Appendix A

Geoscience Focused Desktop Study Proposed Virginia Offshore Wind Test Site Development, Chesapeake Bay, Virginia
GEOSCIENCE-FOCUSED DESKTOP STUDY
PROPOSED VIRGINIA OFFSHORE WIND
TEST SITE DEVELOPMENT
CHESAPEAKE BAY, VIRGINIA

Prepared for:
Virginia Department of Mines, Minerals and Energy
on behalf of James Madison University

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Virginia Department of Mines, Minerals and Energy
on behalf of James Madison University
c/o Timmons Group
1001 Boulders Parkway, Suite 300
Richmond, Virginia 23225

Attention: Mr. Rick Thomas

Subject: Geosciences-focused Desktop Study, Proposed Virginia Offshore Wind Test Site Development, Lower Chesapeake Bay, Virginia

Fugro Atlantic (Fugro) is pleased to submit the referenced report in support of the proposed Virginia Offshore Wind Test Site Development in the lower Chesapeake Bay area of the Virginia Tidewater. Our efforts were authorized by the execution of Timmons Group’s agreement for sub-consultant services. The scope of the study was described in Fugro’s proposal (number 2011.0034) submitted February 2, 2011.

This report describes the bayfloor and subsurface conditions, and their implications relative to the siting and performance of an offshore wind turbine generator for testing and research near either the Chesapeake Bay Bridge Tunnel and/or the Monitor Merrimac Memorial Bridge Tunnel. The study interpretations are based on the accumulation and synthesis of existing public domain data, together with other data within Fugro’s files. Fugro’s draft of this report was provided on August 24, 2011. Your review comments, received on January 27, 2012, were considered when finalizing the document.

We appreciate the opportunity to provide the Virginia Department of Mines, Minerals and Energy, James Madison University, and the Timmons Group with our services in support of the Commonwealth’s efforts for offshore wind energy.

Sincerely,

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EXECUTIVE SUMMARY

PROJECT DESCRIPTION

The Commonwealth of Virginia has proposed to create a future Virginia Offshore Wind Test Site (VOWTS) Development. The development is envisioned to include the siting, design, installation, and operation of at least one offshore-size Wind Turbine Generator (WTG) at one or two locations in the lower Chesapeake Bay area. Fugro Atlantic (Fugro) has prepared this Geoscience-focused Desktop Study (DTS) in support of the efforts being led by the Virginia Department of Mines, Minerals and Energy (DMME); James Madison University; and the Timmons Group on behalf of the Commonwealth of Virginia’s interests in such a potential test site development.

The areas being considered for the VOWTS planned development include: 1) the Chesapeake Bay Bridge-Tunnel (CBBT), 2) the Newport News approach of the Monitor Merrimac Memorial Bridge-Tunnel (MMMBT), and 3) the Suffolk approach of the MMMBT. At the time of this final DTS report, one proposed test turbine site is being considered at each of the three proposed development areas. Two “alternate” locations have also been identified at the proposed Suffolk site.

The desktop study focused on 3 to 5 nautical mile (Nm) areas centered on the three proposed development areas. The areas are intended to be large enough so that the conditions and data near the proposed test areas can be evaluated within the context of the regional conditions.

The geosciences-focused DTS helps to determine: 1) if the site and subsurface conditions pose hazards to the project development; 2) whether or not variations in the site and subsurface conditions will be factors when choosing test structure site locations, and 3) how the site and subsurface conditions could affect foundation-type selection, design, and installation. For cable routing, the desktop study provides input towards identifying the most appropriate, least problematic, and least cost route alignment.

The geosciences DTS also provides valuable information and background that will be useful for planning and scoping conceptual, preliminary, and/or final geophysical survey and geotechnical site investigation programs.

SEAFLOOR AND SUBSURFACE CONDITIONS

We reviewed readily available information and evaluated geoscience conditions of the bay-floor and subsurface for the proposed CBBT, Newport News, and Suffolk wind test turbine sites in the lower Chesapeake Bay region. Where available and appropriate, we compiled data into a GIS system that was used to integrate various types of information and support our evaluation. The geosciences DTS has focused on the:

- Bay-floor geomorphology, bathymetry, slope, and bay-floor conditions,
• Subsurface geology and geologic hazards, and
• Bay-floor and subsurface sediment characteristics.

THE PROPOSED CHESAPEAKE BAY BRIDGE-TUNNEL TEST SITE

Water Depth, Bathymetry, and Seafloor Morphology

The proposed CBBT test site is located at the mouth of the Chesapeake Bay. The proposed east test turbine site is located in False Channel, a natural swale southwest of Nine Foot shoal where the water depth is about 38 feet (MLLW). The natural swale is flanked by the Nine Foot shoal on the northeast and Middle Ground shoal on the southwest. The swale represents a modern low maintained by tidal flushing.

The Bay mouth is a hydrodynamically complex transitional environment between the open inner continental shelf and the large coastal plain estuary that is the Chesapeake Bay. Bay-floor and seafloor morphology revealed in bathymetric data indicate areas dominated by flood and ebb tidal flows and that are strongly influenced by waves. Sand wave bedforms in the bay-mouth indicate that the surficial sediments are dynamic. Burial protection may be reduced for cables laid in areas where mobile sand waves are present when the sand waves migrate and trough locations occupy former crest locations, thus resulting in reduced burial protection or exposure of the cable on the bay-floor. Strong currents that mobilize the bay-mouth sediments also will be capable of inducing localized scour around the base of turbines. Scour should be taken into consideration for future developments along the mouth of the Bay.

Subsurface Conditions

Shallow subsurface stratigraphic units (upper 300 feet) at the proposed CBBT test site are anticipated to be comprised of Holocene, Pleistocene, Pliocene and Miocene deposits. Significant lateral and vertical variations in soil stratigraphy and conditions is expected in the general vicinity of the proposed CBBT test site. Thus, appropriate geophysical surveys and geotechnical ground investigation will need to be conducted early during the project development process in this location.

The subsurface materials were deposited during sea level fluctuations. During sea level lowstands, the area was emergent and subjected to erosion. Deep incised valleys related to ancestral drainages were formed. As sea level rose, the valleys were infilled typically by fine-grained material. Paleochannels at the mouth of the Chesapeake bay can be infilled with clay deposits between 10 and 60 feet thick. The fine grained material is overlain by the Holocene bay-mouth shoal sediments that comprised of sand sediments up to 35 feet thick. The clay paleochannel-infill will not provide adequate bearing capacity for piled foundations, and piles will need to be extended below this unit to develop adequate capacity in lower strata. The Tertiary materials underlying the paleochannel (and erosional surface) are the common end bearing strata for piled foundations (e.g. bridge, waterfront development, etc.) in the area. The precedent of pile foundations for those civil infrastructures, however, should not be considered to provide guidance for large diameter piles designed to support offshore-scale wind turbines.
THE PROPOSED NEWPORT NEWS AND SUFFOLK TEST SITES

Water Depth, Bathymetry, and Seafloor Morphology

The proposed Newport News test site is along the James River just east of the Newport News approach of the Monitor Merrimac Memorial Bridge-Tunnel (MMMBT). The proposed Newport News test turbine site is located about 1,150 feet east of the MMMBT, along the western flank of the Newport News Bar, a shoal feature approximately 1,150 feet north of the Newport News Channel. The water is about 12 feet deep at this location.

The Suffolk test sites are located near the confluence of the James and Nansemond Rivers. The proposed East Inner Test Turbine Site is located on the southern flank of the James River channel near the confluence with the Nansemond River, in about 10 feet of water. One alternate site for the East Inner Test Turbine is located about 4,800 feet west of the MMMBT in about 14 feet of water and the other alternate site is located about 1,800 feet east of the MMMBT alignment on the flat where the water depth is less than 5 feet. The shallow water depth on the flat is anticipated to be problematic for the size of marine plant needed to install a large wind turbine and its foundation and tower.

Surficial sediments at the Newport News and Suffolk test turbine sites range from sandy clay and silt in the bay deposits; to fine to medium sand with silt at the Craney Flats; and silt to silty sand in the natural channels. Tidal variations dominate flow conditions near the proposed Newport News/Suffolk test sites. Prevailing flow is generally in the flood direction along the channels and northern shoals while ebb directional flow is dominant along the Craney Flats.

