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GEOHYDROLOGIC EVALUATION OF A LANDFILL IN A COASTAL AREA, ST. PETERSBURG, FLORIDA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 77–78

Prepared in cooperation with the
CITY OF ST. PETERSBURG

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The horizontal and vertical flow velocities indicate that leachate moves slowly downgradient, and that leachate has not yet seeped through the confining bed after 12 years of landfill operation. Untreated surface run-off from the site averages about 15 inches per year, and ground-water outflow averages about 3.3 inches per year. The Floridan aquifer is used as a limited source of water for domestic supply in this area.

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UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

For use of those readers who may prefer to use metric units rather than English units, the conversion factors for the terms used in this report are listed below:

English	Multiply by	Metric
acres	0.004	km^2 (square kilometers)
ft (feet)	.3048	m (meters)
gal (gallons)	3.79 .00379	L (liter) m^3 (cubic meters)
gal/min (gallons per minute)	6.309×10^{-2}	L/s (liters per second)
in (inches)	25.4	mm (millimeters)
mi (miles)	1.609	km (kilometers)
ft^2 (square feet)	.093	m^2 (square meters)
tons (short)	0.907	t (metric tons)

GEOHYDROLOGIC EVALUATION OF A LANDFILL IN A COASTAL AREA, ST. PETERSBURG, FLORIDA

By

C. B. Hutchinson and J. W. Stewart

ABSTRACT

The 250-acre Toytown landfill site is in a poorly-drained area in coastal Pinellas County. The average altitude of land surface at the landfill is less than 10 feet. About 1,000 tons of solid waste and about 200,000 gallons of digested sewage sludge are disposed of daily at the landfill. Three geohydrologic units are recognized at the site including: (1) sand and shell deposits that comprise a 23-foot-thick surficial aquifer which unconformably overlies (2) a marl and clay confining bed, 27 feet thick, which grades downward to (3) chert and limestone of the Floridan aquifer. The Floridan aquifer is used as a limited source of water for domestic supply in this area.

The velocity of ground-water flow through the surficial aquifer northeast from the landfill toward Old Tampa Bay probably ranges from 1 to 10 feet per year, and downward velocity through the confining bed is about 7.4×10^{-4} foot per day. The horizontal and vertical flow velocities indicate that leachate moves slowly downgradient, and that leachate has not yet seeped through the confining bed after 12 years of landfill operation. Untreated surface runoff from the site averages about 15 inches per year, and ground-water outflow averages about 3.3 inches per year.

The water table in the surficial aquifer is elevated at sludge-reservoir and solid-waste disposal sites, and water quality in these areas is poor. Inside the landfill, both surface and ground water have concentrations of dissolved solids of more than 1,000 milligrams per liter and ammonia nitrogen more than 200 milligrams per liter as nitrogen. Sanitary quality of water is also poor: total coliform counts reach 100,000 colonies per 100 milliliters of sample, total organic carbon concentrations are as much as 1,000 milligrams per liter. Contamination by leachate was not detected in wells more than 15 feet beyond the landfill boundary.

INTRODUCTION

The city of St. Petersburg's Toytown landfill occupies about 250 acres in the southeast part of Pinellas County (fig. 1). Several municipalities including St. Petersburg, Clearwater, Largo, Pinellas Park, and communities along the Gulf beaches dispose of, on the average, 1,000 tons of garbage and refuse daily at this landfill. In addition to disposal of solid waste, about 200,000 gal of digested sewage sludge are deposited daily at the landfill. Operations began in 1961 and the useful life is projected to 1982, based on a planned capacity of about 3 million tons of refuse. A final use plan for the site provides for construction of a golf course, a strip for soapbox-derby racing, multipurpose game courts, and open-space areas (Black and Veatch, 1973).

The development of the Toytown landfill has caused stresses on the water-table aquifer system within the landfill site. Within the boundaries of the landfill, the water table is elevated and water quality is poor. Although the underlying water-table aquifer is not used as a source of water supply, city officials are concerned about the water pollution threat to adjacent properties, which are being rapidly urbanized.

PURPOSE AND SCOPE

This report presents the results of a 2-year investigation by the U.S. Geological Survey, in cooperation with the city of St. Petersburg, to evaluate geohydrologic conditions at a landfill in a coastal area. The report defines and describes the geologic and geohydrologic units underlying the landfill, and examines the controls these units exert on the flow and quality of surface and ground water in the area. The study increases the understanding of the geohydrologic aspects of landfill operations and will be helpful in the selection of future landfill sites in similar coastal areas.

ACKNOWLEDGMENTS

This report was prepared as a part of the cooperative program of water-resources investigations with the city of St. Petersburg. Special appreciation is extended to Mr. Sam Buck, superintendent of the city's Toytown landfill and to Mr. Charles Conrad, Chief of Engineering Design for the city of St. Petersburg.

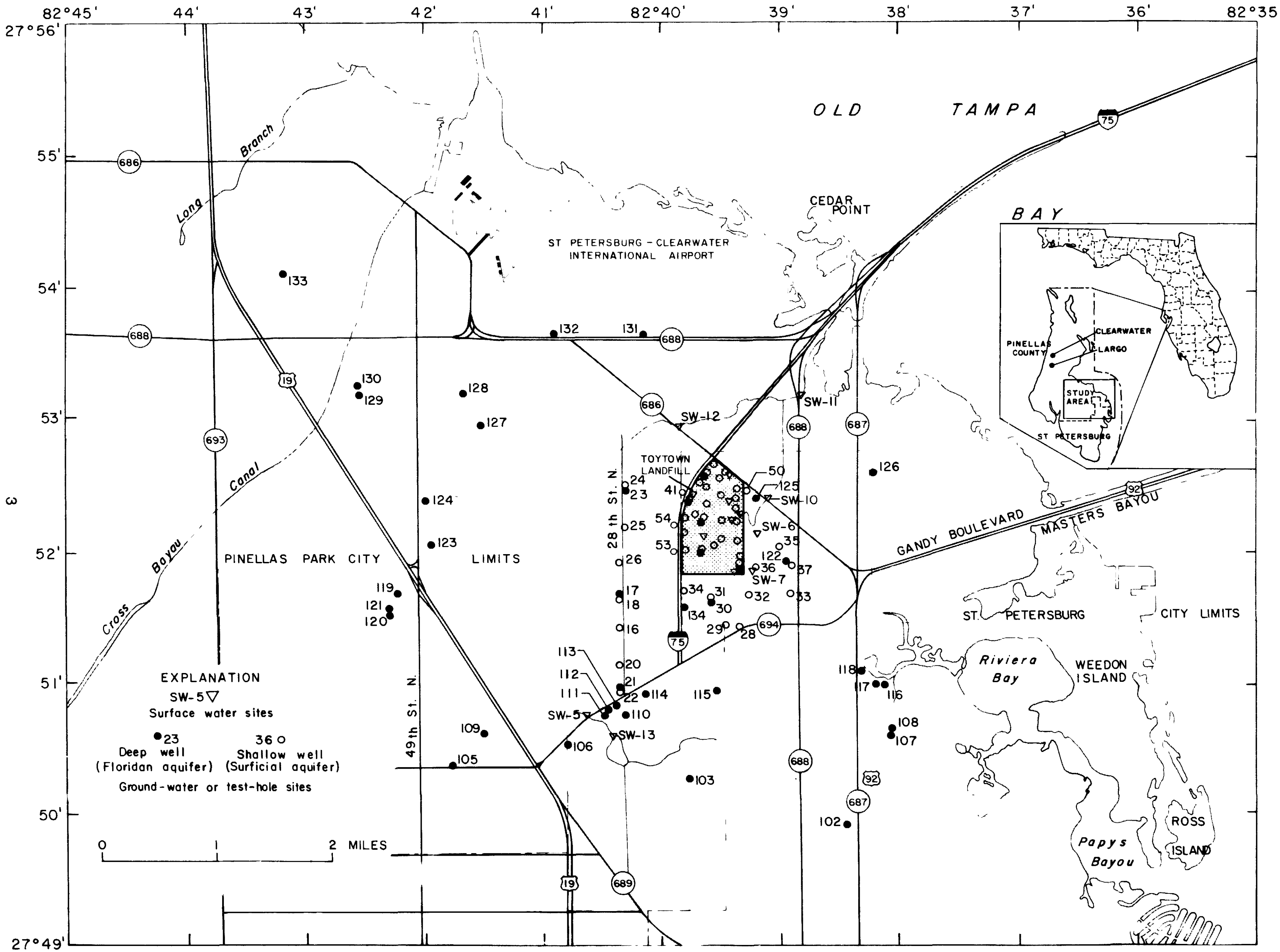

Figure 1.--The Toytown landfill and monitoring network.

DESCRIPTION OF THE AREA

Climate

The climate of the Toytown landfill area is subtropical. At St. Petersburg the normal annual precipitation, based on the period 1941-70, is 54.90 in, and the normal annual temperature is 23.0°C (73.5°F). Rainfall is heaviest and temperatures highest during the hurricane season, June through September. During this period the aquifers are recharged directly by rainfall.

During June 22-24, 1974, a storm resulting from a tropical depression in the Gulf of Mexico caused extensive flooding at the Toytown landfill. Nearly 20 in of rainfall was recorded at the National Weather Service gage 7 miles south of the landfill.

Topography and Drainage

Pinellas County (fig. 1) lies in the nearly flat plain of the Gulf Coastal Lowlands physiographic unit (Puri and Vernon, 1964). The Toytown landfill is located in the southern part of the county and at the northeast limits of St. Petersburg. Land surface altitude within a 5-mi radius of the landfill ranges from msl (mean sea level) along Old Tampa Bay to nearly 20 ft above msl in the inland area. The landfill site averages less than 10 ft above msl. The highest point in the completed site will be nearly 80 ft above msl, at the soap-box derby hill.

Under natural conditions the water table is high and the land is poorly drained. Surface runoff drains northeast to Old Tampa Bay through a network of canals. The landfill site lies just inside the boundary of an area determined flood-prone by the U.S. Geological Survey (1971). According to the Survey's analysis, the area has a 1-percent chance, on the average, of being inundated during any 1 year. Such conditions are considered unsuitable for landfill sites because of the potential for water pollution, and for this reason special care in the construction and operation of the landfill have been used to minimize contamination of the water resources (Stewart and Duerr, 1973, p. 49).

Water-management practices at the landfill are designed to minimize ground-water and surface-water outflow from the site to adjacent properties. Ground-water and surface-water outflow are intercepted by pumping from a 10-ft-deep perimeter canal to a 13-acre holding pond network at the northeast corner of the site (fig. 2). During this investigation, the canal was partitioned into four segments by earth dams near the NE, NW, SE, and SW corners of the landfill. Water was pumped from the south segment almost continually to dewater the area being excavated for solid-waste fill. The segment on the west side of the landfill was not

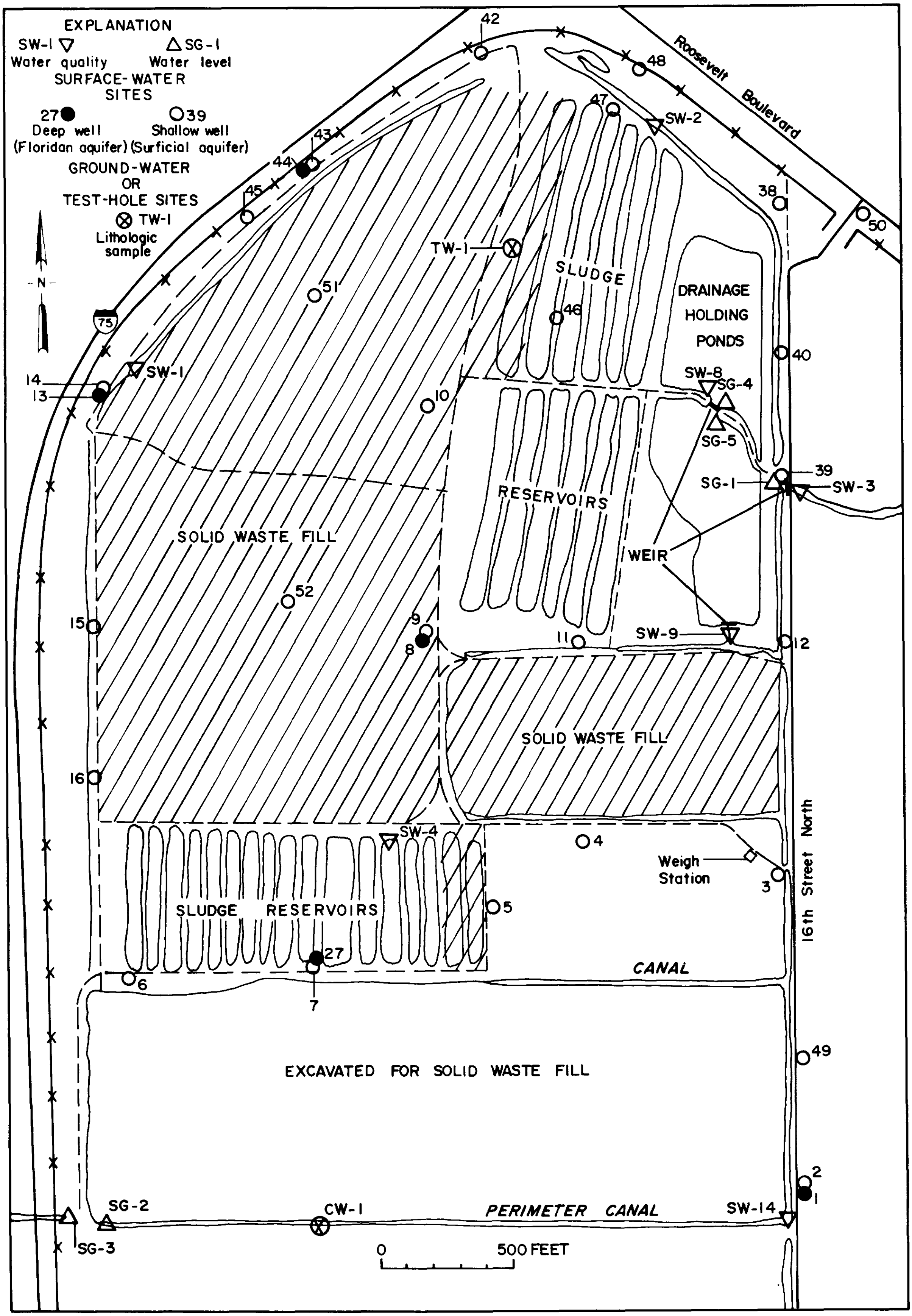

Figure 2.--The design characteristics and location of water-level and water-quality monitor sites at the Toytown landfill, 1973.

