples for physical, chemical, and biological indicators (table 2). Indicators, such as pH, hardness, chemical oxygen demand, tannins, and nitrogen species, may be present in ground water prior to degradation by leachates. For example, pH, a term that is used to express the intensity of an acid or alkaline condition of a solution (ground water), can be low due to natural acid conditions caused by tannins (a natural organic acid produced by decomposition of plant material). Therefore, caution must be used in selecting indicators of leachate and in evaluating their concentration levels when monitoring leachate movement.

Selected constituents and physical properties of leachate less than 1 week and more than 5 years old from filled cells in a Pinellas County landfill are compared in table 3 to the range of these constituents as reported from other landfills. Concentrations of chloride, ammonia nitrogen, and chemical oxygen demand are higher for old leachate than for new leachate. The same is true for specific conductance, a measure of dissolved solids in water. These constituents increase as a result of the anaerobic digestion of refuse. Decrease in nitrate nitrogen is due to the biological conversion of nitrates to nitrogen or ammonia.

In the Pinellas County landfill study, a distinctive peak in concentrations of some constituents (which also reflect leachate production) in ground water was observed in two wells downgradient from and near the landfill. The peaks indicate that the quality of leachate produced is variable. Figure 7 shows concentrations of some constituents "peaking" at about the same time followed by decreasing concentrations. For example, specific conductance, chloride, and ammonia nitrogen in samples from well 2 peaked in mid-1976 and gradually decreased thereafter. Concentrations of these constituents in well 3, more distant from the landfill, peaked in mid-1977, indicating migration of leachate. Although not shown, cyclic peaks have been observed, apparently the result of slugs of water from infiltrating rainfall moving through the landfill and into the adjacent aquifer.



A. Most swamps contain water throughout the year. Generally, this water represents the shallow water table. These swamps are unfavorable for solid-waste sites because contaminating both the surface and ground water is almost certain (Stewart and Duerr, 1973).

B. Swamps that dry up during normal dry weather periods are poor sites for landfills because they flood periodically, are difficult to drain, and buried waste can easily pollute the water.

Figure 6.--Examples of sites that are unfavorable for landfill operations.

Table 2.--Leachate indicators

[Modified from U.S. Environmental Protection Agency, 1977. For further information on the indicators, see: Chiam and DeWalle, 1977; Sawyer and McCarty, 1978; American Public Health Association, 1975; Manahan, 1972; McKinney, 1962; or other references that deal with water chemistry.]

Physical characteristics	Chemical constituents and characteristics		Biological characteristics
	Organic	Inorganic	
Appearance	Phenols	Total bicarbonate solids (TSS, TDS)	Biochemical oxygen demand (BOD)
pH extremes	Chemical oxygen demand (COD)	Volatile solids	Coliform bacteria (total, fecal, and fecal streptococcus)
Oxidation-reduction potential	Total organic carbon (TOC)	Chloride	Standard plate count
Conductivity	Volatile acids	Sulfate	
Color	Tannins, lignins	Phosphate	
Turbidity	Organic nitrogen	Alkalinity and acidity	
Temperature	Ether, soluble (oil and grease)	Nitrate nitrogen	
Odor	Organic functional groups as required	Nitrite nitrogen	
	Chlorinated hydrocarbons	Ammonia nitrogen	
	Methylene blue substance (MBAS)	Sodium	
		Potassium	
		Calcium	
		Magnesium	
		Heavy metals	
		Cyanide	
		Fluoride	

Microbial activity produces numerous organic compounds as indicated by Robertson and others (1974). Their study indicated that compounds ranging from simple organic acids (end products of bacterial decomposition of carbohydrates) to fumigants and salts (used for varnish driers) are leached from decomposed manufactured goods. Some end products of refuse decomposition and leaching are highly toxic. It is important that these "waste products" be identified and monitored to protect ground water from contamination.

