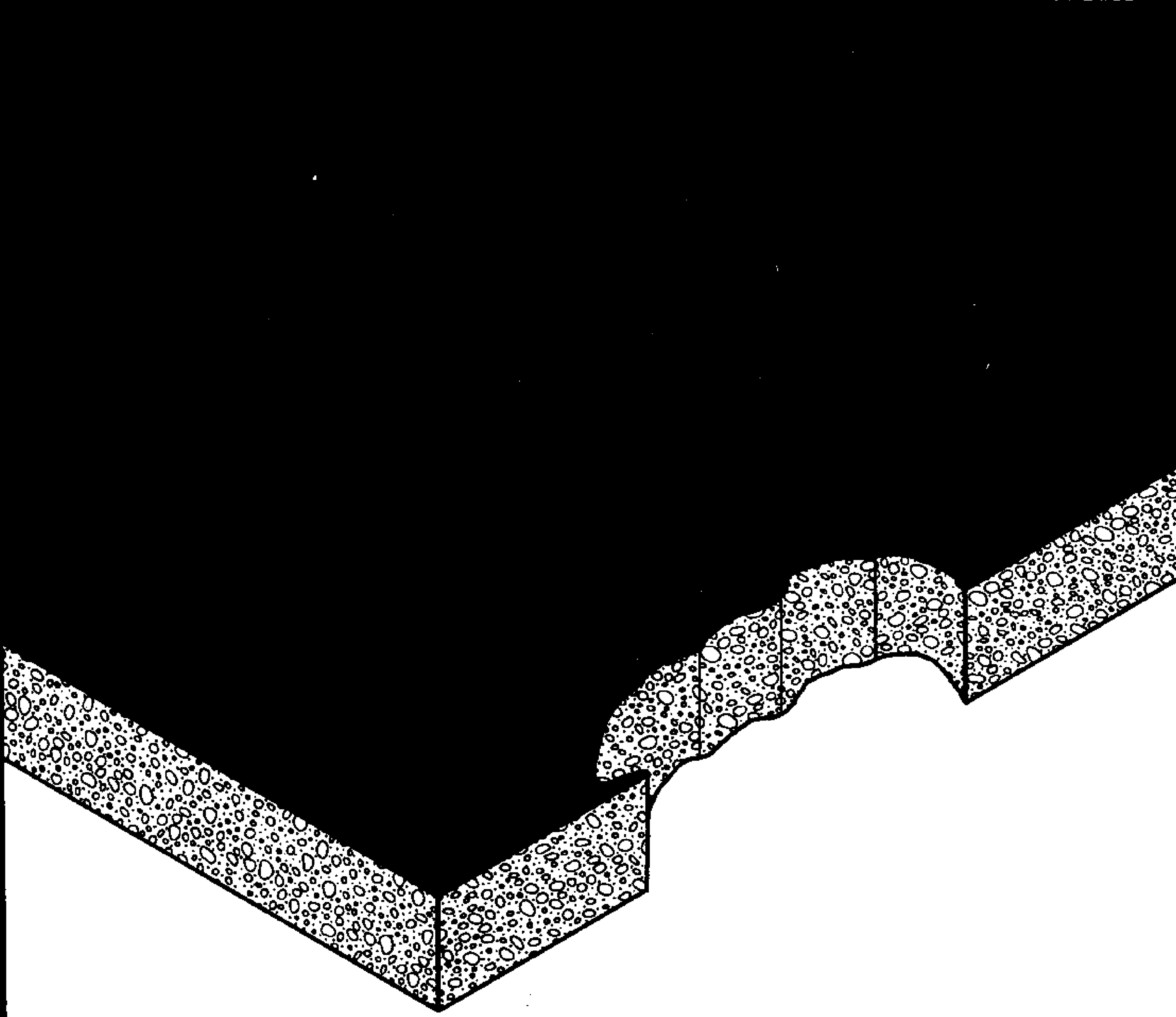

Alan Richter

A Volumetric Analysis of Holocene Sediments

Underlying Present Delaware Salt Marshes Inundated by Delaware Bay Tides

by Alan Richter; DEL-SG-2-74; This work is the result of research sponsored by NOAA Office of Sea Grant, Department of Commerce, under Grant No. 2-35223. College of Marine Studies, University of Delaware, Newark, Delaware 19711.

A VOLUMETRIC ANALYSIS OF HOLOCENE SEDIMENTS UNDERLYING PRESENT DELAWARE SALT MARSHES INUNDATED BY DELAWARE BAY TIDES

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ABSTRACT

Data from 226 borings drilled in Delaware salt marshes lying between Wilmington, New Castle County and Lewes, Sussex County were used to construct isopach maps of Holocene muds. Planimetric analyses of these maps and studies of drill records provided information necessary to make estimates of the volume of fine- and coarse-grained sediment deposited during the greater part of the Holocene epoch. The volume of Holocene muds underlying present salt marshes in the State of Delaware, affected by Delaware Bay tides, is about three billion cubic yards or .55 cubic miles, while the volume of coarse-grained sediment is about .26 billion cubic yards. The mass of fine-grained sediment underlying the marshes, excluding water, is about 1.38 trillion kilograms. This estimated mass is comparable to the amount of suspended sediment contributed to Delaware Bay by all rivers during the last 10,300 years.

INTRODUCTION

Area of Study

The study area comprises Delaware marine tidal marshes (as defined by the Hydrologic Investigations Atlases of Delaware by the United States Geological Survey) inundated by Delaware Bay tidal waters; this area represents 87.3 percent of Delaware's marshes. In calculating the area of marshland and the volume of Holocene sediments, sections that are indicated on the U.S.G.S. soils maps as beaches or filled tracts were excluded, although borings drilled in these places have been used to obtain information about adjacent marshes. The geographic limits of the study area are the Delaware-Pennsylvania border, north of Wilmington and the Penn Central railroad tracks east of Lewes, Delaware (Figure 1).

Purpose of the Investigation

The purpose of this investigation was to determine the amount of fine-grained (less than 62.5 microns) and coarse-grained (greater than 62.5 microns) Holocene material underlying Delaware marshes, and to determine if this mass is comparable to the suspended sediments that have entered Delaware Bay during the last 10,300 years. Information on the amount of material that has been deposited beneath the present marshes is necessary for establishing a suspended sediment balance for Delaware Bay during the Holocene epoch. Drill logs and

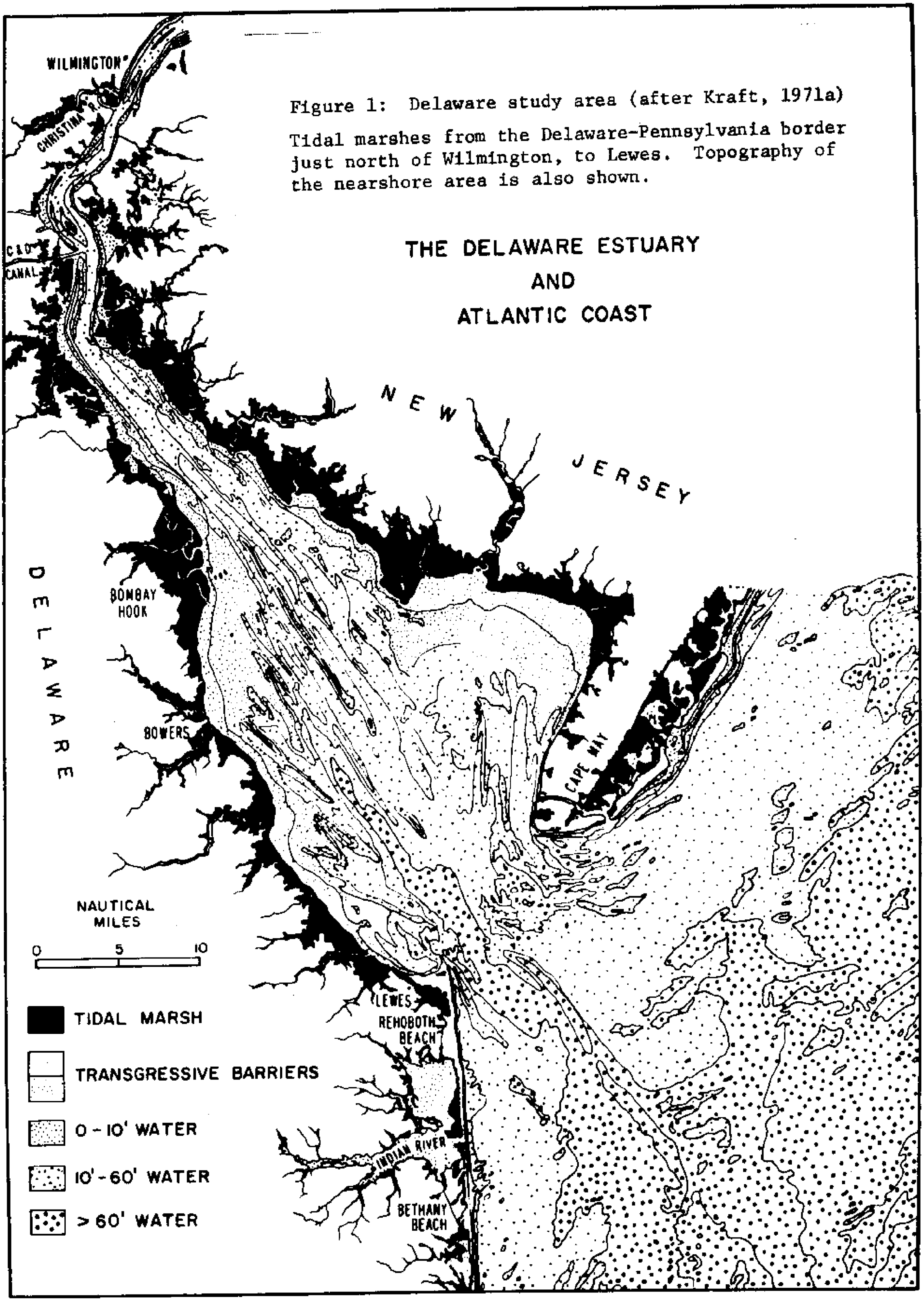

Figure 1: Delaware study area (after Kraft, 1971a)

Tidal marshes from the Delaware-Pennsylvania border just north of Wilmington, to Lewes. Topography of the nearshore area is also shown.

the isopach maps based on them, that were used to determine the volume of the Holocene fine-grained sedimentary deposits underlying the marshes, can also provide preliminary data for engineering studies contemplating development of the Delaware coast.

Field Methods

Drill records were obtained from three sources: the Department of Geology, University of Delaware, The Delaware Geological Survey, and the Delaware State Highway Department. After assembling these data, drill sites were selected to provide data in areas where information was non-existent. The objective was to obtain a general grid pattern of drill data in the study area, subject to a site's accessibility.

The drilling apparatus used (Figures 2 and 3) was set within a sixteen foot, shallow draft Boston Whaler that was able to enter most small tidal creeks and yet was seaworthy enough to enter Delaware Bay under less than ideal conditions. This arrangement permitted drilling of marshes along two or more tidal creeks in a day. Where there were no accessable creeks, roads were used; the drilling equipment being placed in a small truck. This portable drilling system engendered flexibility in the field. Professor Robert B. Biggs of the College of Marine Studies, University of Delaware, developed this drilling rig for penetrating unconsolidated sediments.

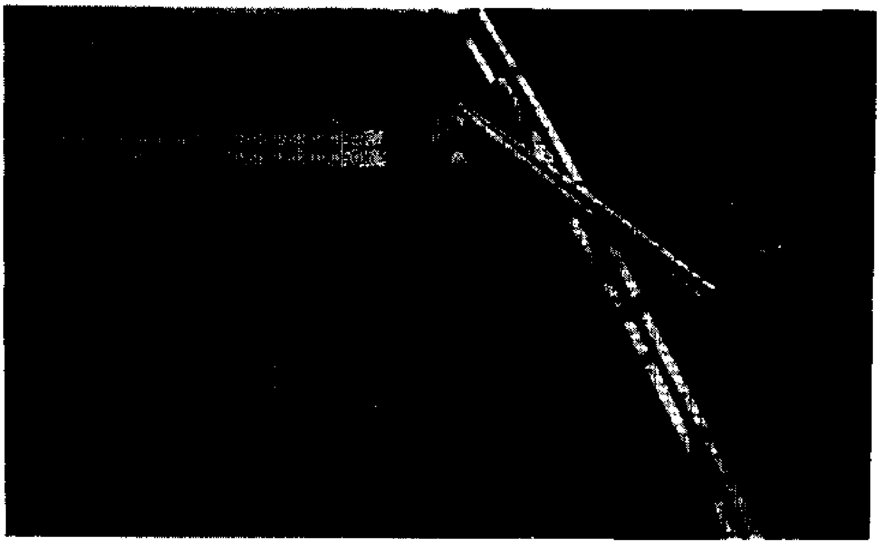

Figure 2: Water-jetting apparatus

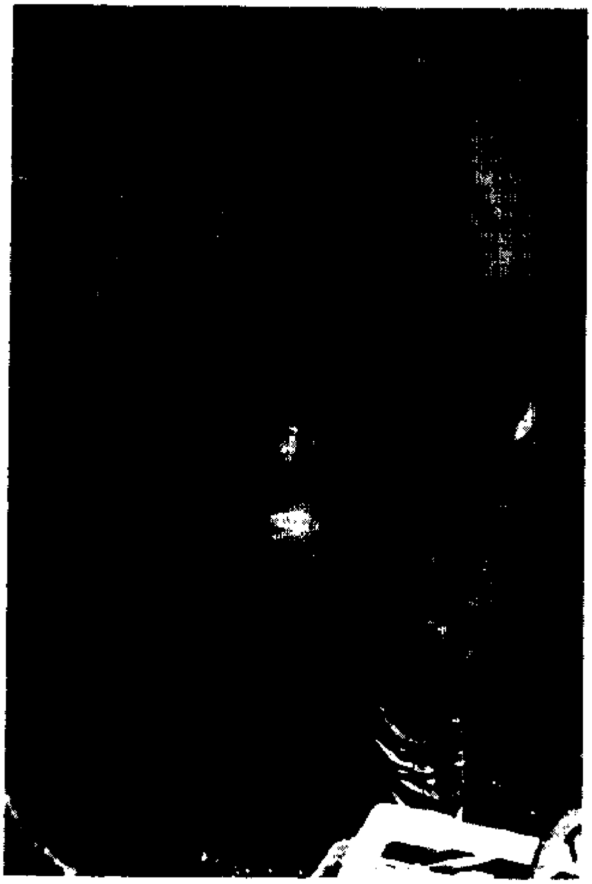

Figure 3: Field operation of water-jetting apparatus

The apparatus is constructed of a three horsepower gasoline pump with three valves, one for water intake and two for discharge; brass couplings connect the intake valve to a ten foot section of three inch diameter heavy walled plastic tubing and one discharge valve to another section of tubing, both are set overboard. The second discharge valve is connected to a twenty foot section of 3/4 inch diameter garden hose, that is in turn connected to a one foot length of steel pipe, that is then coupled to ten foot lengths of 3/4 inch diameter aluminum pipe.

The operating procedure is as follows: the intake hose is primed, (only necessary because the intake contains a foot valve) the engine started, with water now flowing from the stream, through the pump, and back into the stream from the discharge tubing. One of the operators then pounds a three foot section of three inch diameter polyethylene tubing into the marsh surface to act as a casing for the aluminum pipe; the end of the aluminum pipe is constricted to provide greater water pressure, facilitating penetration of the sediments. It is then inserted into the marsh surface through the polyethylene tube; then the control valve is switched to permit water to flow through the aluminum pipe. The operator alternately pushes and lifts the aluminum pipe into and out of the sediments; the water pressure allows the operator to pierce the successive sedimentary layers underlying the marsh surface with a reasonable feel for the sedimentary layers being penetrated; additional lengths of pipe are added as needed. Washings from the borehole can provide additional information; with increasing depths contamination occurs raising doubts about the original depth of the washed materials.

Depths of eighty feet or more can be successfully penetrated using this apparatus. Some sensitivity for the type of material being pierced is lost with depth, but this is to be expected. Depths of 120 feet or more are certainly feasible without encountering untoward difficulties. Advantages of this drilling system as a reconnaissance tool are:

1. a minimum amount of time is required for each borehole (about 1/2 hour);
2. cost per borehole was relatively low, involving only an initial outlay for equipment - about three hundred dollars - and any transportation or labor costs;
3. only two persons are required, one to operate the pump, and another to drill and take the log;
4. the method permits drilling in areas that are inaccessible to other drilling rigs;
5. relatively good drilling logs can be obtained.

The author was able to distinguish the following sedimentary materials: sand, gravel, peat, and mud. Mixtures of the preceding materials can also be described to some degree, especially if the materials are present in some quantity. Thus, muddy peats, sandy gravels, gravelly sands, etc., are detectable. Where these water-jetted holes are drilled in proximity to augur or cored holes, the information is especially useful.

Disadvantages of this drilling method are:

1. no samples can be taken, which can help to verify the lithologies, so no analyses can be performed, including radiocarbon dating;
2. the apparatus may have difficulty piercing thicknesses of sand in excess of 10 feet, because caving in of sands in the borehole often occurs. This could result in the loss of the aluminum pipe, however, "washing out of the hole"(alternately pushing and lifting the pipe into and out of the sediments for a greater period of time than usual) can mitigate this problem.

QUATERNARY STRATIGRAPHY OF COASTAL DELAWARE

The Pleistocene deposits in coastal Delaware are fairly continuous; they are represented by sediments of the Columbia Formation in the northern two thirds of the state and the Columbia Group in the southernmost third. Jordan (1964) has described the Columbia sediments as follows:

> The surficial sands consist mostly of fine-, medium-, and coarse-grained quartz sand. Gravel beds, cobbles, and even boulders conspicuous in northern Delaware and silt beds are found both north and south but are thicker and more common to the south. The volume of all of these materials is small in comparison to that of the sands. The deposits are essentially unconsolidated although locally there may be considerable differences in the degree of induration due to interstitial clay and/or oxides. Heavy bands of limonite-cemented conglomerate are common, especially toward the north. Colors range from white through yellow, tan and brown to reddish-brown.

In southeastern Delaware the Columbia Group can be subdivided into the Omar and Beaverdam Formations. The Omar Formation which overlies the thick, medium- to coarse-grained sands of the Beaverdam Formation is composed of alternating beds of silt and sand (Jordan, 1964).

There are two major environments of deposition for the Columbia sediments in the study area (Figure 4). Fluvial deposits cover most of the northern two thirds of the state; they are variable in thickness due to their occurrence as channel fillings. These sediments display distinct bedding and they have strong coloration, usually tan, brown or reddish brown. The second are sediments which

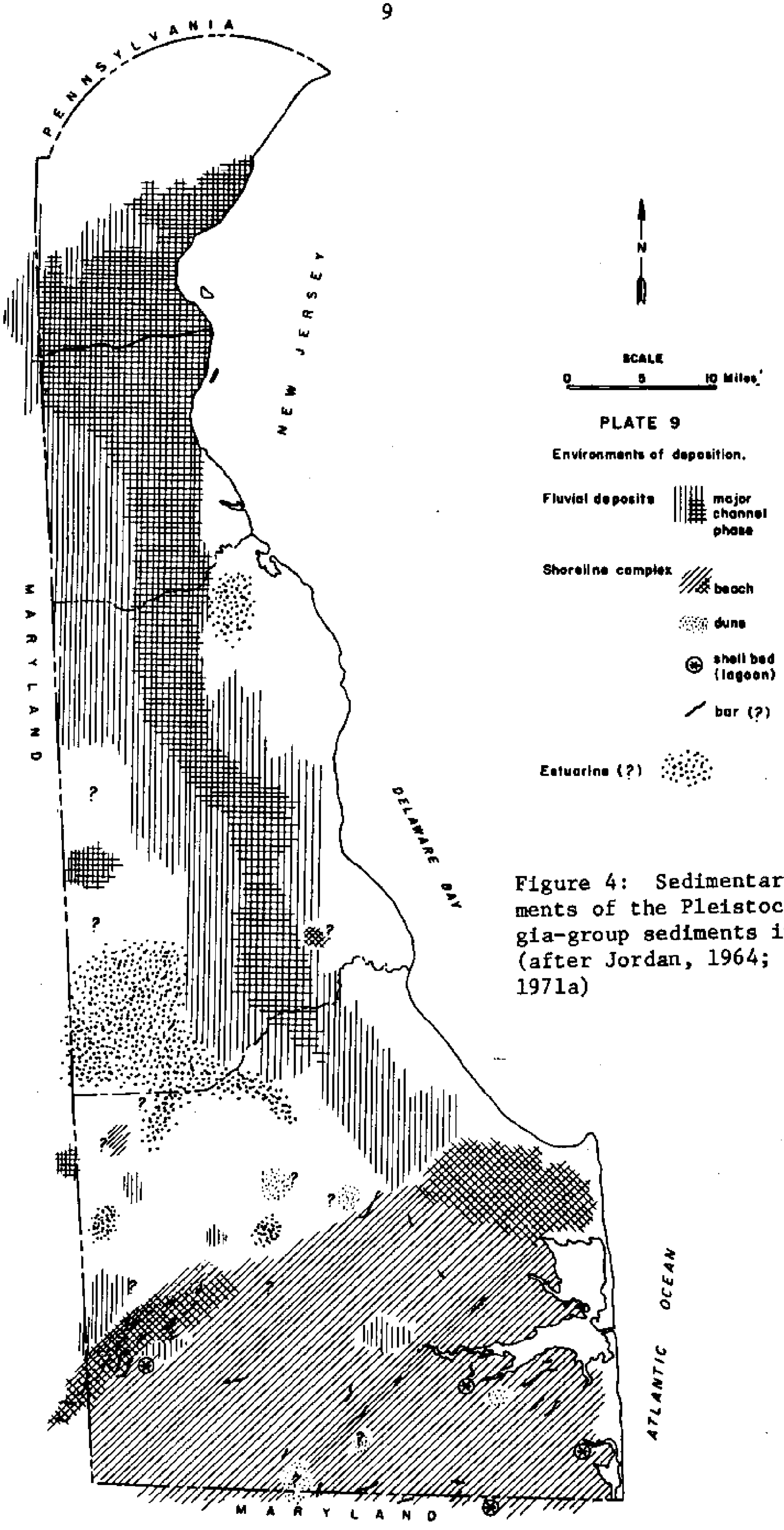

Figure 4: Sedimentary environments of the Pleistocene Columgia-group sediments in Delaware (after Jordan, 1964; in Kraft, 1971a)

may be estuarine in origin. These are present in southern Kent County and northern Sussex County in the general area north of Greenwood, Delaware. The sediments are generally comprised of medium sands but they sometimes range from fine to coarse sands. The deposits ". . . are distinguished by their irregular and indistinct bedding and their abrupt lateral and vertical color changes. Mottling is common . . . the mottling resembles the work of bottom dwelling organisms." (Jordan, 1964)

Sundstrom and Pickett (1969) state that the fluvial Pleistocene sediments of northeastern Sussex County appears to be continuous with fluvial Pleistocene sediments further north. This presents a problem, because there seems to be evidence of marine Pleistocene sedimentation in southern Kent County (Sundstrom and Pickett, 1968). One explanation given by Sundstrom and Pickett (1969) for this enigma is the following sequence of events. Marine Pleistocene sediments were deposited as far north as Bowers Beach, Delaware, and then, following a regression of the seas, these were partially eroded. Fluvial sediments were subsequently deposited in northeastern Sussex County.