pumped -- it is only about 4 ft deep and it was dry except during the rainy season. The segment on the north side of the landfill was pumped much of the time to dewater adjacent areas actively being filled with solid waste. The canal segment at the east side of the landfill receives water pumped from the north and south segments, which is then pumped into the holding ponds. The water in the holding ponds is aerated and chlorinated, and then discharged to Tampa Bay at a rate of 200 gal/min, as estimated by officials of the landfill. When the chlorinator is not operating, evaporation is increased by spraying the water from the holding ponds over a tract of solid-waste fill just south of the ponds. During periods of heavy rainfall, the holding ponds overflow, and runoff to Old Tampa Bay occurs over the outlet weir at the east boundary of the landfill. During the storm of June 22-24, 1974, runoff was measured at 4,000 gal/min.

Landfill Site Design and Operation

The Toytown landfill is rectangular, about 2,700 by 4,000 ft (fig. 2). Solid wastes from municipal collection systems and individuals are deposited at the site daily, Monday through Saturday between 0800 and 1800. Waste is composed of garbage, trash, and some brush; chemical and radioactive wastes are not allowed. The solid waste is deposited in pits as deep as 30 ft which were previously excavated for shell. At the end of each day's operation, the refuse is compacted and covered with earth excavated from the south part of the site. The cover is intended to discourage burrowing by rodents and swarming of insects, prevent blowing of debris, reduce possibility of fire, retard infiltration of moisture, and promote an aesthetically pleasing environment to passing motorists.

Refuse tonnage at the Toytown landfill was increased in 1969 when the city's incinerator and composting facility was abandoned. Selected areas of the landfill site were thereafter used for disposal of sewage sludge which contains about 2 percent solids. The sludge is trucked to the landfill from the city's anaerobic digesters and is deposited in shallow reservoirs about 4 ft deep, 50 ft wide, and as much as 1,000 ft long (fig. 2), constructed atop the solid waste fill. The sludge reservoirs occupy about 40 acres, or about 16 percent of the landfill area. The sludge is black and, because the ratio of surface area to volume of each reservoir is large, optimum conditions are present for evaporation of the liquid content.

To make more efficient use of space at the landfill, the city is investigating alternate methods of sludge disposal. Plans are underway to construct a sod farm where the sludge can be used as a fertilizer. Under this plan, sludge would be piped to the west under highway I-75 from the landfill to an adjacent 50-acre tract. Techniques are being investigated for spraying the sludge on the ground or injecting it into the soil at application rates up to 500,000 gal per week. The potential for marketing the sod and other agricultural products is also being investigated.

GEOHYDROLOGY

Lithology

In November 1971, a drilling program was started to determine the lithology of sediments underlying the landfill. A truck-mounted hollow-stem power auger was used to drill 10 test holes from land surface into bedrock within and adjacent to the landfill site. Lithologic logs of all test holes are on file at the U.S. Geological Survey's subdistrict office, Tampa, Florida.

Three formations were penetrated (table 1), which correlate with formations described by Heath and Smith (1954, p. 12): (1) a surficial layer of fine-grained sand and shells which grades downward to (2), a calcareous clay or marl bed that overlies (3), stiff clay and hard chert and fossiliferous limestone. In all test holes the surficial layer ranges in thickness from 13 to 37 ft and averages 23 ft thick, and is Pleistocene in age (Vernon, personal communication *in* Heath and Smith, 1954, p. 16). The marl bed averages 15 ft thick and is a facies within the Hawthorn Formation of middle Miocene age (Heath and Smith, 1954, p. 15). The marl consists of calcite, aragonite, and quartz with a small amount of clay, and its average cation-exchange capacity is 0.062 meq/g (milliequivalents per gram). The marl unconformably overlies a 12-ft-thick layer of stiff dark-green clay, which is probably a weathered residuum forming the top of the Tampa Formation of early Miocene age. The underlying green clay consists mainly of montmorillonite and mixed-layer clay minerals with small amounts of quartz and feldspar, and its average cation-exchange capacity is 0.278 meq/g.

Near the bottom of each test hole, layers of dark-green rock and clay were encountered in the Tampa Formation. Petrographic analysis revealed that the rock is relatively young chert. The depth to the top of the first chert layer ranges from 26 to 60 ft, and averages 50 ft below land surface. The chert layer could not be penetrated with the power auger; therefore, its thickness could not be determined directly. Logs of test borings 1 mi west of the landfill indicate that the chert layer is about 20 ft thick (Black and Veatch, 1970). Underlying the chert, and still in the Tampa Formation, is a porous, fossiliferous limestone.

Some physical characteristics of the unconsolidated deposits in the landfill area are summarized in table 2. Grain size, total and effective porosities, vertical and horizontal hydraulic conductivities, cation-exchange capacity, and specific gravity of the surficial aquifer and the confining bed were determined at the Geological Survey's laboratory in Denver, Colorado. The characteristics are based on analyses of split-spoon samples from eight test holes, a solid-waste trench, and a perimeter canal wall.

Table 1. -- Geologic formations and geohydrologic units at the Toytown landfill.

Geologic formation	Geologic age	Average depth below land surface (ft)	Average thickness (ft)	Lithology	Geohydrologic unit
Undifferentiated surficial deposits	Pleistocene		23	Fine sand, clayey sand, shell fragments, tan to yellowish brown	Surficial aquifer
		23		Unconformity	
Hawthorn Formation	Middle Miocene		15	Calcareous clay or marl, sandy, greenish gray	Confining bed
		38		Unconformity	
Tampa Limestone	Early Miocene		12	Stiff clay with limestone fragments, dark-green	
		50			
			150	Hard chert and fossiliferous limestone	Upper part of Floridan aquifer

Table 2. -- Characteristics of samples from geohydrologic units identified at the Toytown landfill.

(Analyses by U. S. Geological Survey, Denver, Colorado)

Well or test hole number[1]	Depth below land surface (ft)	Geohydrologic unit[2]	Formation[3]	Median grain size (mm)	Total porosity n (percent)	Effective porosity n_e (percent)	Hydraulic conductivity K (ft/day)	Cation-exchange capacity c (meq/g)	Specific gravity of solids
3	22.5-23.0	C	H	0.001	38.5	19.3	0.000085	.057	2.58
13	12.5-13.0	S	U	.15	41.4	29.2	2.0	--	2.69
13	22.5-23.0	C	H	--	38.3	31.4	.00011	.056	2.77
13	32.5-33.0	C	H	--	45.4	26.6	.0018	.098	2.68
17	40.5-41.0	C	T	--	34.4	11.7	.0019	.3	2.60
21	20.5-21.0	S	U	--	--	--	.69	--	--
21	30.5-31.0	S	U	--	--	--	.59	--	--
21	40.5-41.0	C	T	--	--	--	.0036	--	--
23	30.5-31.0	C	H	--	36.8	31.9	.056	.078	2.62
23	40.5-41.0	C	T	--	41.7	38.4	.00014	.28	2.62
27	28.0-28.5	C	H	.005	36.8	33.2	.00013	.07	2.68
30	20.5-21.0	C	H	.005	46.3	34.3	.0026	.039	2.74
30	40.5-41.0	C	T	--	37.9	14.9	.000031	.23	2.59
30	50.5-51.0	C	T	--	50.5	9.5	.00028	.17	2.50
38	22.0-22.5	C	H	.012	37.0	34.2	.0013	.038	2.72
38	37.5-38.0	C	T	.001	33.8	9.6	.000046	.41	2.65
TW1	8.0- 8.5	C	H	--	--	--	.0029	--	--
CW1	3.0	S	U	.14	34.8	32.2	1.2	--	--

1 TW1 = Sample from solid waste trench well.
CW1 = Sample from south permimeter canal wall.

2 Geohydrologic units: S = surficial aquifer, C = confining bed.

3 Formations: U = undifferentiated surficial deposits, H = Hawthorn Formation, T = Tampa Formation.

4 Values are vertical hydraulic conductivity for all samples except CW1, which represents horizontal hydraulic conductivity.

Aquifer Systems

Three geohydrologic units are identified within the landfill area (table 1) based on test-drilling information and laboratory analyses: (1) a surficial aquifer, consisting of fine-grained sand and shell material; (2) a confining bed, which includes the marl of the Hawthorn Formation and the uppermost clay of the Tampa Formation; and (3) the upper part of the Floridan aquifer consisting of hard chert and limestone. These units are illustrated in figure 3.

The surficial aquifer averages 23 ft in thickness and wells completed in this unit yield less than 5 gal/min. The aquifer is not an important source of water supply in the Toytown landfill area. At the landfill where the aquifer has been replaced with compacted solid-waste fill, wells tapping the fill yield less than 1 gal/min.

The confining bed separates the surficial aquifer from the Floridan aquifer and retards downward movement of water. In the landfill area the thickness of the confining bed averages 27 ft. In some parts of the landfill, the upper few feet of the confining bed has been excavated for cover material and solid-waste fill.

The Floridan aquifer is the principal artesian aquifer in the area. Beneath Pinellas County the aquifer is more than 300 ft thick. It was the principal source for municipal supply in St. Petersburg until the 1920's when excessive pumping caused saltwater encroachment. The upper part of the Floridan aquifer remains as a source for domestic supply and lawn irrigation where city water is not available.

Monitoring Network

A ground-water and surface-water monitoring network was installed to provide a basis for constructing a water-table map and for determining water quality within 4 mi of the Toytown landfill. Ground-water monitors consist of 42 deep wells completed in the Floridan aquifer and 45 shallow wells screened in the surficial aquifer or landfill. Surface-water monitors consist of 5 staff gages and 14 sampling sites at canals, lakes, and ponds. The locations of the monitoring sites are shown in figures 1 and 2.

Water levels were monitored periodically at wells by using a steel tape to measure the depth to water. Water levels in canals and ponds were measured by observing permanently installed staff gages. Water quality was monitored periodically at each well site by pumping until the original water in the casing had been replaced by water drawn into the well from the formation. The quality of the water in ponds and canals was monitored by taking a depth-integrated sample from the surface to the bottom at the site.