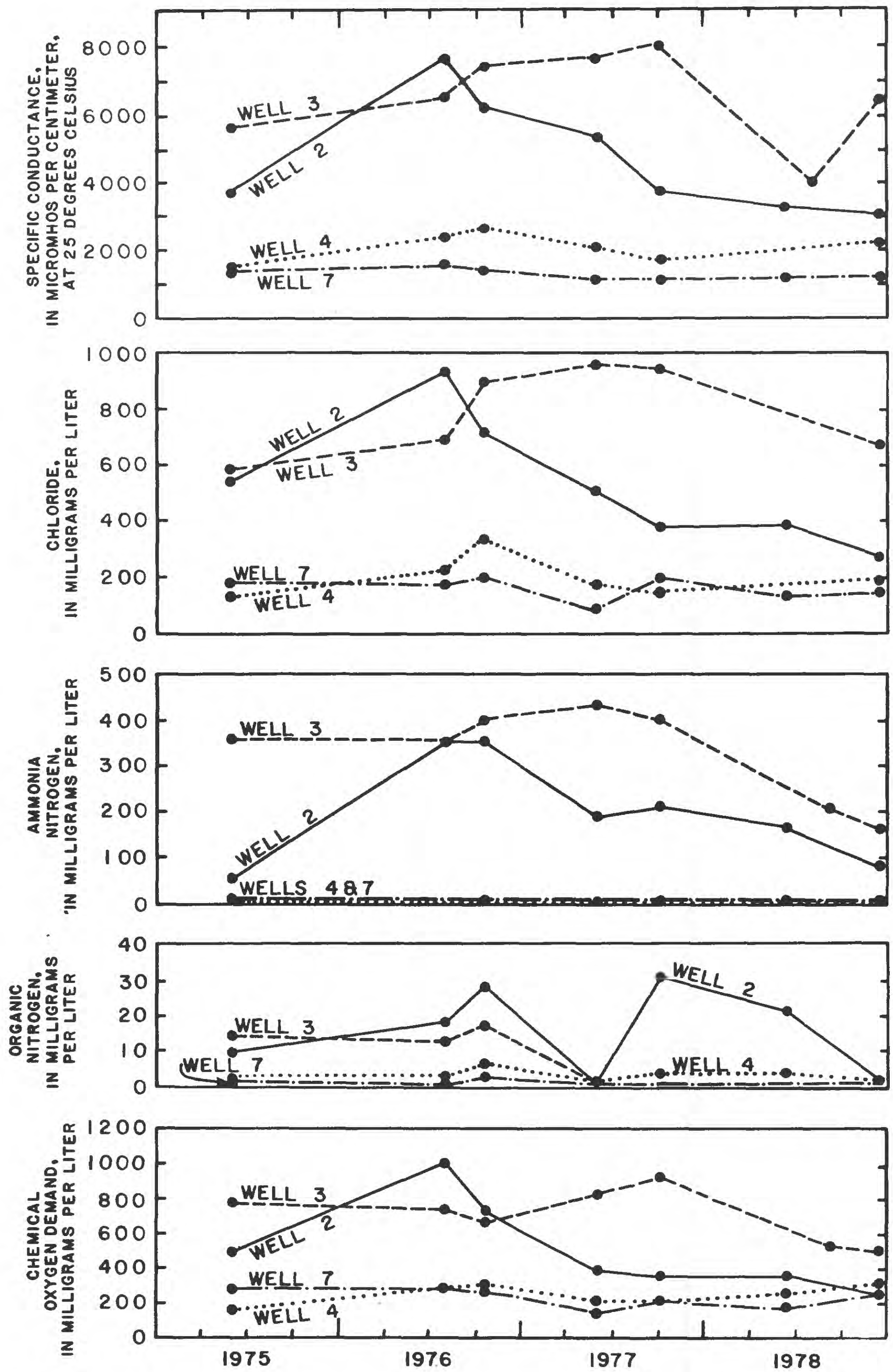


Figure 7.--Concentrations of selected constituents in water from wells at a Pinellas County landfill (from Fernandez, 1982).

Table 3.--Selected constituents of leachate from the Pinellas County landfill and the range of these constituents as reported from other landfills

Parameter	Pinellas County landfill leachate[1/]		Range of composition from different sources
	New[2/]	Old[3/]	
Specific conductance (umho/cm at 25°C)	1,750	4,370	2,810-16,800[4/]
Chloride[5/]	110	420	4.7-2,467[4/]
Total organic nitrogen[5/]	9.3	7.3	2.4-482[6/]
Ammonia nitrogen[5/]	0.81	340	0-1,106[4/]
Nitrite + nitrate nitrogen[5/]	0.23	0.13	0.2-10.29[6/]
Chemical oxygen demand (COD)[5/]	380	535	40-89,520[4/]
Total cadmium (Cd)[7/]	2	0	30-17,000[4/]
Total chromium (Cr)[7/]	140	40	15-18,000[4/]
Total copper (Cu)[7/]	20	13	0-9,900[4/]
Total lead (Pb)[7/]	30	24	200-3,120[4/]
Total zinc (Zn)[7/]	250	70	0-370,000[4/]

1/ Fernandez, 1982.
2/ 24 hours to about 1 week old.
3/ More than 5 years old.
4/ Chiam and DeWalle, 1977.
5/ Concentrations in milligrams per liter.
6/ Brunner and Keller, 1972.
7/ Concentrations in micrograms per liter.

In low-lying coastal areas of Florida, filled landfill trenches or cells are often within the water table. The rate of leachate migration through these landfills is controlled by (1) hydraulic gradient, (2) effective porosity of the unconfined or surficial aquifer, and (3) horizontal hydraulic conductivity. The calculated rate of ground-water flow from the Pinellas County landfill through the surficial aquifer under natural conditions is about 0.0032 foot per day or 1.2 feet per year. Similar values, 0.0029 foot per day or 1 foot per year, were reported by Hutchinson and Stewart (1973) for a landfill about 1 mile east of the Pinellas County landfill. This rate is probably representative of the surficial aquifer in many coastal areas with similar hydrologic conditions.

GAS PRODUCTION

Gas is produced naturally when solid waste decomposes. An example of gas production from decomposition of refuse in completed cells of waste material is shown in figure 8. The figure shows gas bubbling through pooled water at the Toytown landfill, Pinellas County, Fla. The quantity and composition of the gas is dependent on the composition of the solid waste (Brunner and Keller, 1972). Gas is produced as a result of aerobic and anaerobic processes in completed landfill cells and is dependent upon the rate of microbial decomposition.

Figure 8.--Gas production from completed landfill cells, Toytown landfill, Pinellas County.

In a study in California (County of Los Angeles and Engineering-Science, Inc., 1968), the initial gas generated from a landfill was found to be carbon dioxide with traces of methane. Low levels of methane production were probably due to newness of the fill in which methane-producing bacteria had not yet become established. The carbon dioxide was a product of oxidation of organic material. In the California study, methane production increased to levels of up to 60 percent volume to volume at the periphery of the fill. Levels as high as 10 percent volume to volume were found 600 feet from the fill. Methane will burn in air when the volume-to-volume level is greater than 5 percent (Chemical Rubber Company, 1968).

Gases will move upward and laterally by convection and diffusion through voids in the soil. The extent of methane migration will increase as soil porosity increases (Moore, 1976). Methane can be vented by engineering methods and then would not migrate laterally. Observation of stresses on or death of vegetation can be used to estimate distances of migration of methane. Affected vegetation need not be next to the landfill because gas can travel laterally under the soil surface and appear at some distance from the landfill (Flower, 1976).

AQUIFERS: SURFICIAL AND FLORIDAN

In the coastal area of west-central Florida, two basic hydrogeologic conditions occur: (1) unconsolidated permeable sand overlying clay and limestone and (2) unconsolidated permeable sand overlying limestone. The saturated part of the overlying sand composes the surficial aquifer. The sand ranges from medium to very fine and from a few feet to several tens of feet in thickness. In places, clay units up to 50 feet in thickness separate the aquifer from the underlying limestone and dolomite rocks of the confined Floridan (limestone) aquifer.

Water from the surficial aquifer generally is not used except for lawn irrigation. The confined ground water of the Floridan aquifer is the principal aquifer in the area. Of the total freshwater use in 1979 in west-central Florida, about 84 percent was ground water, most of which was obtained from the highly productive limestone aquifer (Duerr and Trommer, 1981). About 28 percent of the ground water was used for domestic purposes, whereas irrigation and industrial use was about 41 and 31 percent, respectively. If this highly productive aquifer were permitted to become contaminated, the results could be disastrous.