Subsurface Conditions

Like the proposed CBBT test site, the upper stratigraphic units in the vicinity of the proposed Newport News and Suffolk test sites are anticipated to be Holocene, Pleistocene, Pliocene and Miocene deposits. The top of the Miocene deposits are found up to an elevation of about -150, MLLW. Deposits of the Yorktown Formation lie above the Miocene sediments and are generally 30 to 100 feet thick. Pleistocene deposits, comprised primarily of the Tabb Formation, overlie the Yorktown Formation. The thickness of the Pleistocene section is variable and ranges from 15 to 40 feet thick at the Suffolk approach and 70 to 120 feet thick at the Newport News approach. The Pleistocene units likely outcrop in the Newport News Channel.

Paleochannels infilled with Holocene sediments also are found in the subsurface near the proposed Newport News and Suffolk test sites. The fine-grained infill material consists of soft silty clay to sandy silt and varies both horizontally and laterally. In the thickest areas, the soft clay is approximately 100 feet thick which corresponds to a basal elevation of about El. -120 feet. The clay sediments thin to about 5 to 20 feet thick near the Newport News approach. The Holocene thins to about 20 to 25 feet thick near the Suffolk/Portsmouth approach along the Craney Flats. However, it is probable that the proposed Suffolk test sites are underlain by about 50 to 75 feet of soft clay due to the projection of the eroded fluvial channels.
1.0 - INTRODUCTION

PROJECT DESCRIPTION

The Commonwealth of Virginia has proposed to create a future Virginia Offshore Wind Test Site (VOWTS) Development. The development is envisioned to include the siting, design, installation, and operation of at least one offshore-size Wind Turbine Generator (WTG) at one or two locations in the lower Chesapeake Bay area. Fugro Atlantic (Fugro) has prepared this Geoscience-focused Desktop Study (DTS) in support of the efforts being led by the Virginia Department of Mines, Minerals and Energy (DMME); James Madison University; and the Timmons Group on behalf of the Commonwealth of Virginia’s interests in such a potential test site development.

The areas being considered for the VOWTS planned development include: 1) the Chesapeake Bay Bridge-Tunnel (CBBT), 2) the Newport News approach of the Monitor Merrimac Memorial Bridge-Tunnel (MMMBT), and 3) the Suffolk approach of the MMMBT. Figures 1-1 and 3-2 through 3-7 show the locations of the proposed test sites.

At the time of this final DTS report, one proposed test turbine site (denoted as "East" [red symbols on figures] is being considered at each of the VOWTS planned development sites; the CBBT, Suffolk and Newport News test site. Two additional "alternate" locations have been identified at the proposed Suffolk site (symbolized by red hollow circle symbols on the figures).

The desktop study focused on 3 to 5 nautical mile (Nm) areas centered on the three proposed development areas. The areas are intended to be large enough so that the conditions and data near the proposed test areas can be evaluated within the context of the regional conditions.

Elevation (El.) of the bay-floor within the study areas vary between about El. -70 feet (referenced to mean lower low water [MLLW]) on the continental shelf offshore of the Chesapeake Bay and El. -20 feet MLLW in the inshore areas. Elevations within the Chesapeake Bay navigation channels near the CBBT and the Newport News/Suffolk sites range from about El. -35 to -80 feet MLLW. On average the surrounding bay-floor elevations near the proposed CBBT site range from about El. -20 to -35 feet MLLW and near the proposed Newport News and Suffolk sites, the bay-floor ranges from about El. -5 to -30 feet MLLW.

IMPORTANCE OF GEOSCIENCES CONSIDERATIONS FOR OFFSHORE WIND DEVELOPMENT

An early and complete understanding of the bay-floor and subsurface conditions and their affect on foundation/sub-structure design, installation, and cost is an important component of the development of offshore wind energy. European project experience has documented the importance of subsurface conditions and their variability, and geotechnical engineering for offshore wind development. The implication is that an early-on appreciation of the conditions, including what insight can be drawn from existing data and what understanding can be gained only by conducting project-specific studies, is an important early activity for planning the development of offshore wind energy projects. Thus the decision to perform a planning-phase, geosciences-focused DTS is an important recognition of the critical importance of the geological and geotechnical conditions and their future importance relative to project development.
DESKTOP STUDY DESCRIPTION

Purposes and Uses

A DTS is intended to accumulate, synthesize, and present information as gleaned and extracted from existing data sources. It is used to help understand and communicate the physical and environmental conditions and associated constraints on project development. Identifying and understanding those issues as early as possible is highly valuable for a project's financial planning and for scoping and scheduling future investigations. The data sources include public data sources and data from Fugro's files.

The geosciences DTS has focused on the:
- Bay-floor geomorphology, bathymetry, slope, and bay-floor conditions,
- Subsurface geology and geologic hazards, and
- Bay-floor and subsurface sediment characteristics.

The geosciences-focused DTS will help to determine: 1) if site and subsurface conditions pose hazards to the project development; 2) whether or not variations in the site and subsurface conditions will be factors when choosing test structure site locations, and 3) how the site and subsurface conditions could affect foundation-type selection, design, and installation. For cable routing, the desktop study provides input towards identifying the most appropriate, least problematic, and least cost route alignment.

A geosciences DTS also provides valuable information and background for planning and scoping conceptual, preliminary, and/or final geophysical survey and geotechnical site investigation programs.

Scope of Work

The work performed for this geoscience DTS has consisted of the following:
- **Literature Review**: Fugro conducted a literature review to gather information and data relevant to defining and evaluating the conditions in the project area.
- **Data Review**: Fugro reviewed readily-available, published geologic maps, geotechnical and geophysical data, and cross sections for the project area. The reviewed data are referenced at the end of this report.
- **Preliminary Geological and Geotechnical Evaluation**: Geologic and geotechnical information from the data review was evaluated to characterize the potential geologic and geotechnical conditions and geohazards in the project area.
- **Development and Mapping of the Bay-floor and Geologic Conditions**: A series of figures have been produced to show the bay-floor and geological conditions.

For this DTS, Fugro has searched available public and internal, non-proprietary sources for data that describe the general physical setting, geologic conditions, bay-floor conditions, and subsurface conditions within the DTS area. We also have used data that were acquired by Fugro at our expense. The relevant data are collected and compiled in a GIS database for the project area.
The compiled data were used to evaluate and describe (to the extent feasible based on the types, quantity, quality, and spatial distribution of the available data) the: bathymetry, bay-floor and geologic features, bay-floor characteristics and sediments types, and anticipated physical properties (if and where appropriate data are available) of the sediments. The DTS describes uncertainties and gaps in the available data that have been obtained for the preparation of the report.

The results of the geosciences-focused DTS are provided in this report that describes our interpretation of the bay-floor and subsurface conditions. The report text includes our evaluation of the uniformity or variability of these conditions in the project areas and evaluates the implications of the conditions relative to the objectives of an offshore wind turbine test site.

**Study Authorization and Draft Report**

This geosciences-focused desktop study was authorized by the July 19, 2011 execution of a Timmons Group agreement for sub-consultant services. The scope of the study was described in Fugro’s proposal (number 2011.0034) submitted February 2, 2011. Fugro’s draft of this report was provided on August 24, 2011. Your review comments, received on January 27, 2012, were considered when finalizing the document.

**REPORT ORGANIZATION**

The report text is followed by various figures that support the descriptions provided in the report text. Figures associated with the 1st section of text are numbered: 1-1, 1-2, etc, while figures associated within the 2nd section of text are numbered 2-1, 2-2, etc. Where data of adequate resolution are available, separate maps of each study area are presented showing more detailed views of pertinent information.

**2.0 - SUMMARY OF AVAILABLE DATA**

**PROCESS OF DATA INTEGRATION**

A desktop study is initiated by accumulating, synthesizing, and presenting information as gleaned and extracted from existing data sources. Fugro has searched available public and internal, non-proprietary sources for data that describe the general physical setting, geologic conditions, bay-floor conditions, and subsurface conditions within the study area. Non proprietary data and reports from Fugro’s files and database as well as data owned by Fugro also have been included. The pertinent data from the various sources have been compiled in a geographic information system (GIS) database for the project area.