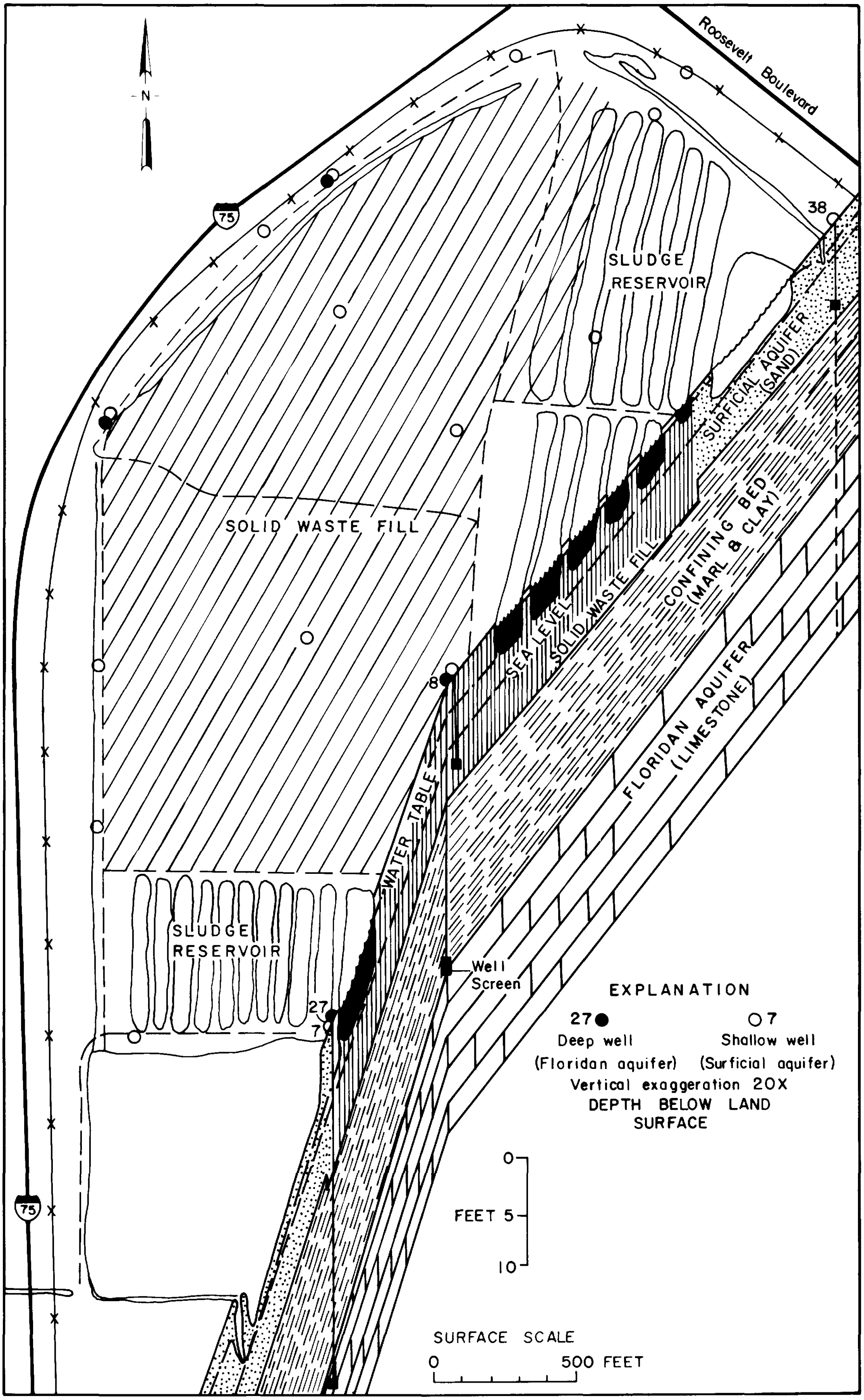

Figure 3.--Geohydrologic units at the Toytown landfill.

The wells that tap the Floridan aquifer range in depth from 18 ft to 265 ft. Nine of these wells were installed by the U.S. Geological Survey for this study and water-level and water-quality information were collected at these sites. The remaining 33 wells are privately owned and were in existence before this study began. There is no access for water-level measurements in most of these wells; however, they were pumped for collection of water samples.

The surficial-aquifer and landfill wells range in depth from 9 to 30 ft. All 45 wells were installed by the U.S. Geological Survey and both water-level measurements and water-quality samples were obtained periodically from them.

Tops of well casings were surveyed to the nearest 0.01 ft and referenced to mean sea level so that an accurate contour map of the water table could be drawn. Wells are constructed of an upper part consisting of plastic casing, and a lower part of plastic screen of varying lengths. All-plastic construction was used since this material is essentially inert. Metal screens or casing were not used because these can add trace metals to the water or can be toxic to bacteria.

Water Levels

The observation-well and staff-gage network is used to monitor water-level fluctuations and determine the direction of ground-water movement. During the dry spring and early summer, discharge exceeds recharge, and the water table in the surficial aquifer declines as a result of: evapotranspiration, downward leakage through the confining bed, discharge to Old Tampa Bay, and discharge to canals and streams. The potentiometric surface of the Floridan aquifer is lowered by pumping of wells for lawn irrigation and by regional discharge from areas of higher potentiometric head to areas of lower potentiometric head.

During the wet late summer and fall months, the water table in the surficial aquifer rises as a result of recharge directly from rainfall. At the landfill, additional recharge is derived from sewage sludge and wetted solid waste. The potentiometric surface of the Floridan aquifer rises by leakage of water through the confining bed.

The water table in the surficial aquifer and the stages of surface water bodies are affected by operations at the Toytown landfill. Figure 4 shows the configuration of the water table on August 1, 1973, when the water table was high. A water-table mound more than 8 ft above msl developed over the west-central part of the landfill in an area where sludge was being deposited and where the surficial aquifer has been replaced by solid-waste fill. Depressions in the water table to less than 4 ft above msl occur in the northern and southern parts of the landfill site as a result of pumping from those segments of the perimeter canal.

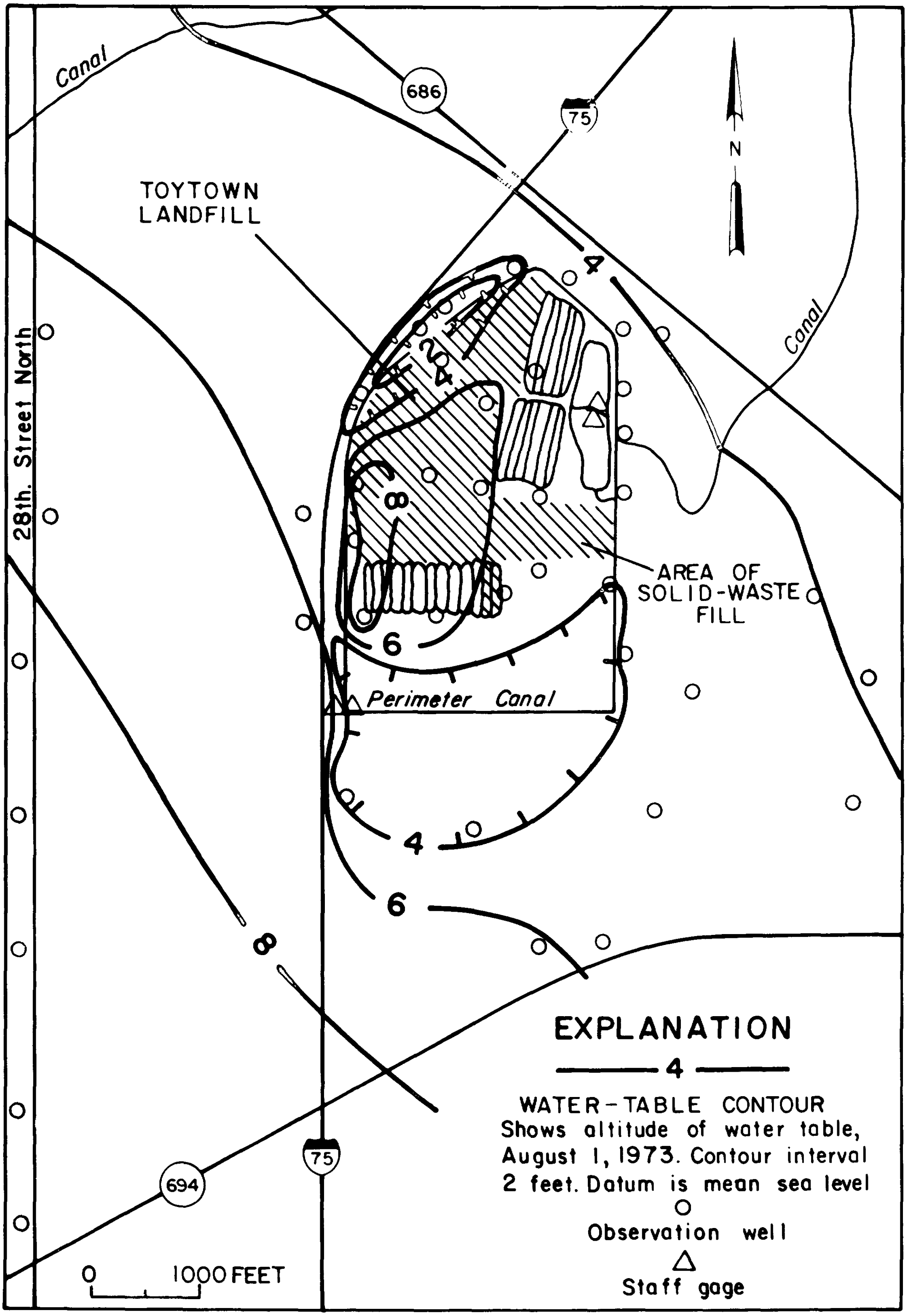

Figure 4. -- The water table in the surficial aquifer in the Toytown landfill area, August 1, 1973.

The regional water-table gradient slopes northeast toward Old Tampa Bay from an altitude of about 7 ft above msl, just southwest of the landfill. The configuration of the water table is controlled by the hydraulic and physical characteristics of the surficial aquifer and by local variations in recharge and discharge.

Hydrographs of wells completed in the surficial and Floridan aquifers at sites upgradient, within, and downgradient from the landfill are shown in figure 5. The water levels fluctuate seasonally in response to recharge by rainfall and discharge by ground-water outflow and evapotranspiration. Water levels are lowest during the dry spring and highest during the wet summer.

The water level in most wells that tap the surficial aquifer generally is less than 10 ft below land surface, and the seasonal range in fluctuation is 4 ft. The potentiometric surface of the Floridan aquifer is about 2 ft lower than the water table in the surficial aquifer, and it has about the same range in fluctuation. Depth to water in both aquifers is greater at sites within the landfill than at upgradient or downgradient sites because the land surface is built up in the disposal process. Drainage to the perimeter canal helps lower the water table in the landfill.

Ground-Water Movement

The velocity of ground-water flow toward Old Tampa Bay from the landfill site was calculated using a modified form of Darcy's equation:

$$V_h = K_h I / n_e$$

where V_h = horizontal velocity of flow through the surficial aquifer, in feet per day,

K_h = horizontal hydraulic conductivity of the aquifer, in feet per day,

I = gradient in feet per foot, and

n_e = effective porosity, dimensionless.

The calculated rate of ground-water flow from the landfill to the nearest point of Old Tampa Bay, 1 mile northeast, is as follows:

$$V_h = 2.9 \times 10^{-3} \text{ ft/d}$$

where K_h = 1.2 ft/d (see table 2, test hole CW1),

I = 4 ft/5280 ft = 7.6×10^{-4} ft/ft, and

n_e = 0.31

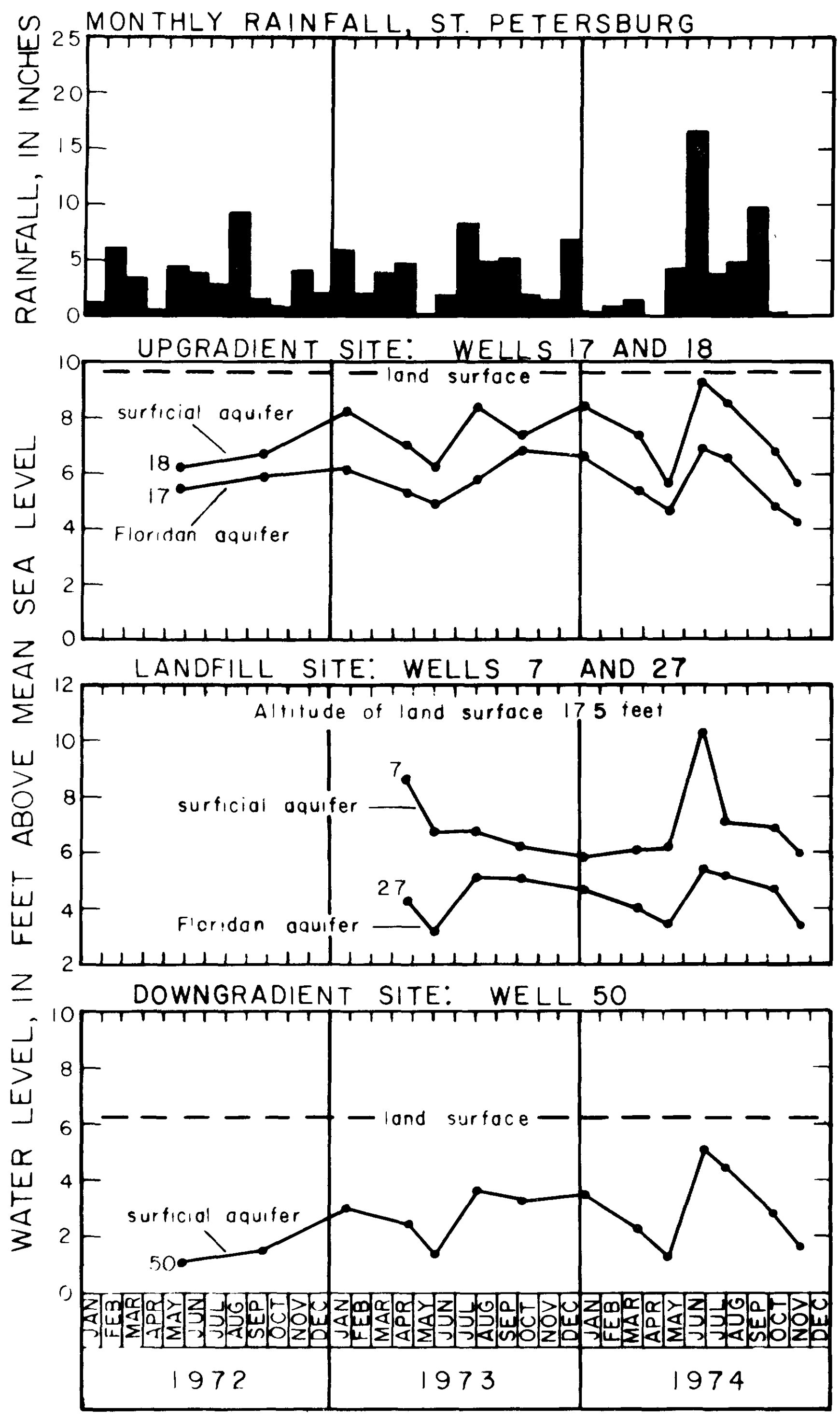

Figure 5. -- The rainfall and water levels in the surficial and Floridan aquifers, Toytown landfill area.