The Holocene stratagraphic section in northern coastal Delaware is generally comprised of marsh muds sometimes overlying Holocene channel sands. There is little or no evidence of lagoonal sediments in coastal Delaware north of Bowers Beach (Kraft, 1971a). In southern coastal Delaware Holocene sediments are often represented by muds of shallow lagoonal origin which make up some forty percent of the Holocene section there (J. C. Kraft, personal communication, 1972). A typical cross-section of Holocene sediments underlying a broad marsh is channel sands overlain by lagoonal muds which, in turn, underlie marsh muds (Elliott, 1972). In southern Delaware beach-shoreline complexes are more highly developed than in the north (Kraft, 1971a). This is possibly due to the landward movement of bottom waters transporting sands into Delaware Bay (Meade, 1969).

IDENTIFICATION OF THE PRE-HOLOCENE - HOLOCENE BOUNDARY

The Pleistocene sediments which are usually in evidence below Holocene sediments can be identified by a soil zone, or intermixture of firm marsh clay-silts with sands, and from their compacted nature (R. B. Biggs, personal communication, 1972). Radiocarbon dating may also be useful where suitable materials are present (Kraft, 1971a). Table I summarizes the radiocarbon data from marshes in eastern Sussex County. Pleistocene sediments may also show evidence of mottling and oxidation of borings, as well as a decrease in the number of organisms and organic material as compared with Holocene deposits (Sundstrom and Pickett, 1969). In northern Delaware it is difficult to determine whether channel sands are Holocene or Pleistocene, and no attempt was made to do so. In southern Delaware it is somewhat easier to differentiate Pleistocene and Holocene sediments since Pleistocene sediments of marine origin sometimes underlie Holocene fluvial channel sands; fossil assemblages and the nature of the deposits serve to distinguish Holocene fluvial sands from Pleistocene sediments of marine origin (Elliott, 1972). In some places (Cherry Island, Appendix A-1) the Holocene is underlain by pre-Pleistocene sediments ranging from Cretaceous to Miocene. These can be distinguished from Holocene sediments by fossil assemblages and lithology.

Table I
(After Elliott, 1972)

Radiocarbon Data from Marshes in Eastern Sussex County

Location	Original Symbol	Age in Years before Present[1]	Material Dated	Sedimentary Environment	Depth Adjusted to MSL (Feet) (Kraft, 1971a)[2]
Great Marsh Lewes Oyster Rocks	U'	2420 ± 95	*Spartina alterniflora* peat	Fringing Marsh	9.6
Great Marsh Lewes	C'	>39,900	Wood fragments in gyttja	Unknown	20.5
Great Marsh Lewes	C'	>39,900	Wood fragments in gyttja	Unknown	25.0
Great Marsh Lewes	C'	>39,900	Wood fragments in gyttja	Unknown	26.0
Canary Creek Marsh	P	2580 ± 95	*Spartina alterniflora* muddy peat and peaty mud	Broad Marsh	13.8
Canary Creek Marsh		2330 ± 100	Rhizome peat with mud	Broad Marsh	13.5

[1] Pre-1950 A. D., 5,568 years half life.

[2] Not adjusted for sediment compaction.

The pre-Holocene-Holocene boundary was already determined for much of the drill data obtained from other sources. These determinations were corroborated by the author through independent study of the existing drill data. In the borings which were water-jetted, the compact sand and/or gravel was assumed to be pre-Holocene. In a few cases water-jetted holes were correlated with auger or other drillholes in which the pre-Holocene boundary had previously been identified. In some cases loose channel sands were encountered beneath Holocene sediments. The age of these sands were not determined as no samples were obtained. For the purpose of this study they are excluded in calculating the volume of Holocene sediments.

ANALYSES AND REDUCTION OF DATA

Reduction of Drill Data

The isopach maps presented in Appendix B were drawn utilizing all available data, which included 226 borings and the pre-depositional Holocene slopes of highlands bordering the marshes. Although the small area of marshes northeast of Wilmington does not appear on any of the isopach maps, it was mapped, plainmetered and included in estimates of the volume and mass of Holocene sediments. The drill records are identified in the following manner. Borings taken for this study are numbered 1-85; borings taken by John C. Kraft of the Department of Geology, University of Delaware, are numbered 101-120, 123-124, 127-132, 136 and 154-156; borings obtained from Elliott (1972) are numbered 121-122, 125-126, 133-135, and 137-153; boring logs obtained from the files of the Delaware Geological Survey are numbered 201-249 and boring logs acquired from the Delaware State Highway Department are numbered 301-345. All boring numbers are indicated on the location map (Figure 5).

Existing river channels were ignored when the isopachs were drawn because: 1) they have a minimal effect on volume, and 2) the present rivers and tidal creeks in the marshes meander, so that portions of them overlie pre-Holocene channels filled with Holocene sediments; in these areas the isopachs would curve upstream. Where

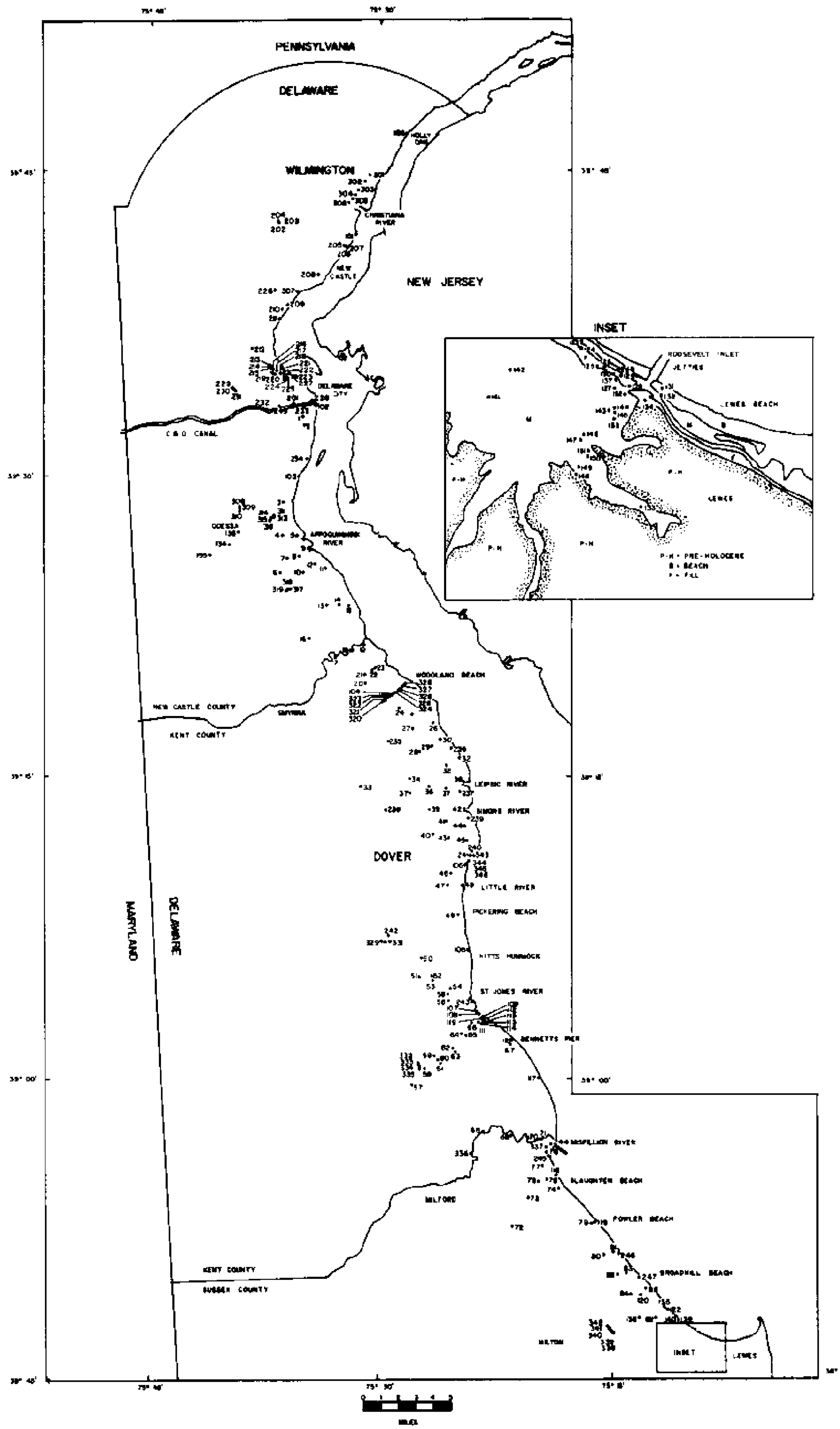

FIGURE 5 LOCATION MAP

this was not the case, the isopachs would curve downstream when one subtracts the water in the river channel. As the information necessary to make a good approximation is simply not available, no attempt was made to modify isopachs crossing rivers or small tidal creeks.

The surface of the marsh was utilized as the base level for the isopach maps. Holes which were drilled on the beaches or in filled areas were adjusted to the local marsh level by surveying or where sufficient data were available, through cross-sectional profiles. In some cases, where neither method was practical, the marsh level was assumed to be two feet above mean sea level and the elevation of each drillhole was adjusted to this height. Errors resulting from this assumption are minimal for the following reasons:

1. about seventy percent of the borings were drilled directly on the marsh, so that arbitrary adjustments were necessary for less than one third of the drillholes;
2. the high tide rarely reaches a height of more than four feet above mean sea level (N. O. A. A. tide tables, 1973), thereby limiting underestimates;
3. in most cases holes drilled in filled areas encountered less than five feet of fill; when the fill was subtracted, the level was often within one half foot of the assumed marsh level.

Errors resulting from correlation of the drill data probably does not exceed two percent of the total volume of sediment.

As many sources of data were used, (boreholes, auger holes, and graphic descriptions) and various people were involved in describing this data, it is necessary to make several assumptions about sediment descriptions. Table II indicates the components of the various class terms used in this study; the table is modified from Wentworth, (1922). It is assumed that most researchers used a similar classification. In order to calculate the volume of fine- and coarse-grained sediment, it was necessary to make several simplifying assumptions. Sediments described as mud or sandy mud were treated as if they were totally composed of fine-grained sediment, while muddy sands were treated wholly as coarse-grained sediment. From my own experience in drilling Holocene sediments in Delaware, sediments which were described as sand and mud were generally interlayered. These are assumed to be fifty percent fine-grained and fifty percent coarse-grained. Sediments described as mud with sand were also interlayered, but mud was dominant. These are assumed to be two thirds fine-grained and one third coarse-grained. Peats were considered as fine-grained sediment.

Table II
(Modified from Wentworth, 1922)

Class Terms for Sediments

Percentage by Grade					Class Term
Gravel	>80%				Gravel
Gravel	>Sand	>10%,	other	<10%	Sandy Gravel
Sand	>Gravel	>10%,	other	<10%	Gravelly Sand
Sand	>80%				Sand
Sand	>Mud*	>10%,	other	<10%	Muddy Sand
Mud	>Sand	>10%,	other	<10%	Sandy Mud
Mud	>80%				Mud

*Note: Mud represents fine-grained sediment (silt and clay).

Identification of the pre-Holocene - Holocene boundary is one of the most important factors affecting the determination of the volume of fine- and coarse-grained sediments. For the fine-grained sediments, the error resulting from incorrect interpretation of the boundary is thought to be small, because the areas where difficulties arose were underlain by channel sands that could be interpreted to be Holocene or Pleistocene. Large volumes of Holocene muds do not appear to underlie the channel sands based on the narrow river channels indicated by analyses of the isopach maps. Hence the volume of Holocene fine-grained sediments would remain relatively unchanged by a reinterpretation of the channel sands, however, the volume of Holocene coarse-grained sediments would be greatly increased if these sediments are Holocene in age.

Planimetering

To facilitate planimetering, the areas of marsh were divided arbitrarily. The total area of these individual areas was determined and then the areas between the isopachs were measured and totaled. The two figures provided a check to see that the area planimetered between the isopachs was within a reasonable range of accuracy (about two percent). Table III shows the results of an area planimetered twice; these results could be considered typical. Another indicator of probable error is the summing of the areas between all the isopachs and comparing this to the area planimetered as a whole. The disparity indicated by this method was ±1.05 percent. The error introduced by planimetering is probably less than two percent and this error is small when compared to the major source of error in this study, i.e., the position of the individual isopachs themselves.

Analyses of Holocene Mud Isopach Maps

The total area of marsh lying between two individual isopachs was determined by planimetering. This area was then multiplied by the average thickness of Holocene fine-grained sediment calculated to be lying between the two isopachs. Thus, if an area of 1,000 square feet were found to be lying between the thirty and forty foot isopachs, the volume of fine-grained sediment would be 35,000 cubic feet (volume figures in cubic feet were converted to cubic yards by using the following conversion factor: 27 ft^3/yd^3). Areas lying between the zero and ten foot isopachs were assumed to represent an average

Table III

Planimetering Error

Isopachs	First Reading*	Second Reading*	Excess*	Deficit*
0-5	.670	.669		.001
0-10	.480	.495	.015	
10-20	.520	.528	.008	
20-30	.552	.562	.010	
30-40	.460	.454		.006
40-50	.302	.302	.000	
50-60	.176	.184	.008	
60-70	.085	.088	.003	
70-80	.015	.016	.001	
80-85	.002	.002	.000	
	3.262	3.300	.045	.007

Total Error = .052

Percentage Error = .052/3.262 = ± 1.59

*Note: These figures are pure numbers; they have not been converted to square miles, as it was unnecessary for this illustration.

thickness of five feet of fine-grained sediment, areas lying between the ten and twenty foot isopachs, fifteen feet, etc.

Within basins, the thickness of fine-grained sediment assumed to be enclosed within a ten foot isopach is twelve and a half feet, (the maximum thickness is assumed to be fifteen feet); the thickness of sediment enclosed within a twenty-foot isopach was twenty-two and a half feet, (the maximum thickness is assumed to be twenty-five feet), etc. For areas which formed ridges in pre-Holocene times, the thickness of fine-grained sediment assumed to be enclosed within a ten foot isopach is seven and a half feet (the minimum thickness is assumed to be five feet); the thickness of sediment assumed to be enclosed within a twenty foot isopach is seventeen and a half feet, (the minimum thickness is assumed to be fifteen feet), etc. For a ten foot isopach terminating at the coast, the thickness of fine-grained sediment assumed is twelve and a half feet, (the maximum thickness is assumed to be fifteen feet); for a twenty-foot isopach terminating at the coast, the thickness of sediment is assumed to be twenty-five feet), etc. It should be noted that an error arises here, because the actual depth at which some of the Holocene fine-grained sediment exists is deeper than that indicated by the isopach maps. This is because interbedded coarse-grained sediments are not indicated in the isopach maps. Therefore, the area indicated by planimetering between two isopachs is larger than it should be. This error is estimated to be no greater than +5 percent.

Only one set of isopach maps of Holocene fine-grained sediments was drawn since coarse-grained sediments in most holes did not comprise a significant proportion of the total Holocene section. (Coarse-grained material comprised an average of only 8.3 percent of the Holocene section in each drillhole - derived from Table V.) Information on the thickness of the Holocene stratigraphic section for all borings can be found in Appendix C.

To provide an indication of the error created by incorrect placing of the isopachs, where data was unavailable, logs of eight drillholes were obtained after the isopach maps were drawn. The locations of these holes were plotted on the isopach maps and a thickness of Holocene fine-grained sediment was estimated for each hole. The logs were then studied to find the actual thickness of fine-grained sediment at each location. Table IV summarizes the results. The total average error was 32 percent.

Thickness of Holocene Sediments

The relatively great slopes on the pre-Holocene sediments in northern Delaware (as indicated by the isopach maps and cross-sections) as opposed to southern Delaware, accounts for the Holocene sediment thicknesses in excess of ninety feet in narrow river valleys such as the Appoquinimink. In southern Delaware the Holocene section is less variable in thickness than in northern Delaware, while the area covered by Holocene sediments in the south is more extensive, although maximum depths are somewhat less than those in the north.

Table IV

Estimated Error Due to Incorrect Placing of Isopachs

Drillhole Number	Estimated Depths from Isopach Maps (In Feet)	Actual Depths (In Feet)	Percent Error
136	36	52	30.8
201	23	9.5	131.6
228	25	37	32.4
249	24	30.5	21.3
312	28	25	12.0
343	32	28	14.3
344	33	30	10.0
345	31	30	3.3

Total Average Error = 255.7/8 = 32.0%
(8 holes)

Average Negative Error = 84.5/3 = 28.2%
(3 holes)

Average Positive Error = 170.2/5 = 34.4%
(5 holes)

Volume of Holocene Fine- and Coarse-Grained Sediment

Computation of the volume of Holocene fine-grained sediment outlined in the preceding sections gives a value of 2.99×10^9 cubic yards ±41 percent. (The error value is the sum of all determinable errors discussed in the preceding sections.)

Given the volume of Holocene fine-grained sediment, an estimate of the volume of Holocene coarse-grained sediment can be made using the following procedure: 222 drill logs were studied to determine the thickness of Holocene fine- and coarse-grained sediment in each hole. The thicknesses in each drillhole were then totaled and divided by the number of drillholes. Table V summarizes the results.

Table V

Mean Thicknesses of Coarse- and Fine-Grained Sediments in Drillholes

Total Number of Drillholes	Total Thickness of Coarse-Grained Sediment in All Drillholes (In Feet)	Mean Thickness of Coarse-Grained Sediment in Each Drillholes (In Feet)
222	518	2.33
	Total Thickness of Fine-Grained Sediment in All Drillholes (In Feet)	Mean Thickness of Fine-Grained Sediment in All Drillholes (In Feet)
	5736	25.84

It should be noted that of the 235 drillholes studied, 13 were excluded because they did not penetrate the pre-Holocene surface.

From Table V, it is found that there is approximately nine percent as much Holocene coarse-grained sediment as Holocene fine-grained sediment (or 8.3 percent of the total Holocene sediment). Since the volume of Holocene fine-grained sediment totals about 3×10^9 cubic yards, one can assume that the volume of Holocene coarse-grained sediment is nine percent of that or about $.3 \times 10^9$ cubic yards. The total volume of Holocene sediment is about 3×10^9 cubic yards.

The procedure used to determine the volume of Holocene fine- and coarse-grained sediments was determined by the evolution of the work. An easier method would have been to draw isopach maps of Holocene sediments and then calculate the volume of Holocene sediments, Holocene fine-grained sediments, and Holocene coarse-grained sediments.

