ENVIRONMENTAL SETTING

The general environmental setting of the project area and vicinity is described in this section, which is divided into two major parts. The first examines changes in the environmental characteristics of the Middle Atlantic coastal region since the beginning of the last Ice Age. It includes a description of the effects of sea level rise and sediment deposition during the post-glacial Holocene geological period.

The second part discusses the project area's submerged terrain. Particular attention is directed to the possible preservation of former subaerial surfaces beneath the bottoms of Smyrna River, Mill Creek, and Leipsic River. Included also is a discussion on interpreting data from geotechnical borings to identify terrain features that were inundated by rising sea level and subsequently buried by sedimentation.

The following discussion is concerned primarily with general processes. Specific discussions concerning the existing subbottom sediment stratigraphy and former subaerial soil horizons of the three bridge crossings are provided later in this report. Those subjects are addressed in each of the sections covering Smyrna River, Mill Creek, and Leipsic River.

Environmental and Physiographic Evolution

Important to understanding the natural environment's evolution to present day conditions are the topics of climatic and ecological changes, glaciation, sea level rise, erosion, and sedimentation. The effects of these processes since about 10,000 B.C. have a direct relationship to prehistoric archeology since the initial human occupation of the region began around that time. It is also worthwhile, however, to consider relevant environmental changes prior to human settlement. Those changes created the setting into which the region's first human inhabitants entered.

Several detailed reconstructions of the Middle Atlantic region's paleoecology and environmental evolution have been published (e.g. Peabody Museum 1979; Edwards and Merrill 1977; Newman and Salwen 1977). Informative discussions of Delaware's environmental evolution over the course of the prehistoric period have also been provided (e.g. Custer 1983, 1984).

Around 40,000 years ago the climate of the Middle Atlantic region approximated the temperate conditions of the present day though it may have been somewhat warmer and drier (Willey 1966). The floral and faunal communities of the region at that time were adapted to an environmental regime that was considerably more temperate than the conditions that characterized the area during the subsequent Ice Age. Sea level in the project area around 40,000 years ago was about the same level as it is currently (Kraft and Thomas 1981).

The dominant fauna in the region at that time was mammalian. However, it

does not appear that the American continents were then inhabited by humans. The limited and controversial evidence for human occupation of the Americas prior to about 12,000 years ago is not convincing (Dillehay and others 1992; Hoffecker and others 1993).

The Earth began to cool markedly subsequent to about 40,000 years ago. The cooling trend continued for about 22,000 years. This situation initiated the last Ice Age, known as the Wisconsin Stage of the Pleistocene Epoch. The resulting cooler worldwide climates caused much of the water falling as precipitation to freeze into snow rather than fall as rain. Since the cooler climatic regime inhibited melting, the accumulated snow led to the formation of great continental glaciers and oceanic ice fields. The glaciers advanced and eventually covered vast portions of the continents' middle latitudes.

There was also an effect on the level of the sea. From 40,000 to 22,000 years ago, sea level gradually fell to an elevation approximately 300 feet lower than it is at present (Pielou 1991). This regression was caused by the evaporation from the oceans of great volumes of water that were not replaced since they remained frozen as ice. At its minimal elevation, sea level was so low that the eastern coastline of the Middle Atlantic region lay near the edge of what is now the submerged plain of the continental shelf, far to the east of its present location.

In the vicinity of Delaware the seacoast was about 75 miles east of its present location. The eastern coastal region of ancient North America formed a vast plain, much of it probably covered by grasslands. It was an environment well suited to Pleistocene fauna, especially herd animals. Evidence of their presence has been found in the form of mammoth, mastodon, and horse remains brought up from presently submerged locations on the continental shelf (Emery 1969).

The lower sea level was a worldwide phenomenon. One of its consequences was the emergence of the sea floor between northeastern Asia and the northwestern tip of North America in the locale now known as the Bering Straits. A vast plain called "the Bering Land Bridge" in archeological literature formed a wide link between the two continents (Hopkins 1967).