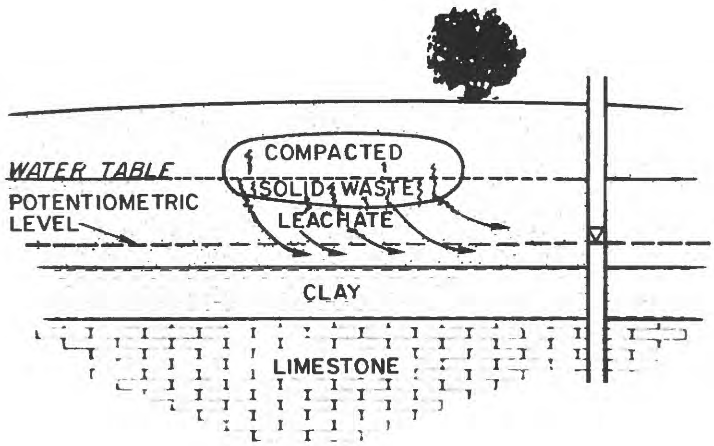
Preferable geologic conditions for the location of landfills in coastal areas of west-central Florida are thick sand beds; a water table that is at least 20 feet below land surface during wet seasons; and an underlying thick, continuous, confining clay layer. In addition, the altitude of the water table should be lower than the potentiometric surface of the underlying aquifer to prevent vertical movement of leachate downward into the limestone or underlying aquifer. The vertical movement of water from the surficial aquifer into the limestone aquifer occurs when the water table is at a higher altitude than the potentiometric surface.

Three typical hydrologic conditions at landfills in coastal west-central Florida are:

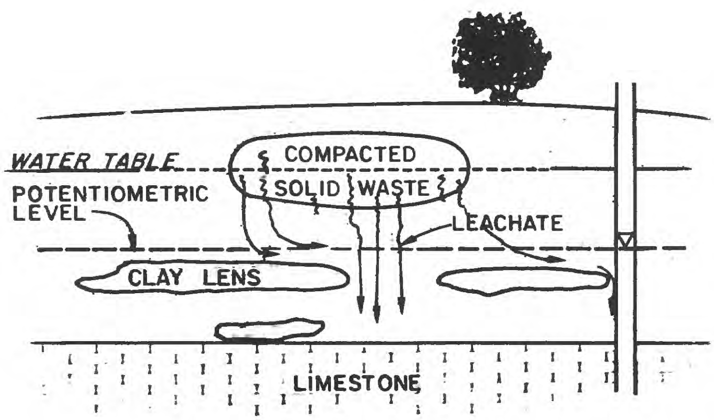
1. The water level in the surficial aquifer is higher than the potentiometric surface of the confined limestone aquifer;
2. The water level in the surficial aquifer is lower than the potentiometric surface; and
3. The surficial aquifer is absent.

Differences in water levels or head differences between the surficial aquifer and the limestone aquifer can be increased by pumping from the limestone aquifer, thus lowering its water level.

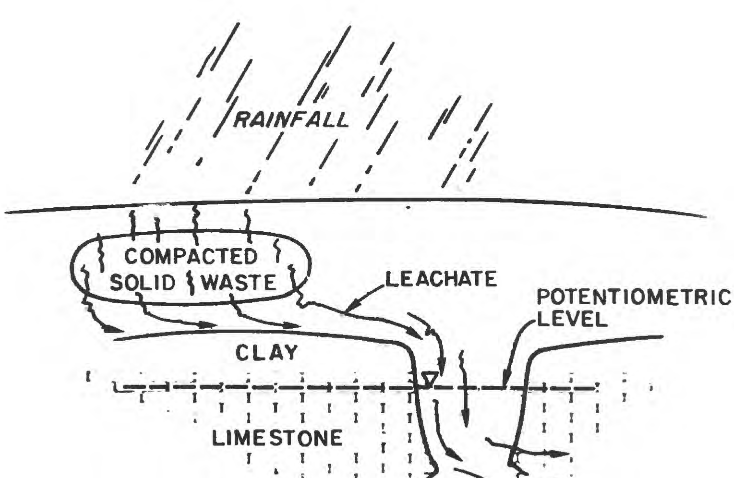
The hydrologic and geologic conditions that may be encountered at landfills and the possible migration of leachate are as follows:



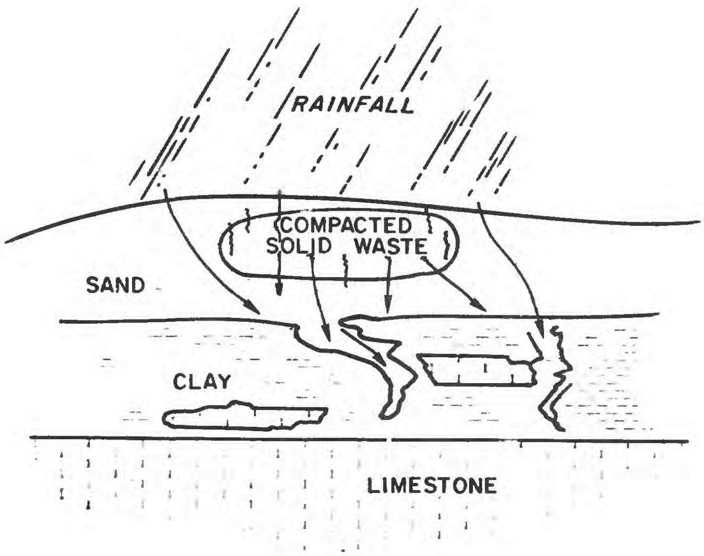
Hydrologic condition: Water table is present and its level is higher than the potentiometric surface in the limestone aquifer. Trench is located in the sandy surficial aquifer with a clay layer between the sand and limestone aquifer. In this condition, leachate moves vertically and then laterally along the most permeable zone above the clay layer.