The studies and data mined for the desktop study provide the basis for understanding and communicating the physical and environmental conditions and associated constraints on project development. Identifying and understanding those issues as early as possible is highly valuable for a project’s financial planning, and for scoping and scheduling future investigations.

Wherever possible, the information entered into the GIS database has been input electronically or extracted electronically from the source files. Only when necessary has other map information been digitized into the GIS. Other data (such as historical sample and boring data) have been entered into the GIS so that the information can be electronically synthesized and subsequently extracted and analyzed using Fugro’s proprietary geotechnical GIS routines.
It has been possible, for some of the study areas, to obtain and reprocess the original electronic multibeam hydrographic data sets that had been previously processed for regional mapping. By reprocessing the data to a more detailed resolution (e.g., smaller grid bin size), it has been possible to resolve bay-floor features that are not well defined when the data are processed for regional mapping. The more detailed, reprocessed data can be valuable in identifying bay-floor features associated with sediment transport, slope instability, and unstable sediments. Moreover, when more than one survey is available (now or in the future), they can provide the ability to identify areas where bay-floor topography has changed due to erosion, deposition, shifting of shoals, sand wave migration, etc. and rates of change, which may be valuable for siting facilities and understanding potential future sediment transport issues for a project.

**TYPES AND SOURCES OF DATA USED**

The available regional data from public sources included:

- Published academic and research agency (e.g., USGS) studies related to:
  - Bay-floor geomorphology, bay-floor conditions, and sediment mobility,
  - The geology (and geological history) of the lower Chesapeake Bay region,
  - Regional geophysical surveys,
  - Geologic hazards, and
  - Subsurface conditions.

- Project reports available in the public record, such as:
  - Geophysical survey reports (such as the 2008 potential borrow site characterization reports for the Craney Island Eastward Expansion Project covering the Newport News Channel and Anchorages (NNCA), Thimble Shoals Channel (TSC), Cape Henry Channel, and the Atlantic Ocean Channel (AOC) and various USACE surveys) and
  - Geotechnical study reports (such as the early-1960s investigation report for the construction of the CBBT, the late-1970s VDOT report for the I-664 MMBT, and the 2008 borrow site characterization reports for the Craney Island Eastward Expansion Project covering the Newport News Channel and Anchorages (NNCA), Thimble Shoals Channel (TSC), and the Atlantic Ocean Channel (AOC) as previously mentioned).

Available data and reports from Fugro files that have been accessed for the study include:

- Documents and data developed for the BOEMRE TA&R seabed scour study (Fugro, 2011),
- Seismic reflection survey data collected by Fugro as part of an internal technology testing program for the southern Chesapeake Bay and surrounding area, and
- More than 300 historical and 300 recent (within the past 5 years) geotechnical explorations in the vicinity of Craney Island and associated borrow sites,
- Deep geotechnical borings conducted by Fugro for the Chesapeake Light Tower.
FUTURE EXTENSION OF GIS-FORMATTED STUDY INFORMATION

As the project moves forward, the GIS can be efficiently used to synthesize and integrate new data into the database developed for the desktop study. One of a GIS database’s core strengths is its ability to integrate data of various types, time periods, coordinate systems and datums into one map view for evaluation or analysis. For example, it will be advantageous to incorporate any future geophysical survey and subsurface exploration into the GIS database.

Other benefits of using a centralized GIS database during the desktop study and subsequent phases of a project include:

- Improved quality control, and
- The ability to appropriately document how various data were collected, when it was collected, by whom, data processing steps used to create those data, and accuracy and precision statements (also known as "metadata").

Use and growth of the GIS database will expedite the synthesis and evaluation of new data, and allow the new information to be communicated to other members of the client’s organization and project team more expeditiously than is otherwise possible. In addition, the framework provided by the database allows the new data to be viewed in context of the prior data and information. This directly benefits the subsequent phases of the project by providing focus and knowledge.

3.0 - BATHYMETRY

WATER DEPTH CONSIDERATIONS RELATIVE TO WIND TURBINE SITING

Water depth is a critical parameter for siting, designing, installing, and operating wind turbine structures. Wind test turbine costs and the complexity of design and installation challenges generally increase as water becomes deeper and the relationship may not be linear.

Figure 3-1 illustrates the typical range of water depths for various types of foundations. Monopile foundations are generally considered to be suitable for water up to 70 or 80 feet deep while transitional multi-pile structures (jacket structures, tri-pods, tri-piles, etc) are considered suitable in water up to 200 feet deep.

A review of bathymetric data provides insightful information regarding the bay-floor geomorphology and the geologic and oceanographic processes that created the bay-floor features and continue to modify those features. Those same processes may have adverse or positive impacts on offshore wind-farm structures. Understanding those processes and how they may affect offshore structures will help: 1) manage and reduce risks, and 2) reduce construction and operating costs.

The ability to evaluate the bay-floor conditions relies heavily on the quality and density of the data available. For this study, we have acquired a multibeam bathymetry dataset from NOAA covering the Hampton Roads Region as well as bathymetry data of the Newport News Channel and Anchorages (NNCA) collected by the U.S. Army Corps of Engineers (USACE) from 2006 to 2007.
Detailed information about the bay-floor is readily observable and bay-floor irregularity and geomorphology is apparent in both datasets. For this study, we have used the available bathymetric information to conduct our evaluation, as described in the following sections of this report.

**Foundation Types and Water Depth**

As illustrated in Figure 4-1, water depth is one of the factors that constrain appropriate foundation types for a site. Water depths being considered for WTG instillation in this study are generally below 65 feet and are deemed feasible depths for monopole foundations.

The monopile foundation design consists of a large diameter steel pile (typically 10 to 16 feet) that is advanced into the bay-floor by drilling, driving, or a combination of both. The monopile foundation is suitable for the loosely-consolidated sediments found in the lower Chesapeake Bay region. However, locations containing deep soft soils would require higher penetration depths. Required penetration depths vary depending on design loads, but typically range from 3.5 to 4.5 times the pile diameter in stiff clay and 7 to 8 times the diameter in softer sediments.

**REGIONAL BATHYMETRY**

The regional bathymetric dataset was created from various data sources. The bathymetry data were acquired during surveys conducted over several decades and are of variable data density. In general, the regional bathymetry data are compiled from NOAA data sources (Taylor et al., 2007) and areas within navigation channels are from the USACE condition surveys. NOAA point data used to generate the bathymetry dataset used in this report are obtained at approximately 10.3 meters (latitude) by 8.3 meters (longitude) spacing. The original point data, referenced to mean high water, were converted to mean lower low water (MLLW) based on the vertical datums defined at the Chesapeake Bay Bridge-Tunnel tidal station #8638863.

The USACE bathymetry dataset of the NNCA covers the Anchorage Opposite Newport News Channel (AONN), Channel to Newport News (CNN), Anchorage Opposite Sewells Point (A OSS), and Norfolk Harbor (NH) surveyed during 2006 and 2007. The NNCA bathymetry shown in this report is a mosaic of the above surveys which are binned at 10 feet and referenced to MLLW.

The regional bathymetry is shown on Figure 3-2 and more detailed bathymetry maps of the CBBT and MMBBT (Newport News and Suffolk) sites are shown on Figures 3-3 through 3-7. The bay-floor in the lower Chesapeake Bay contains various features that determine the water depth in a given area, however regionally, the water depth increases from an average of about 30 feet at the mouth of Chesapeake Bay to about 10 to 210 feet closer to the tributaries. Common large-scale, bay-floor features that influence water depth in the bay include but are not limited to modern natural channels, maintained navigation channels, bay-mouth shoals (bathymetric highs) and associated swales (bathymetric lows). In general, the regional water depth commonly varies by more than 30 feet within the study area. However, local relief associated with shoals and dredged navigation channels exhibit greater local relief. In some areas, shoal complexes rise more than 40 feet above the ambient bay-floor or adjacent swales. Navigation channels can exhibit 30 to 50 feet of relief near the proposed test site areas. Thus,
the largest variation in water depth within a 1.5 mile radius around the proposed test turbine sitting locations is generally related to localized relief associated with shoals or navigation channels.