DETERMINATION OF THE MASS OF HOLOCENE FINE-GRAINED SEDIMENT

The volume of *in situ* Holocene fine-grained sediments is not wholly significant in itself, because of the water contained within. If the mass of water is subtracted, the remainder would represent the volume of inorganic and organic fine-grained sediment. The mass of inorganics and organics can then be related to the suspended sediments introduced into Delaware Bay by all rivers.

Water Content of Holocene Fine-Grained Sediments

The water content of Holocene fine-grained sedimentary materials underlying present Delaware salt marshes exhibits a wide range of values. Table VI lists the weight percentage of water in Holocene fine-grained sediments. The highest values are those of peats, the lowest values, for those sediments containing a small percentage of organics. In general, water content is proportional to the amount of organics present. There is no reason to expect geographic variations in the water contents of lithologically similar sediments (F. M. Swain, personal communication, 1972). With depth, however, there may be differences in water content due to compaction (water content decreasing with depth). However, since the median depth of Holocene sediments is 17 feet (Figure 6), and fifty percent of these sediments have been deposited within the last 3900 years, it is thought that the water content does not vary greatly with depth in lithologically similar sediments.

From the data presented in Table VI, it is found that the average water content, by weight, of Holocene organic silty clays is about fifty percent and of Holocene peats, seventy percent. Peaty sediments comprise about twenty percent of Holocene fine-grained sediments by volume, and organic silty clays, including muds of lagoonal origin, comprise the remainder. Using a weighted average, the estimated water content of Holocene fine-grained sediments is fifty-five percent by weight.

Organic Content of Holocene Fine-Grained Sediments

The organic content of Holocene fine-grained sediment, by weight, before evaporation of water, ranges from 2.7 percent to 10.8 percent (Table VI). Organic silty clays range from about two percent to eight percent, six percent being the average; peats generally range from about eight percent to sixteen percent with ten percent being the average. As peaty sediments represent about twenty percent of the Holocene fine-grained sedimentary materials by volume and organic silty clays making up the remainder, the average organic content, by weight, of Holocene fine-grained sediments, before evaporation of water, is about seven percent.

Inorganic Sediment Content of Holocene Fine-Grained Sediment

If water makes up fifty-five percent of Holocene fine-grained sediments by weight and organics seven percent by weight, then inorganic Holocene sediment will comprise the remainder, or thirty-eight percent.

Table VI

Organic and Water Contents of Holocene Fine-Grained Sediments by Weight

Type of Sediment	Location and Core Number	Depth Below Surface (In Feet)	Percent Organics by Weight	Percent Water by Weight	Bulk Density (Lb/in^3)	Source of Information
Peats	Pigeon Point	11.0-104		67		Richardson Associates
Organic Silty Clay	Pigeon Point	11.0-104		40		Richardson Associates
Organic Silty Clay	Woodland Beach	3.5-5.5	6.5	49.3		Delaware State Highway Department
Peat	Woodland Beach	4.3-5.3	9.5	78.2		Delaware State Highway Department
Organic Silty Clay	Woodland Beach	5.3-5.8	4.9	66.0		Delaware State Highway Department
Organic Silty Clay	Woodland Beach	5.8-6.3	4.3	57.1		Delaware State Highway Department
Organic Silty Clay	Woodland Beach	6.3-8.3	7.3	59.5		Delaware State Highway Department
Organic Silty Clay	Port Mahon U-1	7.0-9.0	6.0	47.9	.051	Delaware State Highway Department
Organic Silty Clay	Port Mahon U-1	12.0-13.0	8.7	60.2	.045	Delaware State Highway Department

Table VI (Cont'd)

Type of Sediment	Location and Core Number	Depth Below Surface (In Feet)	Percent Organics by Weight	Percent Water by Weight	Bulk Density (Lb/in^3)	Source of Information
Organic Silty Clay	Port Mahon U-1	13.0-14.0	6.1	52.4	.051	Delaware State Highway Department
Organic Silty Clay	Canary Creek Marsh	2.0-2.5	9.0	50		Swain (1971)
Dark Peat	Canary Creek Marsh	5.5-6.0	10.8	82		Swain (1971)
Organic Silty Clay	Canary Creek Marsh	12.5-13.0	7.3	57		Swain (1971)
Organic Silty Clay	Canary Creek Marsh	16.0-16.5	6.8	60		Swain (1971)
Organic Silty Clay	Canary Creek Marsh	0.0-1.0		53-76	.039-.051	Field (1971)
Organic Silty Clay	Canary Creek Marsh	6.0		48		Richardson Associates
Peat	Canary Creek Marsh B-5	6.5		55		Richardson Associates
Organic Silty Clay	Canary Creek Marsh B-4	8.0	2.7	30		Richardson Associates

Table VI (Cont'd)

Type of Sediment	Location and Core Number	Depth Below Surface (In Feet)	Percent Organics by Weight	Percent Water by Weight	Bulk Density (Lb/in^3)	Source of Information
Organic Silty Clay	Canary Creek Marsh B-4	9.5		45		Richardson Associates
Organic Silty Clay	Canary Creek Marsh B-2	11.0	7.0	40		Richardson Associates
Organic Silty Clay	Canary Creek Marsh B-2	15.5	7.2	31		Richardson Associates
Organic Silty Clay	Canary Creek Marsh B-3	17.5		30		Richardson Associates
Peat	Canary Creek Marsh B-13	18.0		58		Richardson Associates
Organic Silty Clay	Canary Creek Marsh B-13	20.5	6.7	32		Richardson Associates
Organic Silty Clay	Canary Creek Marsh B-13	25.5		33		Richardson Associates

Estimated Volume of Water, Organic, and Inorganic Sediment Comprising Holocene Fine-Grained Sediments

The densities of .037 lb/in^3 for estuarine water, .040 lb/in^3 for organics and .096 lb/in^3 for sediment are assumed to be reasonable values (R. B. Biggs, personal communication, 1972). Using the weight percents derived in the previous sections, (fifty-five percent water, seven percent organics, and thirty-eight percent inorganic sediment) one can obtain their respective volumes by first dividing their weight percents by their respective densities, since volume equals mass/density.

Water

$55.0\%/.037\ lb/in^3 = 1486\%\ lb/in^3$

Organics

$7.0\%/.040\ lb/in^3 = 175\%\ lb/in^3$

Inorganic Sediment

$38.0\%/.096\ lb/in^3 = 396\%\ lb/in^3$

Then totaling the above three quotients and dividing each quotient by the sum of the three gives the respective volumes in percent.

$$1486\%\ lb/in^3 + 175\%\ lb/in^3 + 396\%\ lb/in^3 = 2057\%\ lb/in^3$$

Estimated Water Volume

$1486\%\ lb/in^3/2057\%\ lb/in^3 = 72.26\%$

Estimated Organics Volume

$175\%\ lb/in^3/2057\%\ lb/in^3 = 8.52\%$

Estimated Inorganic Sediment Volume

$396\%\ lb/in^3/2057\%\ lb/in^3 = 19.22\%$

72.26% water + 8.52% organics + 19.22% inorganic sediment = 100.0%

This is equivalent to the total volume of Holocene fine-grained materials.

Estimated Bulk Density of Holocene Fine-Grained Sediments

The average bulk density of the Holocene fine-grained sediment is derived by multiplying the volume of each component by its respective density and then totaling the products.

$$.037\ \text{lb/in}^3 \times .7226 + .040\ \text{lb/in}^3 \times .0852 + .096\ \text{lb/in}^3 \times .1922 = .048\ \text{lb/in}^3$$

This estimate is comparable to bulk densities of Holocene fine-grained sediments measured directly (.039 - .051 lb/in^3 - Table VI).

Estimated Mass of Water, Organics, and Inorganic Sediment in Holocene Fine-Grained Sediments

The total volume of Holocene fine-grained sediments is 2.99 x 10^9 cubic yards. The volumes of water, organics, and inorganic sediments in cubic yards are as follows:

Water	$.7226 \times 2.99 \times 10^9\ \text{yd}^3 =$	$2.16 \times 10^9\ \text{yd}^3$
Organics	$.0852 \times 2.99 \times 10^9\ \text{yd}^3 =$	$0.25 \times 10^9\ \text{yd}^3$
Inorganic Sediment	$.1922 \times 2.99 \times 10^9\ \text{yd}^3 =$	$0.57 \times 10^9\ \text{yd}^3$
	Total	$2.98 \times 10^9\ \text{yd}^3$

Multiplying the above volumes by their respective densities will give the mass of each of the components. As the density of bay water is .037 lb/in^3 or .9 tons/yd^3, the mass of water in Holocene fine-grained sediment = $.9\ \text{tons/yd}^3 \times 2.16 \times 10^9\ \text{yd}^3 = 1.9 \times 10^9$ tons. As the density of organics is .040 lb/in^3 or .9 tons/yd^3, the mass of organics = $.9\ \text{tons/yd}^3 \times .25 \times 10^9\ \text{yd}^3 = .2 \times 10^9$ tons. As the density of inorganic sediment is .096 lb/in^3 or 2.2 tons/yd^3, the mass of inorganic sediment =

$$2.2 \text{ tons/yd}^3 \times 0.57 \times 10^9 \text{ yd}^3 = 1.3 \times 10^9 \text{ tons}$$

The estimated total mass of Holocene fine-grained sediment is

$$\begin{array}{ccccccc} \text{Water} & + & \text{Organics} & + & \text{Inorganics} & = & \text{Total} \\ 1.9 \times 10^9 \text{ tons} & + & 0.2 \times 10^9 \text{ tons} & + & 1.3 \times 10^9 \text{ tons} & = & 3.4 \times 10^9 \text{ tons} \end{array}$$

As a check, the average bulk density is multiplied by the estimated total volume (bulk density = .048 lb/in^3 = 1.12 tons/yd^3).

$$1.1 \text{ tons/yd}^3 \times 2.98 \times 10^9 \text{ yd}^3 = 3.3 \times 10^9 \text{ tons}$$

Using propagation of errors, the mass of inorganic and organic Holocene fine-grained sediments underlying Delaware marshes affected by Delaware Bay tides is 1.52 x 10^9 tons ± 67%. The probable minimum is therefore 0.51 x 10^9 tons and the probable maximum is 2.54 x 10^9 tons.

It should be noted that no estimate has been made for compaction in deriving the mass of Holocene fine-grained sediment, but since the median depth of the Holocene sediments in the study area is only seventeen feet and they have been deposited approximately in the last 3900 years, the underestimate inherent in the figure for the average mass of fine-grained sediment is small.

MASS OF SUSPENDED SEDIMENT CONTRIBUTED TO DELAWARE BAY DURING THE HOLOCENE EPOCH

Values obtained for denudation rates in the Delaware Bay drainage basin and adjacent areas are fifty tons per square mile per year for Gunpowder Creek, Maryland, (Lull and Sopper, 1969), forty-six tons per square mile per year for East Branch, Delaware River at Fishes Eddy, New York, and thirty-three tons per square mile per year at East Branch, Delaware River at Hale Eddy, New York, (U. S. G. S., Harrisburg, personal communication, 1973). The average of these figures is forty-three tons per square mile per year. As these figures are for areas that are relatively free of man's activities, the average of these rates of erosion will be considered to be the average denudation rate for the Delaware Bay drainage basin during the Holocene epoch. Erosion rates for the entire Delaware drainage basin cannot be used because man's activities have greatly increased the erosion rates (Lull and Sopper, 1969). Factors other than man's activities, such as slopes and lithology of the rocks being eroded, also have a great effect on denudation rates, but they are not considered because of the inherent complexities which arise.

The ratio of suspended sediment load to dissolved load to bed load in the present Delaware River is 10 to 10 to 1 (Parker, et al., 1964; Judson and Ridder, 1964; McCarthy and Kreighton, 1964; U. S. G. S., Harrisburg, personal communications, 1973). This ratio is assumed to hold for the Holocene epoch. Taking forty-three tons per square mile per year as the average erosion rate, twenty and a half tons per square mile per year would represent the suspended sediment load contributed to Delaware Bay by all rivers.

Since the maximum projected depth for the Holocene section is one hundred thirty-five feet (one hundred twenty-five feet of fine-grained sediment plus ten feet of coarse-grained sediment [8.3 percent of one hundred twenty-five feet]) and the alternate sea level rise curve of Kraft (1971a), indicates that 10,300 years ago sea level was one hundred thirty-five feet below its present level, it is assumed that the first Holocene sediment was deposited 10,300 years ago (Figure 6). Since the area of the Delaware Bay drainage basin is 12,765 square miles (Governor's Task Force, 1971-72), and the first Holocene sediment was deposited about 10,300 years ago, the amount of suspended sediment contributed by rivers to Delaware Bay during the last 10,300 years is 20.5 tons per square mile per year x 12,765 square miles x 10,300 years; this is equal to 2.7×10^9 tons.

Biggs (1970) reported that the net amount of organics produced by phytoplankton in northern Chesapeake Bay is two hundred and ten grams per square meter per year. If this value holds for Delaware Bay, the net production per year is 210 grams per square meter per year x 1.866×10^9 square meters (the area of Delaware Bay from Smyrna to the Capes). This is equal to 3.9×10^8 kilograms, or converted to tons (nine hundred and seven kilograms per ton), 4.3×10^5 tons. Assuming this rate of productivity has been stable during the Holocene epoch, the total production during the last 10,300 years would be 4.5×10^9 tons.

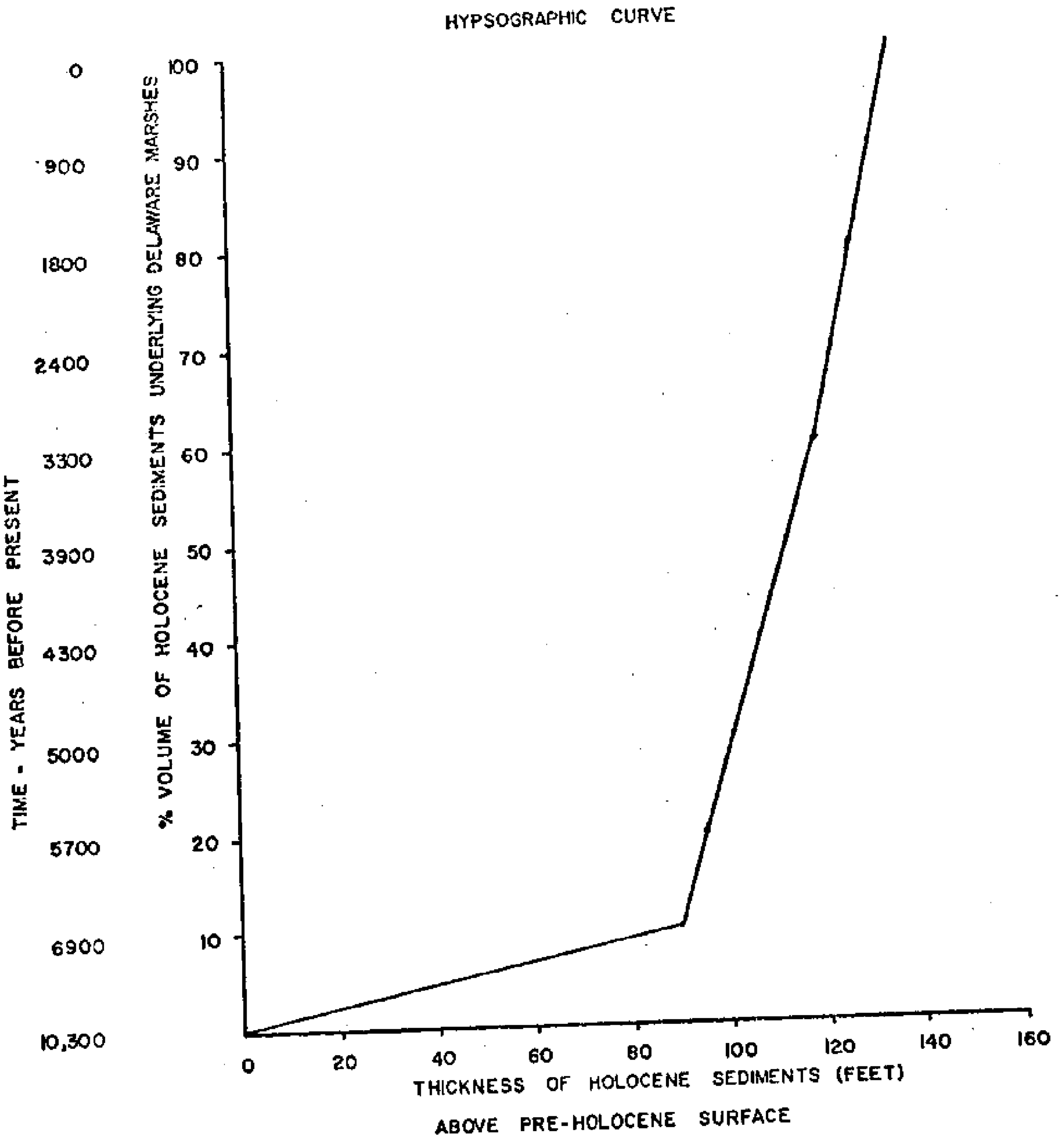

Figure 6: Percent volume of Holocene fine-grained sediments lying above an indicated depth and the time period during which they were deposited (using the alternate sea level rise curve of Kraft [1971a]).

Adding the totals of suspended sediment produced by erosion and suspended sediment produced by phytoplankton in the Delaware Bay gives a value of 7.2×10^9 tons.

COMPARISON OF MASS OF SUSPENDED SEDIMENT CONTRIBUTED BY RIVERS AND PHYTOPLANKTON TO THE DELAWARE BAY DRAINAGE BASIN WITH THE MASS OF FINE-GRAINED SEDIMENTS UNDERLYING DELAWARE BAY MARSHES

New Jersey marshes affected by Delaware Bay tides total about one hundred and sixteen square miles (Stanley Gorski, United States Fish and Wildlife Service, personal communication, 1973) or about eighty-two percent of Delaware's one hundred and forty square miles of marsh affected by Delaware Bay tides. If one assumes that the average thickness of Holocene fine-grained sediments on the New Jersey side of the bay is the same as in Delaware (fifteen and a half feet, Figure 7) and the ratio between organic and inorganic fine-grained sediments is the same, then the mass of organic and inorganic sediment in New Jersey is $.82 \times 1.52 \times 10^9$ tons or 1.25×10^9 tons. The total for New Jersey and Delaware is then 2.77×10^9 tons. This is comparable to the 2.7×10^9 tons of suspended sediment contributed by rivers and the 4.5×10^9 tons of suspended sediment contributed by phytoplankton to Delaware Bay during the last 10,300 years.

There is a possibility that some of the suspended sediment contributed to Delaware Bay during the last 10,300 years has been deposited under Delaware Bay (Strom, 1972) or was passed out to the ocean as net ebb transport (Oostdam, 1971). This supports the theory that the areas underlying the marshes along Delaware Bay have had other sources of fine-grained sediment brought into the bay from the ocean by the salinity intrusion (Meade, 1969) and erosion of uplands bordering the marshes.

