HYDROLOGIC EVALUATION OF A 53-ACRE SECTION OF TOMOKA LANDFILL, VOLUSIA COUNTY, FL.

prepared for

Briley, Wild & Associates, Inc.

and

Volusia County Department of Public Works

David N. Gomberg, Ph.D.
Water Resources Consultant
Cape Coral, Florida

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SUMMARY

An investigation has been completed at Tomoka Landfill, to evaluate the hydrogeology and site suitability of the next area planned for solid waste disposal. The study site encompasses 53 acres, about 35 of which are currently used as a borrow area to obtain landfill cover material. The investigation included coring at 4 sites, field and lab permeabiltiy testing, and an analysis of data from monitoring and from 20 soil borings taken during a previous study.

The generalized sedimentary sequence consists of eight unconsolidated strata overlying the limestone of the Floridan Aquifer, which is found at about 80 feet below ground. The eight units are persistent throughout the study area, and consist of mixtures, in proportions ranging from absent to dominant, of sand, silt, shell and clay. They are arranged to form, alternately, four layers of moderate permeability and three clayey confining beds. Throughout the study area, the cumulative thickness of clayey sediments varies between 20 and 30 feet.

Permeabilities of the various hydrologic units range from 10^{-2} cm/sec for the sandy, upper part of the water table aquifer to 10^{-8} cm/sec for the lowermost confining bed. Shallow groundwater flows northeasterly across the landfill property at rates between 0.2 ft/day in the water table aquifer to less than 0.01 ft/day in the deepest unconsolidated aquifer. Superimposed on this regional pattern is inward-directed, lateral flow towards the active landfill and borrow areas, the result of a reversed hydraulic gradient caused by dewatering and leachate control. Extremely slow vertical flow is directed downward, towards the Floridan Aquifer. Travel time from the water table exceeds several thousand years, as a consequence of the small vertical gradient and an effective vertical permeability of less than 6×10^{-8} cm/sec.

Within the next few years, the borrow area will be completed, and then used for solid waste disposal. The operational and leachate control plan for this area will, through dewatering, cause groundwater to flow very slowly towards the disposal site, both laterally and vertically. Under these conditions, leachate cannot migrate from the area and, as a result, such design elements as a synthetic liner or slurry wall offer no benefit other than to provide additional assurance of leachate containment. A non-traditional alternative that would be equally effective as a backup and probably less costly is a hydraulic barrier, acting as a groundwater divide across which water or leachate cannot flow. Such a barrier consists of an external ditch where water levels are kept higher than adjacent groundwater. This barrier can be designed to be essentially maintenance-free, and it can be moved as the landfill expands.

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INTRODUCTION

Objectives. This report presents the results of an investigation to determine the suitability for solid waste disposal of a 53-acre section of Tomoka Landfill. Work described here was accomplished to allow an evaluation of the area from which cover material for the active landfill is currently obtained, plus a smaller adjacent parcel. The goal of the investigation was to provide guidance, to the County, the engineers responsible for site design, and Regulatory personnel, concerning the hydrology of the site, the potential impact of landfilling activities there, and site modifications that can minimize or prevent impacts. The scope of work included a review of pertinent literature and monitoring data, an evaluation of previous hydrologic work at the landfill, plus coring and hydraulic testing within the study area.

Specific objectives of the investigation are:

a) define the hydrogeology of the site, including the lithology of unconsolidated strata, and the presence and lateral continuity of aquifers and confining layers;

b) evaluate directions and rates of groundwater flow, both laterally and vertically;

c) assess the hydrologic effects of landfilling activities and suggest site or operational modifications to minimize impacts.

Site Description. Figure 1, a reproduction of parts of the U.S.G.S. Daytona Beach and Samsula quadrangle maps, shows the location of Tomoka Landfill. The property (Figure 2) consists of 846 acres located just south of Interstate 4 and west of Tomoka Farms Road. Unimproved portions of the landfill and surrounding areas are predominantly pine-palmetto flatwoods, with very gentle slopes and slow drainage. Along the eastern portions of the property are wetlands that are marginal parts of

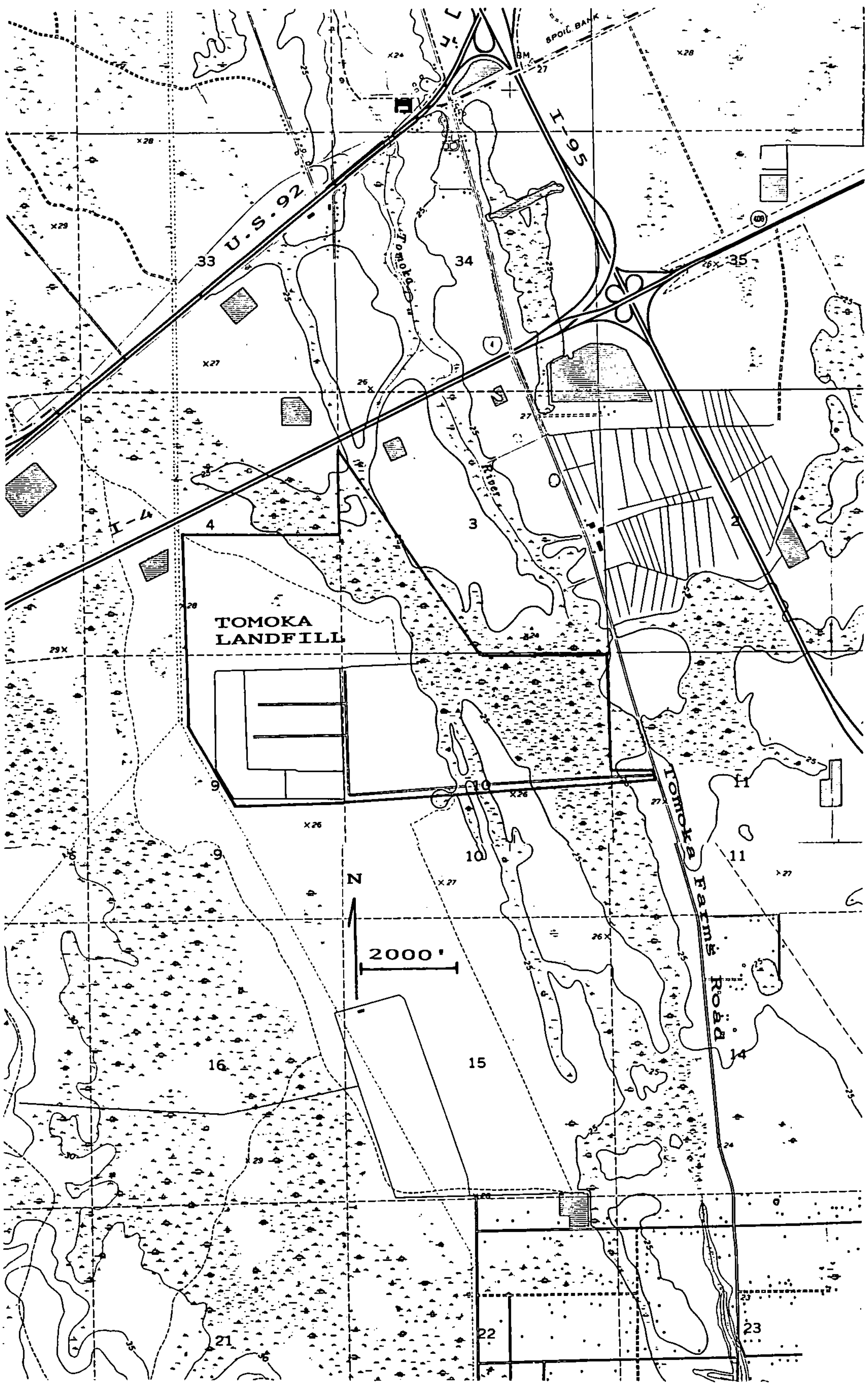


Figure 1. Location of Tomoka Landfill

the Tomoka River, flowing northward, and Spruce Creek, flowing to the south and east. Elevations in the area are mostly between 25 and 29 ft. MSL, and one to a few feet lower in wetland areas.

The property has been used for solid waste disposal for over 15 years, first in the area shown on the map as "old," and currently in the area designated as "active." Cover for the daily accumulation of solid waste is obtained from the shallow, 35-acre borrow pit north of the active fill area. Runoff and internal seepage from the fill area is collected in an encircling perimeter ditch, routed to the holding and natural treatment ponds, and discharged as necessary to an eastward sloping ditch along the south property boundary. While the old area has been filled to less than 10 feet above natural grade, filling in the active area has resulted in accumulations up to 50 feet above grade.

The study area addressed in this report consists of the shallow, 35-acre borrow pit north of the active fill area and the 18± acres to the west and between the fill area and the property boundary (Fig. 2). Cover for the daily accumulation of solid waste is currently obtained by the excavation of silty and clayey sands found in the borrow area, and it is anticipated that this and other parts of the study area will be used for waste disposal when the active area reaches design height.

Dewatering of the borrow area is accomplished through a ditch network leading to a sump in the northeast corner of the pit, from where water is pumped to and discharged farther northeast. The ditches serve, however, mainly to collect and route rainfall, as the low-permeability sediments drain very slowly, and are dewatered largely by evaporation. The eastern half of the borrow pit has been excavated to about 21 ft. MSL, and it is intended that the bottom of the entire pit will be lowered to +15 ft. MSL prior to the introduction of any waste.

Acknowledgements. Jim Griffin, Assistant Director of Public Works, and his staff at the landfill were continually

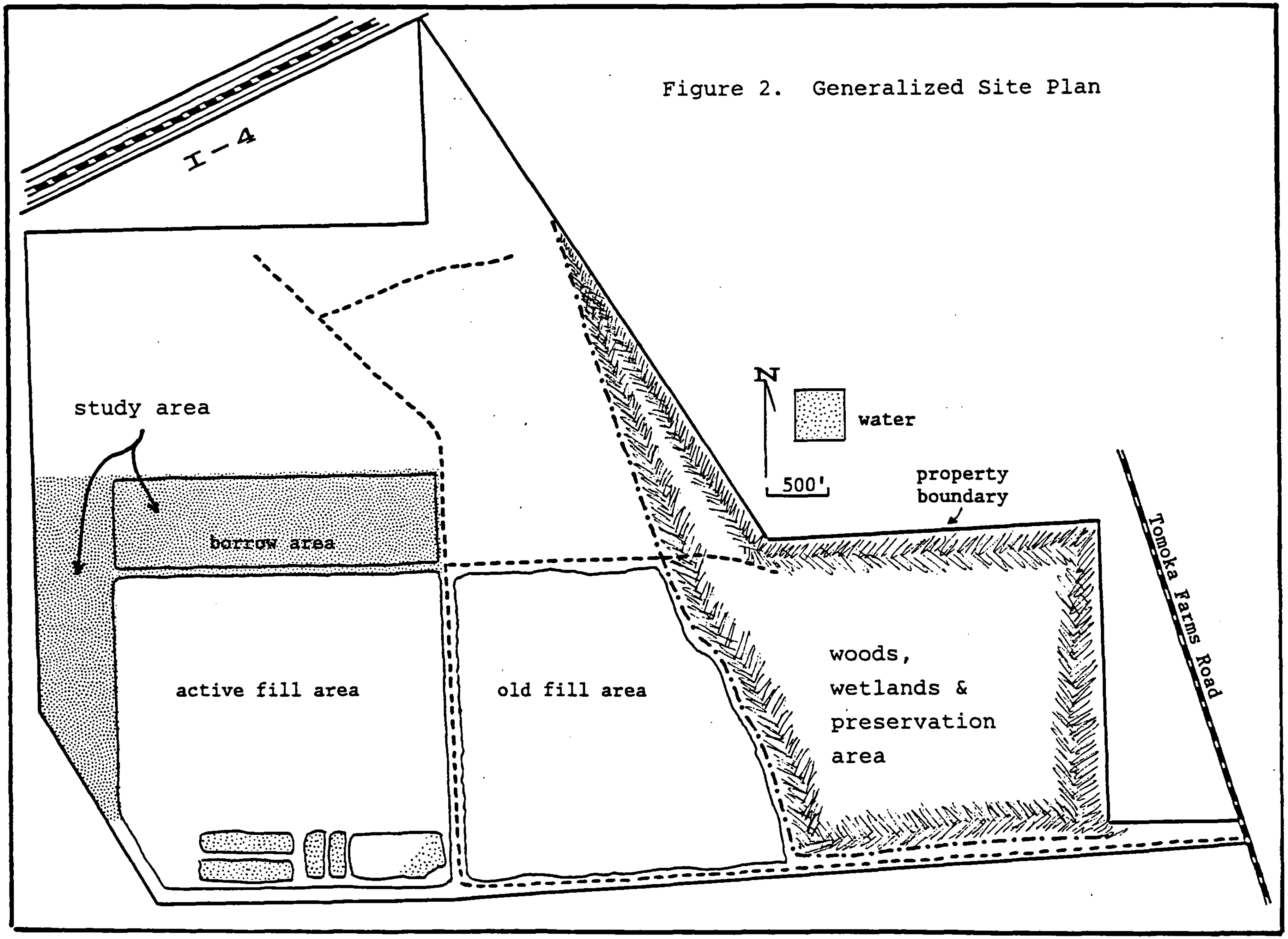


Figure 2. Generalized Site Plan

helpful, Jim particularly in providing background information, and his staff especially with logistic support. Professionals at Briley, Wild & Assoc., Inc., notably Bert Reilly and Lee Powell, furnished essential data and incisive discussion. Universal Engineering & Testing Co. responded capably during the coring procedure, and without complaint to unusual requests. Bob's Well Drilling of Holly Hill was quick and efficient in completing the hydraulic testing, and suffered no mechanical breakdowns.