**BATHYMETRY OF THE PROPOSED CHESAPEAKE BAY BRIDGE-TUNNEL TEST SITE**

The bathymetry of the Bay entrance is shown on Figure 3-3 and a detailed view of the bathymetry of the proposed test site area is shown on Figure 3-4.

The deepest water depths in the vicinity of the Chesapeake Bay Bridge-Tunnel are in the navigation channels as well as the natural channels and swales. The deepest area in the region is located north of Cape Henry point where the Cape Henry and Thimble Shoal Channels meet. Water depths reach 100 feet in this area. The North Channel is located about 3 miles northeast of the proposed east turbine site and contains a bathymetric low, more than 100 feet deep, that is circular in shape where it crosses the CBBT. It is possible that this area could be deepening or maintained at this depth from localized scour around the CBBT bridge piles.

Other than near the shoreline, the shallowest areas are on the crests of the shoals. Water depths on the shoals range from 6 feet along Nine Foot Shoal to 20 feet near the Tail of the Horseshoe and Middle Ground.

The proposed test turbine site in the vicinity of the CBBT is located in the southern section of a swale between two shoal areas, Nine Foot Shoal and Middle Ground. The water depth at this site is about 38 feet. The proposed turbine site is approximately 2 Nautical Miles north of the Cape Henry Channel which is a navigation channel maintained by dredging.

**BATHYMETRY OF THE PROPOSED NEWPORT NEWS AND SUFFOLK TEST SITES**

An overview of the bathymetry at the proposed Newport News and Suffolk sites is provided in Figure 3-5. The deepest water near the proposed Newport News site is within the Newport News Channel whose centerline crosses the bridge about 0.6 miles south of the Newport News approach (Figure 3-6). Water depth within the navigation channel is generally maintained at a depth of 50 feet. Areas where the water depth exceeds 50 feet are likely deeper due to bottom currents that locally erode or scour sediments. Examples of locally deepened areas are in the navigation channel above MMMBT and about 3 km upstream of MMMBT where water depth are up to 80 feet and 72 feet, respectively (Figure 3-6). Those localized depressions suggest that currents capable of eroding bay-floor sediments exist within the navigation channel.

The average depth along the James River, outside of the Newport News channel, is about 15 feet and two shoal areas (Newport News bar and Newport News Middle Ground) are located on the bay-floor on either side of the Newport News Channel east of the bridge alignment. The shallow area to the north is the Newport News Bar, where water depths decrease to about 6 feet, while the area to the south of the channel, named the Newport News Middle Ground, rise to 16 feet at its shallowest.

The proposed Newport News test turbine site is located about 1,150 feet east of the MMMBT on the shoal area of the Newport News Bar, where the water is about 12 feet deep (Figure 3-6). It is probable that the nose of the Newport News bar shifts in response to bottom currents. However, it is uncertain at what rate the Newport News bar may shift. We would
expect that this submarine landform is relatively stable under fair-weather conditions but large, discrete storm events (such as a nor'easter, tropical storm, or hurricane) could modify flow conditions and cause the nose of the bar to shift which would modify the water depth and possibly create water depth similar to the toe of the bar (approximately 20 feet deep). Potential projects at this location should take this potential process into consideration.

The northern dredge cut of the NNCA is located about 1,150 feet south of the proposed test turbine site where the water deepens to over 50 feet.

Detailed bathymetry of the proposed Suffolk test sites is in Figure 3-7. The proposed Suffolk test sites are located near the confluence of the James and Nansemond Rivers (Figure 3-2). The bathymetry in this area is less variable then in the other proposed test site areas. The area is comprised of a large flat extending from the shoreline to the 5-foot-contour (Figure 3-7). Beyond the 5-foot contour the water deepens gently to the north and to the west.

The proposed Suffolk East Inner Test Turbine Site is located on the southern flank of the James River channel near the confluence with the Nansemond River where the water depth is about 10 feet. Two alternate locations are being considered for the Proposed East Inner Test Site. One alternate site is located about 4,800 feet west of the MMBT in about 14 feet of water where the bay-floor slopes gently to the north. The other alternate site is located about 1,800 feet east of the MMBT alignment on the flat where the water depth is less than 5 feet.

A small man-made channel trending northwest-southeast is located about 0.8 nautical miles southwest of the proposed East Inner test site, and is approximately 200 feet wide by 2,000 feet long where the water is about 10 feet deep. Based on a review of historical nautical charts, this channel appears to have been excavated around 1960 and we postulate that it provided vessel access to a former dock facility.

BAY-FLOOR SLOPE GRADIENT

Bay-floor slope gradient data provide valuable insight relative to several important siting, design, and performance considerations. Steep slopes or irregular bay-floor conditions may be indicative of potential geohazards or challenges for anchoring construction vessels, installing structures, and laying cables.

An irregular bay-floor may be indicative of:

- Slope instability features (e.g. landslide scarp, debris flow lobes, etc.),
- Mobile sediments (e.g. actively moving dune complexes or sand waves),
- Escarpments or fault scarp.
- Boulder, cobble, and/or gravelly deposits, or
- Gas escape features.

Site surveys should be conducted to assess bay-floor slope gradient conditions prior to anchoring, setting spuds for lift barges, and laying cables. When installing cables, steeply sloping areas should be avoided and cables should traverse the slope perpendicular to the slope direction as opposed to oblique angles. Traversing slopes at an oblique angle will increase the stress on the cable installation equipment (e.g. jet-trenchers or plough) and/or make it difficult for the cable installation equipment to stay on course; thus, potentially adding installation downtime and/or increasing cable length.
We calculated slope gradient of the bay-floor from the available bathymetric data. Information and scale of features that may be identified in the dataset are based on the original data point spacing. The original bathymetric dataset used to calculate the bay-floor slope gradient is variable across the study area and based on sounding data that are spaced between 25 and several hundred feet. The slope gradient maps of the detailed siting areas are presented in Figures 3-8 to 3-10.

Most of the localized bay-floor relief within the study area is attributed to channel maintenance dredging, modern river and tidal channels, and shoals. The southern flank of the Newport News Bar where the proposed Newport News turbine site is located shows a slope between 1.5 and 5 degrees (Figure 3-9).

Channels within the vicinity of the study area also show increased relief at the channel flanks as seen in Figures 3-8 to 3-10. The east flank of the Cape Henry Channel shows slopes from 0.5 to 2 degrees of which is located approximately 2 Nm from the CBBT proposed east test turbine site and cable alignment (Figure 3-8). The Newport News Channel, located south of the proposed Newport News test turbine site on Figure 3-9 contains slopes up to 10 degrees.

Profiles of the bathymetry as well as slope for selected areas with variable bay-floor in the surrounding area of the CBBT are shown in Figures 3-11 and 3-12. Sections B-B' and C-C' are extended through the approximate location of the proposed 50-foot-wide cable routes. Slopes along the proposed alignments are generally less than 2 degrees. Section A-A' shows an area runs perpendicular across the seaward flank of Nine Foot Shoal and continues to deeper water where sand ripples are present. The slope is steepest (~2.5 degrees) along the flanks of the sand ripples. Section D-D' is located in a high energy area with multiple sand waves and displays the highest slope values of all the profiles. The estimated sand wave amplitude (crest-to-trough height) is 4 feet with a wavelength (crest-to-crest) of 760 feet. Slope values along the sand waves are generally less than 2 degrees but can reach up to 4 degrees.

Within the study area, the available bathymetry data are of a coarse resolution (~30-foot bin size) and therefore can only resolve large features and the slopes derived from the data should be considered approximate. Obtaining a higher-resolution, multibeam-derived bathymetry in the immediate areas of the proposed turbine siting locations will refine the bathymetric data and reveal additional smaller scale features or variability that could be missed otherwise. The small scale features (e.g. sand waves) are likely more mobile than larger features (e.g. shoal). A more refined dataset also could reveal localized gravel outcrops that should be considered when siting export cables, which may present hazard areas or difficult locations to install cables and should be avoided.