It is generally believed that the first humans to inhabit the Americas migrated from Asia across the Bering Land Bridge. They were nomadic or semi-nomadic hunters and gatherers who moved westward into what is now Alaska in search of game. Of northeastern Asian origin, these migrants were the ancestors of American Indians. Over the subsequent millennia their descendants spread throughout North and South America. In the process they encountered new environmental situations and developed cultural adaptations to promote their survival.

Delaware Bay did not exist during much of the period of lower sea level associated with the Wisconsin Ice Age. In its place was a portion of the ancient

Atlantic Coastal Plain across which the ancestral Delaware River flowed towards the sea.

The ancestral Delaware River followed a channel that ran southeastward along the axis of Delaware Bay. Riverine erosional forces eventually cut its elevation down to approximately 100 feet below the present floor of the Bay. At its lowest elevation the width of the ancestral river channel was much narrower than the tidal Delaware River of today. The velocity of its downstream flow was substantially faster and it was not influenced by tides.

During the Wisconsin Ice Age the bridge crossing project areas in Smyrna River, Mill Creek, and Leipsic River were very different than they are at present. Rather than being tidal waterways, they were small inland streams crossing the surrounding uplands. They ran through erosional valleys cut through the upland terrain and had narrow flood plains with adjoining terraces. While today they are first and second order watercourses, they were then second to fourth order streams carrying limited volumes of water as minor tributaries of the dendritic ancestral Delaware River drainage. The channel sediments of those ancient streams were characterized by the presence of coarse materials and contained mixtures or beds of sands, gravels, and cobbles rather than silty mud.

The ancestral Smyrna River, Mill Creek, and Leipsic River flowed in a generally linear configuration. Erosional down cutting of their channels may have limited their potential for meandering, but there is some evidence that the channel of Smyrna River, at least, meandered between the adjoining uplands (see the report section covering Smyrna River).

This may also have been the case for portions of other waterways in the vicinity. However, data from geotechnical borings indicates that Mill Creek and Leipsic River were confined within stable channels at the locations of the bridge crossings, as discussed later in the sections on those waterways.

The closest present day analogy to the ancestral physiography of the project area is the configuration of the upper portions of non-tidal watercourses in the western part of Kent County. These include the undammed portions of Smyrna River, Mill Creek, and Leipsic River upstream of the project area.

The Wisconsin Ice Age eventually drew to a close as the Earth's climate entered a period characterized by a warming trend. This global warming began around 18,000 to 15,000 years ago and had dramatic worldwide effects. Higher temperatures caused the great glacial ice fields to begin melting and receding. This returned massive amounts of water to the oceans causing sea level to begin rising rapidly.

The general trend of rising sea level that began around 16,000 B.C. has continued to the present day. The rate of sea level rise was most rapid from then to about 3000 B.C. This time span included the last part of the Pleistocene and extended well into the Holocene (Recent) epoch, which began in 8000 B.C. The rate at which sea level rose slowed substantially about 5,000 years ago and has

been most gradual since 1000 B.C.

Changes in sea level elevation relative to adjacent landforms can be due to several possible causes. The geological situation in Delaware indicates that at least two factors probably interacted. One of these was worldwide (eustatic) sea level rise due to glacial melting and thermal expansion. The other was land subsidence due to rebounding of the northern portion of the North American tectonic plate as the weight of the glacial ice cap was alleviated.

As mentioned above, the Delaware River in the vicinity of the project area was not a tidal watercourse during the Wisconsin Ice Age. Until about 12,000 years ago it was a swiftly flowing waterway that drained southeastward to the faraway sea coast. As the level of the sea rose, the ancestral Atlantic coastal plain was gradually inundated causing its shoreline to migrate westward. Vast areas that had been subaerial came to be covered by the sea. The lower Bay portion of the ancestral Delaware River began to be drowned around 10,000 B.C. and as it filled a tidal estuary developed.