FIELD INVESTIGATION

Previous Work. Substantial information relevant to the hydrogeology of the study area has previously been collected. Most important are the water level and water quality monitoring data assembled in connection with regulatory requirements, and results from an investigation (Brooks, 1980) of subsurface conditions performed in support of the operating permit for the landfill.

Brooks' work was undertaken to characterize the hydrogeology of the entire property, to compliment the long-range operational plan prepared by Briley, Wild & Assoc., Inc., consulting engineers for the County. The data collection effort included 20 auger borings up to 50 feet deep, and the installation of 7 shallow and 2 Floridan Aquifer wells. Also reported were the results of 31 grain size analyses and determinations of the clay mineral composition of 7 sediment samples. Brooks prepared a potentiometric map of the water table, and analyzed water samples from 9 shallow wells, 6 deep (i.e. Floridan) wells and 3 surface stations. The locations of soil borings, including those taken for this investigation, are shown on Figure 3; boring depths are given in Table 1.

As a result of monitoring and, to a lesser extent, operational needs, 22 wells have been constructed at the landfill. These are shown on Figure 4, along with the locations of surface water sampling stations. Pertinent well data are given in Table 2. As can be seen from the table, a wealth of monitoring data, including both water levels and water quality results, has been collected since monitoring began in 1977.

Where relevant, both the information gathered by Brooks and the results of monitoring are used in this report.

Coring. Four core borings (Fig. 3, Table 1) were taken as part of the investigtion reported here, to supplement information

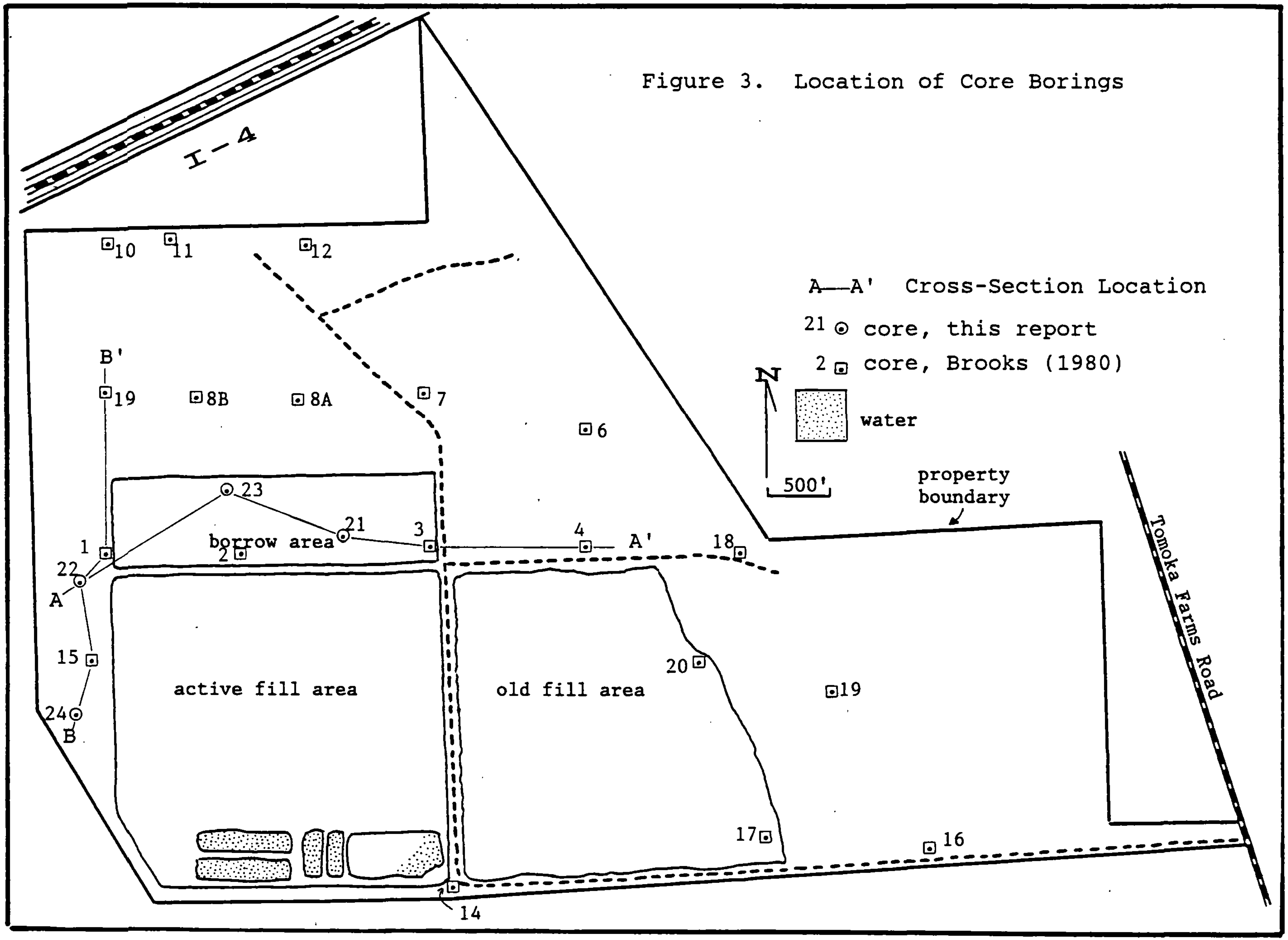


Figure 3. Location of Core Borings

Table 1. Core Depths

Core#	Type	Depth (ft.)
1	auger	35
2	"	45
3	"	22
4	"	45
6	"	30
7	"	40
8a	"	40
8b	"	30
9	"	40
10	"	35
11	"	35
12	"	30
13	"	30
14	"	35
15	"	28
16	"	30
17	"	40
18	"	50
19	"	40
20	"	19
21	split spoon	80
22	"	85
23	"	60
24	"	65

gathered from prior subsurface work and to extend knowledge of hydrogeology to deeper strata. These 4 cores are identified as sites 21 through 24, continuing Brooks' sequential numbering. The site locations were selected to compliment earlier work, and to provide basic areal coverage within the defined investigative boundaries.

Split-spoon sampling was done at all 4 sites. At sites 21 and 22, this sampling was carried out to the top of limestone; at sites 23 and 24, coring was terminated upon encountering the deepest of three clay layers identified from both earlier cores. At all sites, coring was continuous to about 10 ft. depth, following which samples were collected from 2 feet out of each 5-foot interval. The respective depths of the four cores are 80', 85', 60', and 65'. Completed core holes were backfilled with neat cement.

The sediments collected by coring were analyzed visually in the field, to determine lithology, grain-size distribution, color, and texture. Representative samples of each lithology were preserved wet, re-examined under magnification to confirm field observations, and filed in the author's permanent collection. Coherent samples from clay-rich strata were preserved intact and later analyzed for lab permeability. (One clayey sample, from site 22 at 65 feet depth, was collected by Shelby tube sampling.) The appendix contains geologic logs for the core sites, and for nearby sites sampled by Brooks and used in this report to prepare lithologic cross-sections.

Hydraulic Testing. Constant head permeability tests (U. S. Dept. of the Interior, 1981) were conducted at Site 21, to evaluate the general flow characteristics of unconsolidated strata. The depth interval to be tested was selected from core data. An oversized hole was drilled to 10' above this depth, 4" galvanized iron casing was placed in the hole, and the casing was then driven to the pre-determined bottom of the test interval.

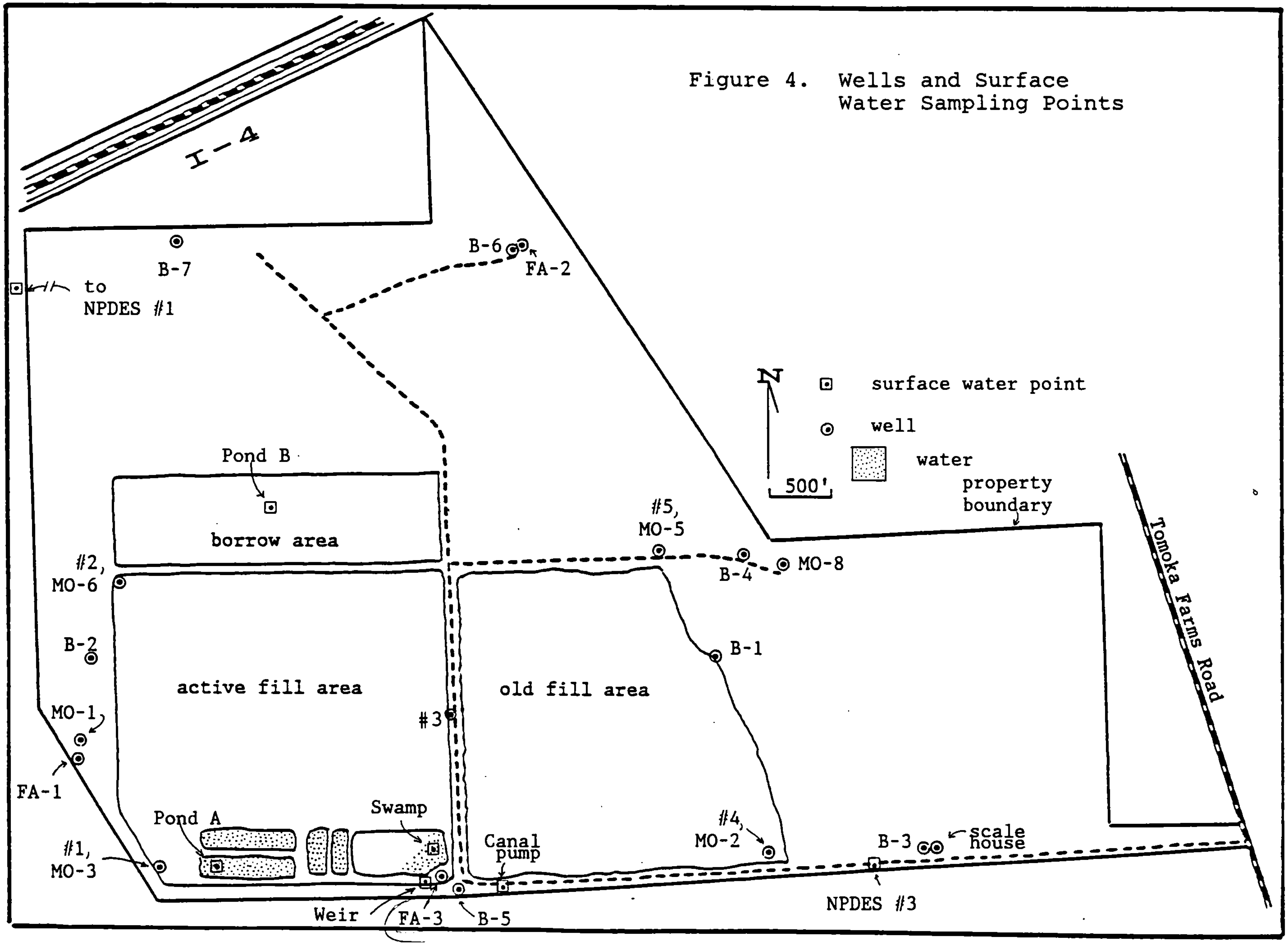


Figure 4. Wells and Surface Water Sampling Points

Table 2. Wells at Tomoka Landfill

Well	Year Installed	Total Depth (ft)	Screened or Open Interval	Remarks
1	1977	10±	?	abandoned; Qw '77-'79
2	"	"	"	abandoned; Qw '77-'79
3	"	"	"	abandoned; Qw '78-'79
4	"	"	"	abandoned; Qw '78-'79
5 or MO-5	"	"	"	DER #64A71M05; Qw '78-'80; W.L. '80-'86
MO-1	1978	20±	"	abandoned; no data
MO-2	"	"	"	abandoned; no data
MO-3	"	"	"	abandoned; no data
MO-6	"	16.5	"	abandoned; DER #64A71M06; W.L. '80-'83
MO-7	"	20±	"	abandoned; no data
MO-8	"	"	"	abandoned; no data
B-1	1980	25	20-25	DER #64A71M16; no Qw; W.L. '80-'86
B-2	"	24	19-24	DER #64A71M01; Qw '80-'86; W.L. '80-'86
B-3	"	25	20-25	abandoned; DER #64A71M15; Qw '80-'83; W.L. '80-'83
B-4	"	25	20-25	DER #64A71M08; Qw '80-'86; W.L. '80-'86
B-5	"	23	18-23	DER #64A71M02; Qw '80-'86; W.L. '80-'86
B-6	"	30	25-30	DER #64A71M11; Qw '80-'86; W.L. '80-'86
B-7	"	25	20-25	no data
FA-1	"	200±	90-200±	DER #64A71M13; Qw '80-'86; W.L. '81-'86
FA-2	"	200±	90-200±	DER #64A71M14; Qw '80-'86; W.L. '81-'86
FA-3	"	?	?	maint. area well; no data
Scale House	1983	?	?	scale house well; no W.L.; Qw '83-'86

Qw = water quality analyses
W.L. = water levels

After drilling out and washing the casing, enough clean, course gravel was added to fill the casing to 2-3 feet above the interval to be tested. The casing was then pulled back to expose the selected interval.