The analysis assumes a 4-ft water-table head at the northeast boundary of the landfill site, and n_e = 0.31 average effective porosity in test hole 13 and CWI (see table 2). At the computed rate, water would move, on the average, 1 ft/yr and it would take about 5,000 years to travel from the landfill to the Bay. Because the landfill has been in operation less than 15 years, ground-water pollutants traveling at the computed average velocity of ground water should not be detectable in wells more than 15 ft from the landfill.

The velocity of ground-water flow is low due to the extreme gentleness of the water-table gradient and the low horizontal hydraulic conductivity of the aquifer. If pumping from the perimeter canal were to cease, the gradient would be increased, thereby increasing the velocity. Because horizontal hydraulic conductivity was estimated from a single sample (CWI), the reliability of this value for use as an average is questionable. The computed velocity of ground-water movement toward the Bay is considered conservative and it approaches the minimum rate under existing conditions. If a ten-fold increase in velocity (that is, hydraulic conductivity) could be considered a reasonable upper limit, the velocity of ground-water movement toward Old Tampa Bay would range between 1 and 10 ft/yr.

In addition to horizontal flow through the surficial aquifer and runoff over the outlet weir, downward flow, or vertical leakage, occurs through the confining bed into the Floridan aquifer. The quantity of water moving through the confining bed was calculated using Darcy's law:

$$Q = 7.48\frac{K_v}{b} hA$$

where Q = leakage through the confining bed, in gallons per day,

K_v = vertical hydraulic conductivity of confining bed, in feet per day,

h = average head difference between the potentiometric surface of the Floridan aquifer and water level in the surficial aquifer, in feet,

A = surface area of the confining bed through which leakage occurs, in square feet, and

b = thickness of the confining bed in feet.

Using average values of

K_v = 0.005 ft/d (see table 2),

b = 27 ft (see table 1),

h = 1.0 ft (observed in well pair 7, 27), and

$A = 11 \times 10^6$ ft^2 (250 acres), then leakage through the confining bed at the landfill is 15,100 gal/d, or about 5.5 million gal/yr. Average leakage through a 1-ft^2 column of the confining bed is less than 1.4×10^{-3} gal/d.

The velocity of vertical flow through the confining bed is calculated by:

$$V = \frac{K_v h}{b\ n_e} \quad .$$

Using average values of

k_v = 0.005 ft/d,

b = 27 ft,

h = 1.0 ft, and

n_e = 0.25 (see table 2),

at steady-state the velocity of vertical flow through the confining bed would be 7.4×10^{-4} ft/d. At the computed rate it would take 100 years for leachate to flow through the confining bed. Because the landfill has been in existence less than 15 years, and because there are no known natural flow conduits across the confining bed, leachate probably has not yet reached the Floridan aquifer.

The calculated leakage figures represent averages for the landfill site. At sludge reservoirs and solid-waste fill areas, head differences between the Floridan and surficial aquifers may be greater than 1 ft thereby increasing both volume and velocity of leakage. In these areas leakage may increase because the thickness of the clay layer has been reduced by excavation (fig. 3), thereby increasing the gradient across the bed. The increase in vertical leakage is probably less than 50 percent. The leakage still would be relatively small and, coupled with the high cation-exchange capacity of the confining bed and the ability of the Floridan aquifer to disperse recharge, contamination of water in the Floridan aquifer probably would be minimal at the present time.

The theoretical values of velocity and quantity of ground-water movement are averages and are based on assumptions that water moves at a uniform rate through the aquifer and confining bed, and that these media are homogeneous. Hydraulic diffusivity of the aquifer media was not considered, and the solid-waste fill zones are not homogeneous. Laboratory analyses of hydraulic conductivity are only approximate indications of actual "in place" values of hydraulic conductivity. Values range widely and, as a result, the samples may not be representative of the overall range in hydraulic conductivity.

Water Budget

The water budget is a method of accounting for the inflow and outflow of the landfill hdyrologic system. Components considered in the water budget are given in the following equation:

$$P + (I_{sw} + I_{gw}) + SL = (E + ET) + L + \Delta S + Q + 0_{sw} + 0_{gw}$$

where:

P = normal annual precipitation (for 30 years of record, 1941-70) at St. Petersburg.

$I_{sw}+I_{gw}$ = annual surface-water inflow and ground-water inflow into the site. Inflow is intercepted by the perimeter canal and total inflow is estimated at one half the total volume of pumpage (Q) from the canal.

SL = net annual sludge input, based on 200,000 gal/d, six days per week, minus 17 x 10^6 gal sprayed at the sod farm in 1975 (M. F. Fernandez, personal commun. 1975).

E = evaporation from holding ponds and sludge reservoir areas occupying 53 acres out of the total 250 acres, estimated from published data (Visher and Hughes, 1968).

ET = evapotranspiration from land areas occupying 197 acres, estimated from regression analysis of precipitation and evapotranspiration tables developed for the Middle Gulf area (Cherry and others, 1970, p. 79).

L = annual leakage through the confining bed of 5.5 million gal, using the quantity computed in this report.

ΔS = annual change in storage of water in the surficial aquifer, assuming 30 percent specific yield (estimated from porosity data in table 2) and average head build-up in the water table of 4 ft during 12 years of landfill operation.

Q = average annual pumpage from the holding ponds to Tampa Bay. Pumpage rate is estimated by landfill officials at 200 gal/min 60 hours per week.

0_{sw} = average annual runoff over the outlet weir on the east side of the landfill.

0_{gw} = ground-water outflow to adjacent properties.

The calculated residual of the water budget equation is:

$$O_{sw} + O_{gw} = P + (I_{sw} + I_{gw}) + SL - E - ET - L - \Delta S - Q$$

or

$$O_{sw} + O_{gw} = 54.9 + (2.8) + 6.7 - 10.8 - 28.6 - 0.8 - 1.2 - 5.5$$
$$= 18.3 \text{ in/yr}$$

and total water outflow from the landfill is

$$O_{sw} + O_{gw} + Q = 23.8 \text{ in/yr.}$$

Most of the total outflow probably occurs as surface runoff over the outlet weir. Runoff from the landfill was not gaged because the height of the weir was changed several times during this investigation. Periodic inspection at the outlet weir indicated that most of the runoff occurred during the rainy season. Cherry and others (1970, p. 76) computed average annual runoff in peninsular Pinellas County from June 1964 to May 1975 to be 10.5 in. During this time precipitation at St. Petersburg averaged 38.72 in/yr, about 30 percent below the 1941-70 normal. If precipitation had been normal, annual runoff (O_{sw}) from the peninsula probably would have been about 50 percent higher, on the order of 15 in/yr. This adjusted value probably represents a close approximation of long-term average surface runoff at the landfill.

The volume of ground-water outflow is low because the saturated thickness of the aquifer at the landfill boundary is reduced by lowering the water levels in the perimeter canal segments. Computation of the quantity of ground-water outflow is complex due to the heterogeneous nature of the deposits and varying head relations resulting from pumping in the perimeter canal segments. If the adjusted estimate of 15 in/yr for runoff is correct, ground-water outflow (O_{gw}) from the landfill area, obtained by subtracting runoff from the residual of the water budget, would be on the order of 3.3 in/yr, or 61,400 gal/d.

Although the estimate of ground-water outflow using the water-budget analysis appears to be reasonably accurate, the water-budget analysis could involve numerous errors in estimating the quantities of water for each component of inflow and outflow. The errors probably are largest in the evaporation and evapotranspiration components of the equation. These errors could be substantially larger than the quantity of ground-water outflow estimated as a residual of the water-budget equation. The extent to which the black color of the sludge might affect the evaporation rate at the sludge reservoirs by increasing the temperature is unknown. It might be higher than the values used or it might be less. On the other hand, the evapotranspiration rate could be lower than the estimated value because much of the landfill is devoid of vegetation.

Hence, the water-budget analysis is considered to show only the relative magnitudes of the components of inflow and outflow based on long-term average conditions at the Toytown landfill.

WATER QUALITY

An evaluation of the impact of the landfill operation on the water quality of the area is made by comparing water quality at the landfill with that at sites upgradient and downgradient of the landfill. Because the Toytown landfill was in operation for several years before the present investigation was begun in 1971, background water-quality data on the site are unavailable for comparison with current data. In this study, water quality at upgradient sites is considered representative of background conditions. Upgradient sites were carefully selected so that they would not be close to sources of contamination such as septic tanks or drainage ditches.

Water at each site was sampled at least once and at some sites as many as seven times during this investigation. Water from all sites was tested for chloride and specific conductance. Water from selected wells was analyzed for a suite of chemical quality constituents such as common ions including chloride, calcium, fluoride, magnesium, sodium, potassium, sulfate, and bicarbonate; nutrients including nitrogen and phosphorus compounds; and trace elements including arsenic, cadmium, copper, iron, lead, manganese, aluminum, strontium and zinc. Water samples were also analyzed for sanitary quality factors such as coliform bacteria, inorganic and organic carbon, and biochemical oxygen demand. Results of analyses are available in the files of the U.S. Geological Survey, National Center, Reston.

Chemical Quality

The chemical properties of water in and around the landfill are evaluated in this report by comparing the common ions, nutrients, and trace metals. The sources of chemical constituents vary with the environment in which the water is located. Chemical properties of water in the surficial aquifer at the landfill are attributable primarily to reactions between the water, soil and rock constituents, or waste constituents, and the resulting fluid is often a heavily mineralized leachate. The chemical properties of water in the confining bed are affected by the adsorption and exchange of cations onto the structural lattice of the clay minerals that comprise this unit. The chemical properties of water in the Floridan aquifer result from saltwater encroachment and reactions of recharge water with limestone. The chemical properties of surface water are controlled primarily by constituents dissolved by runoff.

Surficial Aquifer

Specific conductance, or conductivity, of water in the surficial aquifer inside the landfill ranges from 840 to 6,100 umho/cm (micromhos per centimeter) at 25°C for 40 samples analyzed. Specific conductance of water outside the landfill area ranges from 516 to 4,800 umho/cm for 118 samples analyzed. The wide range in specific conductance outside the landfill probably results from the wide range in concentration of sodium and chloride which are commonly the principal ions present in water in coastal areas.

The relation between average specific conductance and average chloride concentration of samples collected from both the surficial aquifer and the solid-waste fill zones is shown in figure 6. The solid line of regression was fit by the least-squares method using data from all sites outside the landfill boundary. The dashed lines indicate the 95 percent confidence limits. Any point that plots above or below these limits has a conductivity significantly different than that which can be attributed to its chloride concentration. A highly significant correlation exists between average specific conductance and average chloride concentration in water of the surficial aquifer both upgradient and downgradient from the landfill.

Water samples from wells 3, 4, and 11, inside the landfill, plot within the confidence limits. These wells, completed in sand, are more than 15 ft from solid-waste fill areas. All other samples from the landfill plot outside the confidence limits. The conductivity of these samples is probably controlled by constituents dissolved in the leachate. Wells 12, 14, 39 and 40 are less than 15 ft beyond the perimenter canal (average minimum distance that leachate may have traveled), yet they produced no suspect samples.