The climatic warming characteristic of the early Holocene epoch also caused major ecological changes from a cold weather ecosystem to one better suited to more temperate conditions. The floral and faunal communities of the Middle Atlantic region were both affected. Paleoenvironmental studies of the late glacial episode indicate that during the Wisconsin Ice Age the region was characterized by a mosaic of boreal grassland and temperate climate floral and faunal communities (Custer 1983). In that environment a wide variety of animal and plant species were present, being distributed according to their suitability for the microenvironments of specific locales. The dominant upland flora in the vicinity of the project area included spruce and pine trees, and cold climate grasses. Deciduous plants better suited to temperate conditions were concentrated along the valleys of watercourses.

Ecological change began as the late glacial environmental episode gave way to the pre-Boreal/Boreal climatic transition around 10,000 years ago. A major development during that episode was the rising dominance of pine and spruce forest at the expense of the cold climate grasslands. Vegetation in the region came to be dominated by spruce and pine forest. The mosaic-like pattern of deciduous trees and plants continued where local microenvironmental conditions were conducive for their survival. However, the grassland areas that formerly were extensive tended to be taken over by forest.

As conifer-dominated forest spread over most of the former grassland areas, major shifts in the types, distribution, and population of various animal species took place. Several faunal species became extinct for reasons that have not been clearly determined, but which may be related to the grassland-to-forest floral evolution, inability to adapt to environmental changes, and the effects of human predation by hunting.

The Early Holocene pre-Boreal/Boreal episode was eventually succeeded by

an ecological regime characterized by the dominance of northern hardwoods. This was the Atlantic environmental episode, which lasted from 8,500 to 5,100 years ago. As the Earth's climate continued to warm, more temperate conditions in the Middle Atlantic region led to the development of forests in which the predominant species were oak and hemlock.

Beginning around 5,100 years ago and lasting until around 2,800 years ago the environment of the region was characterized by a marked change in climatic conditions. On a worldwide scale this has been termed the hypsithermal. In eastern North America it is called the Sub-Boreal environmental episode. Climatic conditions became warmer and drier than during the preceding Atlantic episode. The floral species that became dominant during this period were northern hardwoods such as oak and hickory. In addition, pine trees made up a substantial portion of the forests.

The Sub-Atlantic environmental episode began around 2,800 years ago and continues to the present. The dominant climatic trend has been towards somewhat cooler and moister conditions. During the early part of this period the ecology of the region came to be characterized by temperate hardwood forest with oak and chestnut being predominant.

While the surrounding region underwent these dramatic climatic and ecological changes, the inundation of the Delaware River valley's lowland terrain by the rising sea continued. This process was not steady and inexorable, however, because the rate at which the sea rose varied according to how quickly or slowly the glaciers underwent melting. There appear to have been intervals of temporary stability (stillstands) as well as limited regressions caused by intermittent glacial re-advances. The overall trend, nonetheless, was a retreat of glaciation with a corresponding generalized upward rise in sea level and the level of the Delaware River.

Geological studies and mapping of Delaware's coastal plain, Delaware Bay, and the nearby Atlantic coast have provided extensive information on changes in physiography since the close of the Pleistocene. While interpretations useful for relating post-Pleistocene geological processes to archeological problems have been prepared (e.g. Kraft and Thomas 1981, Wise 1985), no original field research focusing on inundated prehistoric cultural deposits has yet been accomplished in the Delaware region.