4.0 - GEOLOGY

PHYSIOGRAPHIC SETTING

The proposed test turbine sites being considered for the VOWTS project are located within the Chesapeake Bay and the eastern Coastal Plain Province of Virginia. The primary areas being considered for the proposed test turbine sites include 1) the northern region of the Chesapeake Bay Bridge-Tunnel (CBBT), 2) the Newport News section of the Monitor Merrimac
Memorial Bridge-Tunnel (MMMBT) and 3) the Suffolk section of the MMMBT. Proposed test turbine locations are shown in Figures 3-1.

The proposed CBBT and Newport News/Suffolk test sites are located in regions with different geological and morphological processes. The proposed CBBT is located at the mouth of the Chesapeake Bay where a tide-dominated, partially enclosed estuary system meets an open-water, longshore sediment transport system. This is a morphologically complex transitional region with areas experiencing both high erosion and deposition.

The proposed Newport News/Suffolk sites are located approximately 7.5 miles landward of the proposed CBBT site. The proposed Newport News and Suffolk sites are located near the confluence of the James, Nansemond, and Elizabeth Rivers. The broad, shallow body of water is strongly influenced by riverine and tidal flows. The tidal influence is strong but net flow is generally southeast and the dominant sediment transport is downstream toward the mouth of the Chesapeake Bay.

The Chesapeake Bay is the largest estuary in the United States. It is a partially enclosed coastal water body which extends 200 miles from Virginia Beach, Virginia to Havre de Grace, Maryland and lies within the Coastal Plain Province. The coastal-plain region extends westward from the continental shelf to the Fall Line, an extensive regional scarp, which is 15 to 90 miles west of the bay, and defines the boundary between the Piedmont Plateau and the Coastal Plain. The western shore of the Chesapeake Bay is characterized by a series of scarps and terraces that were carved in the coastal-plain sediments during a series of marine transgressions and regressions of glacial and interglacial periods.

Sea level fluctuations are also responsible for the development of the Delmarva Peninsula, which represents the eastern shore of the Chesapeake Bay. The Delmarva Peninsula originated as a barrier spit and developed southward in response to coastal marine and fluvial processes during relative sea level high and lowstands through the Pleistocene and into the Holocene. The peninsula contains progressive segments delineated by scarp features that mark the limit of maximum sea level during the Quaternary successive highstands. Hobbs III (2004) has correlated these eastern shore segments to various deposits found on the western shore.

PHYSIOGRAPHIC FEATURES OF THE WESTERN SHORE AND SOUTHERN DELMARVA PENINSULA

Scarp/Terrace (Paleoshoreline)

Scars, or rises in the topography separate the terrace features of Virginia's coastal plain. These scarps also are known as regional paleoshorelines and have been carved by maximum marine transgressions during interglacial periods of sea level highstands. Several cycles of glacial advance and retreat caused the sea level to fluctuate or regress (shoreline retreat) and transgress (shoreline advance). Prominent paleoshorelines apparent in the coastal plain topography formed during sea level stillstands. Many researchers (Wentworth, 1930; Krantz 1990; Johnson and Berquist, 1989; among others) have interpreted the history of the scarp-and-terrace region and have applied multiple terminologies to the landforms, which are summarized by Hobbs III (2004). In this report we will use the sequence as defined by Johnson and Hobbs III (1990) shown in Figure 4-1. The Chippenham scarp is inferred to be the
westernmost and oldest scarp, of Miocene Age, separating the Piedmont from the Coastal Plain Province (Johnson and Peebles, 1985). The elevation of the toe of the Chippenham scarp is at approximately 230 to 240 feet. It marks the landward limit of the Richmond Plain that extends to an elevation of about 216 feet. The Richmond plain is underlain by nearshore marine deposits most likely of the Yorktown Formation (Johnson and Ramsey, 1987).

A series of scarps and terraces have been mapped toward the Chesapeake Bay from the Chippenham scarp as seen in Figure 4-1. The Suffolk Scarp mapped by Oaks and Coch (1963) and shown on Figure 4-2 is located about 1.9 miles upstream of the MMBT test turbine site along the James River. It is defined by 30 feet of rise in less than 1150 feet of run and marks the western limit of the Windsor formation deposited during the early Pleistocene. This scarp is a very prominent scarp that can be traced regionally (over 900 ft) across the outer coastal plain of Virginia to North Carolina.

Paleoshorelines are also prevalent on the Eastern Shore. The Mappsburg Scarp, also shown on Figure 4-2, defines the 125-thousand year ago (ka) glacial highstand. It delineates the boundary between the thin section of the Eastern Shore upland, comprised of the Accomack and Nassawadox formations, and the Bell Neck Strand Plain of the Wachapreague formation east of the scarp.

Barrier Spit Complex

A barrier spit is developed through longshore drift creating a recurved island separated from the mainland. With time and a constant sediment source, the spit will accrete and prograde in the direction of the longshore current. Figure 4-4 provides an illustration of this process. At present a southward prograding spit is being built across the mouth of the bay and is prevalent in Fisherman’s Island. Sediment is currently transported southward along the east coast of the Delmarva Peninsula and is extending the tip of the peninsula southward and into the bay. Figure 4-6 shows that the accretion of sand extends beyond the island and 2.5 miles of the proposed east turbine location at the CBBT site (Colman and Mixon, 1988). The typical sedimentary record of a barrier spit complex consists of a fining-upward estuarine sequence beginning with coarse, basal fluvial gravel. It is then capped by a coarsening-upward barrier sand deposit (Mixon, 1985).

The core of the Delmarva Peninsula was formed as a southward prograding barrier spit during successive sea level maxima throughout the Quaternary. Successive periods of progradation are recorded in the Quaternary deposits of the Accomack and Nassawadox spit complexes extending down the Eastern Shore of Virginia. Figure 4-6 shows the extent of these ancient deposits as mapped by Colman and Mixon, 1988. The Accomack barrier-spit system is the oldest, northern-most spit complex that comprises the southern Delmarva Peninsula. It is succeeded to the south by the younger complex of the Nassawadox barrier-spit system, which is differentiated into two segments due to a second order sea level lowstand around 125 ka.

PHYSIOGRAPHIC FEATURES OF THE CHESAPEAKE BAY

Filled Channels (Paleochannels)

Before the development of the Delmarva Peninsula, the Susquehanna River system drained across the continental shelf during sea level lowstands and possibly connected to the Washington and Norfolk Canyons. As the barrier spit complexes prograded southward during
interglacial periods, the main stem of the Susquehanna River system was forced to turn south during the subsequent low-stands, through the shifting mouth of the bay. The incised channels were then typically filled with a fining upward channel-fill sequence and capped by the succeeding barrier spit sequence during the following high-stands. There is no indication from the available seismic data, borehole data and surface exposures of unconformities within each channel fill-barrier spit sequences. This implies that the deposits accumulated during a single transgression (Parsons et al., 2003).

Several generations of filled channels from the ancestral Susquehanna River system have been mapped within the region. Figure 4-6 presents the mapped channels of the deepest channels (main drainage stem) of the ancestral river systems that passed beneath the Eastern Shore peninsula. The successive paleochannels, decrease in age to the south and are named the Exmore, Belle Haven, Eastville, and Cape Charles paleochannels (Figure 4-7). Each paleochannel generation corresponds to a sea level lowstand event. The development of these channels and influence on subsurface conditions are discussed further in the Geologic History section of this report.

Bay-Mouth Shoals

The southern progradation of the barrier spit at the tip of the Eastern Shore Peninsula during the Pleistocene has narrowed the mouth of the Chesapeake Bay to about 11 miles, creating an area of complex interaction of bay-floor processes. The bay mouth is a transitional environment where sediments move from an open inner continental shelf to a large coastal plain estuary. Although there are seasonal and tidal variations in sediment transport within the Chesapeake Bay, bay-mouth shoals are features within this complex transitional environment that are developed by a net bayward transport of sediment (Granat and Ludwick, 1980, and Hobbs Ill et al., 1992).