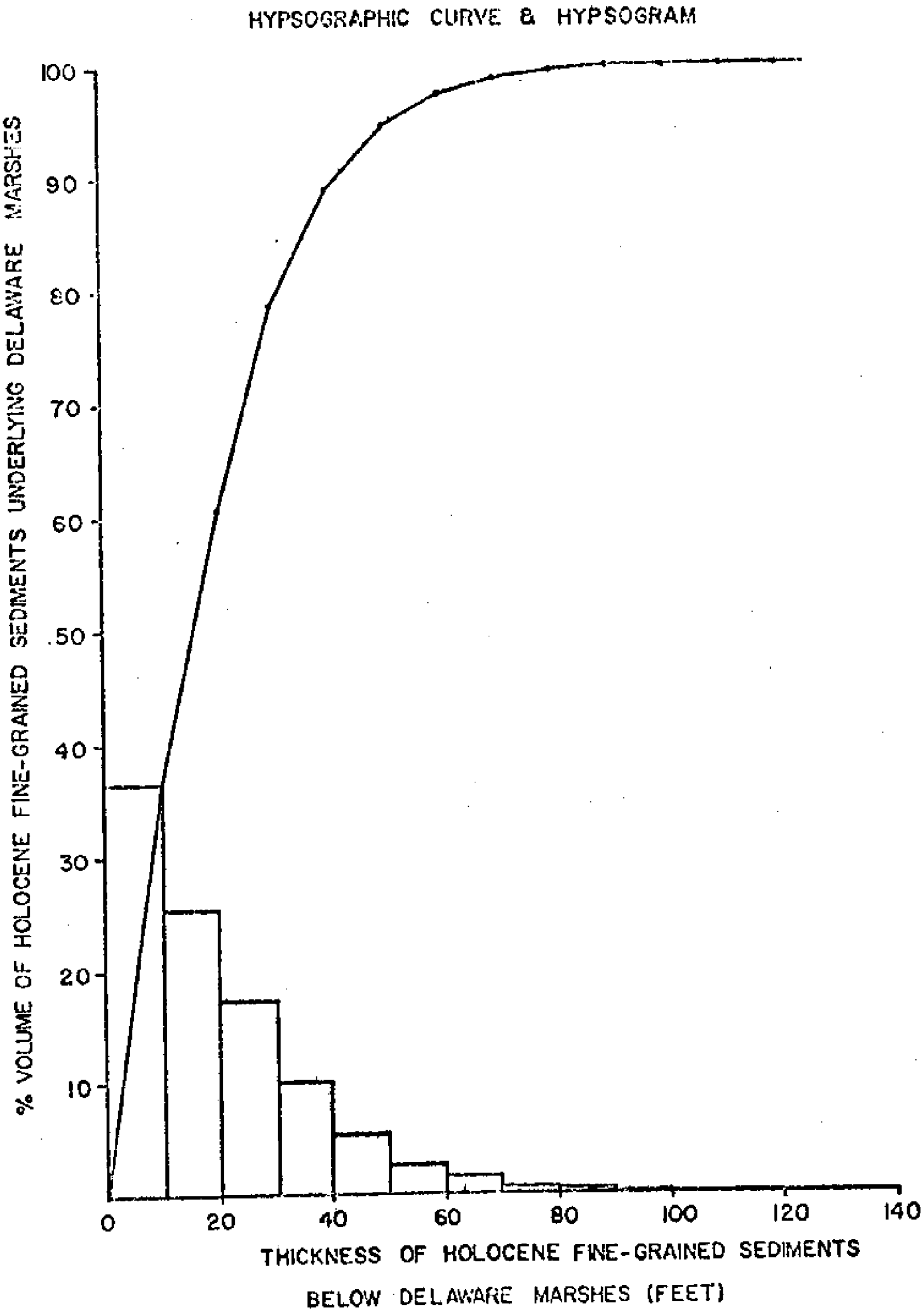

Figure 7: Percent volume of Holocene fine-grained sediments lying above a given isopach and between two given isopachs.

SUMMARY OF
VOLUME AND MASS DETERMINATIONS

The volume of Holocene fine-grained sediments is 2.99 x 10^9 cubic yards ± 41 percent. The volume of Holocene coarse-grained sediment is .26 x 10^9 cubic yards with a probable error greater than that of the fine-grained sediment. The estimated mass of Holocene fine-grained sediment (excluding water) is 1.52 x 10^9 tons ± 67 percent.

USEFULNESS OF HYPSOGRAPHIC CURVES

Figure 6 is a sea level rise curve (Kraft, 1971a) which can also be used to find the time period during which Holocene sediments were deposited. Additionally, it is a hypsographic curve showing the percent volume of Holocene sediments in the study area lying above a given depth. It can be noted that fifty percent of the Holocene sediments in the study area have been deposited within the last 3900 years.

Figure 7 shows the percent volume of Holocene fine-grained sediment in the study area lying between given isopachs or lying above a given isopach.

Figure 8 can be used to find the percent area of marsh in the study area having a given thickness of Holocene fine-grained sediment. The cumulative frequency curve indicates that over fifty percent of Delaware marsh (affected by Delaware Bay tides) has less than a twenty foot thickness of Holocene fine-grained sediment. An estimate of the area of lands adjacent to marshes that will be encroached upon in the next century, should sea level continue to rise at the same rate as it has in the past 3000 years (Kraft, 1971a) can be obtained by studying Figures 6 and 8, given the area of Delaware's marshes affected by Delaware Bay tides.

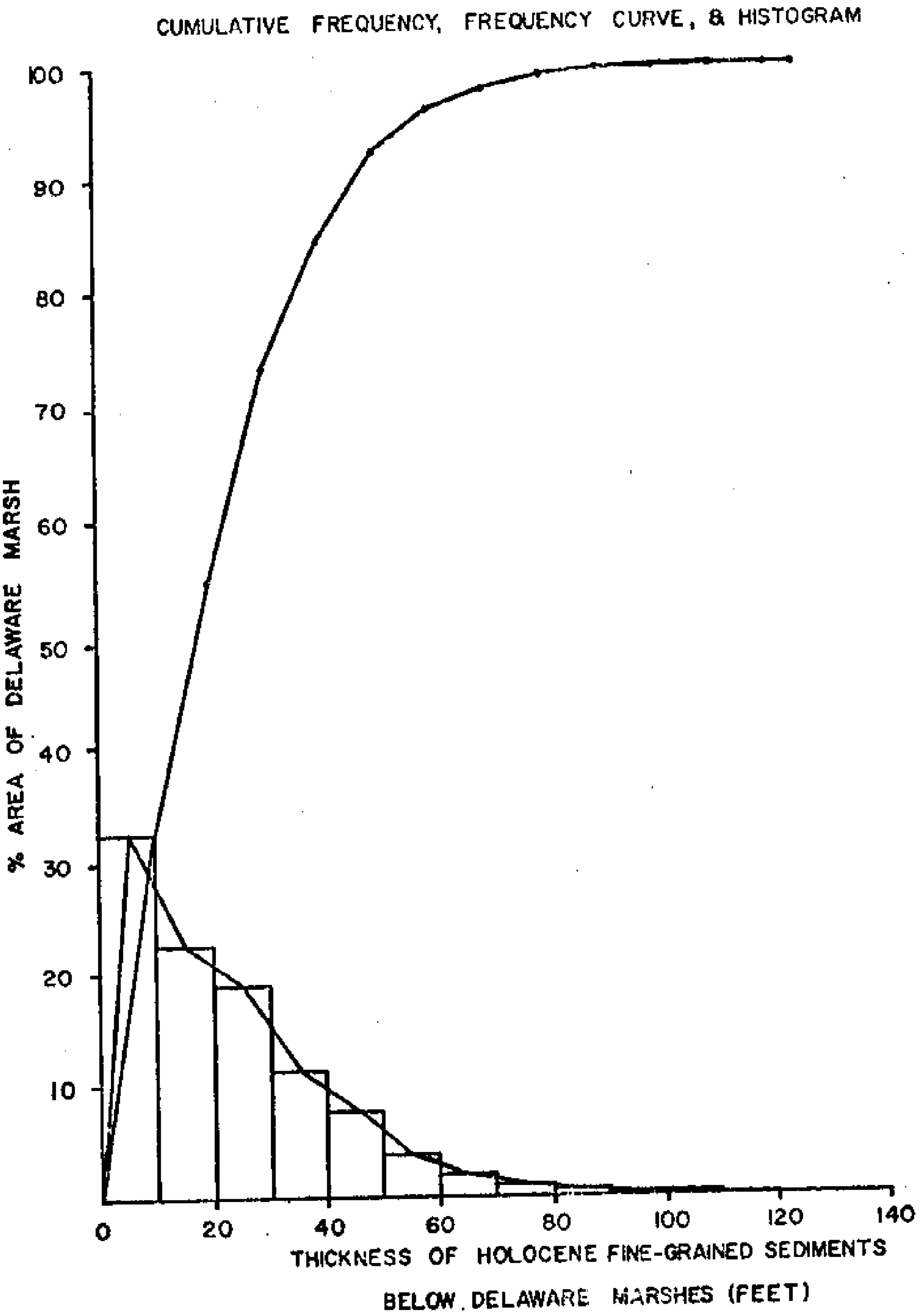

Figure 8: Percent area of marsh having a given thickness of Holocene fine-grained sediments.

RISE IN SEA LEVEL

Since the marshes represent the leading edge of the Holocene transgression, as sea level rises, marshes will continue to encroach upon adjacent farmlands. During the last 3000 years, sea level has been rising at the rate of one half foot per century (Kraft, 1971a). During this period of time, about forty percent of Delaware's present marsh area was formed (Figures 6 and 8). If this rise in sea level were to continue at the same rate and a sufficient supply of fine-grained sediment is available, then during the next century, about two square miles of lands adjacent to marshes will be encroached upon.

CONCLUSIONS

The mass of Holocene organic and inorganic fine-grained sediment underlying present Delaware and New Jersey salt marshes affected by Delaware Bay tides is roughly comparable to the total suspended sediment that has been contributed to Delaware Bay by all rivers in the drainage basin during the last 10,300 years of the Holocene epoch. As the marshes have kept pace with the rise in sea level, the average rate of deposition of fine-grained sediments underlying the bay marshes is one hundred twenty-five feet per 10,300 years, or .15 inches per year.

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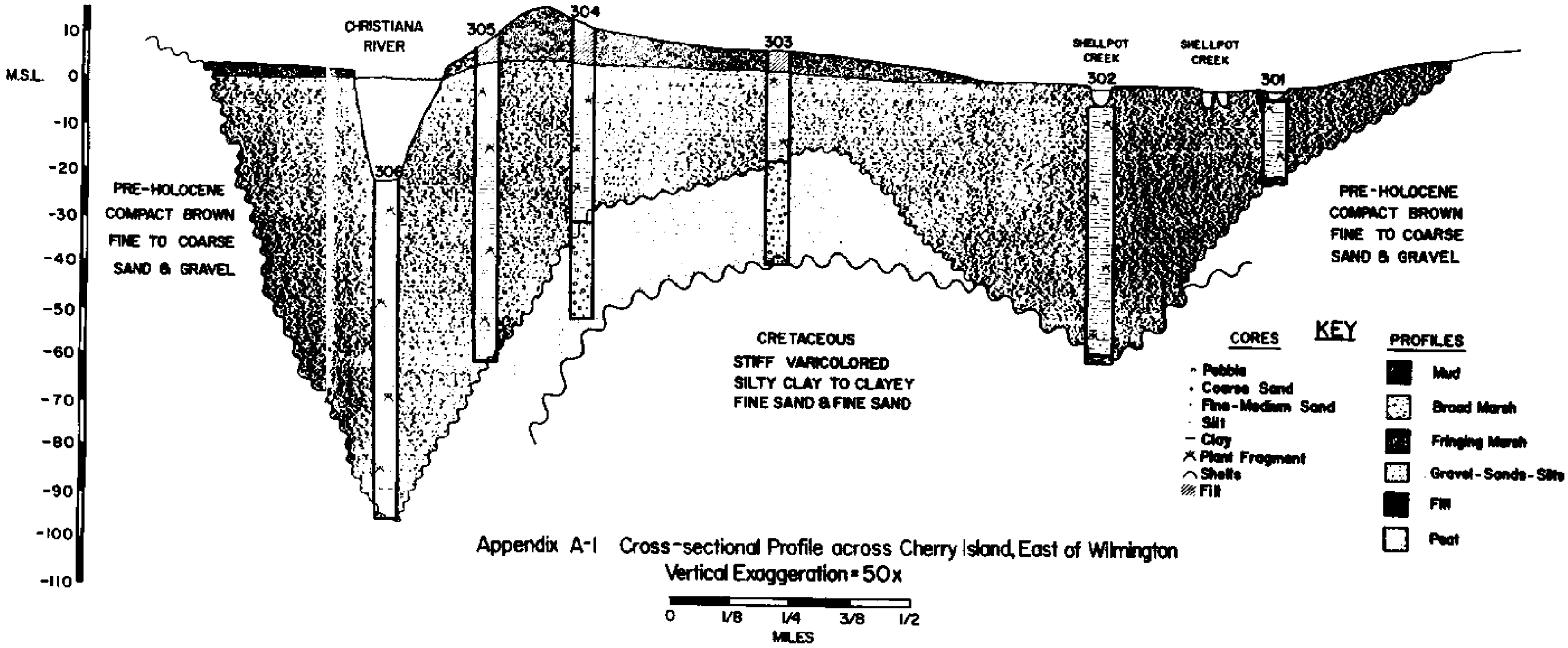
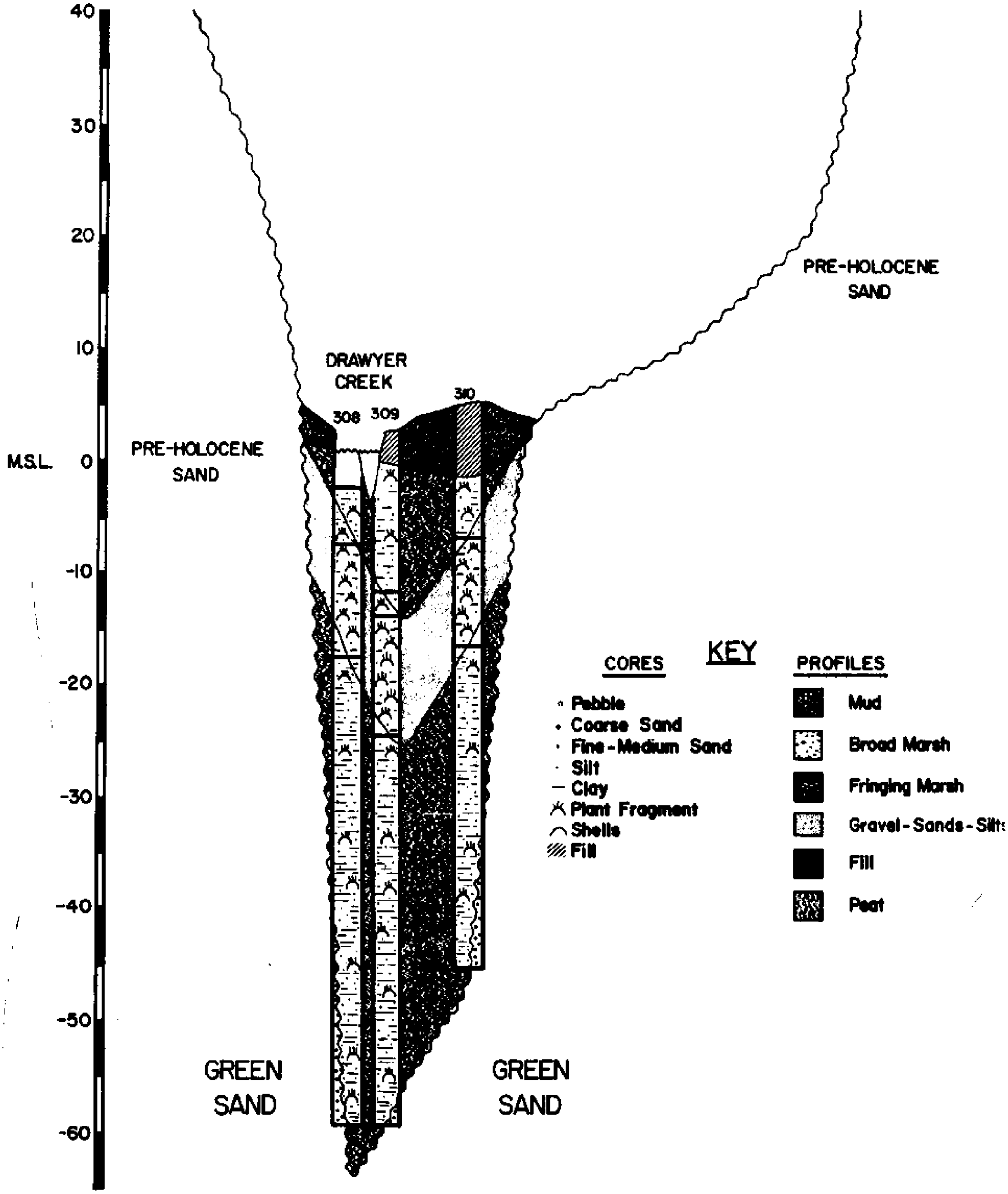
APPENDIX A

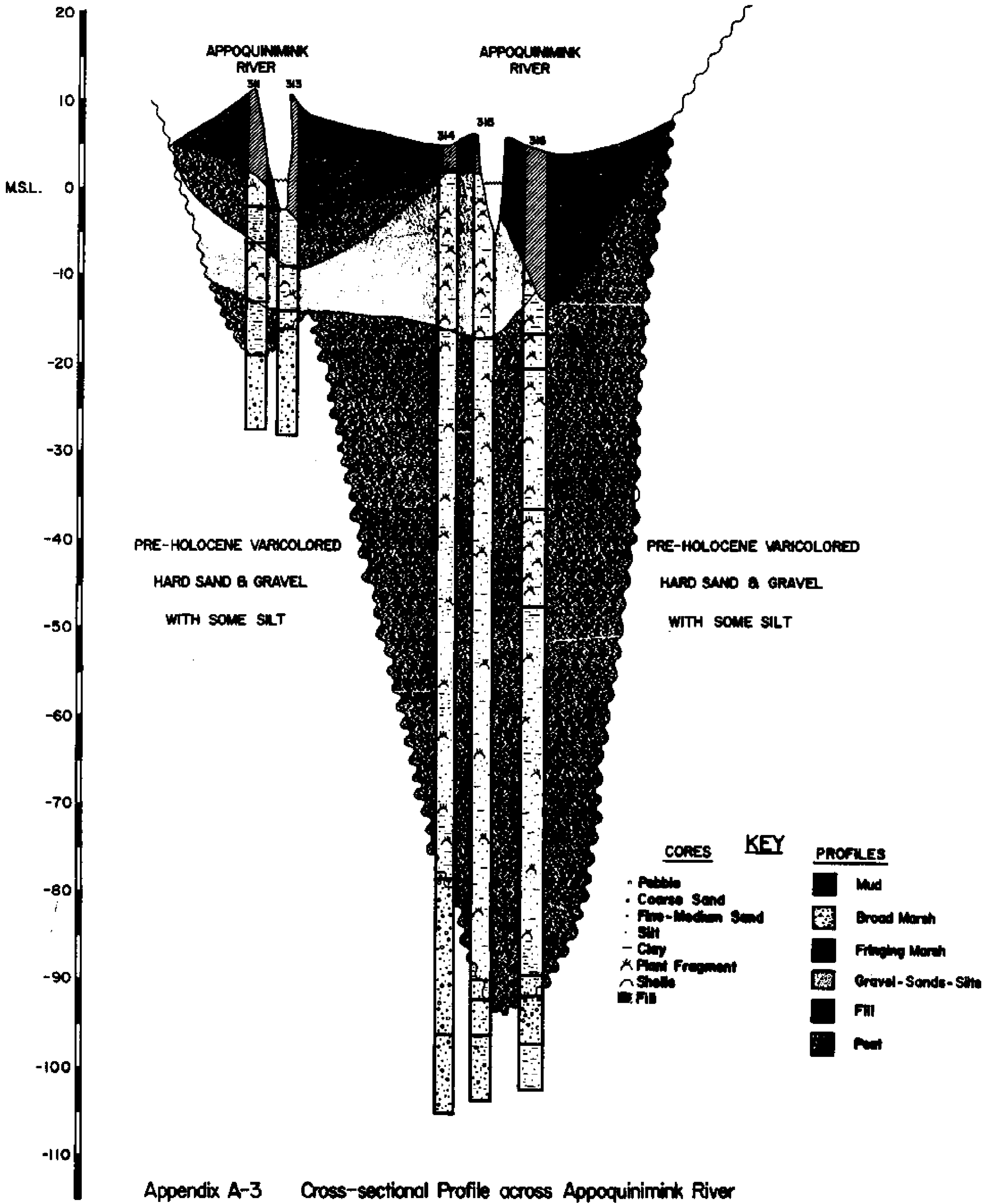
Cross Sections



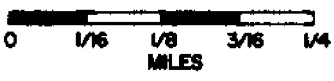
Appendix A-1 Cross-sectional Profile across Cherry Island, East of Wilmington
Vertical Exaggeration = 50x

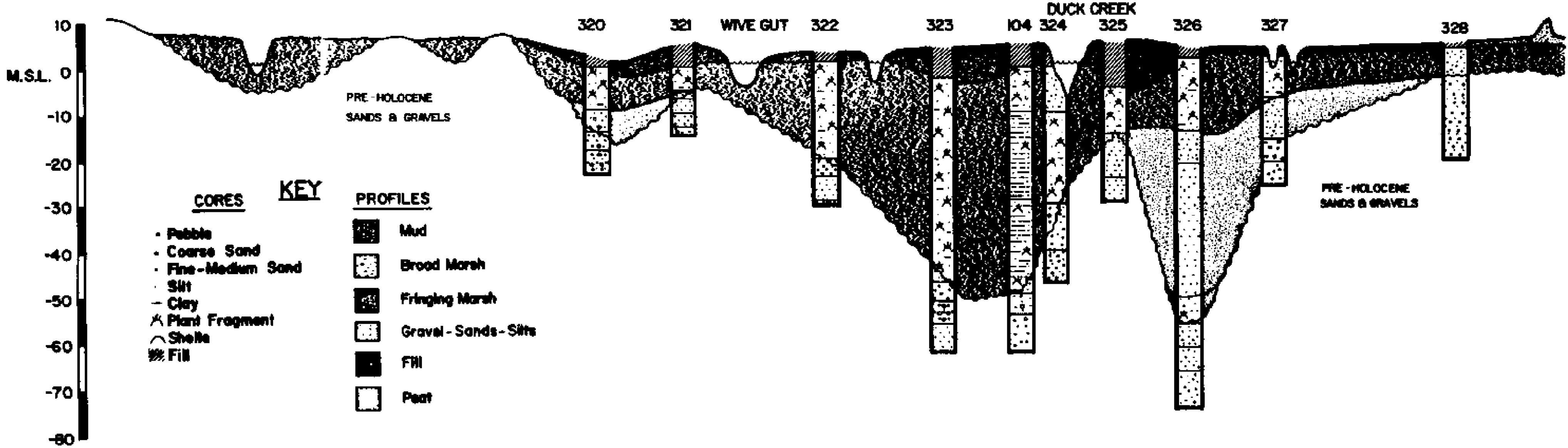


Appendix A-2 Cross-sectional Profile across Drawyers Creek (at Du Pont Hgwy.)
Vertical Exaggeration = 50x