The samples from the landfill are characteristically high in dissolved solids and the ammonia nitrogen concentration is several orders of magnitude greater than the ammonia nitrogen concentration outside the landfill. The high ammonia nitrogen concentration probably results from microbial breakdown of organic material in the sludge or leachate. For the most part, the concentration of each constituent analyzed at landfill sites was higher than those analyzed at sites outside the landfill. An exception is the concentration of sulfate, which is noticeably lower within the landfill. The general increase in all constituents analyzed reflects the diverse chemical composition of the solid waste. Analyses were probably comprehensive as indicated by ionic balances and because the meq/L of cations or anions multiplied by 100 approximates the observed conductivity (Rainwater and Thatcher, 1960, p. 84).

A contour map showing the distribution of specific conductance of water in the surficial aquifer in August 1973 (fig. 7) shows that conductivity of water in the landfill is above regional levels. The high conductivity 1 mile southwest of the landfill is unexplained; however,

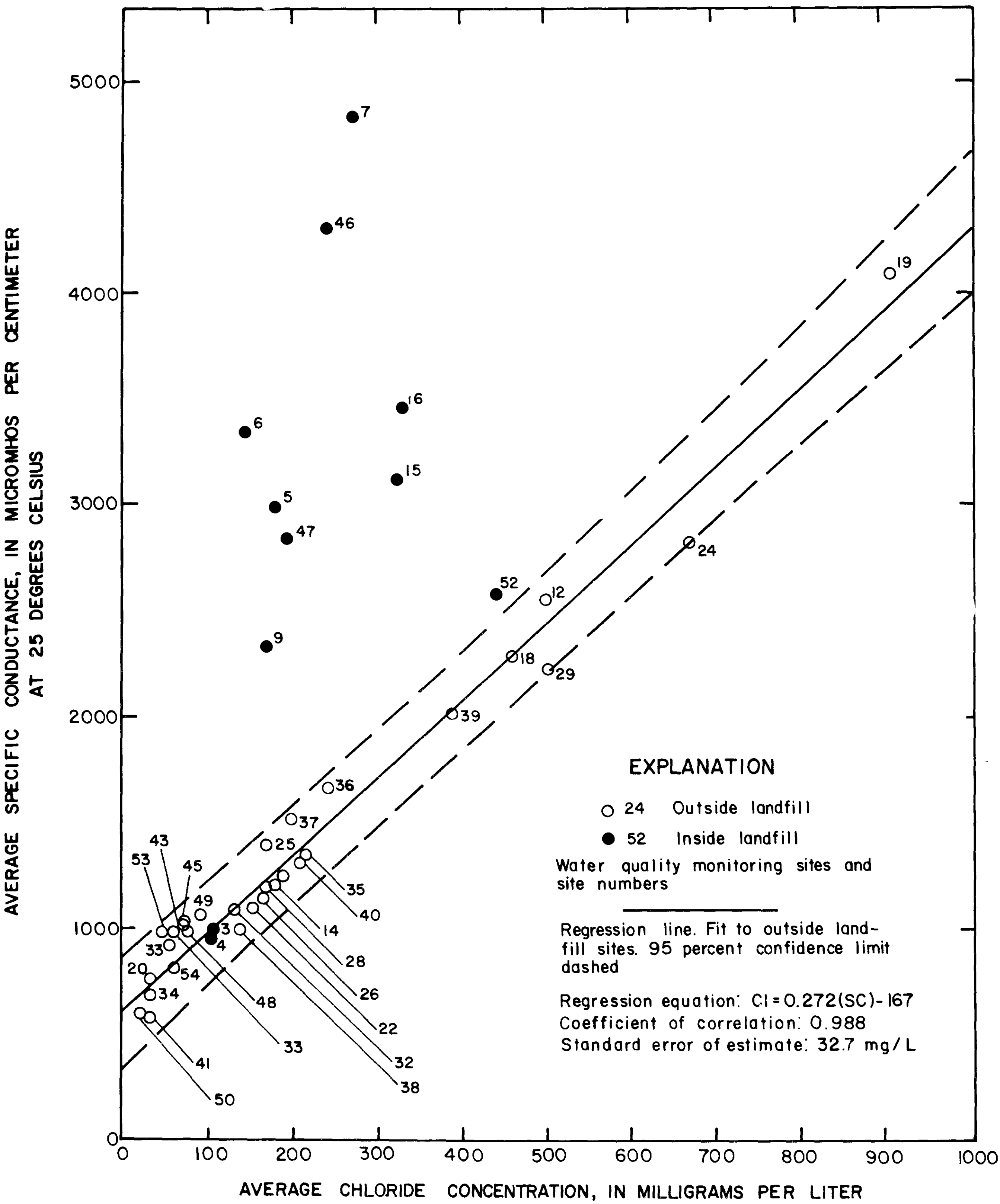

Figure 6.--The average specific conductance versus average chloride concentration of water samples from the surficial aquifer and solid-waste fill zones in the Toytown landfill area, January 1972 to August 1974.

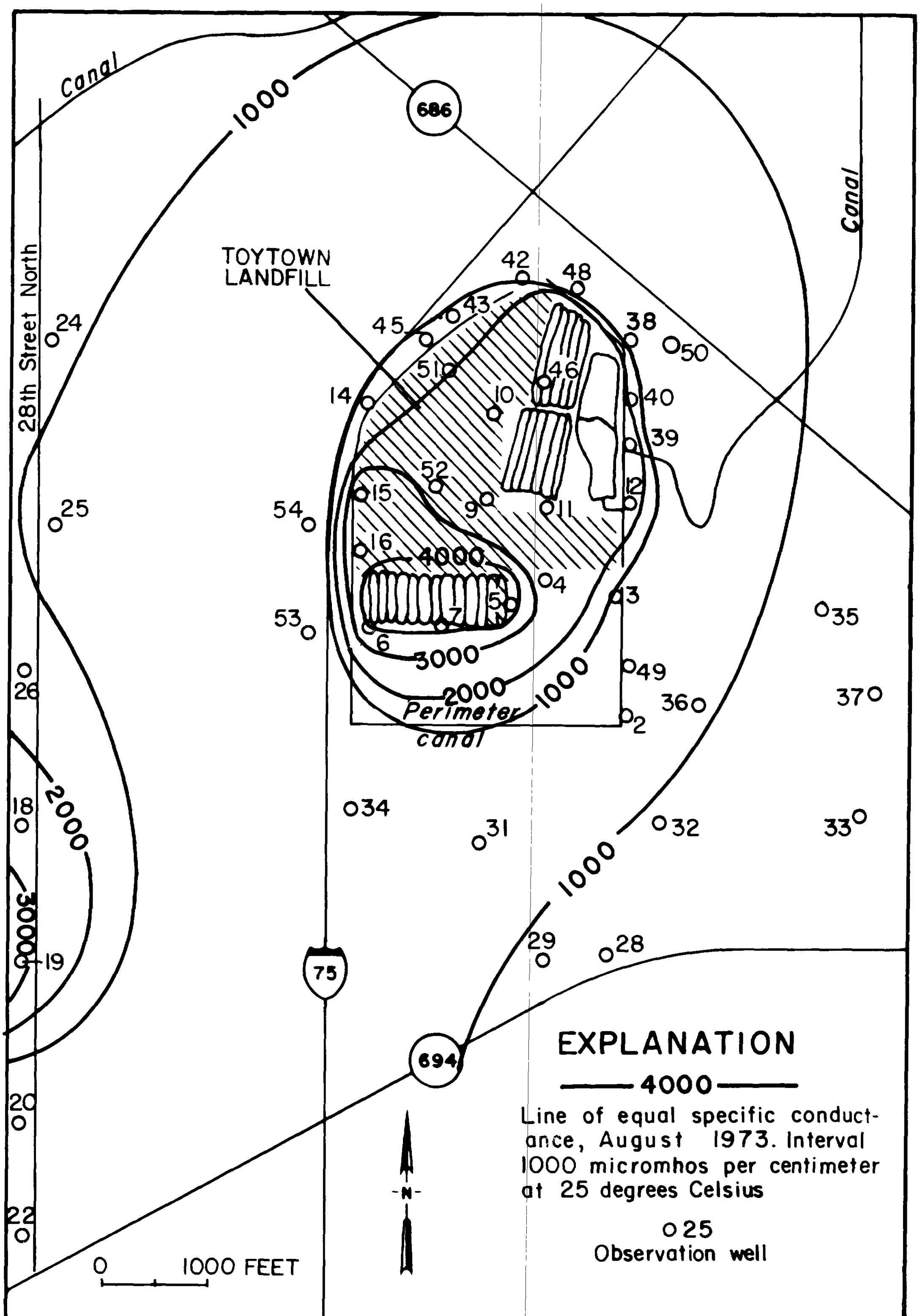

Figure 7 -- The specific conductance of water in the surficial aquifer in the Toytown landfill area, August 1973

it probably is not due to contamination by landfill leachate because less concentrated water exists between this well and the landfill. Conductivity ranges from 4,120 umho/cm at a site near a sludge reservoir (well 7) to 570 umho/cm at well 50, 500 ft downgradient from the landfill. The possible movement of leachate wells to 12, 39, and 40 within 5 ft of the eastern segment of the perimeter canal, is evidenced by high conductivity of water from these wells. The water levels in these wells were slightly lower than the stage in the adjacent canal segment. The conductivities of water at sites 12 and 40 have risen 1,200 and 1,300 umho/cm, respectively, since April 1972.

The low relative conductivities at downgradient wells 38, 42, 48, and 50, more than 10 ft beyond the perimeter canal, as compared at upgradient wells 20, 22, 28, 29, 31, 32, and 34, indicate that leachate is being retained within or near the landfill. From samples collected at these downgradient and upgradient wells, it is apparent that conductivity has either steadily decreased or remained relatively stable throughout this investigation.

The primary nutrient constituent in water of the surficial aquifer is ammonia nitrogen. The ammonium cation probably indicates reducing conditions characteristic of organic decomposition. It is present in concentrations less than 1 mg/L in natural water surrounding the landfill, but in the leachate of the solid-waste fill areas it may be present in concentrations above 200 mg/L. Other minor nutrient constituents analyzed include: nitrate, nitrite, organic nitrogen, ortho-phosphate and phosphorous; they were present in concentrations less than 10 mg/L.

Trace element concentrations in samples from the surficial and Floridan aquifers are compared with public water-supply standards in table 3. In many samples, iron and manganese are higher than upper limits for drinking water. Even small concentrations of these metals in a public water supply are undesirable on the basis of taste or potential for staining. For samples from the surficial aquifer there is no apparent relation between trace element concentration and site location (upgradient, landfill, or downgradient). Even though wells 5, 7, and 10 tap highly mineralized leachate, the levels of trace elements at these wells generally were within the acceptable limits for drinking water. Thus, the presence of unacceptable concentrations of trace elements is not necessarily an indication of pollution by landfill leachate.

The chemical quality of water within the surficial and Floridan aquifers at 15 wells in and around the landfill is illustrated by circular diagrams (fig. 8). The diagrams show that the quality of the water in the surficial aquifer adjacent to the landfill is better than that of the water inside the landfill. Water from upgradient, or background, wells 32 and 53 has about the same relative amounts of dissolved solids and ionic constituents as water from downgradient wells 43, 48, and 50. Concentrations of dissolved solids in water from these wells are less than 1,000 mg/L, ammonia nitrogen is absent, and calcium and bicarbonate, Concentration is recommended upper limit for public water supply (National Academy of Sciences and National Academy of Engineering, 1973)

Dots represent number of analyses determined for each quality constituent.