Sediment budgets suggest that the net accumulation of sand in the bay is supplied by southerly longshore drift along the east coast of the Delmarva Peninsula and then swept into the bay. These processes result in a southward and bayward prograding sand deposition that may reach tens of miles into the bay. Heavy-mineral compositions and seismic data suggest the source of the sand is primarily outside the bay along the nearshore shelf (Hobbs Ill et al., 1992).

As discussed by Colman et al. (1988), the surface expression of this unit is much more complex and reflects an erosion-transportation-deposition regime. Multiple fields of sand waves are present at the surface along the crest of the shoals and within the channels. Current and sediment transport measurements by Ludwick (1974 and 1975) suggest the surface deposits are modified primarily by transient tidal flow conditions whereas the long-term structure is dependent on southerly and bayward progradation.

The bay-mouth shoals are composed mostly of uniform, predominately well-sorted, gray, fine sand (Meisburger, 1972; Berquist Jr., 1986, Colman and Mixon, 1988). The internal structure and position of these deposits are related to the near-present sea level and suggest that the bay-mouth shoal unit is less than a few thousand years old. This sand deposit covers much of the bay-mouth area. Figures 6-7 and 6-8 present contour maps of the deposit's thickness and basal surface at the mouth of the bay.
GEOLOGIC HISTORY AND SIGNIFICANT FEATURES

Flat-lying plains and terraces dominate the Coastal Plain Provenience of Virginia and are comprised of Cretaceous to Holocene age sediments deposited in a structural trough known as the Salisbury Embayment. The Salisbury Embayment extends from southern New Jersey to the Norfolk Arch of Virginia (Figure 4-2) and is characterized by the stratigraphic thinning or truncating of Cretaceous and Tertiary formations at the Fall Line, approximately 70 miles west of the Newport News/Suffolk site. These formations were deposited in fluvial, deltaic and open-shelf environments during multiple marine transgressions and regressions and are comprised mostly of sands, silts and clays that form a wedge of deposits that thicken to the east. The embayment sedimentary deposits overlie a basement complex of crystalline rocks of Precambrian and Paleozoic age, about 1,800 feet below the surface.

Table 4.1 provides a list of stratigraphic units in the upper 350 feet that underlie the study area. The units range in age from Miocene through to the present. Johnson and Berquist (1989) provide the generally accepted contemporary classification used in the Hampton Roads region. Mixon (1985) developed a framework based primarily on mapping on the Eastern Shore. Ward’s (1988) nomenclature represents a framework used prior to Johnson and Berquist (1989). We include it to provide a correlation to contemporary stratigraphic nomenclature since many maps, papers, reports, geotechnical logs, etc. available to this project and future phases of development use this scheme.

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<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Holocene</td>
<td>Alluvium / Recent Marine Deposits</td>
<td>Alluvium / Recent Marine Deposits</td>
<td>Alluvium</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Clay to silt, with variable amount of organic material, may include sand to silty fine sand near spit complexes and shoals or where marine sands are being transported into the Bay or along shorelines</td>
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<tr>
<td>Pleistocene</td>
<td>Sinepuxent, Kent Is., Wachapreague, Ironsh.</td>
<td>Norfolk Formation</td>
<td>Tabb</td>
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<td></td>
<td></td>
<td></td>
<td>Poquoson</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Silty and clayey fine sand</td>
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<td></td>
<td></td>
<td></td>
<td>Lynnhaven</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Fine to coarse sand grading upward into silty sand and sandy silt</td>
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<td></td>
<td></td>
<td></td>
<td>Sedgefield</td>
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<td></td>
<td>Clayey to shelly sand with gravel; may contain cobbles</td>
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<tr>
<td>Nassawadox</td>
<td>Octohinnock</td>
<td></td>
<td>Shirley Formation</td>
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<td></td>
<td>Butlers Bluff</td>
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<td>Sand, gravel, silt, clay and peat; surficial deposits of riverine terraces and relict baymouth barriers or bay-floor plains</td>
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<td></td>
<td>Stumptown</td>
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<td>Chuckatuck</td>
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<td></td>
<td>Omar Formation (Accomack Member)</td>
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<td>Sand, silt, clay and minor amounts of peat; channel fill sands and fluvi-estuarine deposits</td>
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<td></td>
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<td></td>
<td>Charles City</td>
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<td></td>
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<td>Sand, silt, and clay; riverine terraces, bay or shallow shelf deposits</td>
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<tr>
<td>Pliocene</td>
<td>Chowan River Fm</td>
<td>&quot;Moorings&quot; unit</td>
<td>Sand to clay and silt; beach, nearshore, shallow bay, or lagoon deposits west of Surry scarp</td>
</tr>
<tr>
<td></td>
<td>Yorktown Formation</td>
<td>Moore House</td>
<td>Sand and bedded silt, with basal gravel/cobbles; commonly extensively oxidized</td>
</tr>
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<td></td>
<td>Morgarts Beach</td>
<td>Bacon's Castle Formation</td>
<td>Sandy shelly clay that grades upward into silty sand; glauconitic, deposited in shallow marine environment, locally fossiliferous</td>
</tr>
<tr>
<td></td>
<td>Rushmere</td>
<td>Yorktown</td>
<td></td>
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<tr>
<td></td>
<td>Sunken Meadow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miocene</td>
<td>Eastover</td>
<td>Cobham Bay</td>
<td>Silty to clayey fine sand with locally shelly layers; glauconitic and micaceous; marine deposits</td>
</tr>
<tr>
<td></td>
<td>Claremont Manor</td>
<td>Eastover</td>
<td></td>
</tr>
<tr>
<td></td>
<td>St. Marys</td>
<td></td>
<td>Stiff to very stiff clay with localized shell layers; marine deposits</td>
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</table>

**Chesapeake Bay Impact Crater**

Although the study area is located in a tectonically quiet region, the meteorite that impacted near the mouth of the bay 35 Ma during the Eocene caused significant structural changes that influenced deep and shallow geology (Poag, 1995; Poag, 1997; Powers and Bruce, 1999). Post-impact deposits that overlie the crater are inferred to have been affected by post-impact compaction of the inner crater that may have lead to large, rotational block failures and have displaced deposits as young as Pliocene age (e.g. Yorktown formation). Some surface features, or their locations, such as the Suffolk scarp (Figure 4-2) and regional drainages may have also been influenced by the impact crater. We do not anticipate that deformation (if it is currently ongoing) associated with the impact crater to pose a hazard to future structures of the proposed test sites. However, the impact crater may have influenced the depositional locations of various strata (e.g. clay paleochannel infill deposits) that could influence turbine foundation designs.

The Chesapeake Bay Impact Crater, as interpreted from seismic reflection and geological drillhole data, is about 56 miles in diameter and centered about 22 miles east of the present mouth of the York River (Figure 4-2). The proposed CBBT site is located between the inner and outer rims of the crater and the proposed Newport News/Suffolk sites are located within the fracture zone near the edge of the outer rim of the crater.

The subsurface structure consists of an outer rim of terraced normal-fault blocks, covered by a 65 to 100 feet thick ejecta blanket, which encompasses a ~800 feet thick breccia
lens (Exmore Breccia, Figure 4-3). The overlying Eocene to Quaternary sediments appear to be slumping toward the inner basin and also thicken as they cross the rim into the crater. Ramsey (1992) suggests the tectonic activity effecting post impact strata ended by Late Pliocene time. Although some microseismic activity has been recorded within the fracture zone, it is uncertain whether deformation is continuing to occur.

**Buried Ancestral River Channels**

Buried paleochannel deposits are one of the primary sources of variability both horizontally and vertically within the subsurface. River incisions formed during sea level lowstands that were subsequently infilled as sea level rose result in deposits that may be dissimilar or similar, are younger, and likely have different engineering properties than surrounding deposits in which the paleochannels incised. Locations of these paleochannel deposits are typically masked by overlying nearshore marine or bay-floor deposits. The paleochannel deposits are thickest near former thalweg locations except where channels are nested (or stacked) and thin toward the channel edges. Major paleochannels are generally up to 3 Nm wide and 200 feet deep while smaller channels can be about 200 feet wide and can be about 30 to 50 feet deep in this region. Therefore, it is important to understand if where exploratory locations (e.g. borings or CPTs) are located with respect to the locations of the paleochannels if future structures may be offset from the exploration location. Seismic reflection surveys are an effective means for mapping the extent and geometry of the paleochannels while geotechnical exploration aid in defining the material infill type and its engineering properties.