After measuring the static water level relative to the top of the casing, clean water was introduced into the hole by hand-pouring. Water was added in amounts necessary to keep the casing full, while the time to add a known volume was recorded. This procedure was repeated until it was clear that time increments for successive tests had stabilized. At the conclusion of testing of an interval, the casing was extracted, and a new hole was used for the next selected interval. Test results are given in the appendix.

Five clay-rich samples were selected from the core materials for a determination of lab permeability. These were run by Universal Engineering Testing Co. (Orlando), using a standard procedure (Lamb, 1951) that constrains flow in one direction. For coherent clayey samples that are not reconstructed, this direction is co-incident with the coring direction and, as a consequence, the lab procedure results in a determination of vertical permeability.

HYDROGEOLOGY

Geology

Sedimentary Sequence. Information regarding the lithology of unconsolidated strata results from examination of 4 core borings within the study area and 6 well logs reported by Brooks (1980) that are in or near the area. The generalized sedimentary sequence, based on these sites, is as follows:

1. Tan fine sand, 0 to 6' thick
2. Gray silty sand, 5 to 14' thick
3. Brown silty and clayey sand, 0 to 14' thick
4. Tan very fine sand, 5 to 15' thick
5. Green-gray sandy clay, 3 to 15' thick
6. Gray sand and shell, 14 to 20' thick
7. Green-gray shelly clay, 5 to 11' thick
8. Green-gray silty sand and shell, 16 to 20' thick
9. Limestone, to great depths.

While a rather long list for a generalized sequence, it condenses conceptually to a series of beds of alternately low and moderate permeability. The numbering corresponds to numbers on the cross-sections shown in Figures 5 and 6, locations for which are given on Figure 3.

The uppermost unit consists of the soil zone, commonly gray fine sand with organic debris, underlain by tan fine sand to a few feet depth. Soils over approximately 85% of the site consist of Malabar (30±%), Pomona (25±%), Riviera (20±%) and Pineda (10±%) fine sands, all commonly associated with a palmetto-pine flatwoods environment (U. S. Dept. Agriculture, 1980). In its various forms, this stratum blankets the entire site, except where it has been removed by excavation. It overlies designated layer 2, a gray silty sand with, at most locations, minor clayey lamina in its lower parts and intermittent organic-rich zones throughout. Layer 2 contains a sizeable component of shell fragments at sites 22 and 24 and, at site 21, a sandy peat layer near its bottom.

The next lower stratum (layer 3) is brown silty sand, with a variable amount of clay that increase with depth. The clay occurs mostly in thin (i.e. a few mm. thick) lamina whose abundance at some levels results in stiffness. Lenses of clean white sand occur frequently in the upper part of this unit.

Immediately below is the fourth layer, a very fine, mostly tan sand whose most distinguishing characteristic is that it will spontaneously liquefy when disturbed. The geologic logs in the appendix identify this material as "thixotropic," signifying generically the special physical properties of this layer.

Layer 5, found starting at depths of 22 to 37 feet below ground, consists of greenish-gray, sandy clay. It is usually stiff, unlayered, and contains sand-sized grains of tan mica. It is separated from layer 6 by a thin (one to a few inches) bed of coarse, black, silty sand, which served as a convenient marker during coring. Layer 6 is a variable assemblage of sand and shell, usually gray, silty in part, with the two principal constituents dominant in alternating layers. Shiny black sand grains, possibly phosphorite, are common in this stratum.

Sandy, greenish-gray clay comprises layer 7. It is slightly to moderately stiff and, in places, includes an abundant component of coarsly broken mollusk fragments. Below, starting at depths of 57 to 67 feet, is the lowermost unconsolidated unit (layer 8), and the stratum that is consistently thickest. The material is a mixture of sand and shell, in varying proportions but mostly dominated by sand, and in colors ranging through tans and grays and greens. Unlike layer 6, bedding is not apparent within the unit, though various sections of it are often quite silty. Phosphorite (?) is ubiquitous, resulting in a familiar "salt and pepper" pattern.

The deepest layer encountered was the tan limestone that signals the top of the Floridan Aquifer. This was a sandy mudstone with no recognizable fossils. It was found at depths of 78 and 82 feet at, respectively, sites 21 and 22. Information regarding the stratigraphic position of this and other

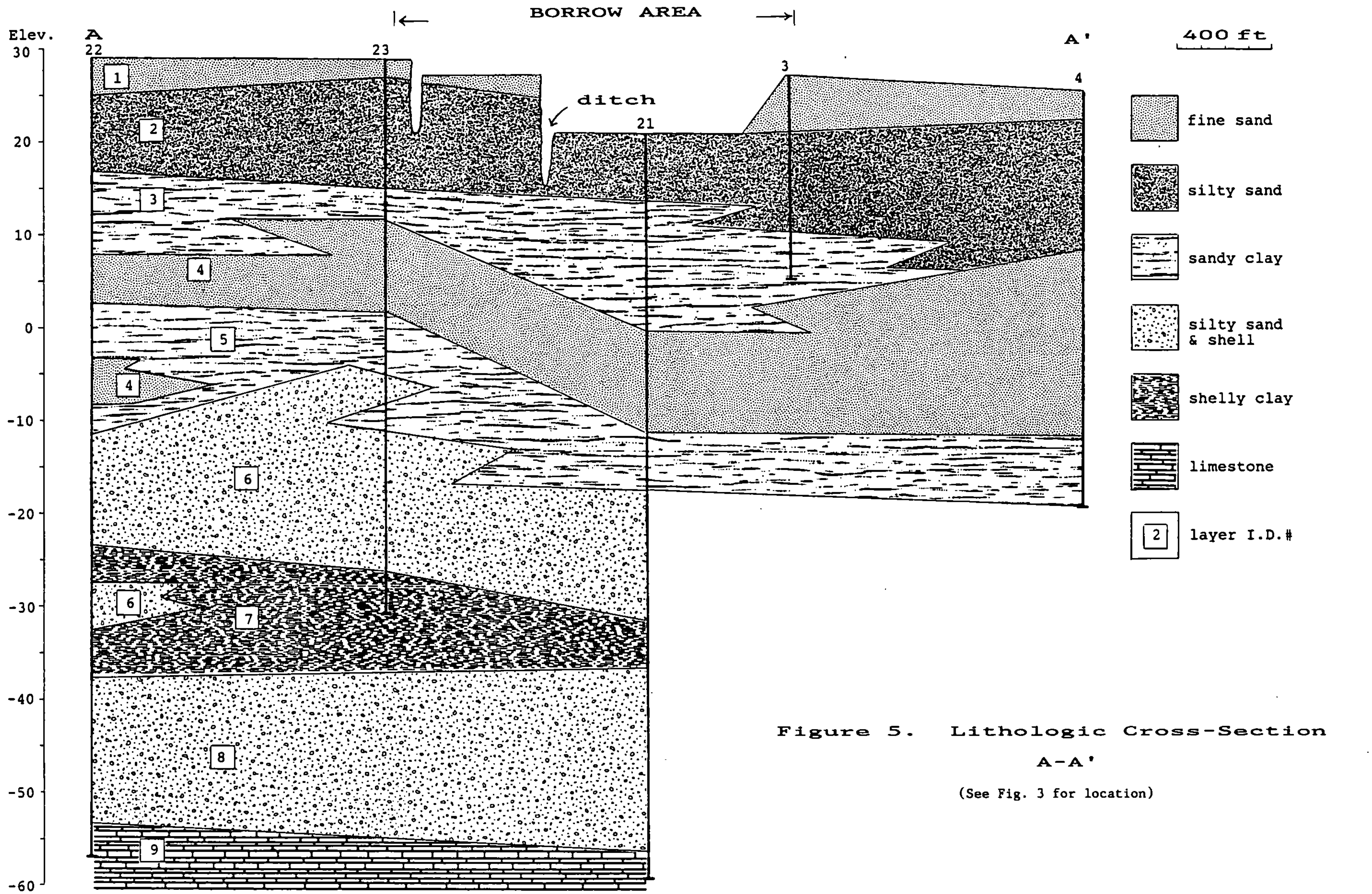


Figure 5. Lithologic Cross-Section A-A'

(See Fig. 3 for location)

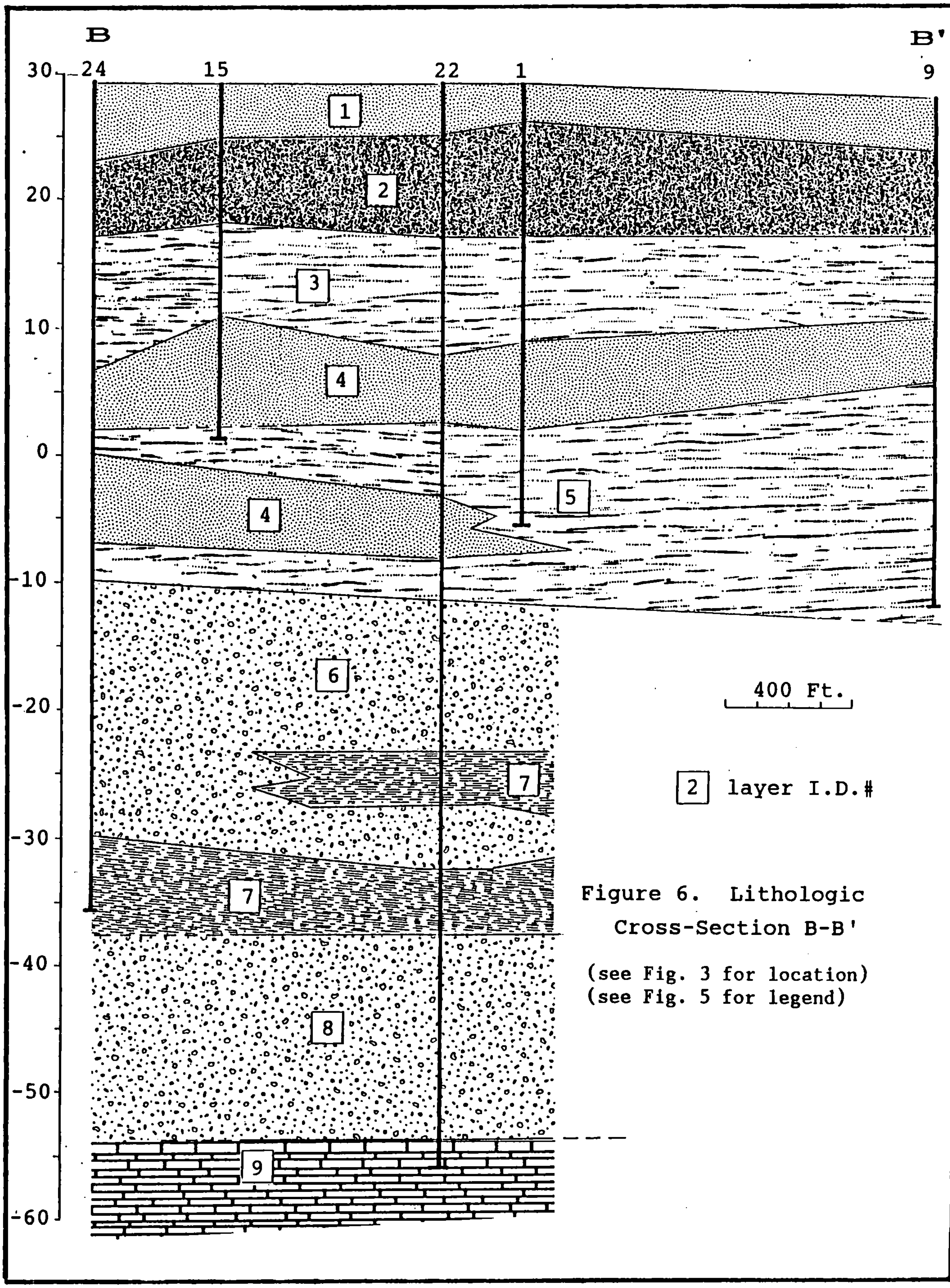


Figure 6. Lithologic Cross-Section B-B'

(see Fig. 3 for location)
(see Fig. 5 for legend)

units described above can be found in Knochenmus and Beard (1971), Wyrick (1960), and Cooke (1945).

Continuity of Strata. The nine layers described above are each numbered and shown on cross-sections A-A' (Fig. 5) and B-B' (Fig. 6). As demonstrated by the illustrations, all but one of the units, that being the uppermost soil-sand zone removed in part of the borrow pit by excavation, occurs throughout and beyond the study area. The brown silty and clayey sand of layer 3 apparently pinches out some distance west of the study area, but is present in considerable thickness at Site 3, the western extent of the area.