QUALITY CONSTITUENT	CONCENTRATION IN (mg/L)	AQUIFER AND SITE NUMBER																
		SURFICIAL													FLORIDAN			
		2	3	4	5	7	10	32	43	48	50	57	60	66	1	27	44	125
ARSENIC (As)	> 0.1																	
	≤ .1	••	••	•	••	••	•	••	••	••	••	•	•	••	•	••	••	•
CADMIUM (Cd)	> .01															•		
	≤ .01	••	••		••	••	•	••	••	••	••	•	•	••		•		•
COPPER (Cu)	> 1															•		
	≤ 1	•••	••	•	••	••	•	••	••	••	••	•	•	••	•	•	••	•
FLUORIDE (F)	> 1.6					•												
	≤ 1.6	••	•••	•	••	•	•	•••	••	•••	••	•	•	••	•	••	••	••
IRON (Fe)	> .3	••	••	•	••				••			•		••				
	≤ .3	•			•	••	•	•••		••	•••		•		•	••	••	••
LEAD (Pb)	> .05																	
	≤ .05	•••	••	•	••	••	•	••	••	••	••	•	•	••	•	••	••	•
MANGANESE (Mn)	> .05	•			•	•		•		•	•	•		•		•	•	
	≤ .05	•		•					•				•					•
ZINC (Zn)	> 5																	
	≤ 5	•••	••	•	•••	•	•	•••	•••	••	••	•	•	••	•	••	••	••
DISSOLVED SOLIDS	>500	••	•••	•	••	••	•	•••	••	•••			•			••	••	••
	≤500										••	•		••	•			

Table 3-- Trace elements dissolved in ground water in the Toytown landfill area as related to drinking water standards

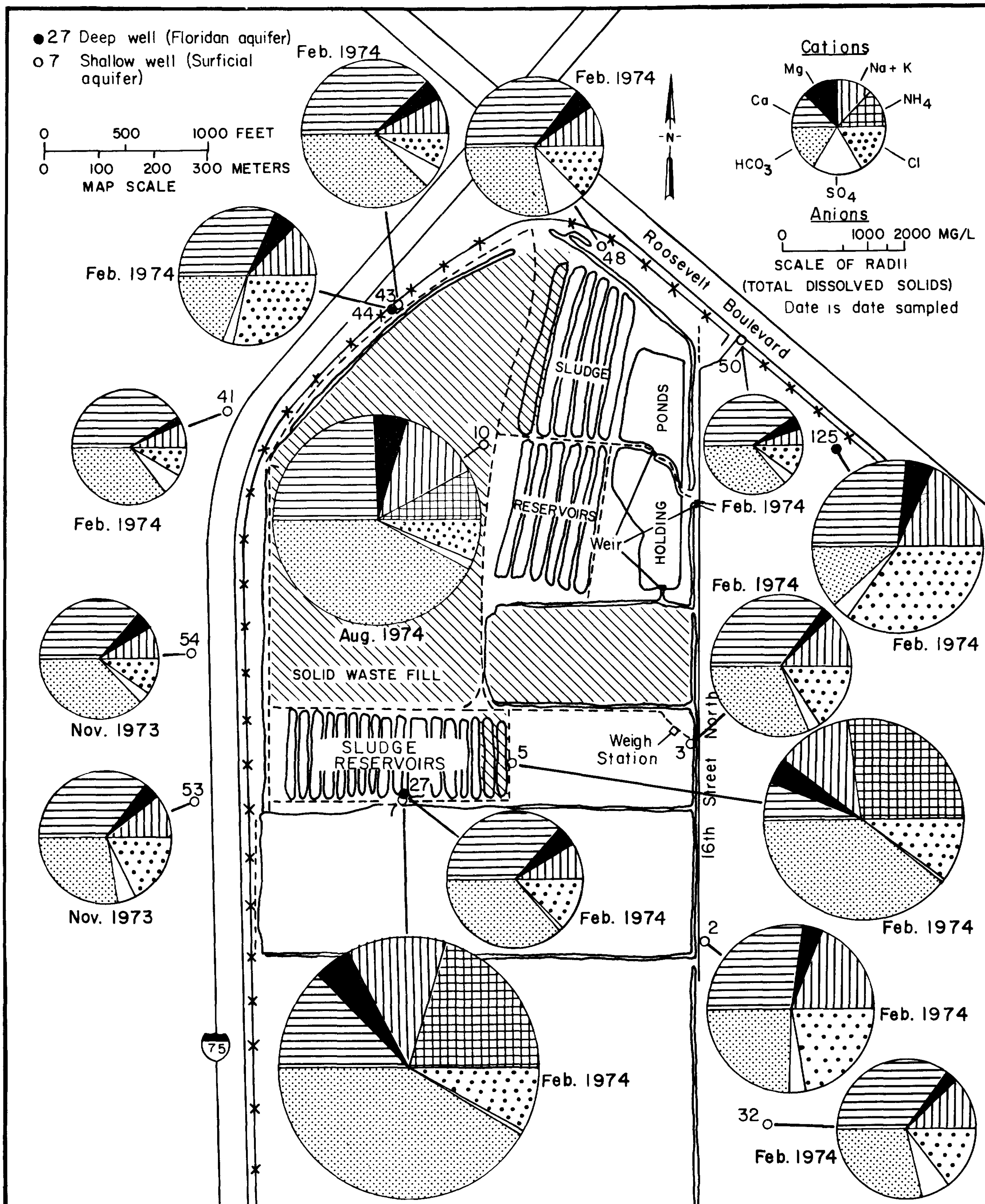

Figure 8 -- Chemical quality of water in the surficial and Floridan aquifers at the Toytown landfill

respectively, constitute more than 50 percent of the cation and anion totals. Moreover, samples from wells 5, 7, and 10 within the landfill, and which tap solid waste fill areas, have dissolved solids concentrations greater than 1,000 mg/L, are high in ammonium and bicarbonate, and contain a lower percentage of chloride.

Confining Bed

The confining bed is important to the chemical quality of water at the Toytown landfill because of its low permeability and its capacity for ion exchange. Because this geohydrologic unit is composed of clay-size particles, pore size is very small and the bed retards the downward movement of leachate. Dissolved cations may be adsorbed to negatively charged areas in the crystal lattice of the clay mineral or exchanged with existing adsorbed cations.

The adsorption capacity of the confining bed for common cations is listed in table 4. Calculations were made using laboratory results of: specific gravity and cation-exchange capacity tests (table 2); test drilling for thickness of the confining bed units; and published tables of conversion factors. Numbers presented in table 4 are maximum values of any element that might be adsorbed to the structural lattice of clay minerals in the confining bed. Thus the confining bed not only impedes the downward movement of water into the Floridan aquifer, but also captures ions which could impair the water quality. The potential for adsorbing ammonium cations is 301 tons/acre, which is a relatively high value and may account for the low ammonium concentrations measured in water of the Floridan aquifer.

Floridan Aquifer

Water of the Floridan aquifer is a calcium bicarbonate type and is generally more saline than water from the overlying surficial aquifer. Conductivity ranges from 260 to 2,760 umho/cm and the chloride concentration ranges from 37 to 720 mg/L in 96 samples analyzed. Figure 9 shows average specific conductance plotted against average chloride concentration of water samples analyzed from the Floridan aquifer. The graph indicates a high correlation between the conductivity and chloride concentration of water in the Floridan aquifer. Of the two wells, 8 and 27, sampled within the landfill, well 27 plots just outside the 95-percent confidence limit. The well has been sampled three times and each succeeding sample plots closer to the 95-percent confidence limit, indicating that the Floridan aquifer is not being contaminated by leachate at this point. None of the averages at 40 monitoring sites outside the landfill is significantly outside the 95-percent confidence limits.

Table 4. -- Adsorption capacity of the confining bed for common cations.

Cation	Adsorption capacity of confining bed	
	(kg/m^2)	(tons/acre)
Ammonium (NH_4)	67.6	301
Calcium (Ca)	75.1	334
Magnesium (Mg)	45.5	202
Potassium (K)	146.3	650
Sodium (Na)	86.1	383

Adsorption capacity of the confining bed was computed from the formula:

$$A = [(C_H \quad M_H) + (C_T \quad M_T)] \; D/Y_i$$

where:

A = Adsorption capacity of the confining bed in kilograms per square meter, or tons per acre

C_H = 0.062 meq/g, average cation-exchange capacity of the Hawthorn Formation

C_T = 0.278 meq/g, average cation-exchange capacity of the Tampa Formation

M_H = 4.5 m, average thickness of the Hawthorn Formation at the landfill

M_T = 4.1 m, average thickness of the Tampa Formation upper clay at the landfill

D = 2.64×10^6 g/m^3, average density of the confining bed estimated from specific gravity data

Y_i = factor for converting grams to milliequivalents (Hem, 1970, p.83)

Y_{NH_4} = 55.4 meq/g

Y_{Ca} = 49.9 meq/g

Y_{Mg} = 82.3 meq/g

Y_K = 25.6 meq/g

Y_{Na} = 43.5 meq/g

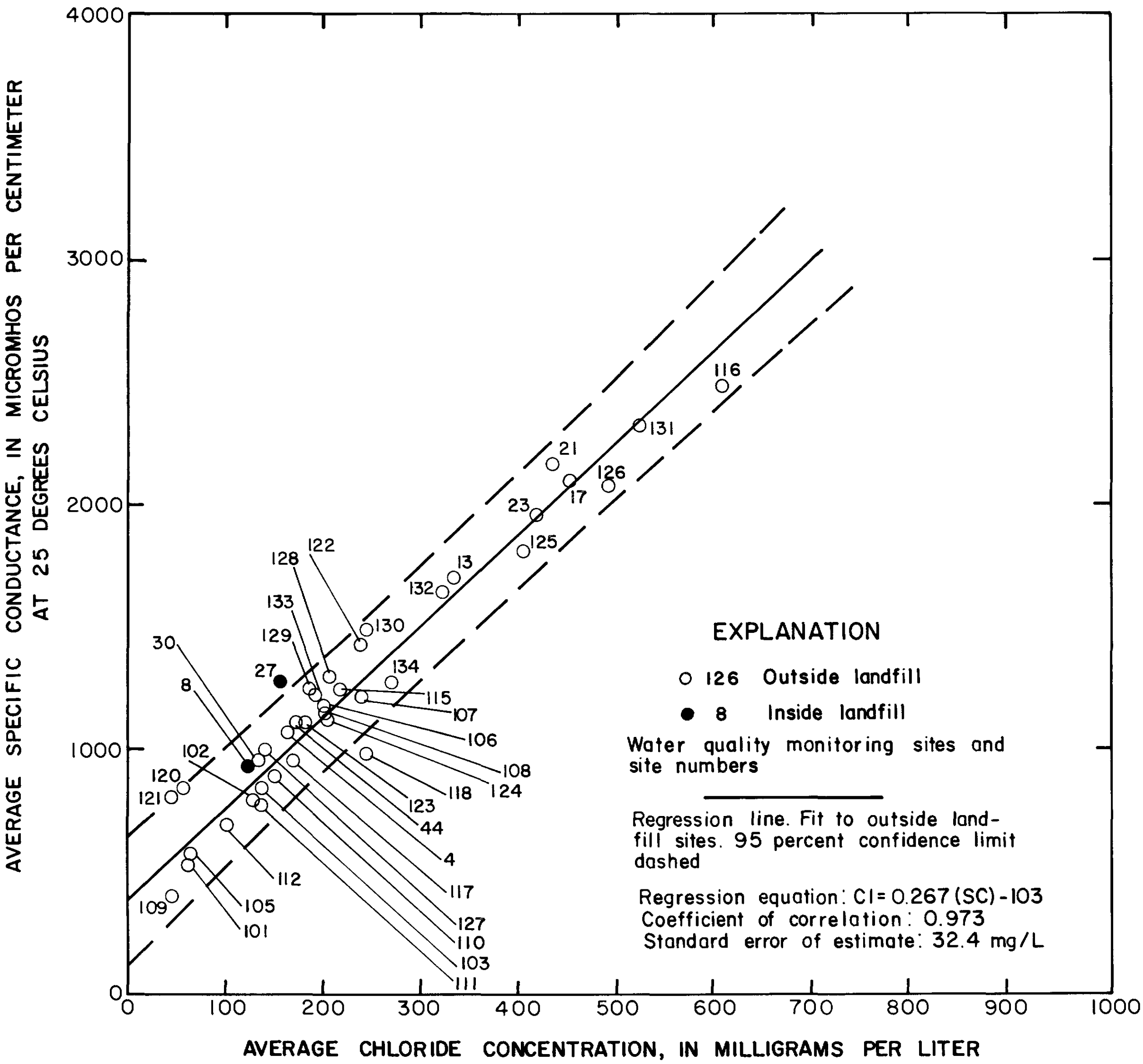

Figure 9. -- The average specific conductance versus average chloride concentration of water samples from the Floridan aquifer in the Toytown landfill area, January 1972 to August 1974.

A contour map showing the distribution of specific conductance of water in the Floridan aquifer in August 1973 (fig. 10) indicates that conductivity in the northern part of the landfill is below regional levels. The regional trend increases seaward from about 500 umho/cm, 2 mi southwest of the landfill, to more than 2,500 umho/cm near the coast, 1 mi to the northeast of the landfill. Heath and Smith (1954, p. 34) show that chloride concentration (and conductivity) of the Floridan aquifer in Pinellas County is related to the depth of a well and its distance from the coast. The depression in the contours at the landfill is probably caused by conductivity readings from wells which are completed just into the top of the aquifer. If contamination by leachate was occurring, conductivity readings above regional levels might be expected.

Nutrient levels of the water in the Floridan aquifer are low. Six wells were sampled at least once and some wells were sampled as many as three times. In all samples, dissolved ammonia nitrogen, nitrate, nitrite, orthophosphate, phosphorus, and total organic nitrogen levels were less than 1 mg/L, respectively. Where surficial aquifer and Floridan aquifer well pairs were sampled (wells 14-13, 22-21, 27-7, 44-43), the concentration of each nutrient constituent in the Floridan aquifer generally, but not always, was lower.

Trace element concentrations of water samples from the Floridan aquifer are consistently within the recommended limits for drinking water set by the U.S. Environmental Protection Agency (National Academy of Sciences and National Academy of Engineering, 1973). Concentrations of arsenic, cadmium, copper, fluoride, lead, manganese, and zinc in the Floridan aquifer are at about the same level as in the surficial aquifer (table 3). The concentration of iron, however, is noticeably lower in the Floridan aquifer.