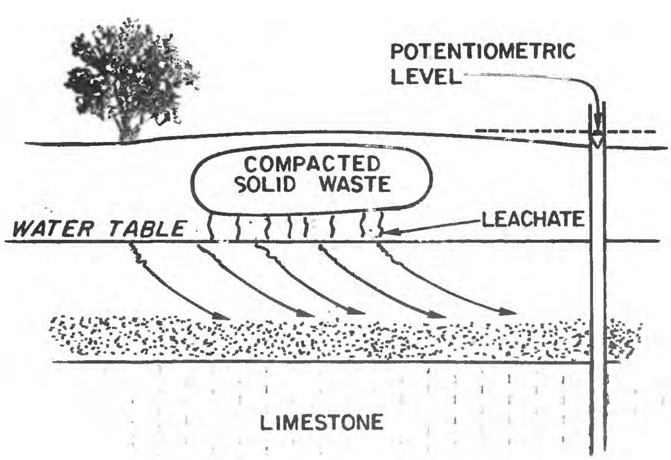
Hydrologic condition: Water table is present and its level is higher than the potentiometric surface. Trench is located in the sandy surficial aquifer and clay lenses occur between the sand and limestone aquifer. In this condition, leachate moves vertically through the sand or laterally along the clay lens. Some flow of leachate to the limestone aquifer may occur.



Hydrologic condition: Water table is absent, clay layer is breached by relict sinkholes, and trench is located in the sandy unconsolidated material with internal drainage. In this condition, rainfall percolates through the filled trench and leachate travels laterally toward the sinkholes and then vertically into the limestone aquifer.



Hydrologic condition: Water table and clay confining layer are absent. Trenches are located in unconsolidated sand, sandy limestone, and clay layers. In this condition, rain percolates through filled trenches and leachate travels vertically through weathered limestone into the limestone aquifer.



Hydrologic condition: Water table is present and its level is lower than the potentiometric surface. Trenches are located in unconsolidated sand and permeability decreases with depth due to relatively impermeable layers consisting mainly of very fine sand to silt overlying the limestone. The silty layer acts as a retardant to flow. In this condition, leachate moves vertically and laterally along the hydraulic gradient. The limestone aquifer has little chance of contamination by leachate because the driving force is up from the limestone aquifer into the surficial aquifer.

MONITORING LANDFILLS

After a prospective landfill site has been selected on the basis of available information, test holes are drilled around and within the site to determine hydrogeologic properties and direction of ground-water movement. Data from test holes include thickness and nature of sediments in the surficial aquifer, thickness of underlying clay layers, and configuration of the top of the limestone aquifer. After wells are established, water levels in the surficial aquifer and the potentiometric surface in the limestone aquifer are measured to determine whether the leachate could migrate into the limestone aquifer.

Locations of wells and the altitude of water levels of the aquifers present are plotted on maps and used to draw contours of the water table and potentiometric surfaces. Direction of ground-water flow can then be determined by drawing lines perpendicular to the contours from the high to low altitudes. These lines indicate the generalized direction of ground-water movement and can be used to locate monitor wells upgradient and downgradient from the landfill.

During drilling of test holes, corings (samples) are obtained for field geologic descriptions and laboratory analyses. The descriptions can be used to make sections showing hydrogeologic units (fig. 9). Once test holes have been drilled and samples collected for soil analysis, selected holes are then equipped with casings of large enough diameter to permit a drop pipe to be installed in the well; sections of screen are installed so the wells may be used for periodic water-level measurements and water-quality monitoring. The drop pipes are installed in each well to prevent any cross contamination between wells that may occur when a hose is used to pump the standing water out of the wells prior to collection of water samples.

Test holes at proposed landfills provide information on depth to water, thickness of the overburden (sands and clays), and depth to the limestone aquifer. Samples taken from corings can be tested in the laboratory for the following physical properties:

1. Grain size -- determines percentage of soil sizes from gravel (2 to 4 millimeters in diameter) to clay (less than 0.004 millimeter in diameter).

2. Permeability (vertical and horizontal) -- determines how fast water moves through the soil.

3. Effective porosity -- determines the available pore spaces for holding water.

4. Ion-exchange capacity -- determines the ability of the sand and clay to adsorb chemicals (cations and anions) in solution.

5. Mineral and clay analysis -- identifies percentage of clay and minerals in the sediments.

After determining the nature and distribution of sediments and geologic descriptions in the field, clusters of wells around the landfill, drilled to various depths, can be used to define lateral and vertical changes in water properties of the soil and chemical conditions of the water. Each well in a cluster is open to only one aquifer or zone. The wells are constructed so that interchange of water will not occur through the annulus space from surface runoff or from other water-bearing zones. Samples from various depth intervals can be used to determine vertical and lateral rates of leachate movement.

When wells are completed, the altitude is determined for the point from which water-level measurements will be made. By establishing the altitude of the wells, water levels can be measured to a common datum--a requirement for drawing contour maps of the water surface of any aquifer.