To varying degrees, all layers undergo thickening and thinning, and, probably, some interfingering with adjacent units. Over the eastern half of the site, the sandy clay of layer 5 intertongues above with the thixotropic sands of layer 4 (see site 22, Fig. 6) and below with sand and shell from layer 6 (see site 23, Fig. 5). Deeper, layers 6 and 7 probably intertongue also, though stratigraphic control on these units is weak. While details of the sedimentary sequence are clearly not simple, the fact that layers, particularly those of low permeability, are continuous provides substantial advantage in modeling or predicting vertical groundwater movement.

Thickness of Low-Permeability Sediments. Relevant to both the volume and flow rate of water that may travel vertically towards the Floridan Aquifer is the thickness of clay-rich strata. Individual thicknesses of clayey units (layers 3, 5, and 7) are given in Table 3, and the sum of thicknesses is contoured in Figure 7. Thicknesses are based on core data and, in a few instances, interpolation between sites (e.g. Site 27, layer 7) or extrapolation from the nearest site (e.g. Site 1, layer 7). The selection of layers 3, 5 and 7 as aquitards is the result of visual inspection and, as discussed later, test data indicating permeabilities less than 10^{-6} cm/sec.

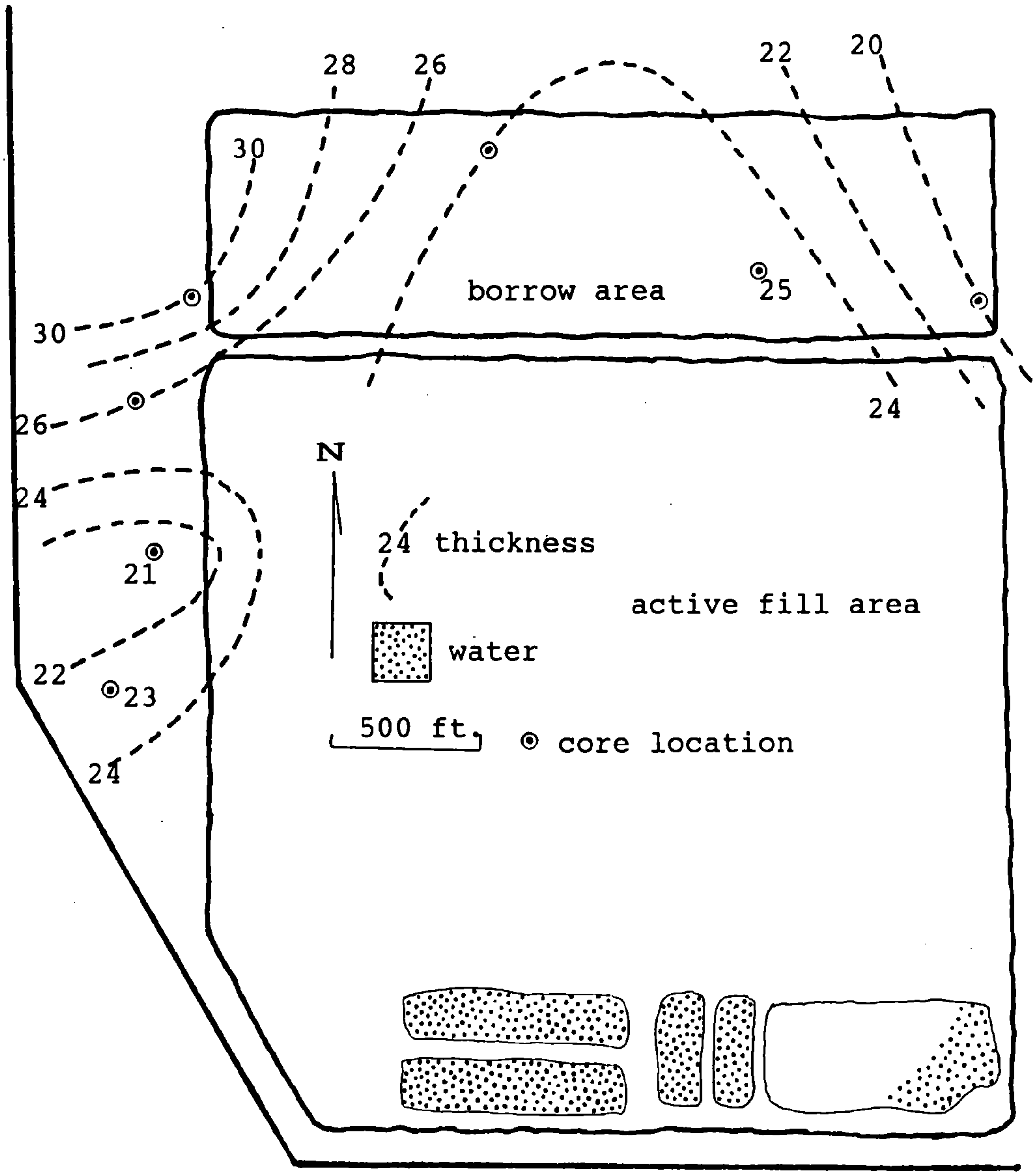


Figure 7. Cumulative Thickness of Clayey Sediments

Table 3. Clayey Sediment Thicknesses (in feet)

Site	Layer 3	Layer 5	Layer 7	Total
24	10	5	8	23
15	8	6	7	21
22	9	9	9	27
1	8	13	9	30
23	3	10	11	24
21	14	6	5	25
3	8	7	5?	20

Because of data limitations, Figure 5 is intended to illustrate areal trends in clayey sediment thickness, rather than details regarding thickening and thinning of clay-rich strata. As shown, cumulative thickness ranges from 20 to 30 feet, with the northwest part of the site having most clay. Slowly decreasing thicknesses are indicated to the east, with variable but generally thinning tendencies towards the south. Total clay thicknesses are comparable, though slightly less than those found at other area landfills, notably the 20-50 feet at Ormond Beach Landfill (Gomberg, 1983) and the 20-40 feet of clayey sediments at Plymouth Road Landfill in DeLand (Gomberg, 1982).

Hydrology

Hydrologic Units. Based on lithologic characteristics (discussed above), hydraulic testing (discussed below), and available literature, the water bearing and confining zones underlying the site can be defined. Corresponding to the moderately transmissive and low-permeability strata shown on the cross-sections (Figs. 5 and 6) are four aquifers (in the loosest sense of the word) and three layers which tend to restrict and retard flow. Water-bearing units are layers numbered 1-2, 4, 6, and 8-9 on the cross-sections, while layers numbered 3, 5 and 7 are confining zones or aquitards. These are shown schematically in Figure 8.

The water table or surficial aquifer encompasses the soil zone and the underlying gray or tan silty sands. This hydrologic unit varies in thickness from about 7 feet in the borrow area, where over half of it has been excavated, to about 14 feet at Site 23, just east of the borrow area. The saturated thickness of the aquifer exhibits considerably variability, particularly as a result of the water table lowering necessitated by the excavation. In the active borrow area, the aquifer has been essentially dewatered, whereas in other areas, the water table fluctuates seasonally from near land surface to, in the case of the most recent Spring dry season, up to 7 feet below ground.

Two units of moderate permeability occur deeper in the sedimentary column, and are separated from one another by the clayey sediments of layer 5 (Fig. 5). These strata, the tan "thixotropic" sand of layer 4 and the silty sand and shell of layer 6, would be gratefully used for well water supply in many parts of the world and are thus, by extension, here called aquifers. They are semi-confined zones, being recharged locally and rapidly by area rainfall but responding to short-term withdrawals with artesian characteristics, and are widespread in the unconsolidated sequence of western Volusia County (see, for example, Gomberg, 1980 and 1981). These and similar units between the water table and Floridan aquifers are commonly denoted as secondary artesian aquifers (SJRWMD, 1977). Their thickness beneath the study area averages about 8 feet for the upper zone and 14 feet for the lower.

Depth below ground (ft.): 0, 10, 20, 30, 40, 50, 60, 70, 80

Lithology	Name	Permeability (cm/sec.)	Layer I.D.#
sand	Water Table Aquifer	10^{-2} to 10^{-4}	1
silty sand		2×10^{-5}	2
clayey sand	Confining Bed	2×10^{-7} (K_v)	3
sand	Semi-unconfined Aquifer	2×10^{-4}	4
sandy clay	Confining Bed	9×10^{-7} 3×10^{-8} (K_v)	5
sand & shell	Secondary Artesian Aquifer	1.7×10^{-4}	6
clay	Confining Bed	1×10^{-8} (K_v)	7
silty sand & shell	-	probably 10^{-4} to 10^{-5}	8
limestone	Floridan Aquifer	variable	9

Figure 8. Generalized Hydrogeologic Section

The top of the Floridan Aquifer in Volusia County is traditionally and informally defined as at or just below the top of Tertiary limestone, found in the study area at approximately -55 ft. (MSL). Directly overlying limestone in the study area, however, are 16 to 20 feet of silty sand and shell, whose permeability is undoubtedly high enough that this unconsolidated stratum acts in hydraulic concert with the limestone. Consequently, the lowermost hydrologic unit in the study area is a combination of loose clastic sediments and limestone, similar in this regard to the hydrologic sequence at Plymouth Road Landfill (Gomberg, 1983).

Hydraulic Characteristics. To evaluate the flow characteristics of unconsolidated sediments, two field and five lab permeability tests were conducted. Results are given in Table 4, along with data from other sources. The lab values in the table represent essentially vertical permeabilities (K_v), whereas the field values are a composite of horizontal (K_h) and vertical permeabilities. Because, particularly for sediments with a substantive clay fraction, K_h is much greater than K_v (Morris and Johnson, 1967), the field values are probably a reasonable approximation of K_h.

The permeability values presented in the table fall well within the accepted range of 10^{-2} to 10^{-5} cm/sec for sandy sediments and 10^{-4} to 10^{-8} cm/sec for silty and clayey materials (Todd, 1980). These values, together with piezometric data, are used below to estimate flow rates and travel times.

Results from layer 5 are noteworthy, because they illustrate permeability variations that occur, both laterally and vertically, within a correlatable stratigraphic unit. At Site 22, the sample from layer 5 was collected near the top of that stratum at that location, and yielded a K of 9.3×10^{-7} cm/sec. Layer 5 becomes more clayey with depth, and a sample from near the bottom of the layer was taken at Site 21. Here, the resulting K was 2.7×10^{-8} cm/sec. Similar circumstances

Table 4. Permeability Data

Layer[1]	Site	Depth (ft)	Material	Field (F) or Lab (L)	K (cm/sec)
1	-	0-7±	fine sand, soil	-[2]	10^{-2} to 10^{-4}
2	21	6	silty sand	L	1.7×10^{-5}
3	21	20	clayey sand	L	2.1×10^{-7}
4	21	22-30	fine sand	F	2.0×10^{-4}
5	22	38	clayey sand	L	9.3×10^{-7}
5	21	37	sandy clay	L	2.7×10^{-8}
6	21	40-50	sand & shell	F	1.7×10^{-4}
7	22	65	shelly clay	L	1.1×10^{-8}
8	-	50-65±	silty sand & shell	-[3]	10^{-4} to 10^{-5}
9	-	80-120	limestone	-[4]	10^{-1} to 10^{-2}

[1]see Figure 5
[2]USDA, 1980
[3]my estimate
[4]SJRWMD, 1977

exist for other confining beds, and it is thus with caution that vertical flow estimates should be applied. Field observations indicate that the more-permeable unconsolidated units are also more consistent in their properties and that, as a consequence, lateral flow estimates will be more reliable.

Permeability and other hydraulic characteristics of the Floridan Aquifer were not investigated as part of this study. Work by others indicates that K in the upper production zone (e.g. the upper 20 to 40 feet) is on the order of 10^{-1} to 10^{-2} cm/sec, and that much higher K's are found with depth. A comprehensive bibliography regarding Floridan Aquifer properties has been compliled by the St. Johns River Water Management District (1977), and supplemented by the recent works of Rutledge (1985a, 1985b).

Water Levels and Lateral Groundwater Flow. The lateral direction of water movement across the project area is established by determining the hydraulic gradient, individually for both the shallow, unconsolidated sediments and the Floridan Aquifer. Relative hydraulic heads between water-bearing strata define the vertical potential for water movement and, together with permeability data, are used to estimate flow rates and travel times. Monthly water level data have been collected from 8 wells (6 shallow and 2 Floridan) since 1982, providing a firm basis for determing vertical gradients (see Table 2).