Three circular diagrams (at wells 27, 44, and 125) in figure 8 illustrate the chemical quality of water in the Floridan aquifer at those locations. Dissolved solids concentration ranges between 500 and 1,000 mg/L. The ammonia nitrogen concentration was less than 1 mg/L at well 27, which is completed in the top of the Floridan aquifer directly beneath a sludge reservoir and solid-waste fill zone; hence, there is probably no direct hydraulic connection between the surficial and Floridan aquifers.

Surface Water

Surface water in the Toytown landfill area is subject to a wide range in chemical composition contributed by runoff and sludge disposal operations and is highly mineralized. Unlike ground water, surface water does not undergo natural filtration, although during periods of base flow, surface water discharge is ground water.

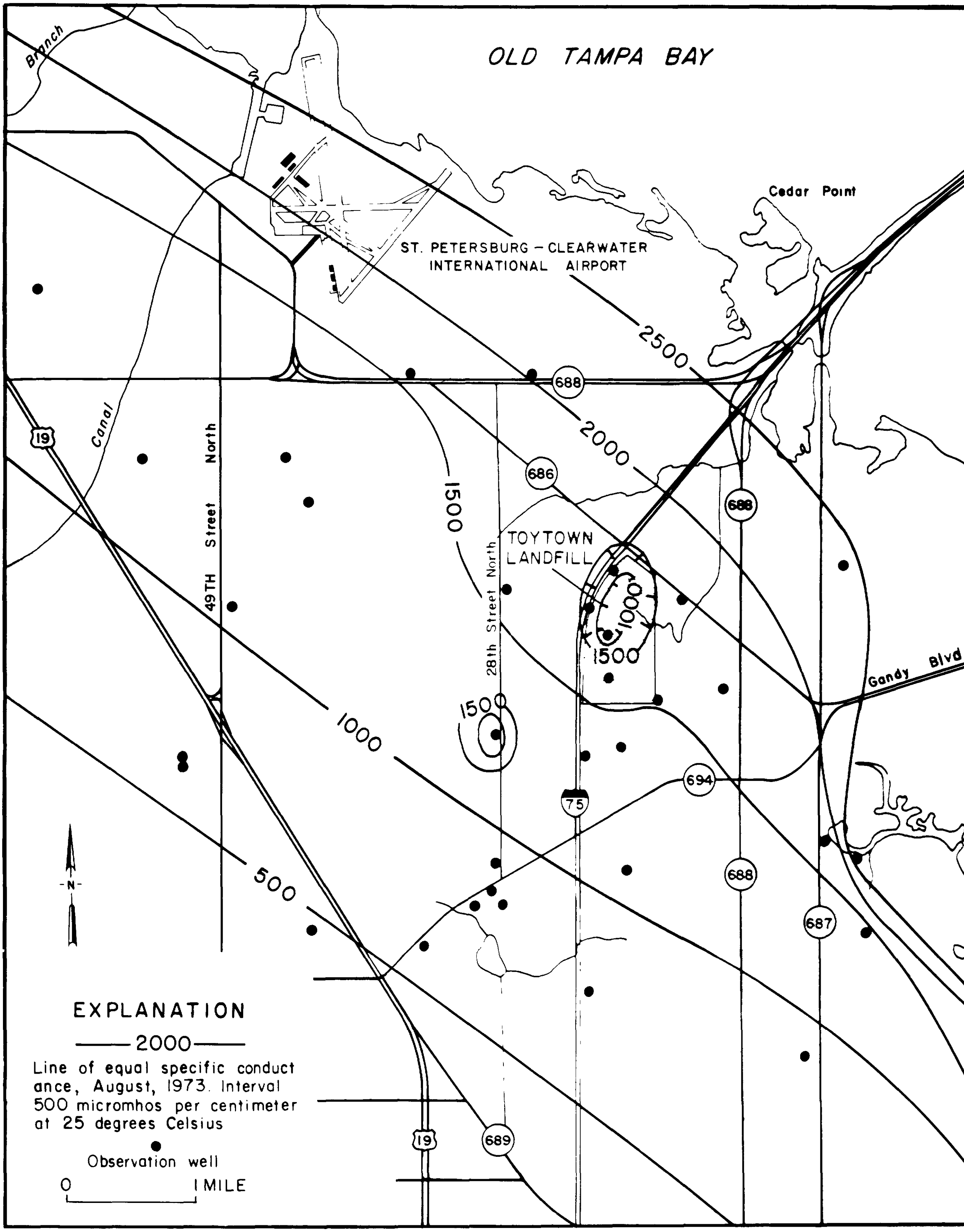

Figure 10. -- The specific conductance of water in the Floridan aquifer in the Toytown landfill area, August 1973.

Conductivity values indicate the quality of surface water at established sites in the Toytown area (fig. 11) on July 23-24, 1973. Conductivity ranges from 444 to 39,700 umho/cm for the 14 samples analyzed. The greatest value occurs at a drainage canal (SW-11) about half a mile upstream from Old Tampa Bay, and the lowest from a canal about 2 mi upstream from the landfill. In general, quality at surface-water sites near the coast (SW-3, -6, -10, and -11) is characterized by high conductivity, while inland sites (SW-5, -12, and -13) have low conductivity. Conductivity in streams outside the influence of the landfill probably is a function of the sodium chloride concentration; and hence, the extent of tidal encroachment, because mineralization decreases at each upstream site.

At the landfill, surface-water quality is poor and it varies with time, thus no comparison was made of average water-quality constituents (conductivity vs. chloride), such as used for ground water. In general, the surface water at the interior site (SW-4) is more mineralized than surface water at the holding ponds (SW-8 and SW-9) or the perimeter canal (SW-1, SW-2, and SW-14). The highest observed conductivity at the interior site is 10,400 umho/cm and the highest ammonia nitrogen concentration is 600 mg/L. At the perimeter canal the highest observed conductivity and ammonia nitrogen concentrations are 5,100 umho/cm and 500 mg/L, respectively. Just downstream from the outfall weir (SW-3), observed conductivity ranges from 695 umho/cm to 11,500 umho/cm and nitrogen concentration ranges from 2 mg/L to 22 mg/L. Conductivity was lowest during the June 1974 storm. At that time dikes on some sludge reservoirs broke and the drainage ponds overflowed. It is evident that dilution by rainfall improved the quality of the runoff from the landfill.

Sanitary Quality

The sanitary quality of water is determined from analyses of several factors that serve as indices of pollution. These include: coliform bacteria, organic carbon, and biochemical oxygen demand. A qualitative assessment of pollutant loads in surface-water and ground-water regimes is made by comparing the coliform bacteria, organic carbon, and biochemical oxygen demand of the water at the landfill, and at sites upgradient and downgradient from the landfill.

Bacteria

Bacteria are microscopic unicellular organisms that have been used as indicators of the sanitary quality of water since 1880. At that time coliforms were shown to be normal inhabitants of feces, soil, water, and vegetation (Geldreich, 1966). The objective of using the coliform group as an indicator of sanitary quality of water is to evaluate the disease-

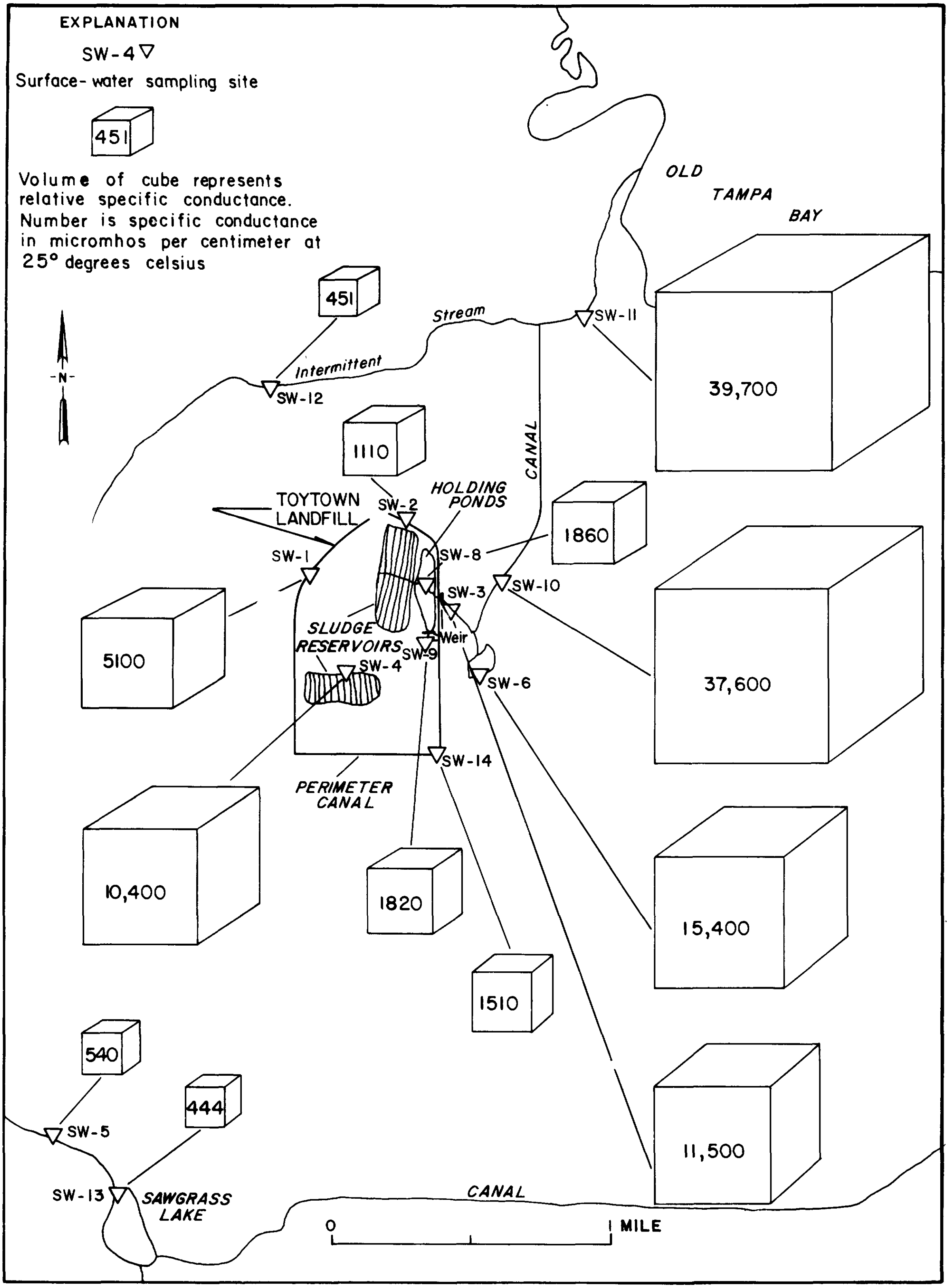

Figure 11.-- Specific conductance at surface-water sites in the Toytown landfill area, July 23-24, 1973.

producing potential of the water. Fecal coliforms are characteristically the inhabitants of warm-blooded animal intestines, and because they are relatively short lived, the presence of these organisms indicates recent fecal pollution and a definite health hazard. The presence of coliforms other than fecal is less definitive and presents only a possibility of fecal pollution. Separation of the total coliform group, into fecal and nonfecal subgroups, should yield greater numbers of fecal coliform organisms than nonfecal coliform organisms in water recently contaminated with sewage. In water that has been contaminated for a considerable time or has been insufficiently chlorinated, the roles of these subgroups may be reversed (Geldreich, 1966, p. 94) because members of the nonfecal subgroup tend to survive longer than members of the fecal subgroup.

The test for coliform is one criterion of suitability of Class III waters, which include those deemed suitable for recreation, and propagation and management of fish and wildlife in Pinellas County (Florida Department of Pollution Control, 1972, p. 11). The accepted standard of the Florida Air and Water Pollution Control Commission limits the total coliform count to average less than 1,000 colonies per 100 ml of sample per month, nor to exceed this number in more than 20 percent of the samples examined during any month; and to not exceed 2,400 colonies per 100 ml of sample on any day. Fecal coliform shall not exceed a monthly average of 200 colonies per 100 ml of sample, nor exceed 400 colonies per 100 ml in 10 percent of the samples; and not exceed 800 fecal coliform on any one day.

Total coliform and fecal coliform counts were made at various surface-water and ground-water sites in and around the landfill. Each surface-water site was sampled at least twice and selected wells were sampled once. Coliform counts varied greatly from one sampling period to the next. In general, surface-water sites are characterized by high total and fecal coliform counts and many samples were consistently above the daily maximum limits set for Class III waters. Of 12 ground-water samples tested, daily total coliform limits were equalled or exceeded in water from wells 53 and 54, west of the landfill. A second sampling of well 54, 3 months later, showed coliform counts well below the maximum limits. Since fecal coliform totals in the ground-water samples represent a small percentage of the total number of organisms, contamination possibly was not recent.