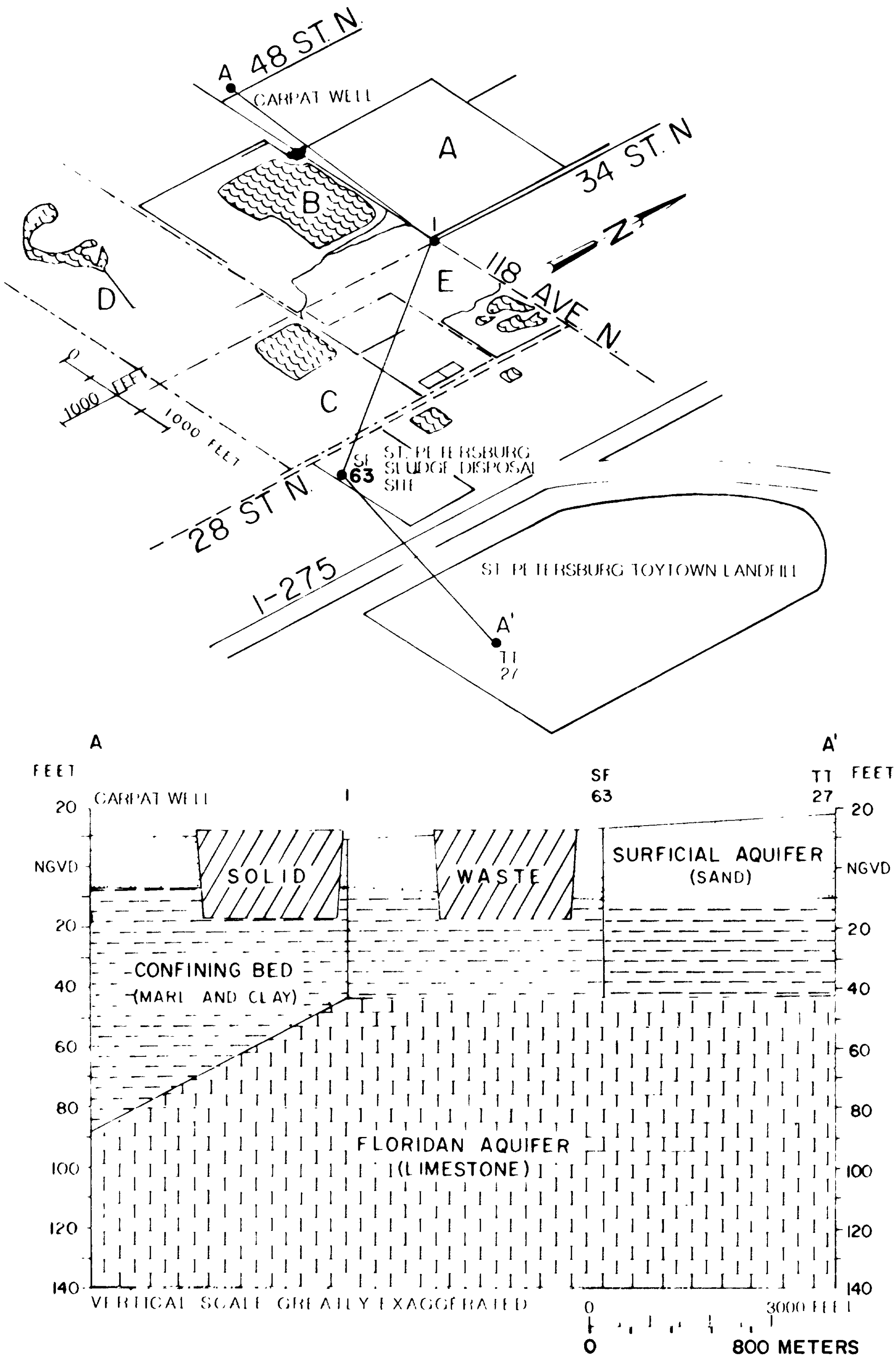


Figure 9.--Generalized hydrogeologic section at Pinellas County landfill (modified from Fernandez, 1982).

Water-Level Measurements

The observation-well network is used to monitor fluctuations in ground-water levels and to determine direction of ground-water movement. The following is an example of how water levels are used in hydrologic studies at a landfill site in Hillsborough County.

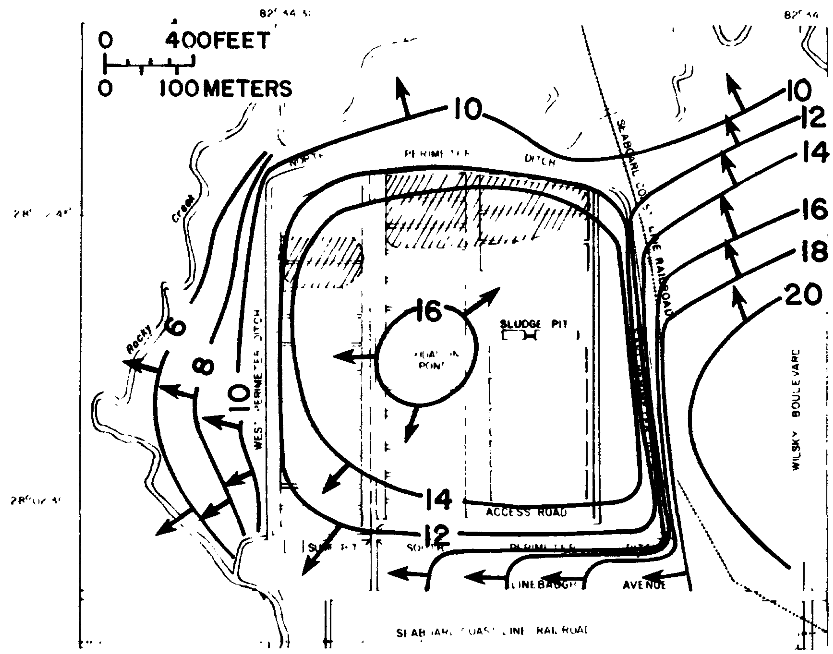
Water levels measured from wells at the Rocky Creek landfill near Tampa, Fla., were used to develop the water-level contour maps shown in figure 10. Figure 10a shows altitudes and direction of ground-water movement in the surficial aquifer, and figure 10b shows similar data for the limestone aquifer. A comparison of water-level contours shows that altitudes of the potentiometric surface of the limestone aquifer are higher than those of the surficial aquifer. As discussed earlier, under these conditions, leachate tends to move laterally and, thus, would not contaminate the limestone aquifer. If the opposite situation occurs, where the water table is higher than the potentiometric surface in the limestone aquifer, leachate would move laterally and vertically. However, existence of confining layers would inhibit vertical movement and contamination of the limestone aquifer.

Water-Quality Monitoring

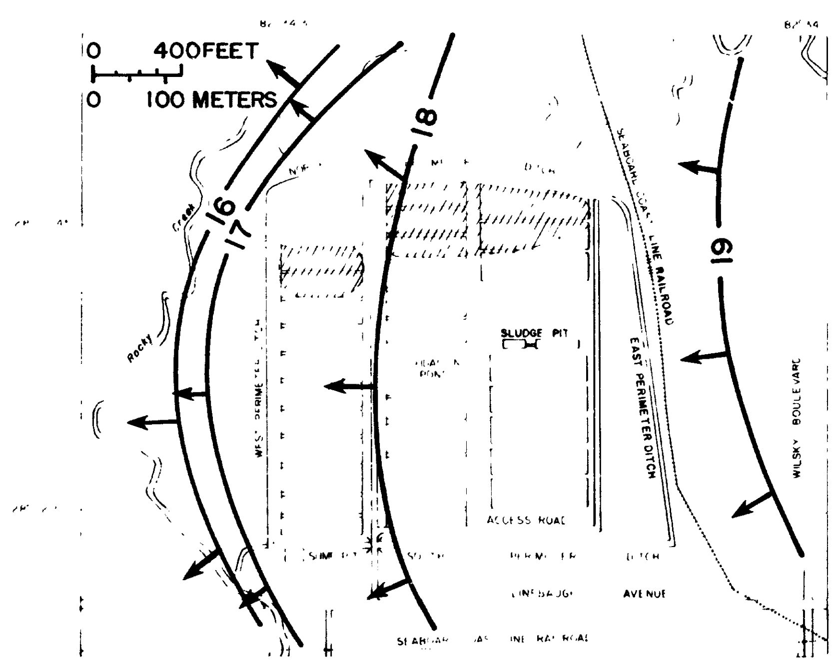
The purpose of monitoring ground-water quality is twofold: (1) to establish ground-water quality before landfill operations begin and (2) to determine changes in water quality over time by comparing results with previous analyses. Because chemical analyses are often expensive, only selected constituents that represent organic and inorganic constituents of leachate need to be analyzed for detecting leachate migration. Selection of indicators to be analyzed depends upon several considerations, including the following (U.S. Environmental Protection Agency, 1977):