Figure 9 shows a contour map of the elevation of the water table, based on data obtained in May, 1980. Contours are based on 14 data points, as shown, including the 6 shallow wells for which subsequent records have been collected. As illustrated, the principal elements of flow in the water table aquifer are a regional pattern of northeasterly flow on which are superimposed drainage and dewatering effects from the active landfill area. A hydrologic divide occurs to the east and north of the fill area, such that shallow groundwater east of the divide moves northeasterly, with the regional flow. West and south of the

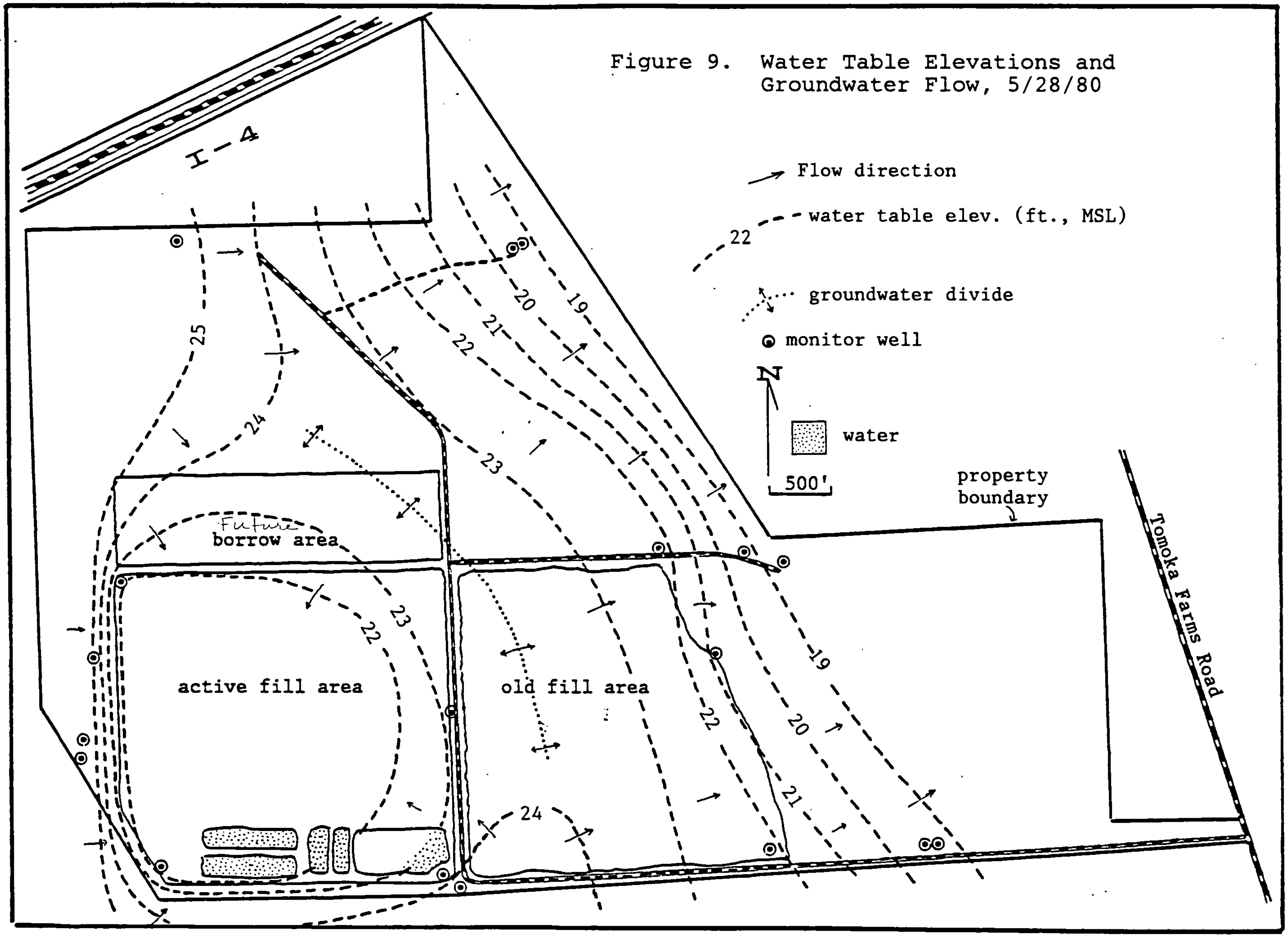


Figure 9. Water Table Elevations and Groundwater Flow, 5/28/80

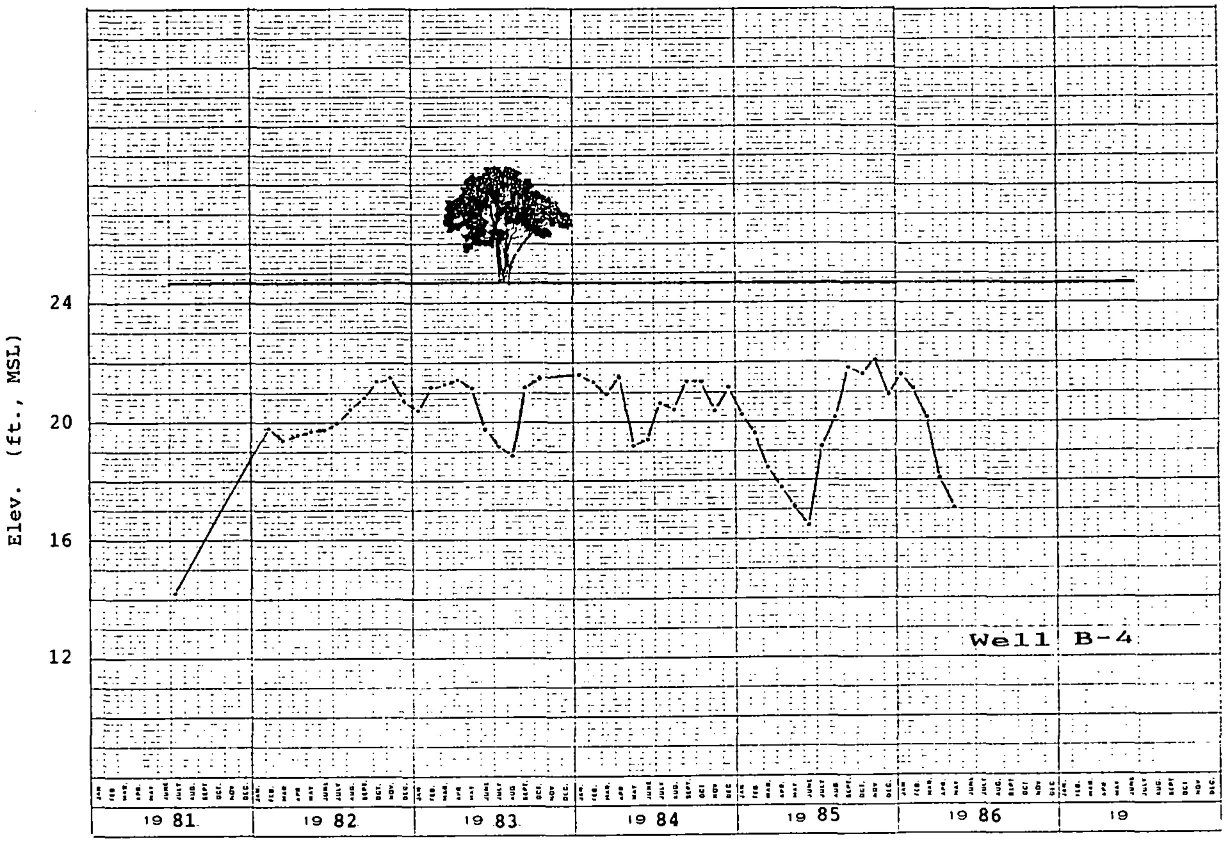
divide, water moves towards the depression created by drainage of the active fill area.

As the borrow pit did not yet exist, there is no impact shown from dewatering there. More recent water levels were not used for Figure 9 because the 6 monitored sites do not provide sufficient coverage with which to contour the area. Based on current operational considerations, it is likely that the water table depression over the active area has broadened to include the borrow pit, and has deepened in the excavation to about 15-17 ft. (MSL), or near the elevation of water in the perimeter ditches. Also probable is that groundwater for several hundred feet around the borrow area defies the regional gradient, and moves towards these ditches, as was the case for the active fill area when the data for Figure 9 were collected.

Water level fluctuations in the surficial aquifer are illustrated by Figure 10. Well B-4, reasonably removed from the influence of landfilling activities (see Fig. 4), shows a seasonal fluctuation of 2.5 to 5.5 feet, and responsiveness to exceptional droughts or wet periods. The variation in depth from land surface to water, ranging mostly between 3 and 8 feet, correlates well with fluctuations observed for other flatwoods communities (Simonds, et al., 1981).

The water level in Well B-5, on the other hand, is influenced principally by the perimeter drainage ditch that encircles the active landfill area, and maintains more stable water levels than would otherwise be the case. Well B-5 shows considerably less variation, either on a seasonal basis or over the 5-year period of record, than does Well B-4. The water table has mostly been 2.5 to 4 feet below ground, with a seasonal fluctuation of 1 to 2.5 feet.

Potentiometric levels in the Floridan Aquifer and their position relative to nearby water table wells are shown in Figure 11. Water levels in Well FA-2 are consistently 3.5 to 4 feet lower than in Well FA-1, 5000 feet away. This agrees



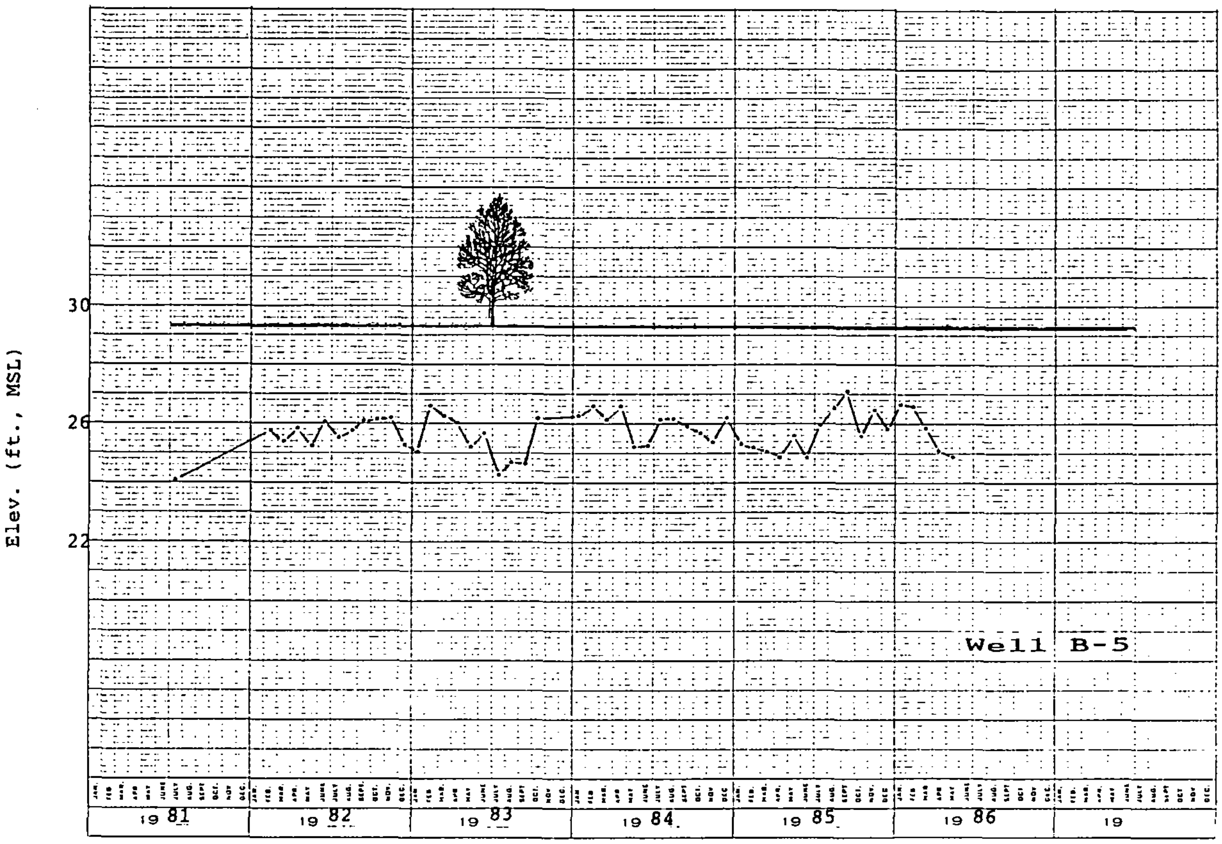
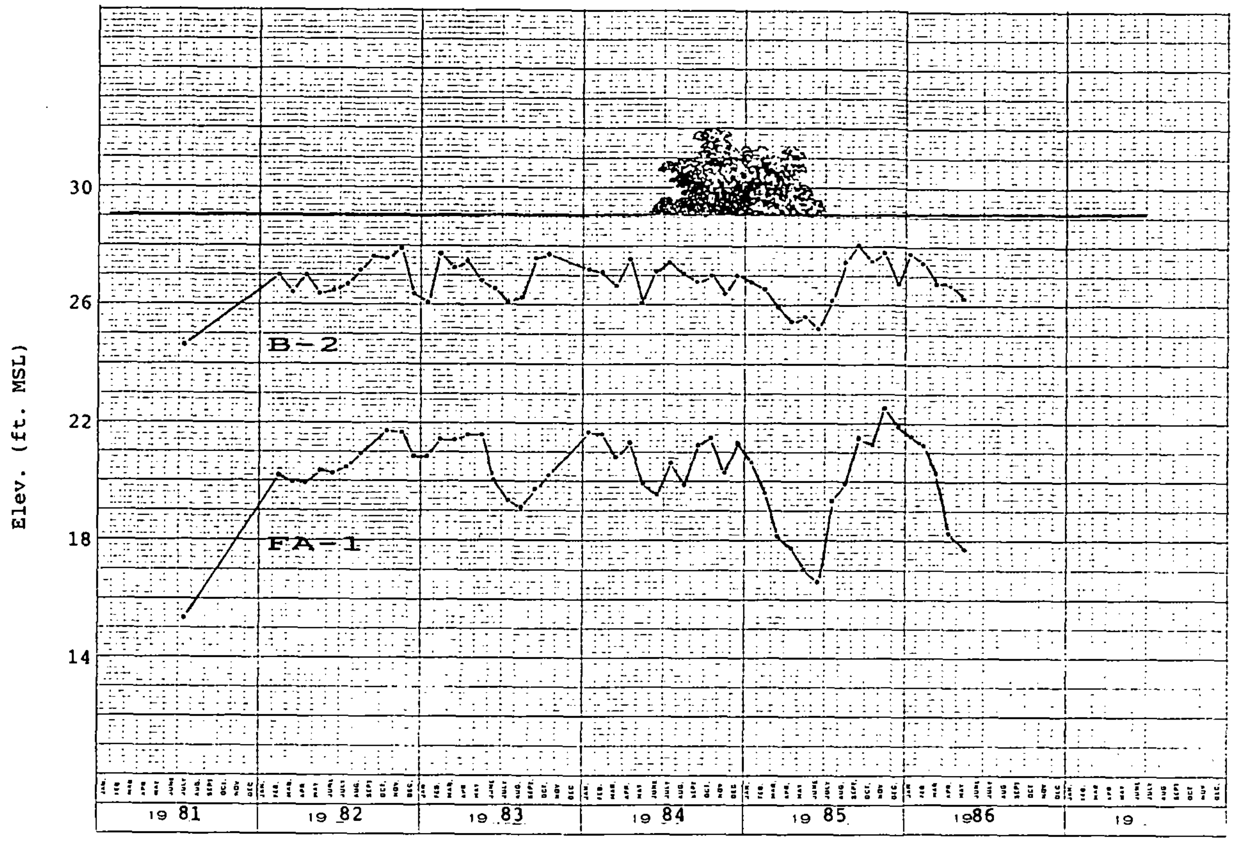