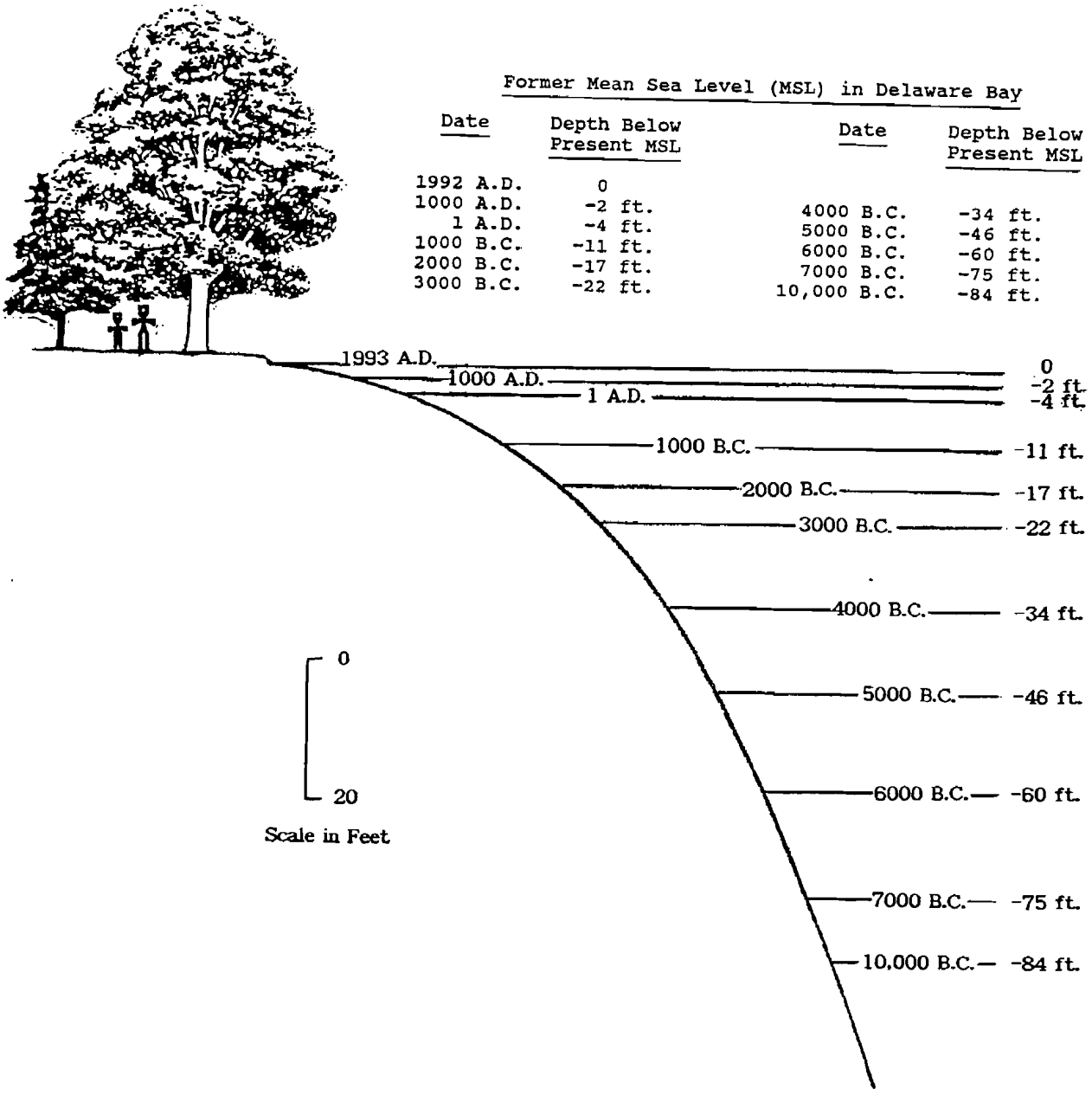
A physiographic evolutionary study of the Cedar Creek and Slaughter Beach vicinity about 30 miles southeast of Smyrna provided information on terrain analogous to the project area (Kayan and Kraft 1980). By about 3000 B.C. at that location, rising sea level resulted in the development of a lagoon-marsh complex along the former valley of Cedar Creek. By analogy, a similar process probably occurred as the ancient stream valleys in the bridge crossing project areas were progressively drowned due to the rising level of Delaware Bay.

To illustrate the process of sea level rise a table has been prepared using

the mean sea level values for the Delaware coast (Figure 3). These data apply to most of Delaware and are presented here as representing the approximate elevation of the Delaware River and Bay at specific times in the prehistoric past.