1. Type of monitoring network: monitoring of the surficial sands compared to locating wells in solution openings or fractures in carbonate rock.
2. Indicator's tendency to decrease.
3. Background-water quality.
4. Location of well being sampled: monitoring wells upgradient to the landfill show the general quality of the ground water before it enters the landfill.
5. Purpose of monitoring: to design leachate control strategy, to collect data for regulatory purposes, and to develop and verify engineering design criteria.
6. Type of solid waste handled: domestic, industrial, or mixed.
7. Other considerations: cost, regulatory standards to be met, availability of laboratory equipment, availability of personnel, and simplicity and precision of determination.

Physical, chemical, and biological constituents and their concentrations in leachate have been presented previously (tables 1 and 2). Examples of how water-quality measurement may be used to detect and determine the extent of



A. Surficial aquifer.



B. Limestone aquifer.

Figure 10.--Water-level contours of the surficial and limestone aquifers, Rocky Creek landfill, Hillsborough County (J. W. Stewart, U.S. Geological Survey, written commun., 1981).

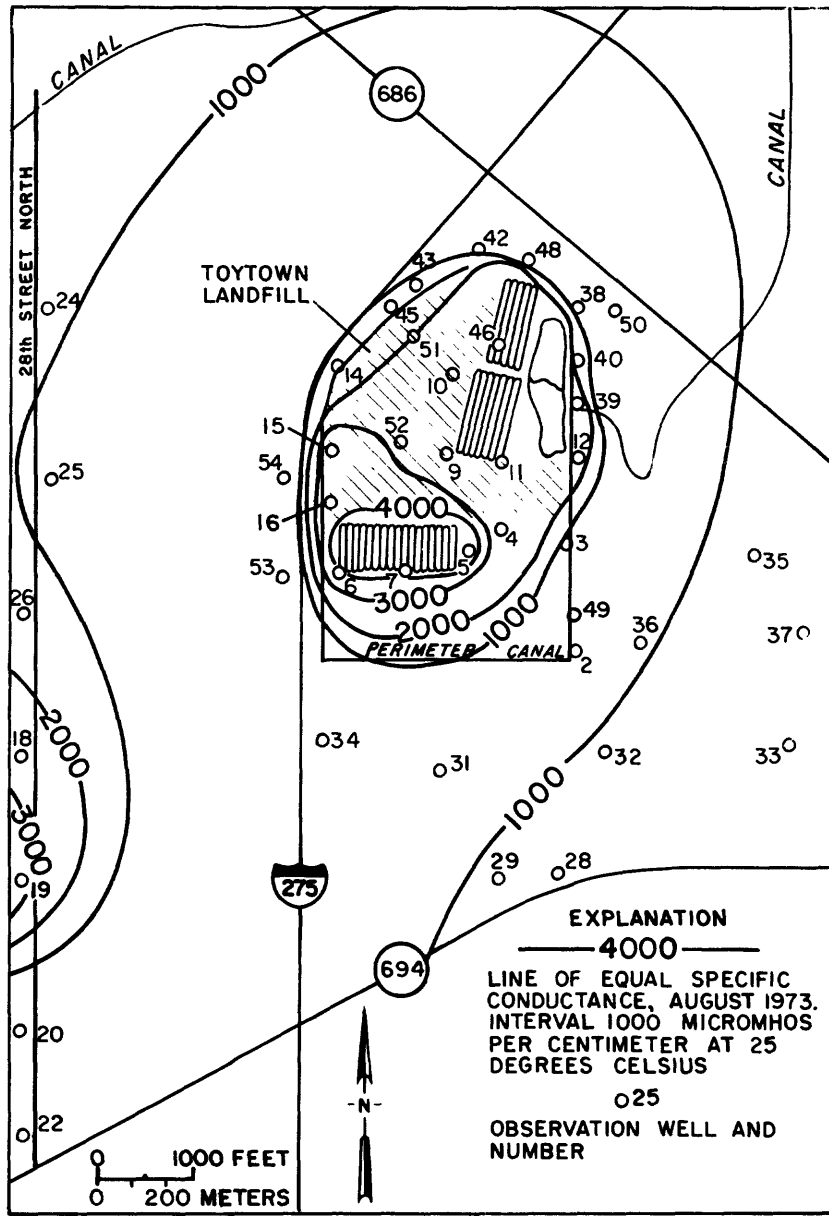
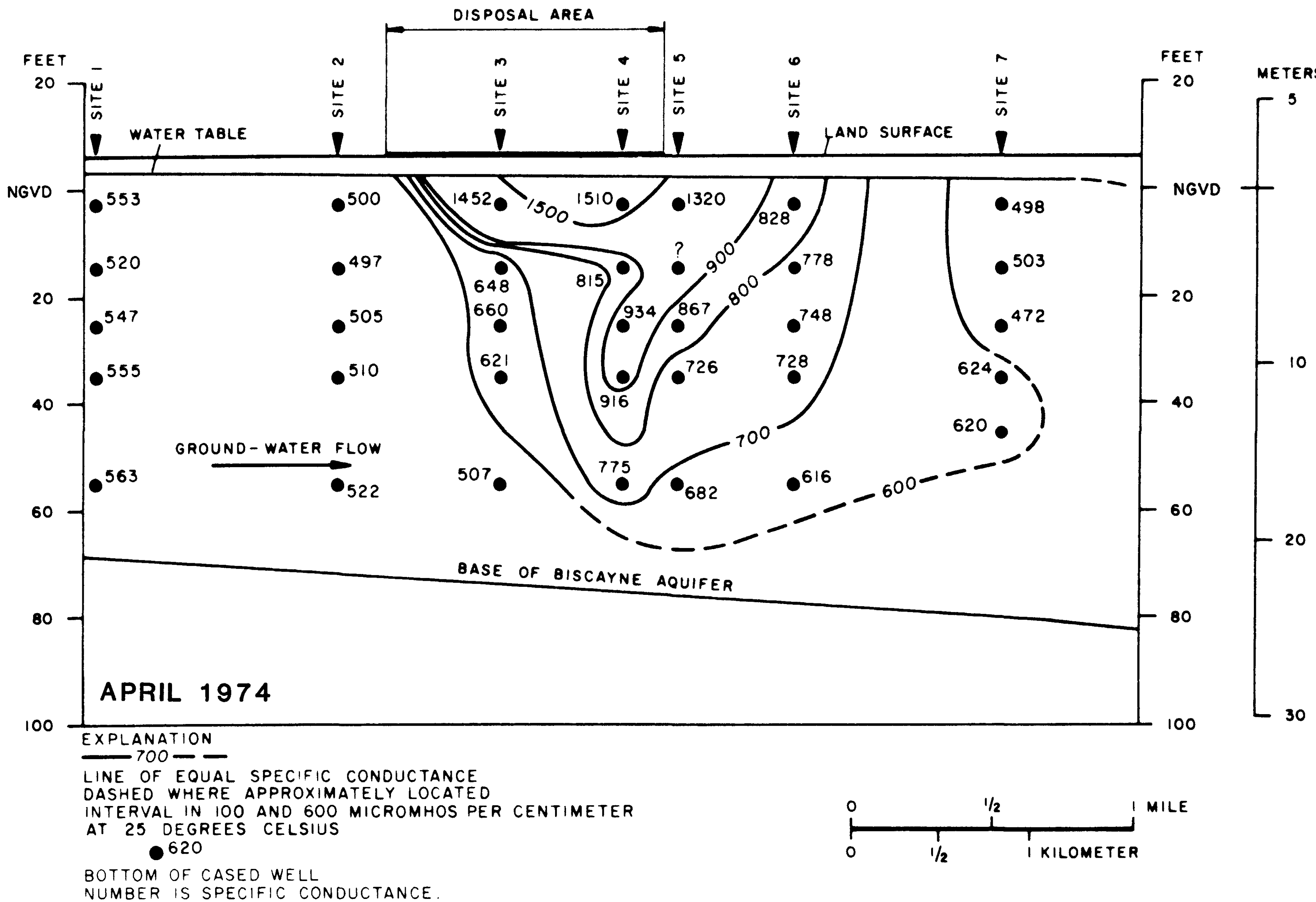