Figure 10. Hydrographs, Wells B-4 and B-5



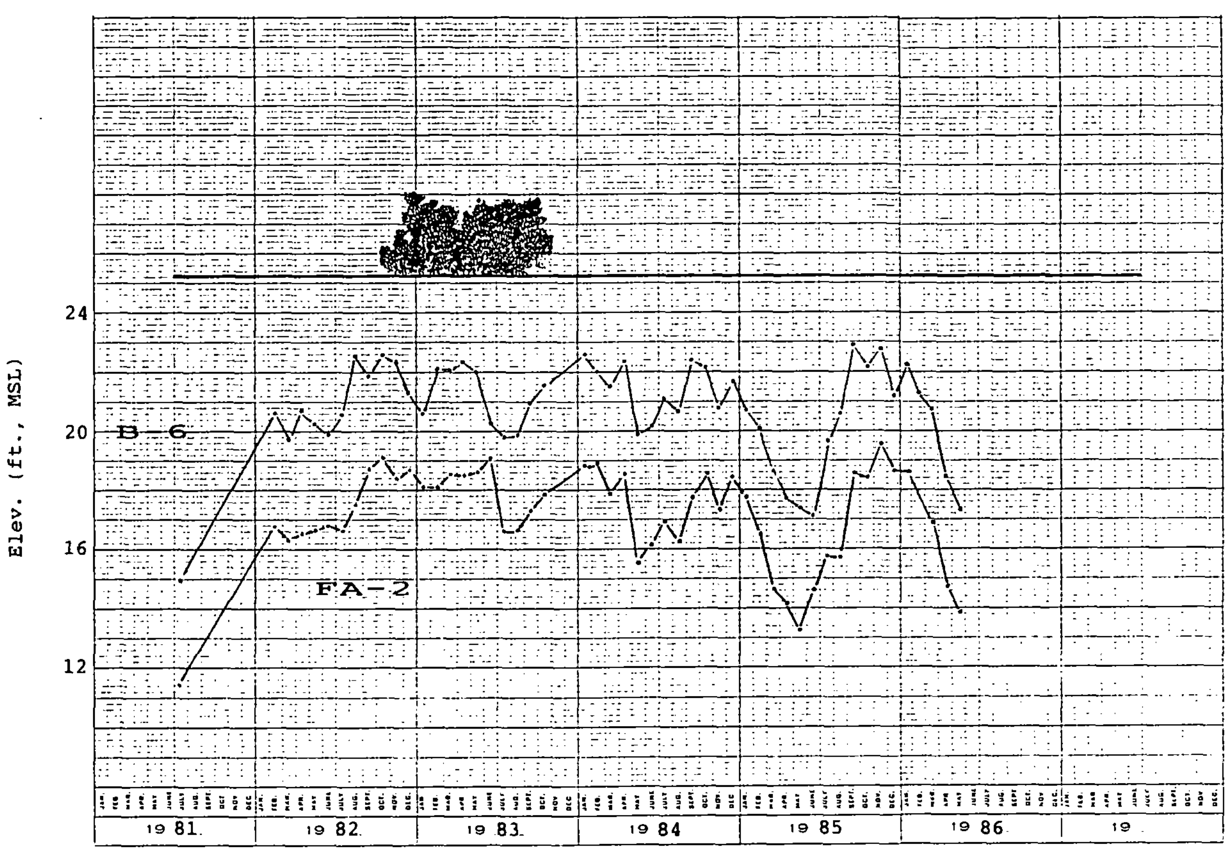


Figure 11. Hydrographs, Wells B-6, FA-2, B-2, FA-1

well with regional data (Schiner and Hayes, 1985) showing Floridan water levels dipping to the northeast at about 4 ft./mile, towards the center of the cone of depression resulting from the City of Daytona Wellfield, approximately 5 miles away. In summary, the direction of flow in the Floridan Aquifer is approximately the same as regional flow in the water table aquifer; the gradient at Tomoka Landfill averages .00075 (3.75 ft/5000 ft).

Lateral flow rates in the Floridan Aquifer can be estimated using a modification of the Darcy equation:

$$\bar{v} = \frac{KI}{n} \qquad (1)$$

where $\bar{v}$ = avg. linear velocity, ft/day
K = permeability, ft/day (= 2835 cm/sec)
I = gradient, ft/ft
n = effective porosity, fraction

To evaluate the range of probably velocities, one can combine the smallest K and greatest n in one calculation, and determine the lowest flow rate. The greatest K and smallest n can also be combined, to determine the high end of a reasonable velocity range. For K, I used .1 to .01 cm/sec (Table 4) as representative of permeabilities in the upper Floridan Aquifer. For porosity, Walton (1970) indicates a range of .01 to 1.0 for limestone. Based on the fact that the upper Floridan is neither highly crystalline nor greatly cavernous, I narrowed this range in porosity to .03 to .06. Using the gradient determined on-site, these selected values yield a linear velocity range of 0.4 to 7 ft/day. As a consequence of much lower permeabilities, the flow rate in the silty sand and shell stratum that directly overlies limestone will be much slower, on the order of one-hundreth to one-thousandth the velocity in limestone.

Flow rates in the water table and secondary artesian aquifers vary greatly, in the same way as do flow directions. A qualitative indication of this is suggested by Figure 9, which shows directional arrows pointing to all compass headings, and a wide variation in the spacing between successive contours. Nevertheless, for each of the three unconsolidated aquifers, a range of velocities can be estimated, using the method described above.

Data used to calculate flow rates are as follows: 1) for all three aquifers, gradients are as shown in Figure 9; 2) permeabilities are as given in Figure 8; 3) the porosity for all permeable unconsolidated strata is taken as 0.35 (Freeze and Cherry, 1979). For each aquifer, the lower velocity limit is at or near zero, along the no-flow boundary or hydrologic divide identified on Figure 9. The area of maximum velocity shown on the figure occurs along the western side of the active fill area, where dewatering has created a steep gradient. [This is probably no longer true. An even steeper gradient should exist along the western and northern sides of the borrow area, which is dewatered to 15-17 ft. (MSL). No data are available to define the gradient in this latter area.] A "normal" flow rate still exists near the northern boundary of the site, where the regularity of contour spacing suggests unaltered flow conditions. Velocities are summarized in Table 5. For the water table aquifer, flow rates given are those calculated for the cleanest sands, with a permeability of 10^{-2} cm/sec.

Table 5. Lateral Flow Rates

Aquifer	Velocity (ft/day)		
	min.	max.	background
Water table	0	1.4	0.2
Upper Secondary Artesian	0	0.03	0.005
Lower Secondary Artesian	0	0.02	0.004
Floridan	-	-	0.4-7

Vertical Groundwater Flow. In this section, aspects of the migration of groundwater, from the water table downward, are examined. The general case of flow under approximate background conditions is considered here, while in the final part of this report, vertical flow near the borrow area and under expected operating circumstances is evaluated. The approach and method are similar in both cases, but the imposed boundary conditions and objectives differ substantially. Vertical flow under background conditions is evaluated in the interests of completing the review of site hydrogeology, and to aid in design of monitoring facilities and interpretation of monitoring data. The analysis of vertical flow under operating conditions is performed to help assess design options for the borrow area, with regard to fulfilling regulatory requirements and minimizing water quality impacts.

Conditions and assumptions used to determine vertical flow rates and travel times are as follows:

a) Thicknesses of individual layers are as shown in Figure 8. These are average thicknesses for the geologic section, use of which will under- or over-estimate equivalent conductivity for any particular location by a small amount;

b) For layers where more than one permeability (K) is available, an average value is used;

c) For permeable layers 1-2, 4 and 6, the vertical K is assumed equal to the horizontal K. This is certainly not the case (Morris and Johnson, 1967) and, for these layers, results in a high flow rate, which is regarded by most workers as a conservative approach;

d) Each layer is assumed to be homogeneous;

e) Layer 8, the silty sand and shell that overlies limestone, is considered as part of the Floridan Aquifer, with no head change across this unit. Again, this assumption shortens travel times, and is in this regard conservative;

f) An average difference in elevation between the water table and Floridan Aquifer is used, based on hydrographs shown in Figure 11.

Permeabilities of the seven units here considered important to vertical flow can be combined, to produce an equivalent vertical hydraulic conductivity. Maasland (1957) provides the theoretical basis for the method, which is described by Todd (1980). The relevant equivalence is:

$$K_z = \frac{z_1 + z_2 + \ldots + z_n}{\frac{z_1}{K_1} + \frac{z_2}{K_2} + \ldots + \frac{z_n}{K_n}} \quad (2)$$

where K_z = equiv. vert. conductivity

z_n = thickness of layer n

K_n = vert. cond. of layer n

Solving for the seven layer system shown in Figure 8 yields:

$$K_z = 5.6 \times 10^{-8} \text{ cm/sec. } (= 1.6 \times 10^{-4} \text{ ft/day}) \quad (3)$$

The downward specific discharge (Darcy velocity) is given by:

$$v = \frac{K_z \, (dH)}{m} \quad (4)$$

where v = spec. discharge, in ft/min.

dH = head change across section of interest, in ft.

m = thickness of section of interest, in ft.

The head difference between the water table and Floridan Aquifers is estimated from Figure 11 as, on average, 5 feet. The thickness of the unit through which flow occurs is 60 feet, or the distance on Figure 8 from a water table 3 feet below ground to the bottom of layer 7. Solving equation (4) yields a Darcy velocity of 1.3×10^{-5} ft/day, or about .06 inches/year. This rate is also called the recharge rate, and is the water "thickness" that moves vertically. The actual in situ velocity is this thickness divided by the effective porosity of unconsolidated sediments, a value that commonly approaches 0.35. Thus the true downward velocity (within the limits of the method) is 3.7×10^{-5} ft/day and, over a 60-foot thickness, it will take water on the order of 4500 years to move from the top of the water table to the top of the Floridan Aquifer.

This dramatically long travel time is the result of the small head difference between aquifers and, even more importantly, the very low permeability of the deepest confining bed. As an illustration, if layer 7 were removed, the downward velocity would be 6.6×10^{-4} ft/day, and the travel time would decrease to 200 years.

DISPOSAL IN THE BORROW AREA

When the borrow area has been excavated to its design depth, it will be used for solid waste disposal. This will be accomplished, of course, in compliance with the rules of jurisdictional agencies, particularly the Dept. of Environmental Regulation. To the extent that guidelines and requirements are performance oriented, there exists some flexibility in landfill design and operation. This flexibility, and the options it makes available to environmentally-safe waste disposal, are discussed below.

Several important aspects of the future waste disposal area are not variables, but are relatively fixed. The depth of excavation, for example, is planned at 15 ft. (MSL), or about 14 feet below natural grade. A leachate collection system will be installed at this depth, per regulatory requirements. Water levels in this new disposal area will be maintained at approximately one foot above the bottom, by pumping from the leachate collection system. These fixed design parameters will create a predictable response in the surrounding hydrologic system, and thus have implications for design elements that are still unspecified, such as liners, lateral containment features (e.g. slurry walls), and perimeter drainage features.

Groundwater Flow Under Operating Conditions. Figure 12 shows, in schematic form, the groundwater flow pattern under current and expected future conditions. The pattern in and under the borrow area is essentially the reverse of the situation examined in the preceeding chapter, where background flow was considered. In that circumstance, the vertical gradient was directed downward, and water moved, albeit very slowly, from the water table towards the Floridan Aquifer.