FIGURE 3

Changes in Sea Level Since 10,000 B.C.



Former Mean Sea Level (MSL) in Delaware Bay

Date	Depth Below Present MSL	Date	Depth Below Present MSL
1992 A.D.	0		
1000 A.D.	-2 ft.	4000 B.C.	-34 ft.
1 A.D.	-4 ft.	5000 B.C.	-46 ft.
1000 B.C.	-11 ft.	6000 B.C.	-60 ft.
2000 B.C.	-17 ft.	7000 B.C.	-75 ft.
3000 B.C.	-22 ft.	10,000 B.C.	-84 ft.

According to this information it would appear that the vicinity of the project area was initially inundated around 4000 B.C. The deepest relict stream channels indicated by geotechnical borings in the project area were from thirty to forty feet below present mean sea level, at an elevation that would have begun to be affected by progressive inundation about that time.

A more precise determination of chronology could perhaps be made from radiocarbon dating the deepest organic marshy peat deposits from the project area. Sediments of those types were initially formed during the inundation process when the subaerial terrain became saturated and developed marshy vegetation. Eventually the oldest marshes became further submerged as the sea level continued rising, and were buried beneath successive sedimentary layers. The stratigraphy that frequently results is characterized by a layer of silt or sand over a stratum of saltwater marsh peat. Beneath that there may be a level of brackish-water peat on top of freshwater peat with stumps of ancient trees whose roots are anchored in the underlying former subaerial ground surface.

This vegetation sequence is sometimes preserved in sedimentary stratigraphies resulting from inundation due to rising sea level. At the present time in coastal areas of Canada's Maritime Provinces, the spruce forest is being drowned as the shoreline recedes (Pielou 1991:22). At the bottom of the wetland strata where the former subaerial ground surface is located there are sometimes preserved remains of trees that were alive up to the time when water covered the land. The first wetland established after terrestrial vegetation is killed is fresh water or brackish-water marsh. In eastern Canada, brackish-water marshes are characteristically dominated by seacoast bulrush (Scirpus maritimus). As the rising sea level leads to further saltwater intrusion, the brackish-water marsh is succeeded by tidal salt marshes of cord grass (Spartina alterniflora) and salt hay (Spartina patens). Eventually the salt marsh is totally inundated by water too deep for it to survive.

Along coastal areas this stratigraphic sequence is characteristically capped by a layer of sand. In estuaries the topmost layer is usually finer and more silty, while off the ocean coast coarser sands are most common. Beneath that upper overburden, however, evidence of the process of Holocene inundation may be preserved largely intact.

By around 4000 B.C. the ancestral Delaware River in the project area vicinity had evolved from a rapidly flowing waterway to a broad tidal embayment. Much of the formerly broad subaerial plain adjoining the ancient river had been covered by the rising waters. Mixing of the river's fresh water with salty sea water created a brackish estuary.

The embayment that was created was bounded by shoreline that progressively receded landward as the sea level rose further. Coastal erosion associated with the receding shoreline reworked and sorted the uppermost soil strata, leaving coarser materials while carrying away finer sediments. It also had a leveling

effect on the terrain's relief.

In tidal estuarine environments the erosive effects of shoreline migration are sometimes less destructive than along ocean or large embayment coastlines. The intensity of this impact, however, varies widely and is influenced by such factors as differences in wave energy and soil stratigraphy. While erosion is highly destructive under certain conditions, its effects are mitigated in others. In cases where inundated subaerial terrain became capped with marshy organic-rich sediments, the destructive effects have probably varied from substantial to minimal depending on local conditions.

Another environmental development was the creation of tidal watercourses as the drainage of tributary streams (such as Smyrna River, Mill Creek, and Leipsic River) became flooded. Until rising sea level finally reached the elevation of the bridge crossings, their physiography probably remained similar to what it had been when the glaciers first began to melt about 10,000 years earlier.