Figure 11.--Lines of equal specific conductance of water in the surficial aquifer at the Toytown landfill area, Pinellas County (from Hutchinson and Stewart, 1978).


DISPOSAL AREA
FEET
20
NGVD
20
40
60
80
100
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
WATER TABLE
LAND SURFACE
553
520
547
555
563
500
497
505
510
522
1452
648
660
621
507
1510
815
934
916
775
1320
?
867
726
682
828
778
748
728
616
498
503
472
624
620
1500
900
800
700
600
GROUND-WATER FLOW
BASE OF BISCAYNE AQUIFER
APRIL 1974
METERS
5
10
20
30
EXPLANATION
700
LINE OF EQUAL SPECIFIC CONDUCTANCE
DASHED WHERE APPROXIMATELY LOCATED
INTERVAL IN 100 AND 600 MICROMHOS PER CENTIMETER
AT 25 DEGREES CELSIUS
620
BOTTOM OF CASED WELL
NUMBER IS SPECIFIC CONDUCTANCE.
0
1/2
1 MILE
0
1/2
1 KILOMETER

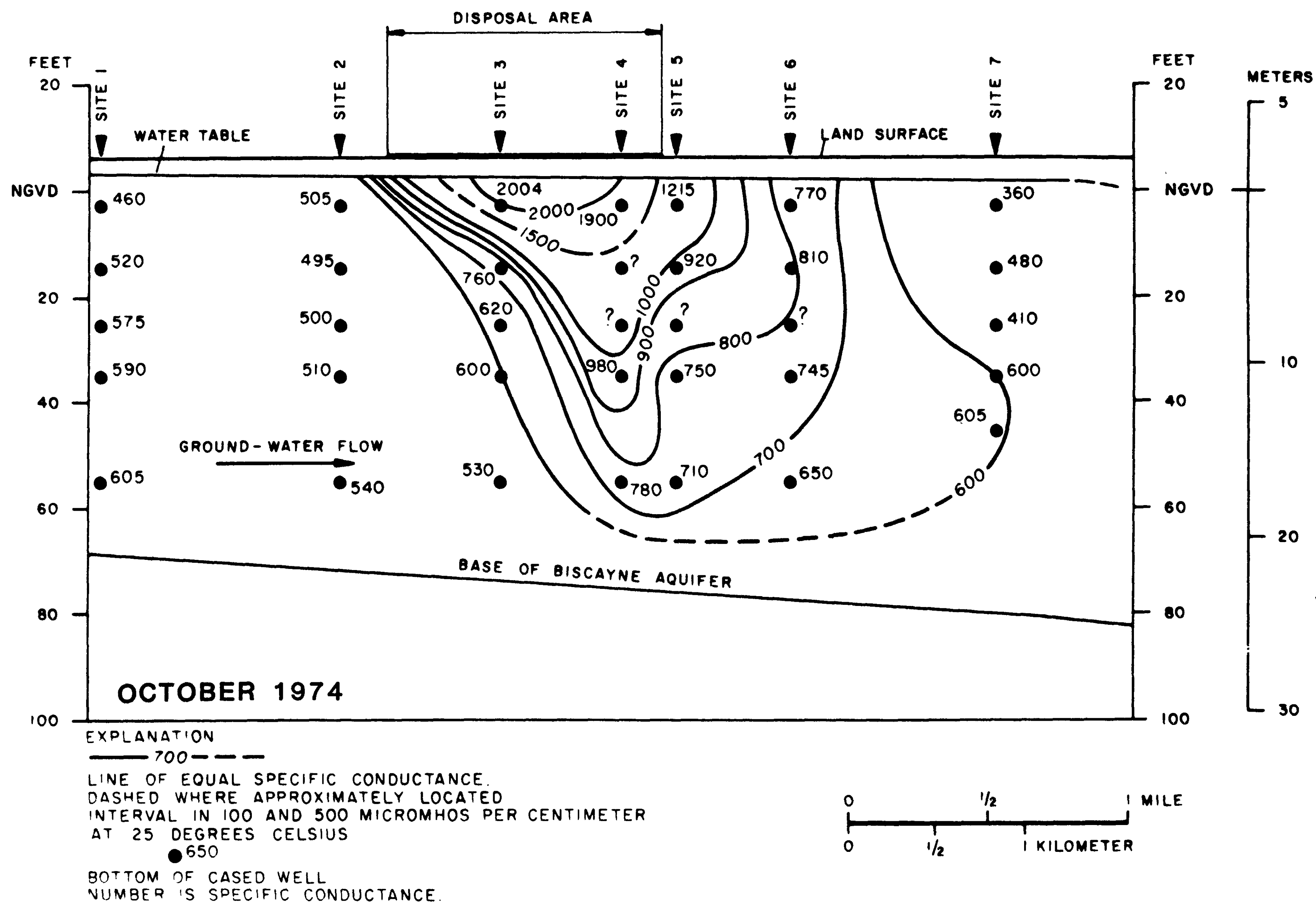


Figure 12.--Lines of equal specific conductance for April and October 1974 in a coastal south Florida landfill (from Mattraw and others, 1978).

leachate migration are presented in figures 11 and 12. Figure 11 shows lines of equal specific conductance of water in the surficial aquifer at the Toytown landfill area, Pinellas County (Hutchinson and Stewart, 1978). Specific conductance levels of 3,000 and 4,000 micromhos in the southwest area of the landfill indicate that migration from ponds that contain anaerobically digested sewage-treatment plant sludge occurred. Leachate appears to be moving laterally to the south from the landfill area. Figure 12 shows movement of leachate in profile or cross section at a landfill in south Florida. The figure shows changes in concentrations over a 6-month period (Mattraw and others, 1978). The leachate moves downward and to the right in the direction of ground-water flow. Profile lines of equal value in figure 12 were determined from data from cluster wells open to several depths. Similar lines of equal value and profiles may be made for any parameter measured periodically.

SUMMARY

This report explains how landfills can affect ground-water resources in a coastal environment, defines solid waste, and briefly describes the four common methods for disposing of solid waste.

There are essentially two landfilling methods used in coastal west-central Florida: the trench method, also called "cut and cover," and the area method. The high water table in coastal areas of west-central Florida presents problems when the trench method is used. Refuse disposed in trenches may come in contact with ground water, creating conditions for potential water-quality degradation.

When water flows through solid waste, a liquid called leachate is produced that contains dissolved and finely suspended inorganic and organic matter. Concentrations of chloride, ammonia nitrogen, and chemical oxygen demand materials have been found to be higher for old leachate (5 years or older) than for new leachate (24 hours to 1 week old). These increases result from long-term anaerobic digestion of refuse where the material decays under conditions where very little or no oxygen is present. Levels of leachate concentrations (indicator parameters) can increase over time, which suggests that the quantity of contaminant production not only is variable but perhaps cyclical. Organic compounds produced by microbial activity are numerous and can range from end products of anaerobic metabolism of carbohydrates, such as acetic and butyric acids, to fumigants and salts similar to those used for varnish driers.