In contrast, the potential for vertical groundwater movement in the borrow area is upward, because, as a consequence of dewatering, the water table is at a lower elevation than the average potentiometric level of the Floridan Aquifer. Similarly,

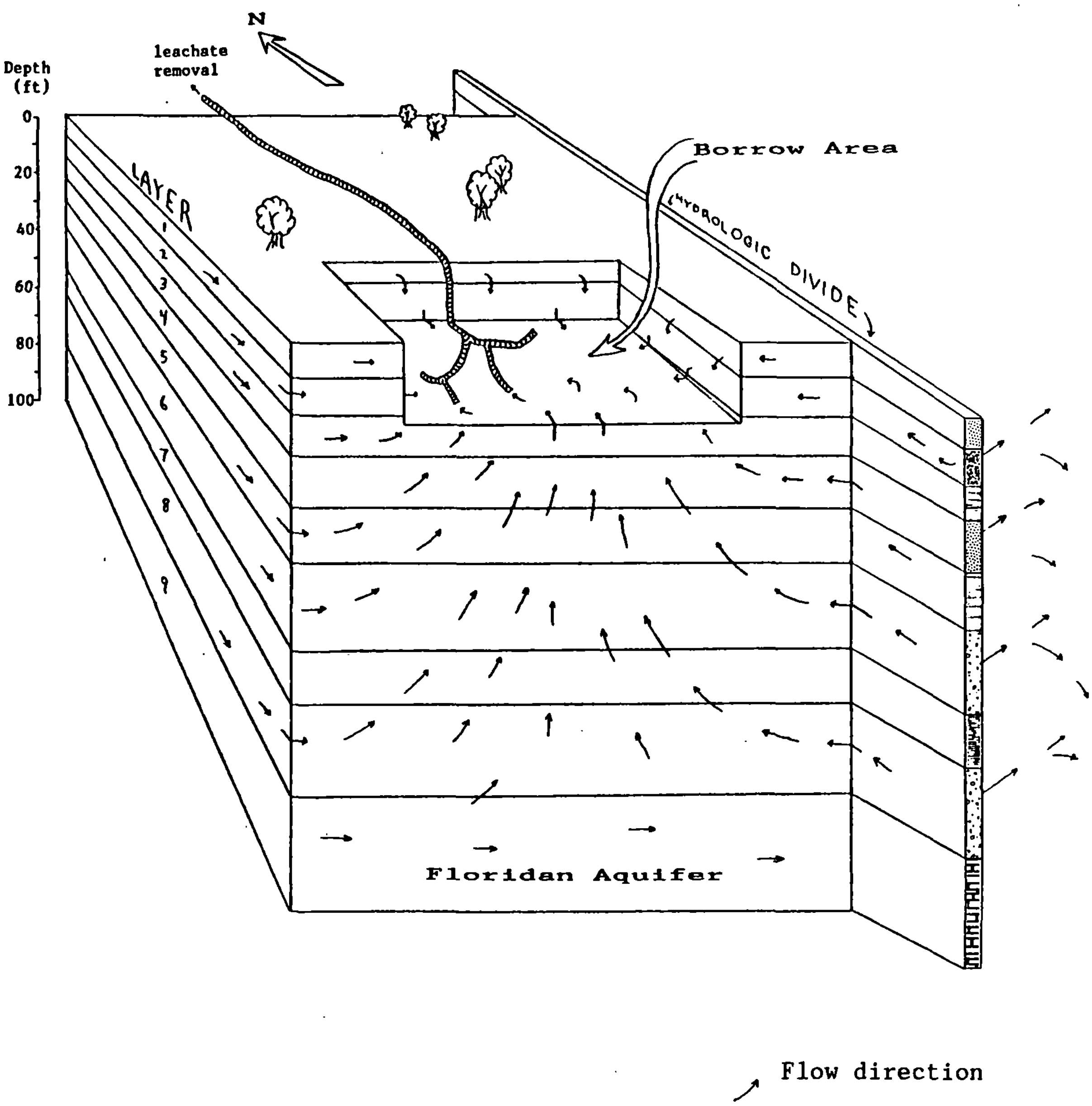


Figure 12. Groundwater Flow in The Borrow Area

lateral flow in the unconsolidated aquifers is diverted from the regional pattern and towards the borrow area. When the area is used for solid waste disposal (in a few years) and thereafter into the distant future, this dewatered condition, as a result of leachate collection and removal, will be maintained. Thus, relative heads and flow configurations will remain as shown in Figure 12 (assuming Floridan potentiometric levels do not change appreciably), and flow will continue to be directed inward and upward.

(It is important to recognize that Figure 12 is deceptive in its suggestion, through the use of flow arrows, of upward water movement. In fact, the vertically upward gradient is less under dewatered conditions than is the downward background gradient. Consequently, the flow rate upward is even less than the extremely slow rate estimated for downward, background flow. For the practical purposes of monitoring and controlling vertical leachate movement, upward groundwater movement in the borrow area is essentially non-existent.)

The hydrologic divide drawn on the east side of the schematic model is introduced to illustrate that, at some distance from the sides of the borrow area, the hydrologic system no longer responds to the impact of dewatering. The divide is a no-flow boundary, "outside" of which groundwater follows background patterns and "inside" of which groundwater is directed towards the borrow area, both vertically and laterally. The distance of the divide from the borrow area is a complex function of gradients and permeabilities, but will be in the range of a hundred to a few hundred feet from the boundaries of the dewatered area. (For example, Figure 9 shows the approximate position of the divide created by leachate control in the active landfill area.) The specific position of the divide, which can be defined, for no particular reason other than academic interest, with closely-spaced monitor wells, will not remain fixed, but will oscillate slightly in an attempt to reach equilibrium with seasonally-changing background water levels.

Experience with operation of the borrow area supports this conceptual model. About half of the area has been excavated, to approximately 21 ft. (MSL). Perimeter ditches and a pump control water elevations, which are maintained near 15 ft. (MSL) in the ditches. Pumping and discharge are infrequent, however, except following substantial rainfall, even though a pronounced water table gradient must exist in the vicinity of the dewatering. Excavation of material for landfill cover is done cautiously, so that only a thin layer of fill is removed at any one time. This is because, even after several years of lowered water levels in the ditches, sluggish flow in the subsurface has not been sufficient to dewater the excavated area. Evaporation from shallow sediments and removal of collected rainfall are the principal mechanisms that allow excavation, indicating both that groundwater recharge is extremely slow and that design elements such as liners, slurry walls and external water control ditches will have little impact on seepage to or from the borrow area.

Design Considerations. Rules of the Dept. of Environmental Regulation address the need to control migration of leachate through the use of natural or synthetic liners. The design standard for a natural, *in situ* soil liner is that the saturated hydraulic conductivity shall be no greater than 1×10^{-7} cm/sec. for the 3-foot thickness of material underlying the disposal area [DER Rule 17-7.05(4d)]. No distinction between vertical and horizontal conductivity is made, suggesting that both K_v and K_h must meet this standard simultaneously. An accompanying rule (17-7.078) designates the procedure by which relief may be sought from a requirement inappropriate to the circumstances of a particular landfill. This is noteworthy, because the geologic setting of Tomoka Landfill lends itself to innovative design features that can provide assurance of leachate containment, but are not specifically addressed by DER Rules for landfill criteria.

Regarding the saturated hydraulic conductivity (a.k.a. permeability) of in-place sediments underlying the borrow area, a determination of K_v (see Table 4) yielded 2×10^{-7} cm/sec. for the clayey sands that will comprise the base of the area when excavation is completed (layer 3). K_h was not determined, but is probably considerably greater. On the face of it, therefore, this clayey stratum does not meet the criterion for a natural liner. On the other hand, the unit thickness averages 8-10 feet throughout the area and, as a consequence, its ability to restrict vertical leachate movement is equivalent to or greater than the implied regulatory performance standard.

In addition, and again this circumstance is not covered by DER rule, the sedimentary column <u>behaves</u> as if the vertical permeability were 5.6×10^{-8} cm/sec, not for a 3-foot thickness, but for the entire 80± feet of unconsolidated sediments (see p. 32). When excavation has been completed, the equivalent vertical hydraulic conductivity will decrease slightly (see Eq. 2), to 4.7×10^{-8} cm/sec., though in this instance, for a sediment thickness of approximately 65 feet. Thus, for purposes of vertical leachate control, the geologic setting appears to satisfy, and exceed, the intent of the regulatory requirement.

Permeability considerations notwithstanding, the operational plan for the borrow area, both currently and when it is used for waste disposal, provides a compelling argument that migration of leachate will be controlled as effectively without a synthetic liner as with one. As discussed earlier, continuously lowered water levels in the borrow area will sustain gradients and groundwater flow towards the area, thus, by hydraulic means, confining leachate to the waste disposal site. A liner provides no direct benefit, under these conditions, for environmental protection and leachate control. In addition, and as demonstrated by experience with dewatering, a liner will furnish only slight benefits in reducing the volume of leachate generated because seepage to the dewatered area is so small.

For lateral control of leachate migration, a liner might be brought up the sides of the disposal area, or an encircling slurry wall could be constructed. A slurry wall, however, is most useful when a synthetic liner is not employed, and the wall is keyed into an existing clay layer (i.e. a natural liner).

This would be a difficult task in the borrow area, because the relatively thin, sandy clay of layer 5 (see Fig. 5), at about 35 feet depth, is the shallowest and most likely candidate. Consequently, a slurry wall would need to be 40-50 feet deep to accomplish its objective.

The same reasoning that argues against a synthetic liner is relevant for a slurry wall. No tangible benefit would result from the wall because, with hydraulic gradients and groundwater flow directed inward, the wall would be accomplishing nothing towards preventing lateral leachate movement away from the waste disposal area. A slurry wall would also make no significant contribution in reducing the volume of leachate generated, because lateral seepage to the borrow area is not substantial.

The primary benefit of a synthetic liner, slurry wall, or other constructed barrier is that it provides "additional assurance", following closure of the landfill, that leachate will remain contained and controlled, even if the collection and treatment systems are inoperative. The passive nature of such backup systems enhances their attractiveness because, once emplaced, they do not require, and essentially, will not allow maintenance. These features, however, may be equally well provided with the less costly option of a perimeter hydraulic barrier.

Figure 13 shows the configuration of a ditch that can be used as a hydraulic barrier for the borrow area and, in this example, the adjacent area along the western property boundary. The operating concept is simply that, by maintaining the water level in the ditch higher than adjacent groundwater levels, a hydrologic divide is created across or below which there is no flow. Thus leachate is precluded from migrating laterally beyond the barrier.

The hydraulic barrier is presented here conceptually, because design specifics are beyond the scope of this document (and the competence of the author). A ditch is one option to satisfy the principle, though a heavily-irrigated, linear swale could also serve. This barrier would be slightly external