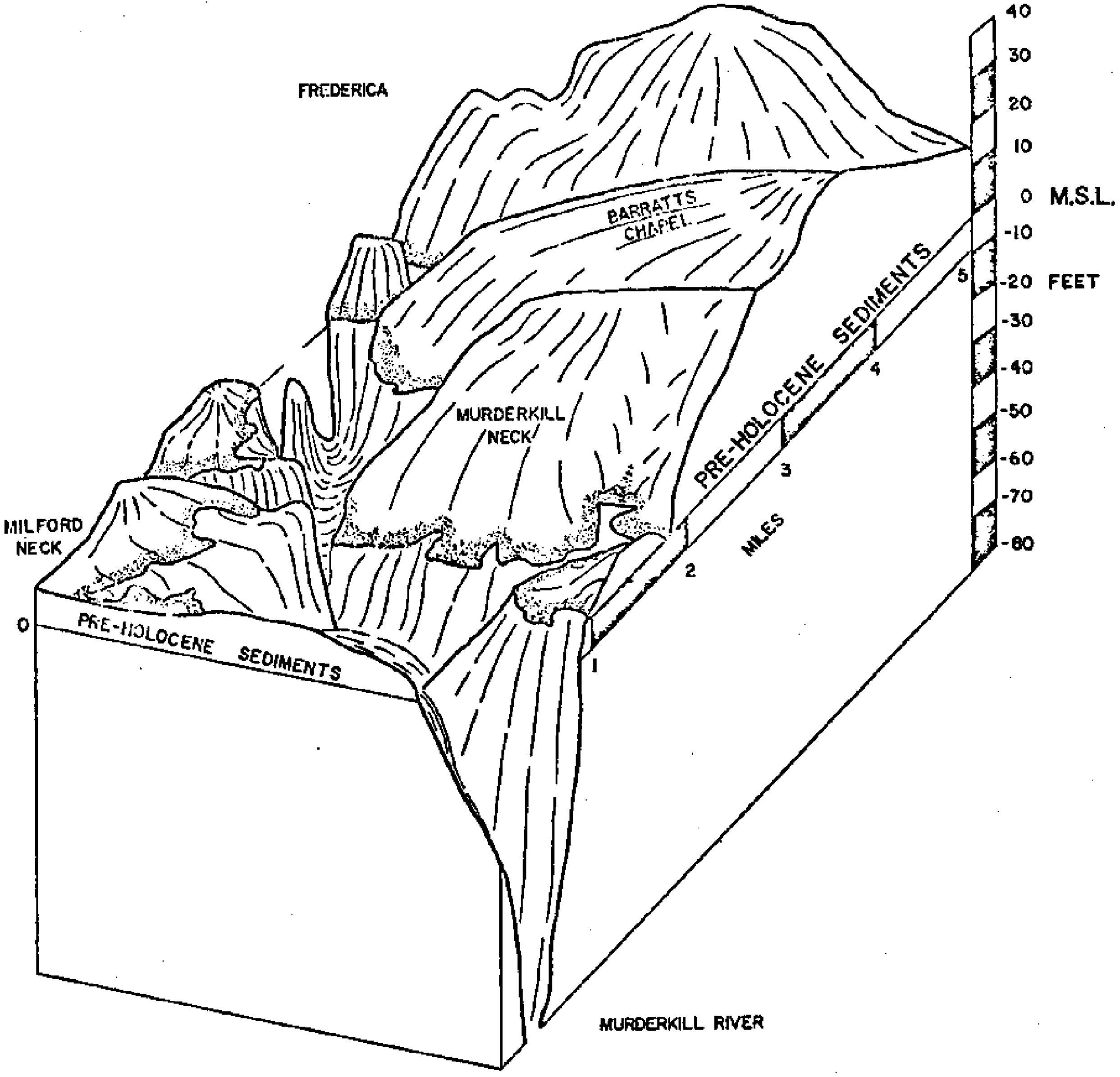
Appendix A-3 Cross-sectional Profile across Appoquinimink River
(at Route 9)
Vertical Exaggeration = 50x



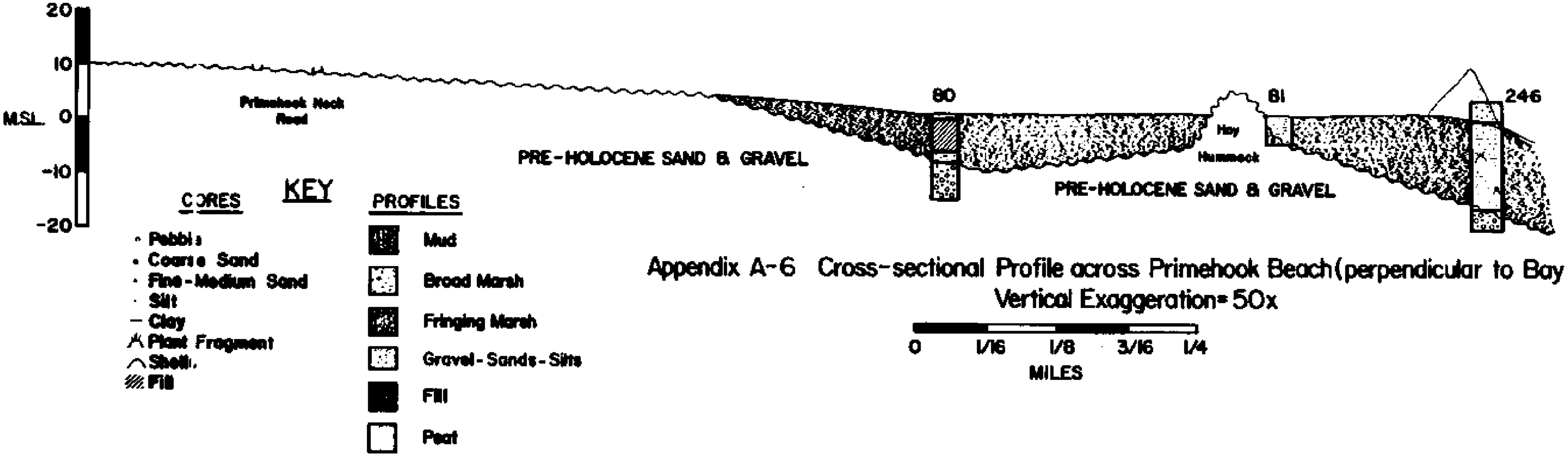


Appendix A-4 Cross-sectional Profile across Woodland Beach Wildlife Area (along Rte. 6)

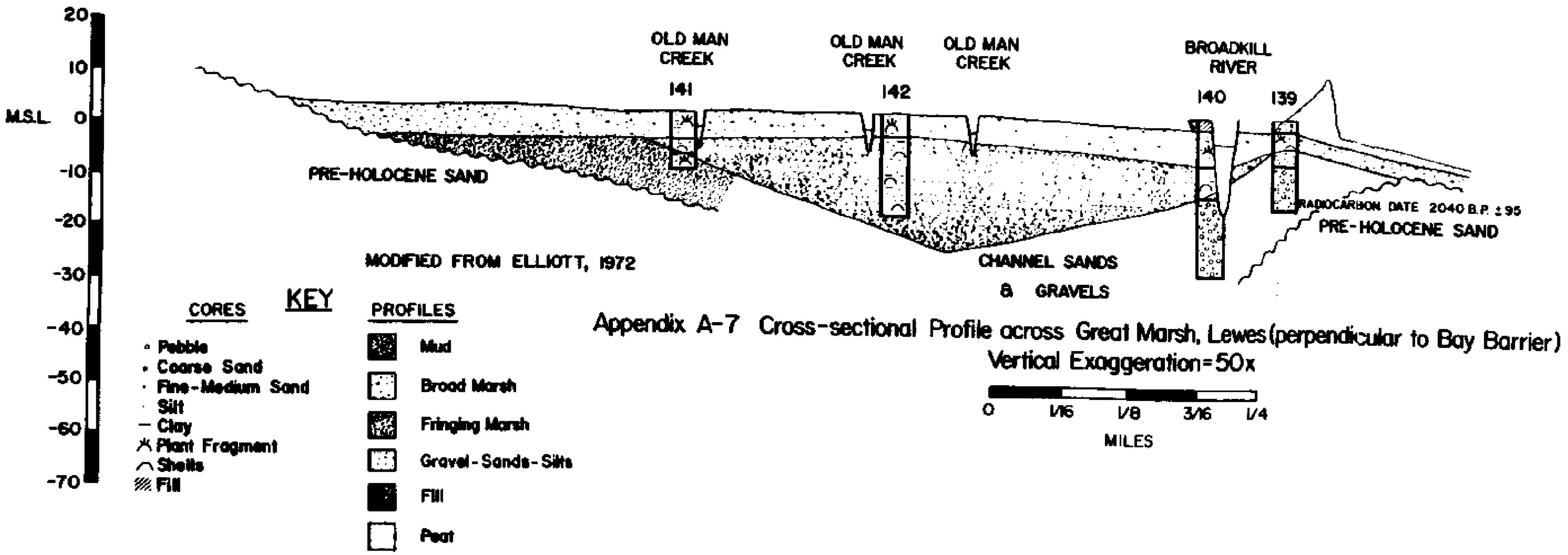
Vertical Exaggeration = 50x



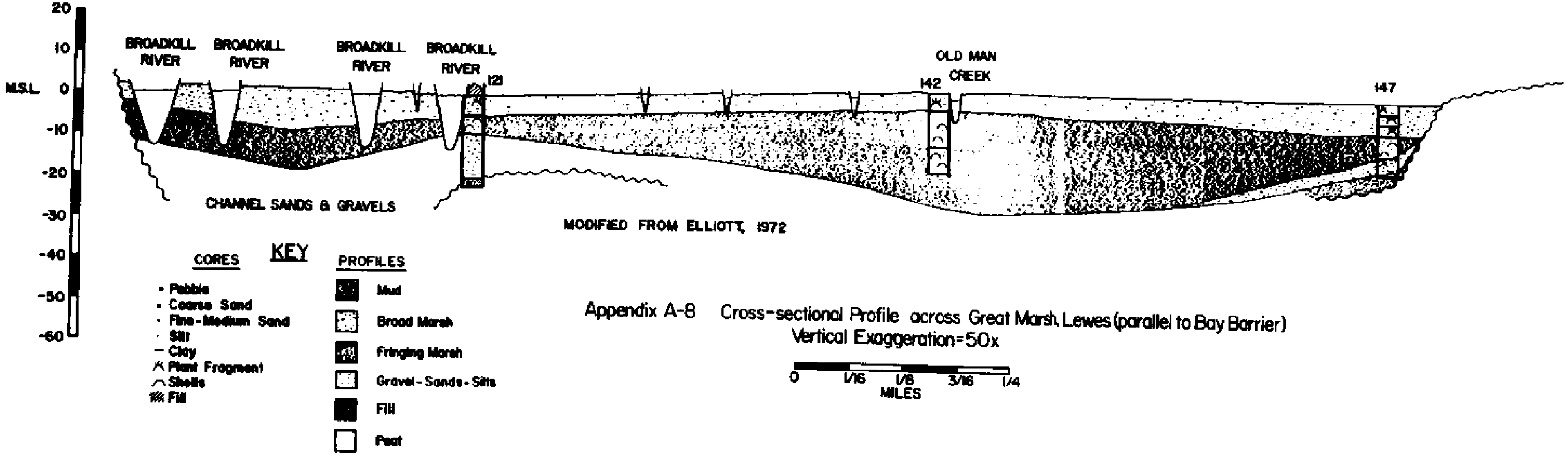
APPENDIX A-5 OBLIQUE VIEW OF MURDERKILL RIVER VALLEY SHOWING MARSH AND PRE-HOLCENE SURFACES (VERTICAL EXAGGERATION = 150X)



Appendix A-6 Cross-sectional Profile across Primehook Beach (perpendicular to Bay Barrier)
Vertical Exaggeration = 50x



Appendix A-7 Cross-sectional Profile across Great Marsh, Lewes (perpendicular to Bay Barrier)
Vertical Exaggeration=50x



MODIFIED FROM ELLIOTT, 1972

Appendix A-8 Cross-sectional Profile across Great Marsh, Lewes (parallel to Bay Barrier)
Vertical Exaggeration=50x

APPENDIX B

Holocene Mud Isopach Maps
(enclosed in envelope)

APPENDIX C

Drillhole Data

Appendix C contains all drillhole records of holes drilled for the study (nos. 1-85) and summary information for the remaining drillholes (nos. 101-345). Drillhole records 101-120, 123-124, 127-132, 136 and 154-156 were obtained from John C. Kraft, Department of Geology, University of Delaware; nos. 121-122, 125-126, 133-135, and 137-153 were obtained from Elliott (1972); nos. 201-249 were acquired from the files of the Delaware Geological Survey, and nos. 301-345 were acquired from the Delaware State Highway Department.

The format used to describe the drillhole data is detailed below.

Study No.	Original No.	Map No.	Latitude & Longitude	Elevation Above MSL (Feet)	Thickness of Holocene Coarse- and Fine-Grained Sediments (Feet)	Thickness of Holocene Fine-Grained Sediments (Feet)
2	2	2	39°32'26"N 75°34'48"W	m.l.*	13	12.5

LOG

Depth Below Surface (Feet)	Lithologic Description
0 - 9	Organic mud
9 - 9.5	Gravel
9.5-13	Organic mud
13	Hard, sandy surface end of hole

*Note: m.l. is the abbreviation for marsh level.

1	1	2	39°32'50"N 75°34'51"W	m.l.	8	6
0 - 2				Loose sand (fill)		
2 - 8				Organic mud		
8 -10				Sand		
10				Hard, sandy surface	end of hole	
2	2	2	39°32'26"N 75°34'48"W	m.l.	13	12.5
0 - 9				Organic mud		
9 - 9.5				Gravel		
9.5-13				Organic mud		
13				Hard, sandy surface	end of hole	
3	3	3	39°28'38"N 75°36'11"W		4	4
0 - 1				Loose sand (fill)		
1 - 5				Organic mud		
5				Hard, sandy surface	end of hole	
4	4	3	39°26'56"N 75°36'16"W	m.l.	42	35
0 - 5				Organic mud		
5 -16				Organic mud and dense peat		
16 -26				Organic mud with thin interlayers of peat		
26 -28				Peat		
28 -29				Sandy peat		
29 -34				Sand		

34 -35			Peat			
35 -42			Sand and gravel with interlayers of mud			
42 -45			Sand and gravel end of hole			
5	5	3	39°26'56"N 75°36'29"W	m.l.	26	23
0 -10			Organic mud			
10 -16			Peat			
16 -18			Sandy peat			
18 -19			Sand			
19 -23			Mud and peat interlayered			
23 -25			Sand			
25 -26			Mud			
26 -30			Sand end of hole			
6	6	3	39°25'10"N 75°36'29"W	m.l.	39	36
0 -10			Organic mud and peat interlayered			
10 -17			Peat			
17 -26			Dense peat and organic mud interlayered			
26 -28			Sandy peat with thin sand layer at 28 feet			
28 -31			Mud with interlayers of sand			
31 -33			Sand			
33 -35			Mud			
35 -39			Sandy peat			
39			Hard, sandy surface end of hole			

7	7	3	39°25'54"N 75°36'00"W	m.l.	33	26.5
0 -11			Organic mud			
11 -19			Peat with thin interlayers of organic mud			
19 -21			Sandy peat			
21 -23			Sand with a thin gravel layer at 22 feet			
23 -24			Peat			
24 -33			Sand and mud interlayered			
33			Hard, sandy surface		end of hole	
8	8	3	39°25'59"N 75°35'12"W	m.l.	16	15.5
0 -12			Organic mud			
12 -13			Peat			
13 -15			Dense peat			
15 -15.5			Sand			
15.5-16			Sandy peat			
16 -23			Sand with shell fragments			
23			Hard, sandy surface		end of hole	
9	9	3	39°26'20"N 75°34'31"W	m.l.	33	23.5

The mud bank along the tidal creek has a surficial coating of sand.

0 -18			Organic mud with interlayers of peat			
18 -20			Sand			
20 -21			Mud			
21 -28			Sand and mud interlayered			

28 -31			Sand			
31 -32			Muddy sand			
32 -33			Mud			
33 -40			Sand	end of hole		
10	10	3	39°25'23"N 75°34'56"W	m.l.	41	33
0 -10			Organic mud			
10 -20			Peat			
20 -23			Dense peat			
23 -24			Organic mud			
24 -27			Peat			
27 -28			Sand			
28 -31			Mud with a thin peat layer at 29 feet			
31 -33			Sand			
33 -34			Mud			
34 -36			Sand			
36 -39			Muddy sand			
39 -41			Mud			
41 -42			Sand			
42			Hard, gravelly surface		end of hole	
11	11	3	39°25'19"N 75°33'32"W	m.l.	27	23
0 -15			Organic mud			
15 -21			Dense peat			
21 -25			Sand			

25 -27							Sandy peat	
27 -29							Sand	
29							Hard, sandy surface	end of hole
12	12	3	39°25'37"N 75°34'06"W	m.l.	34	34		
0 -14							Organic mud	
14 -34							Dense peat, very dense 31-33 feet	
34							Hard, gravelly, sandy surface	end of hole
13	13	3	39°23'34"N 75°33'13"W	m.l.	51	51		
0 - 8							Organic mud	
8 -11							Peat	
11 -14							Organic mud and peat interlayered	
14 -21							Organic mud	
21 -27							Organic mud and peat interlayered	
27 -40							Peat	
40 -43							Dense peat	
43 -47							Organic mud	
47 -50							Peat	
50 -51							Dense peat	
51							Hard, sandy surface	end of hole

14	14	3	39°23'32"N 75°32'37"W	m.l.	57	54
0 - 5.5				Organic mud		
5.5-9				Peat		
9 -22				Organic mud and peat interlayered		
22 -34				Dense peat		
34 -51				Organic mud and peat interlayered		
51 -52				Gravel		
52 -54				Sand and gravel		
54 -57				Mud and peat interlayered		
57				Hard, gravelly, sandy surface end of hole		
15	15	3	39°23'24"N 75°31'55"W	m.l.	13+	13+
0 - 2.5				Organic mud		
2.5-7				Sand and gravel interlayered, sand sample from depth of 4 feet is tan-colored and well-sorted		
7 - 8				Compact gravel		
8 -13				Sand and gravel with thin interlayers of mud end of hole		
16	16	4	39°21'56"N 75°34'39"W	m.l.	23	20.5
0 -13				Organic mud		
13 -15				Pebbly sand		
15 -18				Mud		
18 -18.5				Sandy gravel		
18.5-23				Mud		
23 -24				Compact sand end of hole		

17	17	4	39°21'03"N 75°32'54"W	m.l.	12	12
0 - 1			Loose, gravelly sand (fill)			
1 -12			Organic mud			
12 -13			Loose, muddy sand and gravel			
13			Hard, sandy and gravelly surface end of hole			
18	18	4	39°21'15"N 75°31'49"W	m.l.	21	21
0 - 6			Organic mud			
6 -16			Organic mud and peat			
16 -21			Dense peat			
21			Hard, sandy surface end of hole			
19	19	4	39°21'34"N 75°31'04"W	m.l.	18	18
0 - 9			Organic mud			
9 -10			Peat			
10 -16			Organic mud			
16 -18			Dense peat			
18			Hard, sandy surface end of hole			
20	20	4	39°19'40"N 75°30'57"W		4	4
0 - 1			Loose, gravelly sand (fill)			
1 - 5			Organic mud			
5 - 7			Loose sand and gravel			
7			Hard, gravelly, sandy surface end of hole			

21	21	4	39°20'08"N 75°30'57"W	m.l.	20	20
0 -12			Organic mud			
12 -18			Peat (hit a wooden log at 16 feet in an adjacent hole)			
18 -20			Gray mud			
20			Compact sand end of hole			
22	22	4	39°20'29"N 75°30'16"W	m.l.	24	24
0 -24			Organic mud			
24			Compact sand end of hole			
23	23	4	39°20'33"N 75°29'57"W	m.l.	29	29
0 -29			Organic mud			
29			Compact, gravelly sand end of hole			
24	24	4	39°18'12"N 75°28'48"W	m.l.	37	37
0 -37			Organic mud and peat interlayered			
37			Compact gravel end of hole			
25	25	4	39°18'27"N 75°27'53"W	m.l.	37	37
0 -35			Organic mud and peat interlayered			
35 -37			Gray, clayey silt			
37 -38			Gravelly sand			
38			Hard, gravelly, sandy surface end of hole			

26	26	4	39°17'42"N 75°28'34"W	m.l.	28	28
0 -21			Organic mud			
21 -22			Peat			
22 -28			Mud			
28 -30			Gravelly sand			
30			Hard, gravelly, sandy surface end of hole			
27	27	4	39°17'27"N 75°28'10"W	m.l.	39	37.5
0 -36			Organic mud			
36 -37.5			Gravelly sand			
37.5-39			Peat			
39			Hard, gravelly, sandy surface end of hole			
28	28	4	39°16'16"N 75°27'23"W	m.l.	27	27
0 -15			Organic mud			
15 -16			Peat			
16 -23			Organic mud			
23 -27			Peat			
27 -32			Fine to medium sand			
32 -35			Sand and gravel interlayered			
35			Hard, gravelly surface		end of hole	

29	29	4	39°16'31"N 75°26'38"W	m.l.	37	37
0 -12				Organic mud		
12 -13				Peat		
13 -23				Organic mud		
23 -25				Peat		
25 -37				Mud		
37 -40				Fine to medium sand and gravel interlayered end of hole		
30	30	4	39°16'50"N 75°26'04"W	m.l.	40	38
0 -14				Organic mud		
14 -15				Peat		
15 -21				Organic mud		
21 -22				Peat		
22 -28				Organic mud		
28 -29				Peat		
29 -37				Organic mud		
37 -38				Peat		
38 -40				Muddy sand?		
40				Hard, gravelly surface end of hole		
31	31	4	39°15'35"N 75°25'44"W	m.l.	39	39
0 -17				Organic mud		
17 -28				Light gray mud		
28 -32				Peat		

32 -36				Organic gray mud		
36 -39				Peat		
39				Compact fine to medium sand	end of hole	
32	32	4	39°15'51"N 75°24'40"W	m.l.	42	42
0 -19				Organic mud		
19 -24				Peat		
24 -27				Organic mud		
27 -29				Peat		
29 -37				Organic mud		
37 -38				Peat		
38 -40				Organic mud		
40 -42				Sandy peat		
42				Compact, fine sand	end of hole	
33	33	5	39°14'18"N 75°31'20"W	m.l.	33	32
0 -28				Organic mud		
28 -29				Muddy sand and gravel		
29 -33				Mud		
33				Very hard, sandy and gravelly surface end of hole		
34	34	5	39°14'57"N 75°28'08"W	m.l.	16	11

The bank along the river has cobble sized material outcropping in places. A layer of pebbles and grayish green to light orange, muddy sand covers the mud bank along the river.