In the coastal area of west-central Florida, two basic hydrogeologic conditions occur: (1) permeable sands overlying clay and limestone, and (2) permeable sand overlying limestone. The staurated part of the overlying sand comprises the surficial aquifer. In places, clay units act to separate the aquifer from the limestone (Floridan) aquifer, which is the principal source of water in the area. The rate of migration of ground water in the surficial aquifer from the Pinellas County landfill was calculated to be about 1.2 feet per year.

Factors in landfill site selection are divided into two broad groups: visible and hidden. The visible factors include (1) land development, (2) surface drainage, (3) soil types, (4) swamps, streams, and lakes, (5) sinkholes, and (6) nearby individual and public-supply wells. Hidden factors are those that cannot be observed directly, such as (1) thickness and permeability of surficial sand, silt, and clay, (2) depth to top of limestone, and (3) any connection between the surficial aquifer and the underlying limestone aquifer.

Once a prospective landfill site has been selected, based on available information, additional information needed for a final decision might include the following: drilling of test holes around and within the site to determine the hydrogeologic properties; collection of core drillings from test holes for soil analysis of soil properties such as grain size, permeability, effective porosity, ion-exchange, and mineral and clay qualities; and installing monitor wells for water-level measurements and water-quality monitoring.

Water levels measured in wells can be used to develop water-level contour maps for determining the direction of ground-water movement and can be used to locate monitor wells upgradient and downgradient from the landfill. Clusters of wells are drilled to obtain samples from various depth intervals to determine vertical and lateral rates of leachate movement.

The purpose of monitoring ground water is twofold: (1) to establish the quality of the ground water before landfill operations begin and (2) to determine movement of leachate and resultant changes in water quality over time by comparing results with a previous analysis. This information is valuable in determining whether the landfill has altered the quality of the ground water.

In a landfill study in Pinellas County, tests were run on five parameters with peak values as follow: (1) specific conductance, 7,800 umho/cm; (2) chlorides, 960 mg/L; (3) organic nitrogen, 32 mg/L; (4) ammonia nitrogen, 430 mg/L; and (5) chemical oxygen demand, 1,000 mg/L. Distinctive peaks in concentration for these five constituents were noted in wells 2 and 3 near the landfill. The concentrations indicate that the quality of leachate produced is variable and that the leachate in the ground water is moving away from the landfill.

Introduction of refuse into the ground-water system creates degradation. However, with careful site selection and well-planned monitoring, the impact of a landfill upon surrounding areas can be minimized and the public health protected.

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