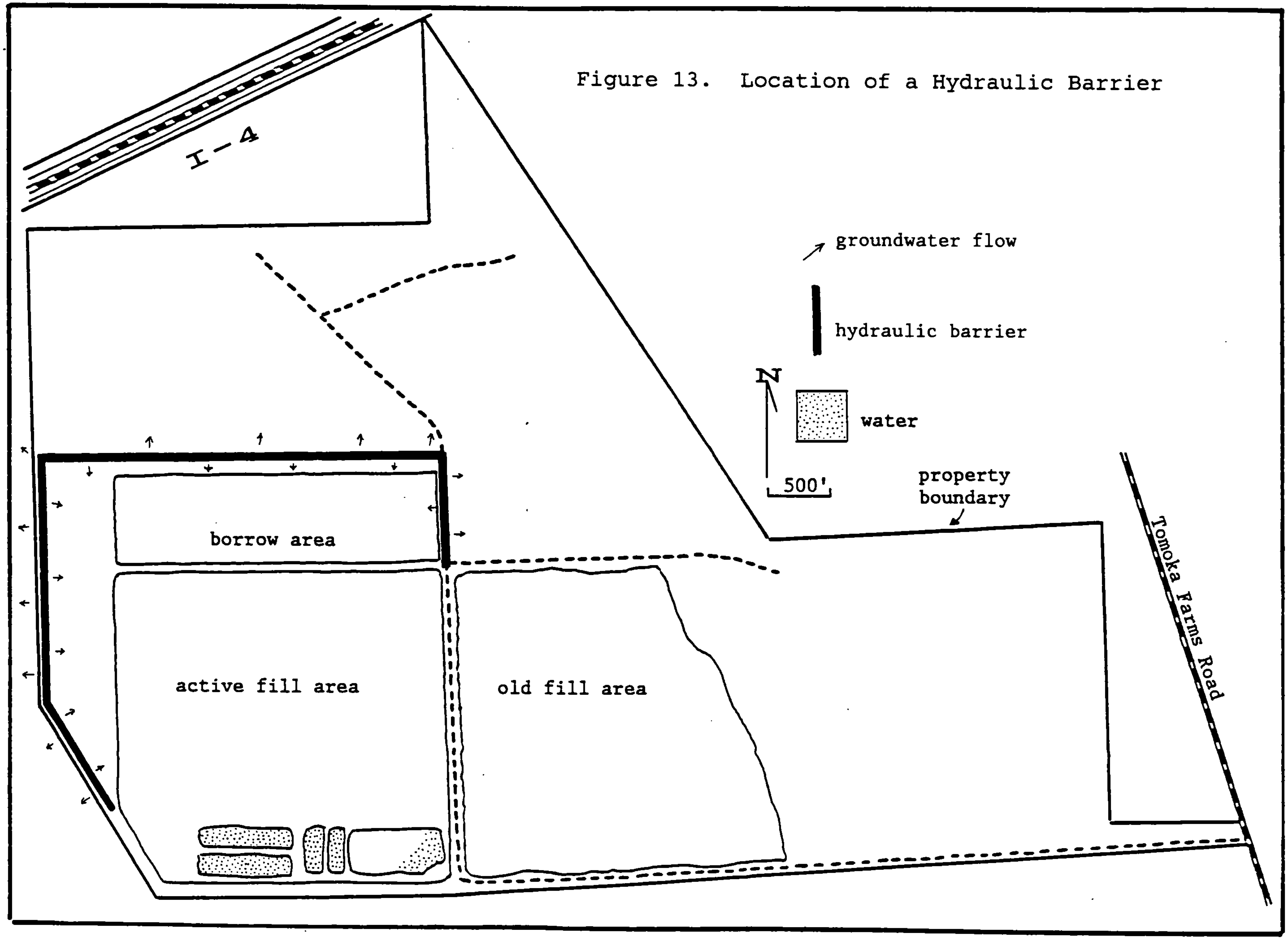


Figure 13. Location of a Hydraulic Barrier

(e.g. 50-100 feet) to the borrow area, but can be partially relocated later, to encompass the next area selected for waste disposal. Water to keep the barrier elevation higher than surrounding water levels can be obtained by incorporating the barrier into the surface water management system via water control structures or pumping. For added assurance, a Floridan Aquifer well, on standby and activated by water levels in the ditch, might be used to supplement occasional low water levels. Because seepage from the barrier would be about as slow as is current seepage to the borrow area, the volume of water needed to maintain an acceptable elevation in the ditch would equal largely that lost through evaporation. Water level monitoring for a year or two prior to construction would furnish data needed for purposes of design and establishing control elevations.

A hydraulic barrier that is essentially maintenace-free would provide additional assurance of leachate containment with, probably, less expense than other alternatives. As with other options, it will serve only as a backup, though, as opposed to a liner or slurry wall, it is movable and fixable. The fact that a responsible governmental entity will retain control of the facility into the foreseeable future is an additional factor that favors selecting this non-traditional yet cost-effective option.

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APPENDIX

Geologic Logs, Cores 21-24

Well Logs (from Brooks, 1980) - Sites 1,2,3,4,9,15

Permeability Test Data

Geologic Log - Site 21

Description	Depth (ft.)	Thickness (ft.)
Silty sand, quartz, fine to med., tan, with thin lenses of brn.-gray, med.-stiff, clayey sand; brn. to dk.-brn. sl. cemented silty fine sand (hardpan) at 0-0.8 with gray med.-stiff clay at 0.8-1	0-3	3
Silty and sl. clayey sand, fine, gray, with roots and org. debris at 3-3.1, lenses of white fine sand at 3.1-7	3-7	4
Peat, v. sandy, mottled brn. and v. dk. brn., with lamina of brn. clayey fine sand; org. mat'l. decreases at 9-11	7-11	4
Clayey sand, med. soft, silty, brn. to olive-gray, fine to med.; stiff sandy clay layers up to 0.5 ft. thick at 18-20	11-21	10
Sand, v. fine, lt. olive to gray with occ. blk.-stained lamina; thixotropic; gray clay lamina at 29-30	21-32	11
Clay, sandy, dk. green-gray, stiff, with common fine-sized, tan mica	32-38	6
Sand, shelly to v. shelly; shell consists of pink, tan and blk. pelecypod frags up to 1" diam.; sand is v. fine to med. quartz, gray, v. sl. silty in part; shell content decreases downward, from 50% at 38' to 10-15% at 50'	38-52	14
Clay, greenish-gray, med.-stiff to stiff, sl. sandy, with thin layers of silty sand and shell	52-57	5
Silty sand, fine, brn. to lt. gray to lt. green-gray; v. minor, fine shell frags to 63', increasing in size and abundance downward to 30-40% at 75'; sand-sized, blk. (phosphorite ?) grains common at 59-75'; shell includes mostly pelecypods, minor echinoids, corals	57-78	23
Limestone, soft, pink-tan	78-	

Geologic Log - Site 22

Description	Depth (ft.)	Thickness (ft.)
Sand, quartz, fine, tan-gray; dk.-brn. with lg. roots and org. debris at 0-.2; peaty and blk. to dk. red-brn. at 1.2-1.8	0-4	4
Silty sand, fine-sized, lt. gray to gray, with numerous gray clay lamina at 5-8'; common lt. tan to white shell frags and valves at 9-10'	4-12	8
Silty sand, sl. clayey, brn., fine-sized, with lenses of white to lt. tan fine sand	12-19	7
Clayey sand, silty, stiff in part, tan to brn.	19-21	2
Sand, v. fine, tan, thixotropic	21-24	3
Clayey sand, fine-sized, lt. to dk. gray, with common gray, med. stiff clay lamina	24-32	8
Silty sand, fine-sized, v. dk. gray, thixotropic	32-37	5
Clay, dk. green-gray, v. sandy, slightly to med. stiff, with common, fine-sized tan mica	37-40	3
Silty sand, fine to v. fine, gray to gray-brn. with common tan, sand-sized mica; v. minor tan shell frags at 45' increasing to 15% at 48'; occ. gray clay lamina	40-52	12
Clay, sandy, dk. green-gray, slightly to med. stiff, with tan sand-sized mica; minor tan, fine-sized shell frags; hard dk. gray clay nodule (1.5" diam.) at 55'	52-56	4
Sand, shelly, gray, fine-sized, with occ. lamina of sl. clayey to clayey gray sand; shell is fine-sized, tan, gray or blk. mollusk frags; common blk. sand-sized grains (phosphorite) throughout	56-61	5
Clay, gray to dk. gray, shelly, sandy to sl. sandy, med. stiff to stiff; shell is white to tan, coarse mollusk and occ. echinoid frags	61-66	5

Geologic Log - Site 22 (cont.)

Description	Depth (ft.)	Thickness (ft.)
Silty sand and shell, fine to v. fine, tan to gray to, at 78-80', lt. green-gray; phosphorite (?) common throughout	66-82	16
Limestone, lt. tan, soft, mudstone	82-	

Geologic Log - Site 23

Description	Depth (ft.)	Thickness (ft.)
Sand, quartz, fine-sized, v. lt. tan at 0-.3' to red-brn. to gray-brn. at 2'; sl. silty in part	0-2	2
Silty sand, lt. gray to lt. gray-brn., fine-sized; minor org. debris at 7.5-8'; occ. gray clay lamina at 4-10'	2-12	10
Clayey sand, fine-sized, lt. gray-brn., slightly stiff	12-17	5
Sand, v. fine, tan to tan-olive to gray, sl. silty in part, thixotropic	17-26	9
Clay, sandy, soft to med. stiff, lt. green-gray to dk. green; occ. lenses and lamina of v. dk. green fine silty sand	26-34	8
Sand and shell, dk. green-gray, sl. silty and clayey throughout; shell is white to blk., mostly fine-sized mollusk frags	34-37	3
Clay, sandy and shelly, gray-green, slightly stiff; shell is white to tan, fine to coarse mollusk frags, up to 10%	37-40	3
Sand and shell, v. lt. gray to gray, in part sl. to v. silty; sand is v. fine-sized; shell is tan to blk., rare to 48', up to 50% at 48-55'; gray sandstone nodules common at 43-45'	40-55	15
Clay, sandy and shelly, green-gray to dk. green-gray, stiff; shell is white to blk., fine to coarse mollusk frags	55-60	5

Geologic Log - Site 24

Description	Depth (ft.)	Thickness (ft.)
Sand, quartz, fine to med., lt. to dk. gray to 1.5', then interbedded tan to dk. brn. with roots and org. debris; dk. brn. peaty sand at 2.5-3'	0-5	5
Silty sand, gray to gray-tan, fine, silty throughout, sl. clayey at 7-7.5'; up to 20% white, mostly unbroken shell (mollusks) at 9-10' with occ. lenses of clean gray sand	5-12	7
Silty sand, brn., fine-sized	12-19	7
Clayey sand, sl. stiff, v. fine, lt. green-tan, v. silty in part	19-22	3
Sand, v. fine, lt. green-gray, sl. silty, thixotropic	22-27	5
Clay, sandy, sl. stiff, brn. to green-clay	27-29	2
Sand, v. fine, green-gray to gray, v. sl. silty in part, thixotropic	29-37	8
Clay, sandy, dk. gray-green, med. stiff	37-39	2
Sand and shell, gray; minor, fine-sized tan shell to 53', increasing to 50%, fine to coarse, tan to blk. mollusk frags at 56'; sl. silty in part	39-59	20
Clay, v. sandy, green-gray to tan-gray to green, sl. stiff	59-65	6

From Brooks (1980)

Well Logs - Volusia County Sanitary Landfill

V-1

Location: NW corner of cleared landfill area, at intersection of 3 fences by NW corner of canal. Depth in feet:

0 - 1½	sand, fine, tan
1½ - 2½	sand, hardpan, brown to dark brown
2½ - 7½	sand, fine, silty, greenish-gray
7½ - 12	sand, fine, silty, a little shell, greenish-gray
12 - 17	sand, clayey, stiff, dark gray
17 - 18½	sand, clayey, not quite as stiff, dark gray
18½ - 20	sand, clayey, stiff, dark gray
20 - 24½	sand, very fine, silty, micaceous, olive-green
24½ - 27	shell, broken
27 - 33	clay, dark gray
33 - 35	sand, clayey, organic, black

V-2

Location: ¼ mile due east of V-1, near fence line. Depth in feet:

0 - ½	sand, tan to light orange
½ - 2½	sand, fine, brown, humate
2½ - 7	sand, fine to medium, tan Pen. $2.5^{T}/ft^{2}$
7 - 17	sand, fine, silty, cohesive, gray to light brown, with marsh grass stems, Pen. 0.5
17 - 27½	sand, fine, silty, tan, trixotrophic, becomes clayey downward with cohesive lenses, Pen. 0.00
27½ - 36	clay, gray, becomes sandy downward, Pen. 0.25
36 - 41	clay, dark gray, Pen. 0.25
41 - 45	sand, fine, with fine broken shell, gray

V-3

Location: East of V-3 at road intersection, just north of perimeter canal. Depth in feet:

0 - 1	sand, brown
1 - 3	sand, dark brown, humate
3 - 4	sand, slightly clayey, tan
4 - 6	sand, dark brown, humate
6 - 17	sand, silty, trixotrophic, light tan
17 - 22	sand, clayey, light gray to tan, very stiff (Note: sediment was so tight that auger created a vacuum and could not be directly withdrawn, no sample recovery)
22	sand, clayey, greenish-grey, hole abandoned because of drilling conditions described above

Logs from Brooks (1980), cont'd.

V-4

Location: ¼ mile east of V-3, just north of fence line. Depth in feet:

0 - 2	sand, gray to light tan
2 - 3	sand, dark brown, humate
3 - 16	sand, silty, trixotrophic, gray, becoming darker downward
16 - 17	sand, dark brown, humate
17 - 33	sand, silty, trixotrophic, micaceous, greenish-gray, with clay lense
33 - 37	sand, silty, micaceous, dark gray
37 - 45	clay, plastic, cohesive, with stringers of shell, greenish-grey, Pen. 0.25T/ft2

V-9

Location: ½ mile north of V-1, 300 yards east of western property boundary. Depth in feet:

0 - 3	sand, fine, tan
3 - 4	sand, fine, orange
4 - 17	sand, fine, clayey, trixotropic, gray
17 - 22	sand, very fine, micaceous, trixotropic, tan
22 - 27	sand, clayey, gray
27 - 34	clay, gray, with dark gray clayey sand
34 - 40	clay, less sandy, plastic, green, with thin stringer of shell at 38'

V-15

Location: South-western portion of property on west side of perimeter canal. Depth in feet:

0 - 1	sand, tan
1 - 2	hardpan, dark brown
2 - 4	sand, chocolate brown
4 - 11	sand, clayey, gray
11 - 17	clay, sandy, stiff
17 - 18	sand, soft
18 - 18½	sand, clayey, stiff
18½ - 28	sand, very fine, silty, tan

Well: slotted pvc 19-24'

Permeability Test Data

1. Site 21, Test Interval 22-30' below ground
   Static water level: 6.20' below ground
   Total Test Head: 8.20'
   Time to add 1 gallon under test head:

Trial	Time (sec.)
1	41
2	40
3	42
4	41
5	41
6	41

2. Site 21, Test Interval 40-50' below ground
   Static water level: 3.60' below ground
   Total Test Head: 5.33'
   Time to add 1 gallon under test head:

Trial	Time (sec.)
1	43
2	42
3	43
4	51
5	49
6	54
7	55
8	54
9	55
10	55