The Chesapeake Bay is classified as a classic coastal plain estuary. It formed as a result of a series of marine transgressions and regressions during the late Pliocene through the Pleistocene. It is primarily fed by a dendritic structure of rivers and streams that make up the Susquehanna River system. Currently the Susquehanna River system contains three main-stem tributaries that converge within the bay to form the Chesapeake Channel that continues south through the bay entrance below Fisherman’s Island at the tip of the Delmarva Peninsula. The three tributaries 1) the Susquehanna River, 2) the Potomac River and 3) the James River contribute over 80 percent of the bay’s fresh water. Throughout the development of the estuary these tributaries have carved a progression of paleochannels beneath the southern tip of the Delmarva Peninsula, also known as the Eastern Shore of Virginia.

The paleochannels that underlie the Eastern Shore were incised by the Susquehanna River in response to sea level lowstands during successive glacial periods in the Late Pliocene and Pleistocene. As sea level rose during the interglacial periods the channels would infill with sediment from longshore currents and become capped by the southern extension of the Eastern Shore. During each lowstand, the main stem channel of the Susquehanna River was diverted south as the Delmarva Peninsula lengthened causing the progression of paleochannels to become younger toward the south.

Several generations of filled channels from the ancestral Susquehanna River system have been mapped within the region. Figure 4-6 presents the mapped locations of the deepest channels (main drainage stem) of the ancestral river systems that passed beneath the Eastern Shore peninsula. The successive paleochannels, decrease in age to the south and are named the Exmore, Belle Haven, Eastville, and Cape Charles paleochannels (Figure 4-7). Each paleochannel generation corresponds to a sea level lowstand event.
The location of the Cape Charles paleochannel, mapped through seismic reflection data interpretation, along with correlation to historical boring logs is projected just south of Fisherman’s Island. Radiocarbon dates of the paleochannel infill sediments range from 8 to 15 ka and the incision is estimated to be about 18 ka (Harrison et al., 1965; Meisburger, 1972; Colman and Mixon, 1988). In some areas the Cape Charles paleochannel is as deep as 150 and 200 feet thick. The proposed CBBT test turbine east site is located approximately 2 miles southwest of the flank of the mapped Cape Charles paleochannel. We note that Figure 4-6 presents the interpreted main stem of the paleodrainage and it is highly likely that secondary and tertiary tributaries fed into the main stem and formed a complex drainage network. Figure 4-5 presents an example of how those complex drainage networks develop during sea level lowstands, and then are infilled and masked by sediments as sea level rises. It is possible that buried secondary and tertiary tributaries may underlie the proposed CBBT site. Those channels may be on the order of 25 to 150 feet deep.

Despite being an ancestral channel, the Cape Charles paleochannel is not fully buried on the bay side of the peninsula. Currently an expression of the remnant Cape Charles paleochannel exists on the bay side of the peninsula, evident in the bathymetry data. However, there is no visible expression of the paleochannel seaward of the bay mouth. This could possibly be the result of a combined effect of the lack of sediment being transported from the river tributaries as well as the effect of tidal and storm currents eroding what small amount of sediment is accumulated within the mouth of the bay (Colman and Mixon, 1988 and Parsons et al., 2003). Conversely, higher sedimentation rates have infilled the former river valley and masked the former location of the ancestral river seaward of the bay mouth.

Since the last glacial maximum (about 18 ka), the axial channel of the bay has migrated as far as 7.5 miles from its former position over the Cape Charles paleochannel due to the progradation of the current barrier spit. The modern channel’s present position is now the Chesapeake Channel extending from the mouth of the bay past the CBBT to the open ocean.

5.0 – BAY-FLOOR CONDITIONS

BAY-FLOOR MORPHOLOGY

The mouth of the Chesapeake Bay is a morphologically dynamic area. The mouth is relatively narrow, approximately 6.8 miles, but widens up to more than 15.5 miles west of the entrance. The mouth represents a convergence zone of two depositional environments, a partially enclosed estuary and an open water environment, that have very different morphological processes. The nearshore shelf area east of the CBBT is characterized by ridge and swale topography supplied by longshore currents and southerly sediment transport. Although heavy metal analysis from sediment samples and the subsurface structure of the Holocene bay-mouth shoal suggests a net sediment transport south to southwest moving into the bay, surface features along the bay-floor suggest a strong influence by tidal fluctuations at the Chesapeake Bay mouth.

Tidal fluctuations between ebb and flood tides are the primary influence of sediment movement along the bay-floor. Side scan sonar image at location A-A’ is shown on Figure 5-3, inset A. The image shows asymmetrical flood-facing megaripples, with wavelengths less than 30 feet from within the Chesapeake Channel (Zone 1). This suggests that during the flood tide,
the higher velocity areas are at the channel axes. It is suggested that this is due to the lower surface friction associated with natural (Zone 2) and maintained (Zone 1) channels. Sand waves and megaripples also are prevalent outside the channels in the bay deposits of Zone 3 in Figures 5-1 and 5-3. These features are ebb-facing (steeper seaward than landward flanks) and suggest flow is primarily seaward. Cross section D-D' shown in Figure 3-12 displays a profile view of the bathymetry and associated slope gradient in an area containing numerous sand waves. The average amplitude (trough to crest height) is 4 feet and wavelength (crest to crest) is 750 feet in this area, located west of the Chesapeake Channel. Zone 4, which includes the shoal deposits, show evidence of lobe termination on the seaward side of the majority of the features. This suggests that the primary flow in the shallower areas of the shoals is with the ebb tide.

Inset B of Figure 5-3 provides an oblique 3-D view of the various large-scale bedforms present at the mouth of the Chesapeake Bay. Typical sand wave features are several feet high with wavelengths of 100s of feet, while megaripples are several feet high with wavelengths from 10s to a few hundred feet.

Figure 5-2 shows the prominent morphological zones within the vicinity of the proposed Newport News/Suffolk test sites. The proposed Newport News test site is located in Zone 4, on the Newport News Bar. The Newport News Bar is a shoal feature that shows dominant surface flow in the flood direction to the south-southwest. The test turbine site is located about 1,500 feet north of the Newport News Channel and approximately 500 feet north of a naturally developed channel that is about 10 ft deeper than the elevation at the proposed test turbine location. The water depth at the proposed east inner test turbine is about 11 feet and is located at the boundary between the Craney Flats (Zone 5) and the bay deposits (Zone 3).

BAY-FLOOR SEDIMENTS

Hydrodynamic forcing mechanisms shape the bayfloor today and will be the mechanisms that drive sediment transport and scour processes that will affect project development in the Chesapeake Bay. The extent of sediment movement and transport cannot be quantified (based on the data available for this study) in the bay mouth, but historical processes can give us insight into the stability of the features.

Sedimentation rates vary largely across the Chesapeake Bay region, from 0.1 to greater than 1.0 cm yr⁻¹. Brush (1989) reported that sedimentation rates obtained from 39 cores in 10 tributaries of the Chesapeake Bay average 0.30 cm yr⁻¹. Rates were higher in the upper portion of the tributaries and lower at the mouth. As much as 40% of the bay's net deposition enters the bay mouth from northern longshore drift. Hobbs III et al. (1992) reports that between 1.0x10⁹ and 2.92x10⁹ metric tons of sediment accumulated in the bay in a 100-year-span ending in the mid-1950s.

Bay-floor sediments play a critical role in the following wind turbine aspects:

- Grain size is a critical parameter for evaluating scour and sediment transport hazards,
- Evaluating how the introduction of wind turbine foundations and cable trenches will increase scour and erosion susceptibility,
Conducting cable burial assessments, and
Selection of cable installation equipment.