Total and fecal coliform counts at the landfill, and at upstream and downstream surface-water sites on July 23-24, 1973, are compared in the bar graphs of figure 12. The graphs indicate that during the designated time coliform counts at both upstream and landfill sites were generally above the limits set for Class III waters. Downstream sites, except that at the exit from the landfill (SW-3), were well below the daily limits. The outlet weir at SW-3 had been fortified with sand bags and surface runoff from the landfill consisted of a small amount of leakage through this barrier.

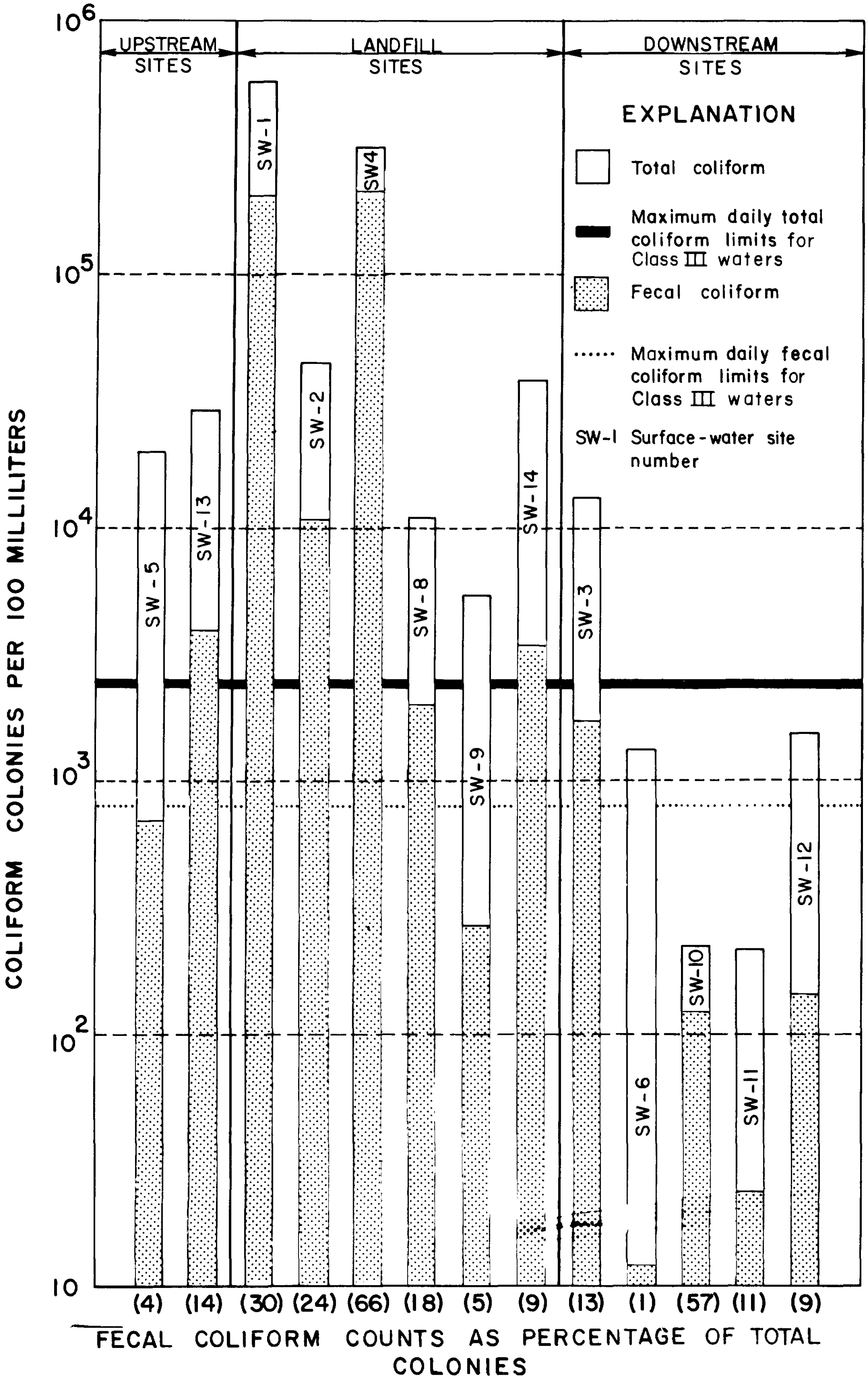

Figure 12. -- The fecal and total coliform counts at surface-water sites in the Toytown landfill area, July 23-24, 1973.

Total and fecal coliform counts at the upstream sites (SW-5 and SW-13) were highest on July 23-24, 1973. Prior and subsequent samples each showed significantly lower coliform counts at these sites. The percentage of fecal organisms is small, therefore, contamination probably was not recent.

The landfill sites are characterized by high total and fecal coliform counts, and the high percentages of fecal organisms probably indicates a recent source of contamination. As might be expected, the sludge reservoirs (SW-4) have one of the highest coliform counts, ranging into the hundreds of thousands and even into the millions. On February 15, 1974, the total coliform count of the sludge measured over 5 million as it was deposited into a pit at SW-4. The coliform count at south holding pond site SW-9 was probably reduced by the addition of chlorine during July 1973.

Water at all downstream sites, except SW-3, is relatively low in total and fecal coliform counts when compared to counts in water at upstream sites and in the landfill proper. The reason is not clear. Coliform counts range widely, however, and at times they are lower at upstream sites. The reason for the changes in coliform count at specific sites is not clear either; however, there may be a correlation between coliform totals and rainfall or salinity.

Carbon

Concentrations of organic and inorganic carbon may be used qualitatively to evaluate pollution loads. Total organic carbon, dissolved organic carbon, and total inorganic carbon concentrations were analyzed at 14 surface-water sites, in and around the landfill.

Organic carbon is an indicator of the level of organic matter in a water body. Total organic carbon ranged from 0 to 1,075 mg/L for all samples analyzed, and the median is 14 mg/L. Total organic carbon was greatest at the sludge reservoir site (SW-4) and high values were also observed at shallow wells 5 and 7 within the landfill, which are completed in zones of solid waste. At least 70 percent of the organic carbon in ground water is dissolved.

Inorganic carbon levels in and around the landfill usually reflect bicarbonate concentrations because carbonate and carbon dioxide is virtually absent in ground-water and surface-water samples. The range in total inorganic carbon is 54 to 575 mg/L. The highest values, as in the case of organic carbon totals, occurred at the sludge-reservoir site SW-4, and in water from wells 5 and 7 within the landfill. The sludge-reservoir site SW-4 produced the only sample which was higher in total organic carbon than total inorganic carbon.

Biochemical Oxygen Demand

BOD (biochemical oxygen demand) is commonly used as a measure of the detrimental effects of organic matter upon the quality of surface water. McKee and Wolf (1963, p. 147) state that, "BOD is important only insofar as it produces septicity or decreased dissolved oxygen, or subsequent growth of saprophytic bacteria which increase turbidity or other undesirable characteristics." BOD determinations were made at least twice; at nearly all of the 14 surface-water sites.

Rules of the Florida Department of Pollution Control concerning regulation of BOD levels are imprecise. Some states limit concentrations in Class III waters to 50 mg/L (Todd, 1970, p. 312). In the Toytown area, BOD ranged from 1.6 to 1,100 mg/L for all samples collected. BOD in samples from upstream sites SW-5 and -13 and downstream sites SW-3, -6, -10, -11, and -12 was consistently below 50 mg/L; BOD in samples from landfill sites SW-1, -2, -4, -8, -9, and -14 ranged widely, but were generally above 50 mg/L. The values correlate well with the bacterial and organic carbon aspects of water quality discussed earlier.

SUGGESTIONS FOR FURTHER STUDY

Because the volume and velocity of ground-water outflow is low when compared to surface-water discharge, a skeleton well network would be adequate for detecting the movement of leachate to adjacent property. However, the emphasis should be placed on continued water sampling for detection of surface-water contamination. A continued program of water-quality and water-level monitoring at the Toytown landfill may determine long-term trends resulting from landfill operations and could include:

I. Ground water

  A. Surficial aquifer

    1. Monitoring of all sites in late August for specific conductance and water level.

    2. Measurement of water levels in and collection of samples from wells 7, 32, 38, 41, 48, 50, and 53 in May and August. Analysis of samples for: common ions, trace metals, nutrients, BOD, and coliform bacteria.

  B. Floridan aquifer

    1. Monitoring all wells in late August for specific conductance and water levels.

    2. Monitoring wells 8 and 27 in May and August for water levels and a suite of water-quality constituents including: common ions, trace metals, nutrients, BOD, and coliform bacteria.

II. Surface water

A. Monitoring sites SW-1, SW-2, SW-9, SW-14, SW-3, SW-10, SW-11, and SW-12 monthly for a suite of water-quality constituents including: common ions, trace metals, nutrients, BOD, and coliform bacteria.

B. Monitoring sites 3 and 10 monthly for volume of flow.

Steady rises in time-trend plots of the data collected under the recommended program would detect movement of leachate outward from the landfill as well as signal any threat to the quality of Class III receiving waters of Old Tampa Bay. If leachate movement is detected, pumpage from the nearest perimeter canal segment could be stepped up to reverse the gradient and withdraw the contaminated water from the surficial aquifer. If a quality threat to Old Tampa Bay is detected, additional treatment would be necessary before water is discharged.

SUMMARY AND CONCLUSIONS

The 250-acre Toytown landfill was selected for study to determine the effects of landfill practices upon the hydrologic regime in a coastal area. There is a large potential for contamination of streams and aquifers by leachate from the landfill because the area is flood prone, has a high water table, and is subject to excessive runoff conditions. Moreover, contamination at a landfill will continue for decades after operations cease; thus, water in these areas cannot be utilized for most purposes until decomposition and flushing have occurred.

The Toytown landfill operations consist of the area-fill methods of solid-waste and digested sewage sludge disposal. A perimeter canal surrounds the landfill. Surface runoff and ground-water outflow are intercepted by pumping from the perimeter canal to on-site holding ponds where the water is evaporated or treated before discharging to Old Tampa Bay.

Three geohydrologic units are recognized at the site: (1) a surficial aquifer, 23 ft thick, that comprises the upper layer of fine-grained sand and shell material; (2) a confining bed consisting of 27 ft of stiff calcareous clay or marl, which grades downward to (3) a dense chert section that forms the upper part of the Floridan aquifer. The hydraulic properties of these units control the flow of ground water both horizontally and vertically from the landfill.

Water levels in the surficial and Floridan aquifers fluctuate seasonally with a 4-ft range. The water-table gradient in the surficial aquifer is 4 ft/mi northeast from the landfill toward Old Tampa Bay. Downgradient horizontal velocity of ground water under existing head conditions is probably between 1 to 10 ft/yr. Lateral flow in the surficial aquifer away from the landfill, calculated as a residual in the water budget, averages about 61,400 gal/d. The average rate of movement is slow because of low hydraulic conductivity and low water-table gradient. Vertical leakage of leachate into the confining bed averages 15,100 gal/d over the 250-acre landfill site. Velocity of flow through the confining bed is 7.4×10^{-4} ft/d. The confining bed, therefore, impedes the downward flow of leachate.

Characteristically, the specific conductance of ground water in Pinellas County is a function of its chloride concentration. At the landfill this relation does not hold true for the surficial aquifer. The chemical and sanitary quality of the water in that aquifer, and in surface ponds and canals, has been degraded by the decomposition of solid waste and digested sewage sludge. Water from the surficial aquifer and surface-water sites within the landfill boundaries has dissolved-solids concentrations above 1,000 mg/L and ammonia nitrogen concentrations above 200 mg/L. Concentrations of trace elements at the landfill appear to coincide with regional levels. At these sites, analyses of sanitary quality factors including coliform, organic carbon, and biochemical oxygen demand also indicate high levels of ground-water and surface-water pollution within the landfill. Contamination by leachate was not detected in wells more than 15 ft beyond the perimeter.

Inside the landfill, ground-water and surface-water quality is poor. Outside the landfill boundaries, and beneath the solid-waste zones, the chemical and sanitary quality of ground water and surface water apparently is unaffected by landfill operations, except for a few feet downgradient, because of the following: the filtering capacity of the sand; favorable hydrologic conditions, including low hydraulic conductivity and low water-table gradient; pumping from the perimeter canal, which restricts ground-water seepage and prevents surface runoff; and the diluting effect of rainfall. Quality of water in the Floridan aquifer is protected by the confining bed. The bed retards downward leakage of leachate because of its low hydraulic conductivity and its high capacity for ion exchange and ion adsorption.

With proper planning and operation, a landfill can function in a coastal area with geohydrologic characteristics similar to this one without short-term detrimental effects upon ground-water resources. It is anticipated that long-term effects would be detected by a continuing program of water-quality and water-level monitoring at the Toytown landfill.

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