0 - 2				Organic mud				
2 - 4				Sandy mud				
4 -13				Peat with thin interlayers of sand				
13 -15				Sand and gravel				
15 -16				Mud				
16 -21				Gravelly sand				end of hole
35	35	5	39°14'14"N 75°28'03"W		m.l.	9	9	
0 - 9				Organic mud				
9 -10				Sand				
10				Hard, gravelly surface				end of hole
36	36	5	39°14'32"N 75°26'54"W		m.l.	75	64	
0 -10				Organic mud				
10 -12				Peat				
12 -15				Organic mud				
15 -16				Peat				
16 -20				Organic mud				
20 -21				Peat				
21 -23				Sandy peat?				
23 -31				Peat				
31 -33				Sandy peat				
33 -34				Sand				
34 -35				Mud				
35 -43				Peat				

43 -45			Dense peat			
45 -50			Peat			
50 -57			Muddy sand with interlayers of mud and peat			
57 -62			Peat			
62 -66			Gravelly, muddy sand			
66 -68			Mud with interlayers of peat			
68 -70			Sand			
70 -71			Peat			
71 -73			Mud			
73 -75			Peat			
75 -78			Sand and gravel			
78 -79			Sand end of hole			
37	37	5	39°14'36"N 75°25'41"W	m.l.	46+	46+
0 -17			Organic mud			
17 -20			Peat			
20 -24			Organic mud			
24 -33			Peat			
33 -35			Dense peat			
35 -38			Peat			
38 -40			Sandy peat			
40 -42			Dense peat			
42 -46			Peat end of hole			

38	38	5	39°14'45"N 75°24'35"W	m.l.	35	35
0 -17			Organic mud			
17 -22			Peat			
22 -31			Dense peat			
31 -32			Sandy peat			
32 -35			Dense peat			
35 -36			Sand			
36			Compact gravel		end of hole	
39	39	5	39°13'24"N 75°26'48"W	m.l.	20	20
0 -13			Organic mud			
13 -17			Peat			
17 -20			Dense peat (hit wooden log at 18 feet in an adjacent hole)			
20 -21			Compact sand		end of hole	
40	40	5	39°12'16"N 75°26'32"W	m.l.	35	34
0 -14			Organic mud			
14 -15			Peat			
15 -21			Mud			
21 -22			Sand			
22 -25			Peat			
25 -33			Mud			
33 -34			Dense peat			
34 -35			Sandy peat			

35 -36				Sand		
36				Compact gravel end of hole		
41	41	5	39°12'48"N 75°25'36"W	m.l.	31	30
0 -18				Organic mud		
18 -20				Peat		
20 -27				Mud		
27 -28				Gravel		
28 -31				Light gray mud		
31 -34				Sand end of hole		
42	42	5	39°13'27"N 75°24'28"W	m.l.	52	52
0 -27				Organic mud		
27 -28				Peat		
28 -33				Organic mud		
33 -35				Dense peat		
35 -37				Organic mud		
37 -38				Sandy peat		
38 -40				Stiff, dense, muddy peat		
40 -42				Organic mud and peat interlayered		
42 -43				Stiff, dense, muddy peat		
43 -50				Organic mud and peat interlayered		
50 -52				Sandy peat		
52 -53				Sand and gravel interlayered		
53				Compact, coarse sand and gravel end of hole		

43	43	5	39°11'57"N 75°25'29"W	m.l.	23	23
0 -15				Organic mud		
15 -16				Peat		
16 -23				Mud		
23 -26				Sand and interlayers of gravel		
26				Hard, gravelly surface	end of hole	
44	44	5	39°12'32"N 75°24'34"W	m.l.	27	27
0 -17				Organic mud		
17 -18				Peat		
18 -20				Organic mud		
20 -21				Peat		
21 -25				Organic mud		
25 -27				Sandy peat		
27 -30				Sand	end of hole	
45	45	5	39°11'43"N 75°24'20"W	m.l.	31	24.5
0 -17				Organic mud		
17 -20				Peat		
20 -22				Sandy peat		
22 -26				Muddy sand		
26 -31				Sand and mud interlayered		
31 -35				Sand	end of hole	

46	46	5	39°10'17"N 75°25'25"W	m.l.	12	12
0 - 7			Organic mud			
7 -12			Muddy peat			
12			Compact sand and gravel		end of hole	
47	47	5	39°09'34"N 75°25'29"W	m.l.	14	14
0 - 2			Sandy organic mud (the sand is derived from an adjacent spoil bank)			
2 -14			Peat			
14			Hard, gravelly, sandy surface end of hole			
48	48	5	39°09'32"N 75°24'40"W	m.l.	17	17
0 -12			Peat			
12 -17			Dense peat			
17			Very hard, gravelly surface end of hole			
49	49	5	39°08'11"N 75°24'49"W	m.l.	8	8
0 - 8			Organic mud			
8			Compact sand	end of hole		
50	50	6	39°05'31"N 75°27'22"W	m.l.	12	11
0 - 6			Organic mud			
6 - 6.5			Gravel			
6.5-8.5			Mud			

8.5-9				Gravel			
9 -12				Mud			
12 -19				Sand	end of hole		
51	51	6	39°05'07"N 75°27'28"W		m.l.	9	9
0 - 9				Organic mud			
9				Compact sand	end of hole		
52	52	6	39°05'07"N 75°26'35"W		m.l.	48	48
0 -47				Organic mud			
47 -48				Peat			
48				Sand	end of hole		
53	53	6	39°04'53"N 75°26'37"W		m.l.	63	63
0 -28				Organic mud			
28 -63				Peat			
63				Sand	end of hole		
54	54	6	39°04'31"N 75°25'25"W		m.l.	51	51
0 -24				Organic mud			
24 -51				Peat			
51				Sand	end of hole		
55	55	6	39°04'16"N 75°25'35"W		m.l.	63	63
0 -58				Mud			

58 -63				Peat			
63				Sand	end of hole		
56	56	6	39°03'55"N 75°25'34"W		m.l.	20	20
0 -20				Organic mud			
20				Hard, sandy surface	end of hole		
57	57	6	39°00'57"N 75°28'11"W		m.l.	24	24
0 -24				Organic mud			
24				Gravel	end of gravel		
58	58	6	39°00'32"N 75°27'04"W		m.l.	27	27
0 -12				Organic mud			
12 -27				Light gray mud			
27				Gravel	end of hole		
59	59	6	39°01'05"N 75°26'29"W		m.l.	54	54
0 -54				Mud			
54				Gravel	end of hole		
60	60	6	39°00'52"N 75°26'12"W		m.l.	36	36
0 -36				Mud			
36				Sand and gravel	end of hole		
61	61	6	39°00'47"N 75°26'04"W		m.l.	14	14
0 -14				Muddy peat			

14				Sand	end of hole	
62	62	6	39°01'26"N 75°25'14"W	m.l.	60+	60+
0 -60				Organic mud	end of hole	
63	63	6	39°01'17"N 75°25'11"W	m.l.	24	24
0 -24				Organic mud		
24				Sand	end of hole	
64	64	6	39°02'13"N 75°24'42"W	m.l.	27	27
0 -27				Organic mud		
27				Sand	end of hole	
65	65	6	39°02'05"N 75°24'28"W	m.l.	21	21
0 -21				Gray clay and silt		
21 -36				Gray, silty sand	end of hole	
66	66	6	39°02'46"N 75°24'08"W	m.l.	60	60
0 -60				Organic mud		
60				Sand	end of hole	
67	67	6	39°01'41"N 75°21'36"W	m.l.	5	5
0 - 5				Organic mud		
5				Compact, gravelly sand	end of hole	

68	68	7	38°57'40"N 75°22'39"W	m.l.	32	24
0 -10			Organic mud			
10 -11			Peat			
11 -12			Organic mud			
12 -13			Peat			
13 -16			Mud			
16 -18			Sand			
18 -19			Peaty sand			
19 -20			Sand and gravel interlayered			
20 -32			Thin interlayers of sand, mud and peat			
32 -33			Gravel			
33 -36			Sand end of hole			
69	69	7	38°57'40"N 75°21'30"W	m.l.	48	33
0 -11			Organic mud			
11 -13			Dense peat			
13 -15			Organic mud			
15 -17			Peat			
17 -18			Sandy peat			
18 -48			Sand and mud, sandy mud and muddy sand interlayered			
48 -50			Sand end of hole			
70	70	7	38°57'05"N 75°20'31"W	m.l.	50	37.5
0 -25			Light gray organic mud			

25 -26			Peat			
26 -27			Mud			
27 -29			Sandy mud			
29 -32			Mud			
32 -34			Muddy sand			
34 -38			Mud			
38 -39			Muddy sand			
39 -40			Mud			
40 -45			Muddy sand			
45 -45.5			Peat			
45.5-50			Muddy sand and sand interlayered			
50			Compact gravel end of hole			
71	71	7	38°57'05"N 75°19'26"W	m.l.	42	31
0 - 9			Organic mud			
9 -12			Gravel			
12 -15			Mud			
15 -18			Gravel			
18 -20			Peat			
20 -25			Mud and muddy peat interlayered			
25 -28			Sand and gravel			
28 -36			Mud and peat interalyered			
36 -38			Gravelly sand			
38 -40			Mud and peat interlayered			
40 -42			Mud			

42 -45			Gravel			
45 -51			Coarse sand end of hole			
72	72	7	38°52'41"N 75°21'32"W	m.l.	19	19
0 -.5			Organic mud			
.5 - 2			Loose sand (fill)			
2 - 8			Muddy peat			
8 -19			Mud			
19			Very hard, gravelly surface end of hole			
73	73	7	38°54'03"N 75°20'29"W	m.l.	35	30
0 -27			Organic mud			
27 -28			Sandy peat			
28 -35			Sand with thin interlayers of mud			
35 -38			Gravelly sand			
38 -40			Sand end of hole			
74	74	7	38°54'33"N 75°18'26"W	m.l.	3	3
0 - 3			Organic mud			
3 - 5			Sand end of hole			
75	75	7	38°54'56"N 75°19'12"W	m.l.	32	28.5
0 -10			Organic mud			
10 -11			Peat			
11 -13			Mud			

13 -14			Gravel			
14 -18			Peat			
18 -18.5			Gravel			
18.5-22			Mud			
22 -26			Sandy peat			
26 -26.5			Gravel			
26.5-28			Sand			
28 -30			Mud			
30 -32			Sandy peat			
32 -38			Sand with layer of gravel at 33 feet end of hole			
76	76	7	38°54'57"N 75°19'48"W	m.l.	45	30
0 -12			Organic mud			
12 -13			Peat			
13 -19			Organic mud			
19 -21			Sandy peat?			
21 -22			Peat			
22 -24			Sandy peat			
24 -25			Mud			
25 -28			Sand			
28 -32			Mud and sand interlayered			
32 -35			Sand			
35 -43			Muddy sand			
43 -45			Mud			
45			Compact sand and gravel end of hole			

77	77	7	38°55'42"N 75°19'31"W	m.l.	26	26
0 -16				Organic mud		
16 -25				Peat		
25 -26				Sandy peat		
26 -27				Sand		
27				Compact sand and gravel		end of hole
78	78	7	38°56'28"N 75°19'14"W	m.l.	17	15.5
0 -12				Organic mud		
12 -13				Sand		
13 -14				Peat		
14 -15				Organic mud		
15 -16				Peat		
16 -16.5				Gravel		
16.5-17				Dense peat		
17 -23				Sand and gravel interlayered		
23				Hard, gravelly surface		end of hole
79	79	7	38°52'48"N 75°16'19"W	m.l.	5	5
0 - 4				Organic mud		
4 - 5				Sandy mud		
5				Oxidized, compact, muddy sand end of hole		
80	80	8	38°51'13"N 75°15'37"W	m.l.	9	9
0 -.5				Organic mud		

.5 - 7			Loose sand (fill)			
7 - 9			Mud			
9 -16			Gravel and gravelly sand interlayered end of hole			
81	81	8	38°51'18"N 75°14'59"W	m.l.	5	5
0 - 5			Organic mud			
5 - 5.5			Clean, compact sand and pea sized gravel end of hole			
82	82	8	38°50'16"N 75°14'45"W	m.l.	36	36
0 - 1			Freshwater peat			
1 - 7			Organic mud			
7 -12			Peat			
12 -16			Organic mud			
16 -17			Peat			
17 -18			Organic mud			
18 -26			Peat and organic mud interlayered			
26 -36			Dense peat			
36			Hard, gravelly surface end of hole			
83	83	8	38°50'23"N 75°14'09"W	m.l.	37	37
0 - 1			Freshwater organic mud			
1 - 6			Organic mud			
6 - 7			Peat			
7 -13			Organic mud			

13 -14				Peat		
14 -21				Organic mud		
21 -24				Peat		
24 -26				Organic mud		
26 -35				Peat and organic mud interlayered		
35 -37				Sandy mud		
37 -39				Sand		
39 -40				Sand and gravel		
40				Hard, gravelly surface	end of hole	
84	84	8	38°49'12"N 75°13'48"W	m.l.	22	22
0 - 7				Clean, fine to medium sand with shell fragments (fill)		
7 -22				Mud		
22				Compact, gravelly sand	end of hole	
85	85	8	38°49'32"N 75°12'53"W	m.l.	16	11
0 - 6				Organic mud		
6 -16				Sand and mud interlayered		
16 -16.5				Compact gravel		
16.5				Compact sand	end of hole	

101	JCK DH 4-72	1	39°42'02"N 75°31'31"W	2.5	27	27
102	JCK DH 1-72	2	39°33'33"N 75°33'53"W	4.5	29	29
103	JCK DH 3-72	3	39°29'43"N 75°35'20"W	3	50	50
104	JCK DH 2-72	4	39°19'11"N 75°29'01"W	4	52	52
105	JCK DH 8-71	5	39°10'41"N 75°24'25"W		23	23
106	JCK DH 7-71	6	39°06'30"N 75°24'15"W	5	13	13
107	JCK DH 2-71	6	39°03'20"N 75°23'40"W	4	76	76
108	JCK DH 3-71	6	39°03'20"N 75°23'40"W	4	86	86
109	JCK DH 1-69	6	39°03'07"N 75°23'25"W		24.5	21
110	DH 5-69	6	39°03'03"N 75°23'28"W		22.5	20
111	DH 6-69	6	39°02'52"N 75°23'32"W	m.l.	11	5
112	JCK 1-68	6	39°02'55"N 75°23'18"W	m.l.	10+	9+
113	JCK 2-68	6	39°02'52"N 75°23'20"W	m.l.	9+	5+

114	JCK 3-68	6	39°02'52"N 75°23'21"W	m.l.	4.5+	3.5+
115	Core 11-69	6	39°02'52"N 75°23'13"W	m.l.	10	8
116	JCK DH 9-71	6	39°01'57"N 75°21'27"W	4	9	9
117	JCK DH 5-69	6	39°00'02"N 75°19'43"W		8	8
118	DH-11-71	7	38°55'15"N 75°18'39"W	7	55	50
119	JCK DH 1-71	7	38°52'52"N 75°16'09"W	6	7	7
120	JCK DH 10-71	8	38°49'17"N 75°13'08"W		7	7
121	GKE DH 5-69	8	38°48'07"N 75°12'13"W	3	23	12
122	GKE DH 1-69	8	38°48'25"N 75°11'32"W	7	78	68
123	Core JCK 11-69	8	38°47'47"N 75°10'29"W	m.l.	9+	7+
124	JCK DH 5-68	8	38°47'43"N 75°10'29"W	2	35	12
125	GKE DH 2-69	8	38°47'33"N 75°10'17"W	-1	21.5	11
126	GKE DH 3-69	8	38°47'31"N 75°10'11"W	-1	22	0

127	DH 10-69	8	38°47'23"N 75°10'06"W	6	22.5	22.5
128	DH 11-69	8	38°47'21"N 75°09'54"W	5	13	3
129	DH 12-69	8	38°47'17"N 75°10'06"W	10	10	6
130	DH 13-69	8	38°47'28"N 75°10'05"W	6	33	33
131	GCR-1 DH-70	8	38°47'21"N 75°09'29"W	7	21	12.5
132	GCR-2 DH-70	8	38°47'16"N 75°09'30"W	7	15	9.5
133	GKE DH 4-69	8	38°46'14"N 75°09'43"W	3	18	15.5
134	C	8	38°47'14"N 75°09'42"W	5	3	3
135	A"	8	38°48'37"N 75°11'41"W	7	49	0
136	JCK DH 3-73	3	39°27'04"N 75°39'17"W	3.5	54	54
137	I	8	38°47'26"N 75°10'01"W	7	6	6
138	O"	8	38°48'08"N 75°13'10"W	m.l.	14	14
139	U"	8	38°47'58"N 75°10'50"W	2	14	4

140	S'	8	38°47'54"N 75°10'57"W	3	30	15
141	V'	8	38°47'15"N 75°11'36"W	m.l.	11+	11+
142	Q'	8	38°47'30"N 75°11'21"W	m.l.	19.5+	19.5+
143	K	8	38°47'08"N 75°10'08"W	m.l.	6	6
144	L	8	38°47'08"N 75°10'06"W	m.l.	10	10
145	M	8	38°47'06"N 75°10'05"W	m.l.	7	7
146	O	8	38°46'54"N 75°10'27"W	m.l.	10	10
147	P	8	38°46'53"N 75°10'29"W	m.l.	17.5+	17.5+
148	Y	8	38°46'33"N 75°10'32"W	m.l.	6	5
149	X	8	38°46'36"N 75°10'30"W	m.l.	17.5+	17.5+
150	W	8	38°46'42"N 75°10'25"W	m.l.	12.5	12.5
151	V	8	38°46'44"N 75°10'22"W	m.l.	7	7
152	E	8	38°47'18"N 75°09'57"W	m.l.	8.5	8.5

153	N	8	38°47'05"N 75°10'05"W	m.l.	8	8
154	JCK 72 Appoquinimink River	3	38°26'38"N 75°39'50"W		13.5	13.5
155	JCK 72 Noxontown Dam	3	38°26'06"N 75°40'56"W		25	25
156	JCK DH 2-73				13.5	13.5