As those streams began to be affected by inundation, their valleys were increasingly drowned. A major consequence of this was the deposition of marshy and lagoonal silts and clays over much of the former subaerial land surface. Most of these sediments probably originated as alluvium transported from upstream. The oldest early holocene sediments may have been deposited directly on top of the original subaerial Pleistocene surface. Later deposits formed strata of overburden atop earlier ones.

Over time a substantial amount of sediment was deposited within the former subaerial stream valleys. For example, the subsurface stratigraphy of Mill Creek contains several distinct depositional strata totalling more than thirty feet in thickness.

In comparison to well drained waterways, tidal streams are generally characterized by a lessening of the forces that move water and sediments downstream. Tidal stream channels often act as catchment basins for alluvial sediments that are normally transported downstream by non-tidal currents. Sediments settling onto inundated terrain often form thick deposits of silty mud containing abundant organic remains of marshy flora and fauna. The stratigraphy of holocene sediment deposits in a tidal watercourse serves to record its evolution and development since the end of the last Ice Age.

The net effect on formerly subaerial watercourses by the inundation of the ancestral Delaware River and the creation of Delaware Bay has been tremendous. Vast expanses of former terrain surfaces have been subject to varying degrees of erosion and the deposition of marshy silts and alluvial sediments. This complex process has substantially altered the original subaerial terrain. However, its effects on prehistoric cultural deposits are still poorly understood.

Existing Physiography, Sub-bottom Stratigraphy and Soil Boring Interpretation

The present day physiography of the submerged lands in Smyrna River, Mill Creek, and Leipsic River certainly does not resemble the ancient subaerial configuration. One of the major inundation processes that reconfigured their former topography was sediment deposition subsequent to inundation. This has capped the former subaerial surfaces of the ancestral stream valleys by several feet of gravels, sand, silt, clay, and marshy sediments. Erosion has also probably occurred, but its effects are unclear and probably varied a great deal depending on localized circumstances.

The effects on prehistoric sites from inundation due to rising sea level have not been adequately studied. Some useful information concerning analogous situations has been provided by research into the effects on archeological sites from inundation in man-made reservoirs (Lenihan and others 1981). More recently, research on the submerged Gulf of Mexico continental shelf has sought to identify locations of Paleoindian habitation (Dunbar and others 1992).

The results of those investigations and others concerning this subject area are encouraging. While sites that are clearly of Paleoindian vintage have not been found, diagnostic evidence of human activity dating to the Archaic period has been located at several underwater sites.

It is possible to reconstruct the general physiographic characteristics of drowned river valleys as they existed prior to inundation. Based on that information, hypothetical interpretations can then be proposed concerning the potential distribution and integrity of submerged prehistoric cultural deposits. In the bridge crossing project areas, the potential range of prehistoric occupation extends from the initial human occupation of the region (circa 10,000 B.C.) to the final inundation of the project area around 4000 B.C.

Prior to their submergence, the bridge crossing areas were subaerial portions of the Coastal Plain physiographic province. The topography of the surrounding uplands was probably similar to the present configuration, with the terrain being generally level to rolling in contour and dissected by a dendritic pattern of streams that were tributaries of the ancestral Delaware River.

At that time the stream valleys were more deeply incised than at present. Adjacent to the ancient stream channels were terraces left by the process of erosional down cutting. Presently subaerial terraces in similar settings have often been found to contain archeological evidence of prehistoric settlement.

Formerly subaerial terrain that has the potential for containing prehistoric cultural remains has frequently been subject to both erosion and sediment deposition subsequent to inundation. Erosion may have occurred as the rising water level first affected the ancient subaerial surface. That process often disturbed or removed some portion or all of the uppermost soil strata.

As shoreline erosion took place, lithic artifacts, for example, may have become scattered. Another possible outcome was that they remained in

approximately the same horizontal location while becoming compressed vertically as the soil matrix was reworked or removed by erosion. The degree to which the soil matrix would have been affected probably varied depending on the nature of the soil itself, characteristics of the cultural deposit (for example, lithic scatters versus shell midden), and the specific location. A site's position relative to other terrain features nearby may serve to make it more protected or more vulnerable.