201	Army C.E. 145 C&D Canal	2	39°33'26"N 75°35'39"W	m.l.	14	9.5
202	Cc34-26	1	39°42'33"N 75°36'25"W	3.6	21	21
203	Cc34-27	1	39°42'35"N 75°36'27"W	3.7	25.5	25.5
204	Cc34-28	1	39°42'38"N 75°36'29"W	-0.6	16.5	16.5
205	Cd43-2	1	39°41'23"N 75°32'13"W	m.l.	6	6
206	Cd43-7	1	39°41'23"N 75°32'09"W	4.2	31	31
207	Cd43-8	1	39°41'22"N 75°32'05"W	6.3	39.5	39.5
208	Dd12-3	1	39°39'53"N 75°33'47"W	m.l.	4	4
209	Dc25-18	1	39°38'22"N 75°35'54"W	10	3	3
210	Dc24-7	1	39°38'08"N 75°36'10"W	9.5	3	3
211	Dc34-2	2	39°37'28"N 75°36'19"W	m.l.	13	13
212	Dc42-5	2	39°36'20"N 75°38'13"W		12	11.5

213	Dc53-14	2	39°35'28"N 75°36'59"W	m.l.	14	14
214	Dc53-15	2	39°35'24"N 75°37'07"W	m.l.	1	1
215	Dc53-16	2	39°35'20"N 75°37'00"W	m.l.	17	17
216	Dc54-1	2	39°35'19"N 75°36'53"W	m.l.	28.5	23
217	Dc54-4	2	39°35'11"N 75°36'42"W	m.l.	27	27
218	Dc53-21	2	39°35'07"N 75°37'00"W	3	15.5	15.5
219	Ec14-6	2	39°35'00"N 75°36'50"W	4	14.5	14.5
220	Dc54-5	2	39°35'06"N 75°36'23"W	3	7.5	7.5
221	Dc54-3	2	39°35'18"N 75°36'16"W	m.l.	7	7
222	Dc54-2	2	39°35'14"N 75°36'11"W	m.l.	21	20
223	Ec15-4	2	39°34'53"N 75°35'58"W	m.l.	7.5	7.5
224	Ec15-14	2	39°34'55"N 75°35'54"W	m.l.	8.5	8.5
225	Ec15-20	2	39°34'55"N 75°35'51"W	m.l.	7+	6+

226	Army Creek test hole 9	1	39°39'14" 75°36'22"	.5	28	28
227	Ec15-17	2	39°34'56"N 75°35'33"W	0	25	25
228	Army C.E. 152 C&D Canal	2	39°33'42"N 75°34'00"W	m.l.	42	37
229	Ec12-8	2	39°34'15"N 75°38'22"W	m.l.	4	4
230	Ec12-6	2	39°34'01"N 75°38'22"W	3.8	17	17
231	Ec12-4	2	39°34'01"N 75°38'22"W	m.l.	28	28
232	Ec23-11	2	39°33'17"N 75°37'50"W		25	12.5
233	Ed21-4	2	39°33'24"N 75°34'55"W	10	7+	5.5+
234	Ed51-3	2	39°30'49"N 75°34'39"W	10	51	45
235	He32-1	4	39°17'06"N 75°28'22"W	m.l.	25	25
236	He45-1	4	39°16'26"N 75°25'26"W	m.l.	44	44
237	If11-1	5	39°14'20"N 75°24'48"W	m.l.	65	47.5

238	Ie21-1	5	39°13'21"N 75°29'35"W	10	27	19.5
239	If21-1	5	39°13'02"N 75°24'15"W	m.l.	53	53
240	If42-1	5	39°11'19"N 75°23'54"W	m.l.	20	20
241	If41-1	5	39°11'08"N 75°24'02"W	m.l.	35	35
242	Jd35-2	5	39°07'51"N 75°30'03"W	10	1	1
243	Kf21-1	6	39°03'52"N 75°23'59"W		16	0
244	Lg42-1	7	38°56'48"N 75°18'57"W	2	38	38
245	Lg42-1	7	38°56'07"N 75°19'12"W		12.5	12.5
246	Mh41-1	8	38°51'19"N 75°14'35"W		17	12
247	Mh52-1	8	38°50'08"N 75°13'24"W		12	9
248	Nh35-1	8	38°47'30"N 75°10'03"W	7	19	1
249	Army C.E. 135 C&D Canal	2	39°33'23"N 75°34'00"W	m.l.	30.5	30.5

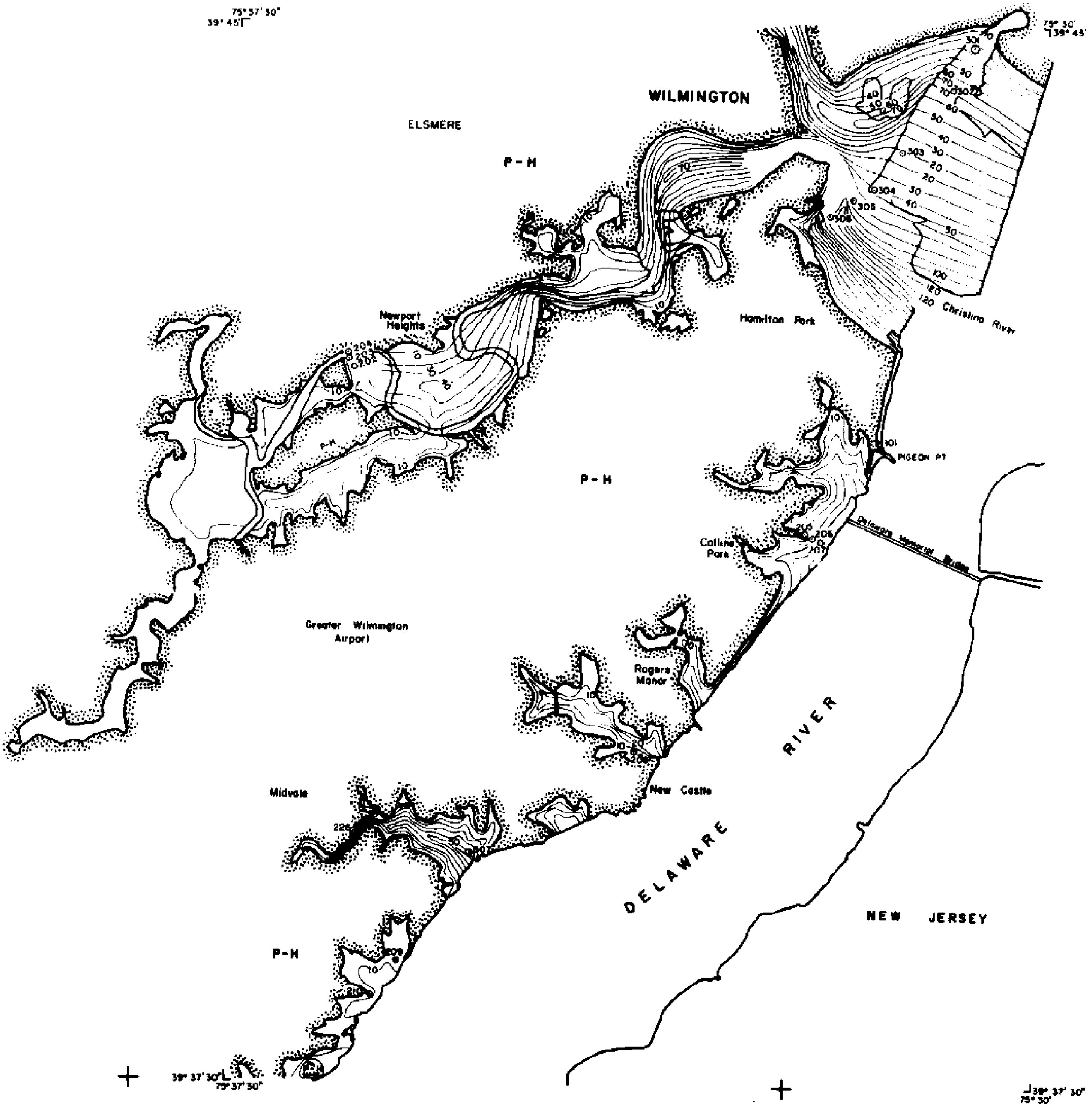
301	Cherry Island B-60	1	39°44'52"N 75°30'43"W	0	26	26
302	Cherry Island B-49	1	39°44'35"N 75°30'54"W	0	71	71
303	Cherry Island B-41	1	39°44'08"N 75°31'21"W	7	20	20
304	Cherry Island B-28	1	39°43'51"N 75°31'37"W	13	31	31
305	Cherry Island B-16	1	39°43'45"N 75°31'50"W	8	64	64
306	Christiana River W-8	1	39°43'40"N 75°32'02"W	0	103	103
307	Route 9 south of Deemers Beach 6	1	39°39'07"N 75°35'29"W	2.4	60	60
308	Route 13 at Drawyer Creek B-10	3	39°28'22"N 75°39'02"W	0	61	61
309	Route 13 at Drawyer Creek B-9	3	39°28'18"N 75°39'04"W	3	61	61
310	Route 13 Drawyer at Creek B-3	3	39°28'13"N 75°39'04"W	5	50	50

311	Fenimore Bridge DB-6	3	39°27'57"N 75°36'48"W	11.6	21.5	21.5
312	Port Mahon Road B-5	5	39°10'46"N 75°24'19"W		25	25
313	Fenimore Bridge DB-4	3	39°27'56"N 75°36'52"W	10.9	18	18
314	Fenimore Bridge DB-3	3	39°27'51"N 75°37'00"W	5.8	83	83
315	Fenimore Bridge DB-2	3	39°27'49"N 75°37'02"W	7.2	94	89
316	Fenimore Bridge DB-1	3	39°27'47"N 75°37'04"W	5.8	93	83.5
317	Taylor's Bridge 8	3	39°24'20"N 75°35'55"W	3.9	55	55
318	Taylor's Bridge 7	3	39°24'19"N 75°35'59"W	7.8	81	81
319	Taylor's Bridge 5	3	39°24'16"N 75°35'64"W	3.7	51	51
320	Woodland Beach Causeway 2	4	39°18'43"N 75°29'48"W	5.5	14	12.5
321	Woodland Beach Causeway 4	4	39°18'50"N 75°29'38"W	5.8	6	6

322	Woodland Beach Causeway 8	4	39°18'59"N 75°29'22"W	4.2	21	21
323	Woodland Beach Causeway 11	4	39°19'07"N 75°29'10"W	4.9	48	48
324	Woodland Beach Causeway 16	4	39°19'13"N 75°28'57"W	5.8	31	27.5
325	Woodland Beach Causeway 18	4	39°19'18"N 75°28'51"W	6.4	15.5	15.5
326	Woodland Beach Causeway 21	4	39°19'23"N 75°28'43"W	4.9	58	32
327	Woodland Beach Causeway 23	4	39°19'31"N 75°28'32"W	5.6	18	9
328	Woodland Beach Causeway 25	4	39°19'45"N 75°28'23"W	6.0	7	7
329	Route 10 at St. Jones River B-16	6	39°06'53"N 75°29'56"W	m.l.	29	29
330	Route 10 at St. Jones River B-28	6	39°06'56"N 75°29'42"W	m.l.	24	22
331	Route 10 at St. Jones River B-35	6	39°06'49"N 75°29'31"W	6.4	38.5	38.5

332	Route 13 at Murderkill River BB-7	6	39°00'42"N 75°27'27"W	m.l.	36.5	36.5
333	Route 13 at Murderkill River BB-1	6	39°00'40"N 75°27'26"W	m.l.	50	48.5
334	Route 13 at Murderkill River BB-15	6	39°00'36"N 75°27'25"W	m.l.	30	30
335	Route 13 at Murderkill River BB-10	6	39°00'34"N 75°27'24"W	m.l.	32	32
336	Route 14 at Swan Creek 8	7	38°56'18"N 75°24'17"W	m.l.	11.5	11.5
337	Mispillion Light B-1	7	38°56'31"N 75°19'10"W		19	18
338	Route 14 at Broadkill River B-5	8	38°47'27"N 75°15'03"W	m.l.	10	10
339	Route 14 at Broadkill River B-10	8	38°47'28"N 75°15'04"W	0	20	20
340	Route 14 at Broadkill River B-20	8	38°47'30"N 75°15'08"W	m.l.	30	30
341	Route 14 at Broadkill River B-24	8	38°47'33"N 75°15'11"W	m.l.	31	31

342	Route 14 at Broadkill River B-28	8	38°47'35"N 75°15'16"W	m.l.	30	30
343	Port Mahon Road B-5	6	39°11'08"N 75°24'02"W		28	28
344	Port Mahon Road B-3	6	39°10'53"N 75°24'12"W		30	30
345	Port Mahon Road B-2	6	39°10'50"N 75°24'15"W		30	30



APPENDIX B-1 HOLOCENE MUD ISOPACH MAP OF THE WILMINGTON AREA, DELAWARE

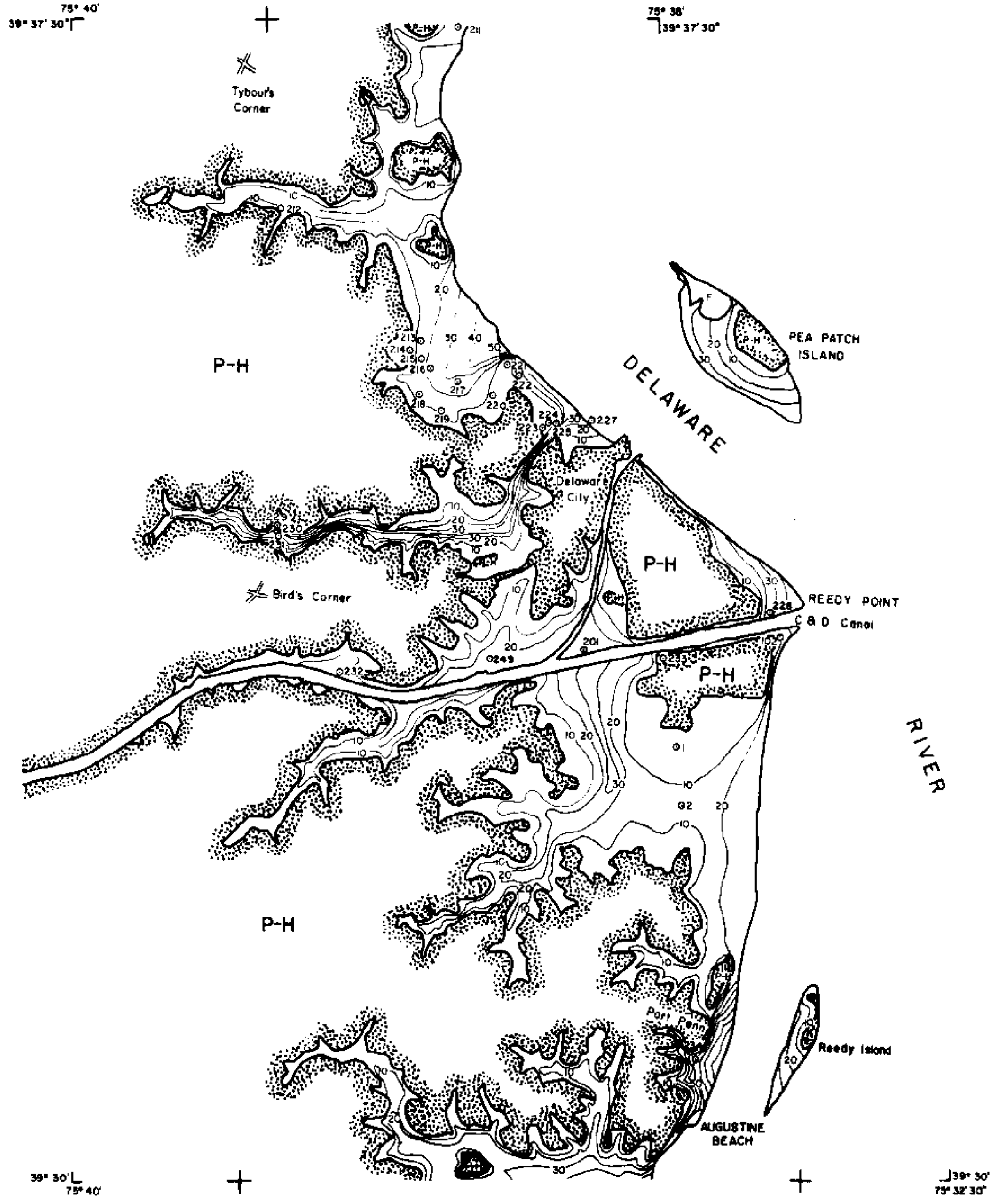
Contour Interval = 10 feet
Base Level is Marsh Surface

N

Base from U S G S Hydrologic Investigations Atlases HA-79 and HA-64 of the Wilmington (1964) and Newark (1963) Areas, Delaware

0 1/2 1
MILES

P-H = Pre-Holocene



Appendix B-2 Holocene Mud Isopach Map of the St. Georges Area, Delaware

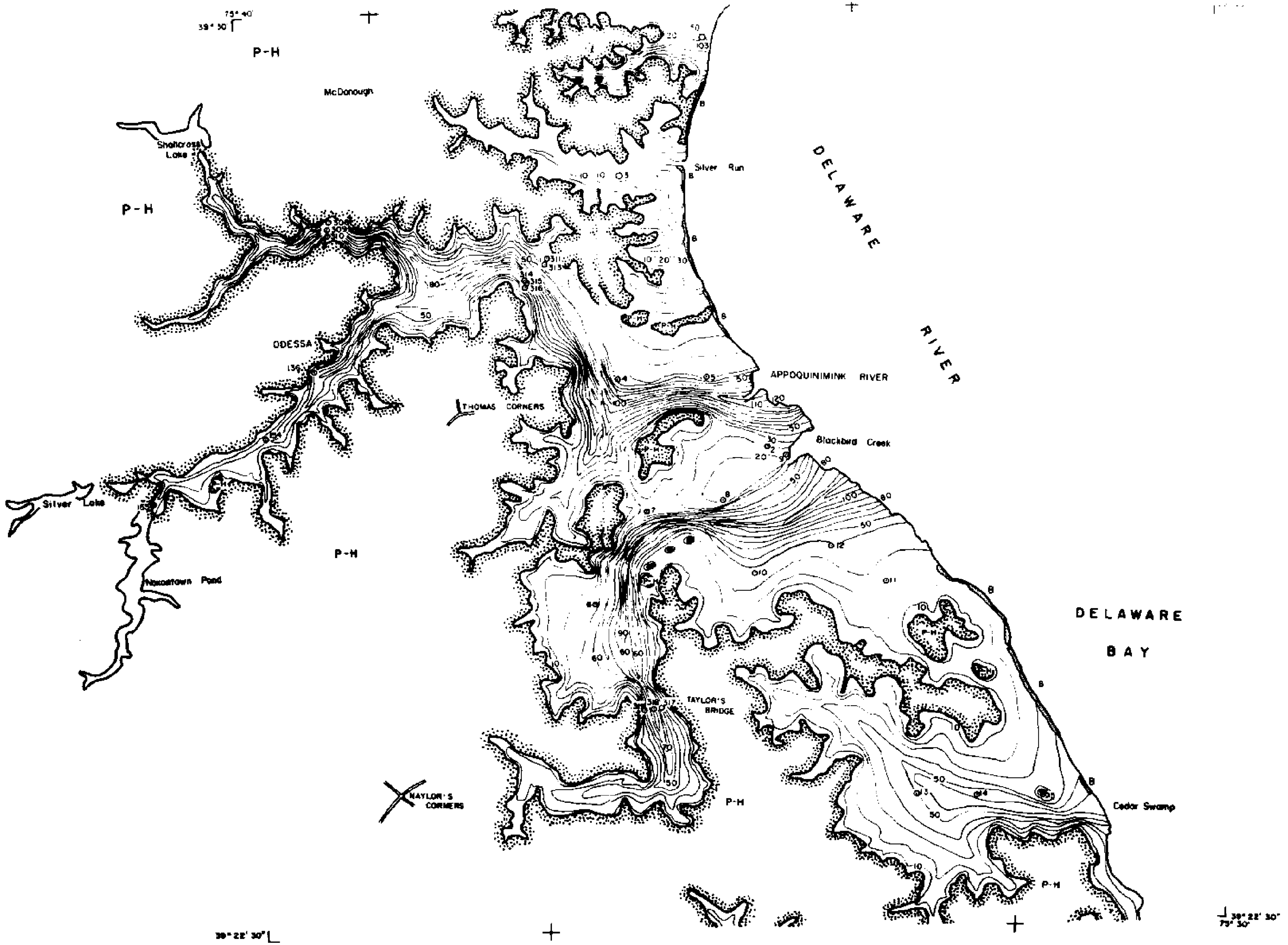
Base from U.S.G.S. Hydrologic Investigations Atlas HA-60 of the St. Georges Area, Delaware, 1963