The establishment of marsh vegetation at a specific location would probably have alleviated subsequent destructive effects from erosion. Deposition of organic-rich silts and mud on top of terrain that had lost some portion or all of its uppermost soil horizons is likely to have covered the locations of aboriginal human activity and protected them from further disturbance by erosion. At places where erosion was not a major factor, the marshy sediments may have capped cultural deposits that largely retained their original integrity.

Following the commencement of tidal inundation and marsh development, reduced energy levels of a stream's downstream current would have inhibited the erosion of sediments from the inundated terrain. Depending on the locality, this process is likely to have resulted in the deposition of additional sediments onto the former subaerial stream channels and their adjoining lower terraces. In relict terrain feature locations having lower elevations, the amount of sediments deposited may amount to several tens of feet in thickness.

In the project area the ancestral stream channels are buried beneath more than thirty feet of sediments. The deposition of these sediment strata appears to have begun at the time inundation started around 4000 B.C. It has continued to the present and is still going on.

The most recent sediments deposited in the bridge crossing project areas postdate the beginning of European settlement during the 1600's. The clearing of land for agriculture removed natural vegetation and served to greatly accelerate erosion. Alluvial erosional transport subsequently deposited massive amounts of soil into Kent County's tidal waterways including Smyrna River, Mill Creek, and Leipsic River.

In some locales this siltation progressed more rapidly than in others. Limitations on the navigability of several tidal streams (including Smyrna River) as a consequence of shoaling were reported as early as the 18th century. The deposit of silty mud is likely to continue, though present day measures to alleviate erosion have been adopted to slow its rate of progress.

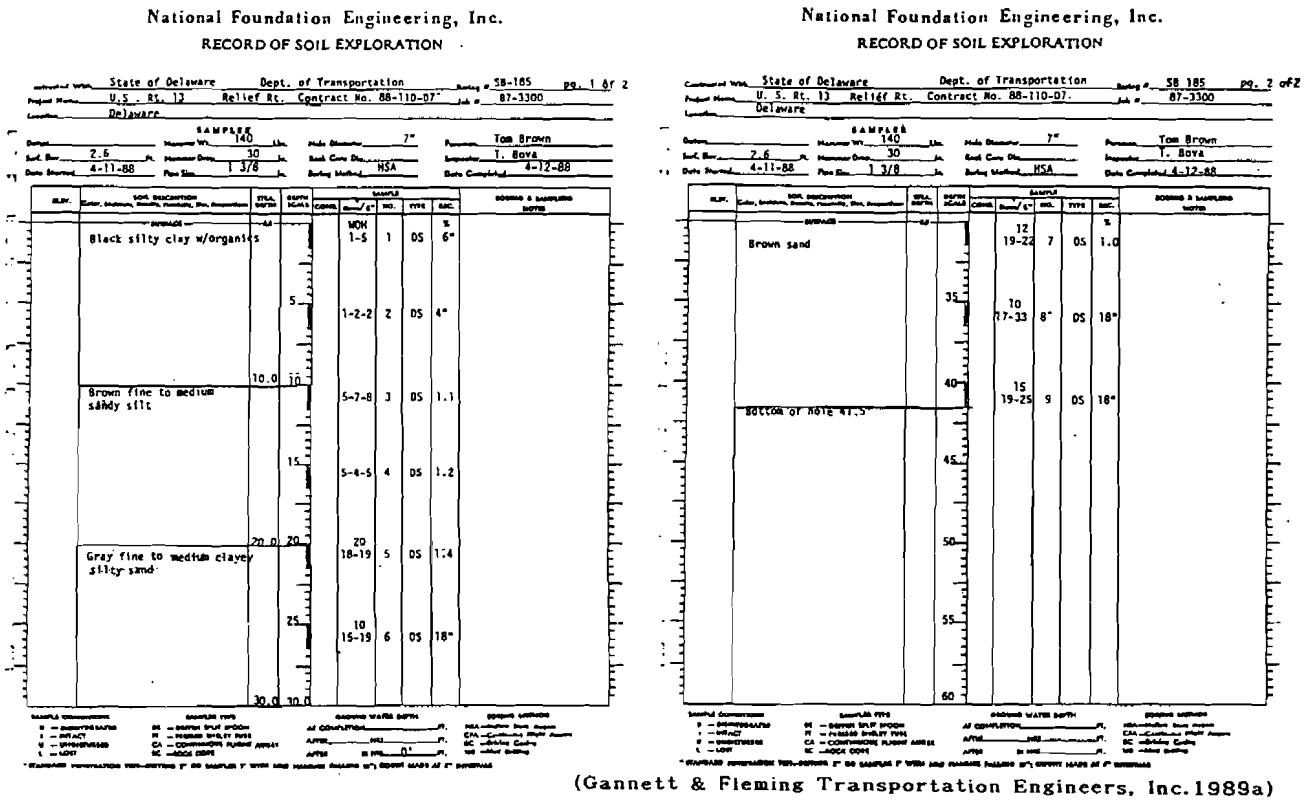
An information resource that is useful for reconstructing ancient terrain physiography consists of the data records from geotechnical soil borings. This data is readily available because borings are routinely conducted as part of highway or other construction project engineering studies.

An example of a soil boring log from the Smyrna River bridge crossing project area is shown as Figure 4. Data such as these allow inundated and buried

ancient terrain features to be identified and mapped both vertically and horizontally.

FIGURE 4

Geotechnical Soil Boring Data Record



(Gannett & Fleming Transportation Engineers, Inc.1989a)

Archeological interpretations derived from soil borings for the three bridge crossings are presented in the individual bridge crossing sections later in this report. They describe the configurations of ancient terrain features buried by sediments accumulated in the project's waterways as a consequence of sea level rise.

The soil boring interpretation technique employed in this investigation consisted of using data logs to prepare stratigraphic cross sections of subbottom sedimentary stratigraphy. By correlating each boring log with a horizontal datum and placing them in correct horizontal order, a series of soil profiles was established. The stratigraphy of territory between the borings' profiles was interpolated to develop a continuous cross section.

Cross sections such as these characteristically reveal ancient stream channels and lower terraces that were drowned by rising sea level and subsequently buried beneath sediments. The stream channels are identifiable by the coarseness of their sediments, commonly sands and/or gravels and/or cobbles. Terraces are shown by the presence of level sandy clay and/or clay subsoil adjacent to but higher in elevation than ancient former stream channels. Depending on local conditions, a chronological series of relict channels and their associated terraces may be identified. These are usually staggered horizontally and vertically, but are sometimes superimposed. Horizontal staggering of relict channels provides evidence of steam meandering.

While soil borings are useful for identifying stratigraphy, interpreting former physiography, and relative dating, they do not provide data enabling buried terrain features to be dated absolutely. However, such dating is possible. It can be accomplished by obtaining radiocarbon dating samples of organic material (such as peat, shell, or wood) from specific buried strata. This is normally accomplished by conducting core sampling or careful soil borings. The locations, depths, and sediment associations of the samples recovered must be accurately recorded. Procedures that would provide samples useful for dating purposes, however, are not routinely performed in highway project geotechnical or engineering studies.

Subsurface testing for the possible presence of buried prehistoric sites in underwater locales is presently not a standard procedure in archeological studies performed for cultural resource management purposes. However, investigations of that nature have the potential to locate sites that may be present, as well as provide important information relating to the process of land inundation.

Further research focusing on prehistoric sites in underwater locations is likely to provide significant information concerning the distribution of aboriginal cultural deposits. It is possible that such sites will predate cultural deposits found in terrestrial settings along those same waterways.

The data collection and interpretation procedures described above are feasible under existing historic preservation and archeological procedures. Even more improved survey, excavation, and analytical techniques would certainly be developed if Archeology would direct more attention to the study of ancient prehistoric cultural deposits on lands that are presently underwater.