N

Contour Interval = 10'
Base Level is Marsh Surface

0 1/2 1
Miles

SYMBOLS
P-H = Pre Holocene
F = Fill



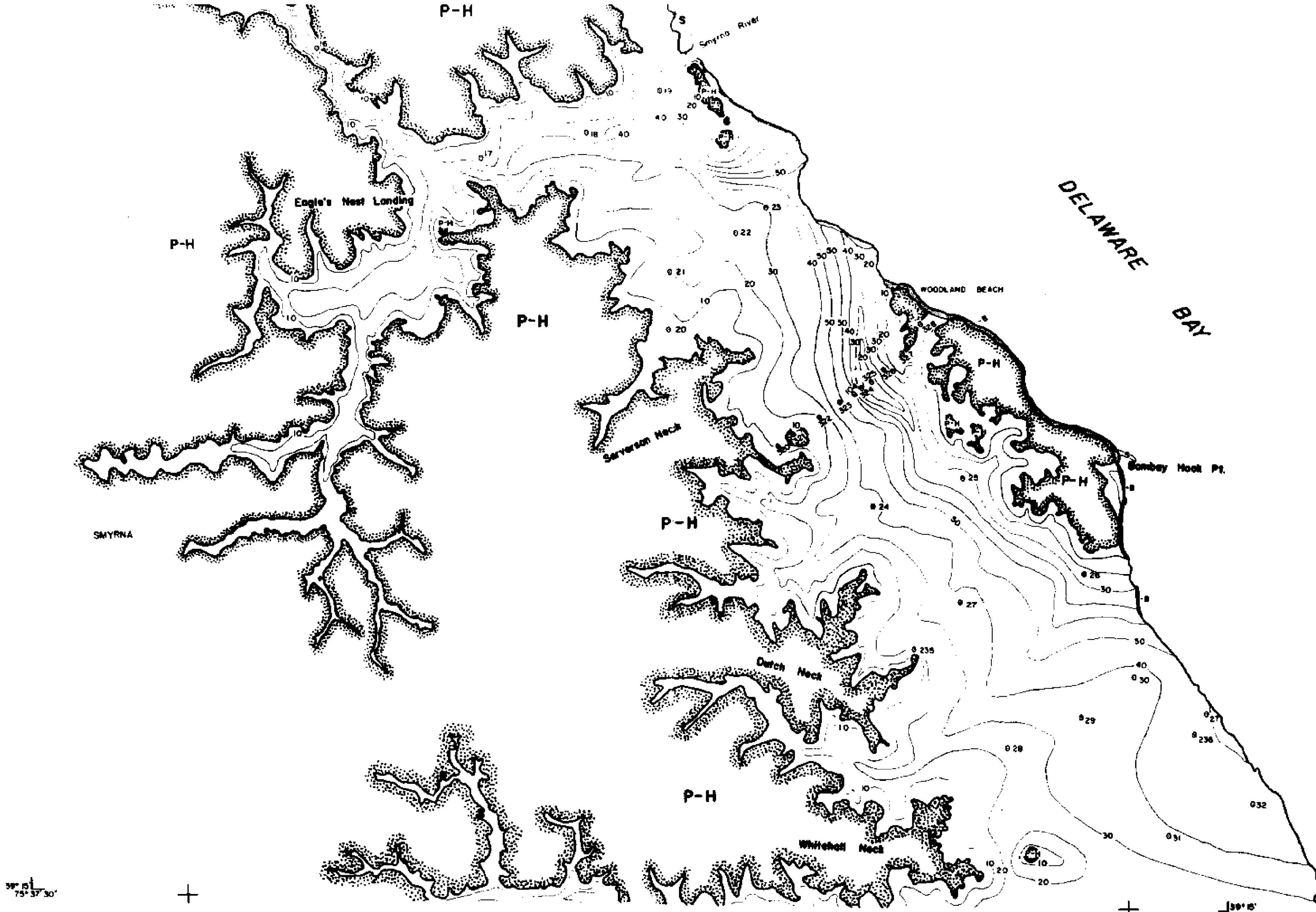
Appendix B-3 Holocene Mud Isopach Map of the Taylor's Bridge Area, Delaware

Contour interval = 10'

Base Level is Marsh Surface

Base from U S G S Hydrologic Investigations Atlases HA-80 and HA-82 of the Taylor's Bridge (1964) and Middletown (1964) Areas, Delaware

SYMBOLS
P-H = Pre-Holocene
B = Beach ▨



Appendix B-4 Holocene Mud Isopach Map of the Smyrna Area, Delaware

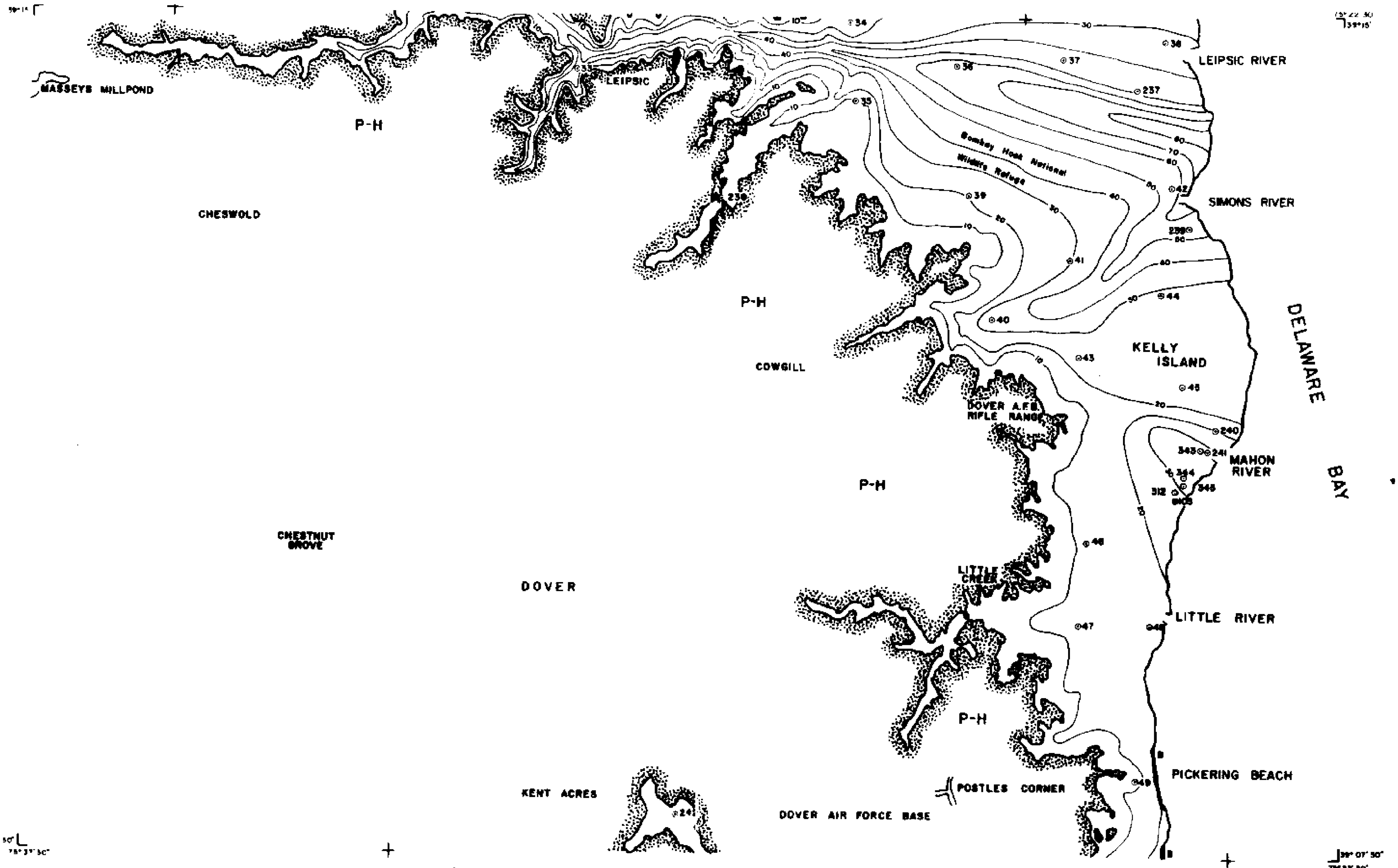
Contour interval is 10 feet
Base level is Marsh Surface

N

0 1/2 1

Symbols
P-H = Pre-Holocene
B = Beach
S = Sand

Base from USGS Hydrologic
Investigations Atlas HA - 81
of the Smyrna Area, Dela., 1964



Appendix B-5 Holocene Mud Isopach Map of the Dover and Little Creek Quadrangles

Base from U S G S Hydrologic
Investigations Atlases HA-134
and HA-139 of the Little Creek (1965)
and Dover (1964) Quadrangles

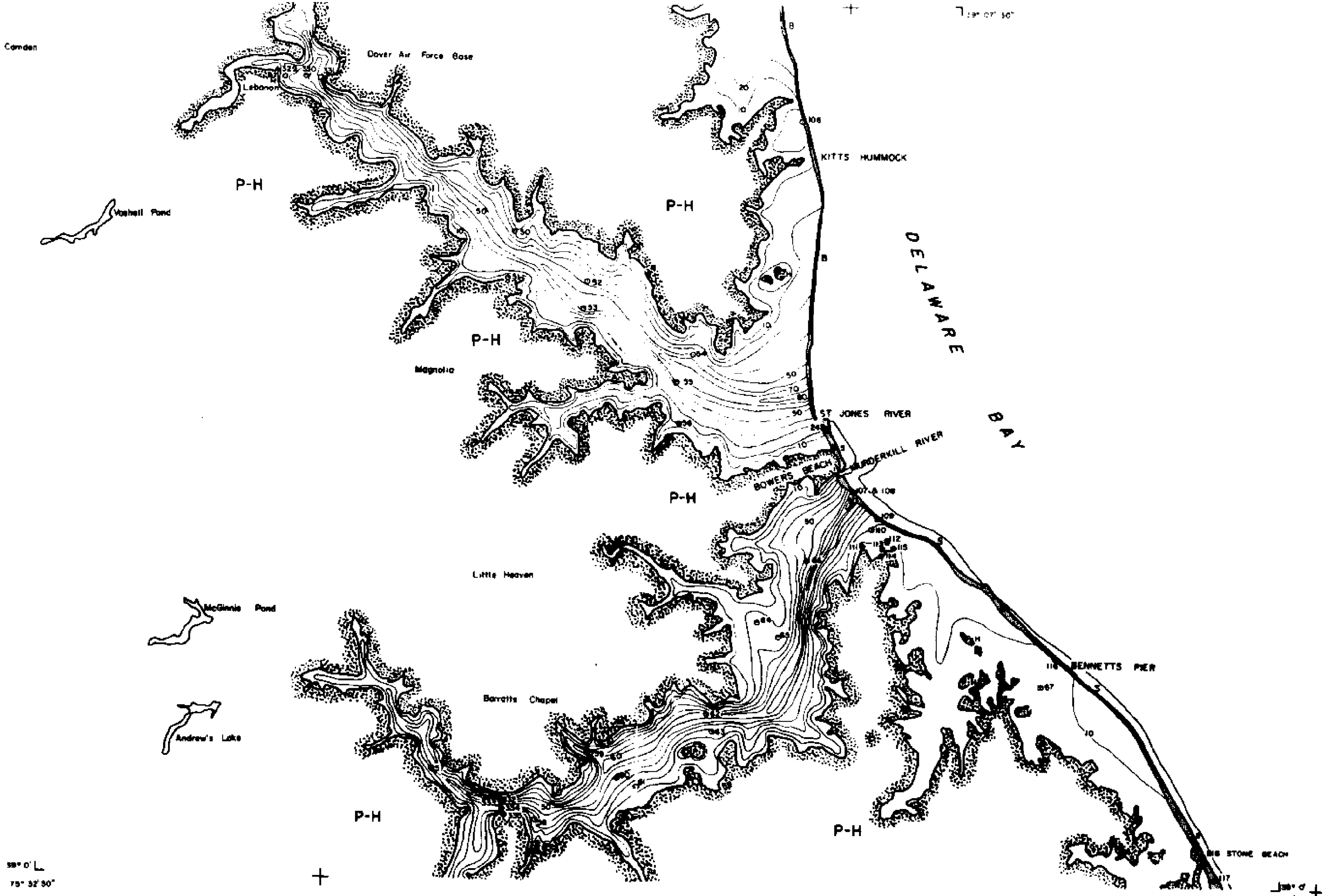
N

CONTOUR INTERVAL IS 10 FEET
BASE LEVEL IS MARSH SURFACE

0 1/2 1

SYMBOLS

P-H = Pre Holocene
B = Beach ☐



Appendix B-6 Holocene Mud Isopach Map of the Fredrica Area, Delaware

Base from USGS Hydrologic
Investigations Atlases HA-140 & HA-141
of the Fredrica Area (1965) and
the Wyoming Quadrangle (1965), Delaware

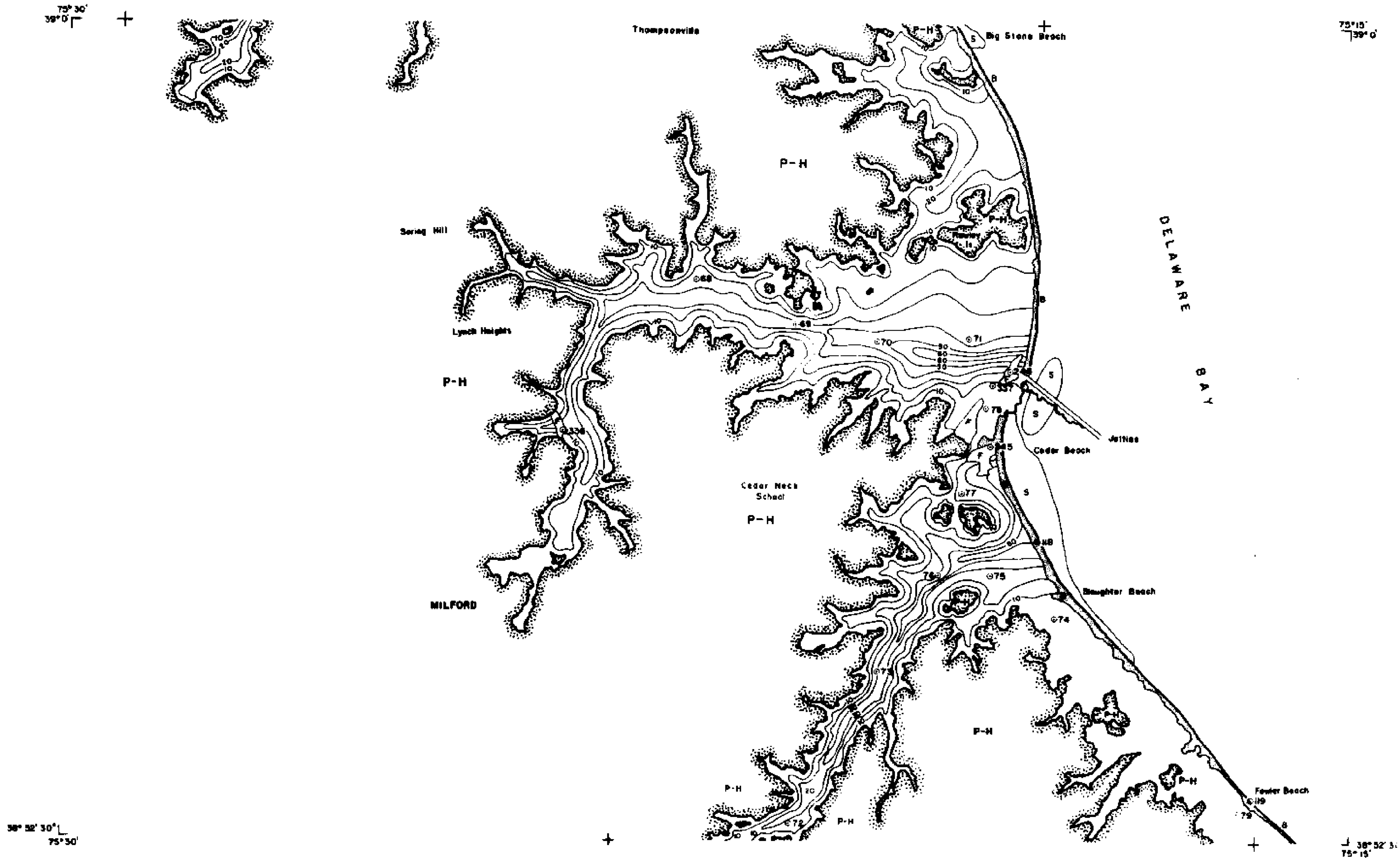
N

CONTOUR INTERVAL IS 10 FEET

0 1/2 1
MILES

BASE LEVEL IS MARSH SURFACE

SYMBOLS
P-H = Pre-Holocene
B = Beach ▨
S = Sand



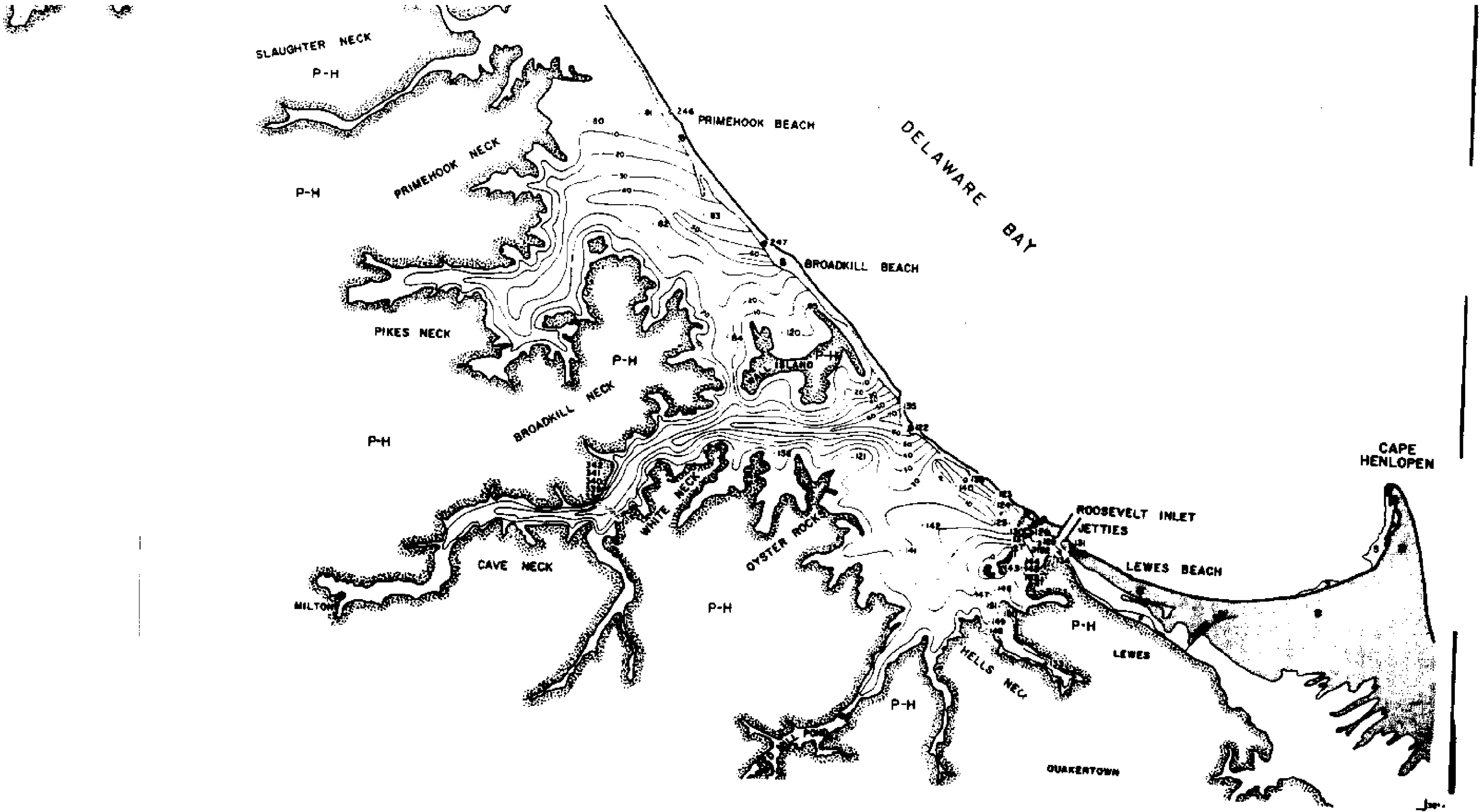
Appendix B-7 Holocene Mud Isopach Map of the Mispillion River Area, Delaware

Base from U.S.G.S. Hydrologic Investigations Atlases HA-137 and HA-133

N

Contour Interval is 10 feet
Base Level is Marsh Surface

Symbols
P-H = Pre-Holocene
B = Beach ☐



Appendix B-8 Holocene Mud Isopach Map of the Lewes Area, Delaware

Base from U.S.G.S. Hydrologic Investigations Atlases HA-103, HA-102, and HA-101 of the Lewes Area (1964), Milton Quadrangle (1964), and Ellendale Quadrangle (1964), Delaware