Proposed CBBT Test Site Area Bay-floor Sediments

Longshore drift transports sediments south along the eastern coast from a northern source causing fine-grained sediments to be deposited toward the bay mouth. Therefore, the surficial sediment in the bay mouth is predominantly fine to very fine loose sand. Sediment grain size grades to gravelly pebbly sand toward the shorelines where Pleistocene units outcrop. Coarse gravelly Pleistocene sand is also exposed in Thimble Shoal Channel, the southernmost channel at the bay mouth. Dredging in the Thimble Shoal Channel area for beach nourishment projects encountered gravel and cobbles that likely represented older, Pleistocene age sediments exposed or shallowly buried beneath the Holocene marine sands.

Within the proposed test site area, the surficial sediments are generally comprised of the bay-mouth shoal unit. The unit consists of quartzose sand with shell fragments and mica. Predominant grain size is fine-grained sand with lesser amounts of medium and very fine-grained sand and silt. Meisburger (1972) reported the upper 12 feet in 95 samples that the average mean particle-size diameter of the deposit was 0.147 mm with a standard deviation of 0.024 mm. It is also postulated that in this area of the bay-mouth shoals, grain size shows no pronounced relation to the bathymetry (Meisburger, 1972; Colman et al., 1988; Colman and Mixon, 1988). Bedding in the bay-mouth sand is massive, however small fining-upward sequences have been observed. Data suggest the sand appears to be finer toward the center of the bay mouth and grades to coarse sand and locally gravel near the shoreline. It is underlain by an erosional unconformity that represents the upper limit of the Tertiary nearshore marine deposits, primarily the Yorktown Formation. Locally, the bay-mouth sand deposit overlies thick and soft, fine-grained Quaternary channel infill deposits.

Outside the bay-mouth shoal deposits, finer-grained sediments are interlaced in the natural channels of the bay mouth. The fine-grained sediments are commonly thin veneers and may be underlain by sandy layers. During large storms, the fine-grained sediments may be ripped up thus exposing the underlying sandy sediments (Swift, personal communication 2010). During fair weather conditions, the fine-grained sediments may begin to accumulate in the swales once again. Fine-grained sediment accumulation in the channels, thus indicates areas where bottom currents are not as strong as areas where sandy sediments are the predominant sediment type.

Proposed Newport News/Suffolk Test Site Area Bay-floor Sediments

Surficial sediments from bottom samples in the vicinity of the proposed Newport News/Suffolk test sites vary from sandy clay and silt in the bay deposits (Figure 5-2, Zone 3) to fine to medium sand with silt at the Craney Flats (Figure 5-2, Zone 5) and silt to silty sand in the natural channels to the north (Figure 5-2, Zone 2).

Sediment Transport and Cabling Considerations

Storm events, primarily nor'easters and hurricanes, are the driving force for sediment transport within the Chesapeake Bay. The storms bring increased wind speeds, current velocities, and orbital wave motions that resuspends sediment on the bay-floor. The loosened
sediments are then susceptible to transport by lower energy tidal processes (Cronin et al., 2003). Future structures should take into consideration the potential for sediment transport and scour induced by storm conditions.

Cabling and turbine installation will disturb the fine-grained sediments, thus increasing the seabed roughness and friction along the water-seabed interface. This effect will increase the potential for erosion or scour along cable trenches and around turbines.

Gravelly deposits can create difficult conditions for installing cables to the target burial depth. Multiple passes may be required to install cables in gravelly areas if they cannot be avoided. If cables cannot be buried to target depth, then burial protection from fishing and anchoring activities will be reduced. Cable protection measures (e.g. rock dump, concrete mats, etc.) may be required to protect cables if they cannot be buried due to gravel or hard substrate.

6.0 - SUBSURFACE STRATIGRAPHY AND CONDITIONS

AVAILABLE SUBSURFACE DATA FOR REVIEW

Subsurface data is limited in the vicinity of the proposed test turbine sites. Data that exist within the test turbine project areas are generally limited to shallow (<20 feet deep) vibrocoring exploration programs for sand search programs and typically do not penetrate to the Tertiary units. Several historical seismic reflection survey studies were performed at broad regional scales and provide regional scale information. Few seismic reflection surveys related to navigation channel dredging programs are also available. Available geotechnical and geophysical data in the surrounding areas of the proposed CBBT and Newport News/Suffolk test sites are shown in Figures 6-1 and 6-2.

Geotechnical borings conducted in the 1960s for the construction of the Chesapeake Bay Bridge-Tunnel includes over 90 borings. Those borings were used to provide support for regional seismic reflection surveys and subsurface interpretation reported by Harrison et al., 1965; MEISBURGER, 1972; BERQUIST JR., 1986; Colman et al. 1988; Colman and Mixon, 1988. Figure 6-3 provides a geologic cross section along the CBBT alignment based on the borings and seismic reflection surveys performed in the 1960s (Colman and Hobbs III, 1987).

Approximately 70 borings were drilled in the late 1970s for the MMBBT project. The borings penetrated up to 230 feet deep. Figures 6-4 and 6-5 present a geologic profile from along the MMBBT and include soil types and standard penetration test blow counts from the 1970 borings.

In addition to the regional and navigation channel seismic surveys, Fugro conducted a self-funded regional test survey program to test latest developments of seismic reflection technology in the area. Test program tied survey lines into regional subsurface exploration locations and transected key geologic features of interest. One of the test lines (Line 415) is located parallel to the MMBBT and is in close proximity to the proposed Suffolk test site (Figure 6-2).

In terms of subsurface materials that will influence wind turbine foundations, the upper 150 to 300 feet of materials within the study area are likely to be comprised of Holocene,
Pleistocene, and Tertiary aged materials. Turbine foundations that may be embedded on the order of 100 to 150 feet below the bay-floor will likely penetrate Holocene sediments and be embedded into Pleistocene or Tertiary deposits. Therefore, as described in Section 5, geologic processes occurring during the Quaternary (last 1.6 million years and includes the Pleistocene and Holocene) will have the most influence on the design and installation of turbine foundations.

**Holocene Age Sequence**

The surficial (uppermost) Holocene age sediments are generally a sequence of baymouth sand deposits and marsh/fluviial-estuarine deposits. As the sea level rose from last glacial sea level low-stand about 18,000 years and the shoreline transgressed throughout the bay, a channel-fill sequence infilled the incised fluvial channels and former drainages within the estuary. The channel-fill sequence typically consists of sand and gravel lag deposits at the base and grades upward into finer-grained sediments (e.g. silt and clay). The fine-grained sediments are typically normally consolidated and increase with depth from very soft to firm.

**Proposed Chesapeake Bay Bridge-Tunnel Test Site**

The fine-grained, estuarine and organic marsh deposits infilled the channels and deposited behind pockets of localized gravel and coarse grained sediments. Then as the sea level continued to rise, barrier-spt sediment were deposited in concurrence with the fine-grained sediments in the bay-mouth region. As the area transitioned to a partially enclosed, estuarine environment, a blanket of marine sand from longshore drift outside the estuarine mouth was transported and deposited at the bay mouth and up to tens of miles into the bay called the bay-mouth shoal deposits. The bay-mouth sand sheet is generally comprised of fine to medium grained sands. The modern sand sheet and underlying barrier-spt deposits may have a combined thickness of 3 to 20 feet; however, it is interpreted to infill the former Cape Charles Channel located just below Fisherman’s Island where it is roughly 160 feet thick.

Figures 6-7 and 6-8 are structural contour maps that display the depth to the base and isopach thickness of the bay-mouth shoal deposits, respectively. Although the sand is blanketed over much of the Chesapeake Bay region the contoured extent shown in Figures 6-7 and 6-8 is limited to the thin distinctive deposit from Cape Charles to the Chesapeake Channel. This data is modeled after Coleman et al. 1988 contours and based on more than 100 cores, deep borings from the Chesapeake Bay Bridge-Tunnel (Harrison et al., 1965; Meisburger, 1972) and numerous shallow vibrocores. The thickest section is located over the mapped extent of the Cape Charles paleochannel and thins to less than 16 feet toward the Chesapeake Channel. The sand also thickens to 65 feet at Nine Foot Shoal. The sand unit typically has a very low fines content (<10%) and penetration resistance can range from low to high.

The marsh and fluvial-estuarine deposits are expected to be normally consolidated soft to firm clay with local varying amounts of organics and peat. Typically, they are expected to be about 10 to 20 feet thick, but where they infill former river valleys and paleo-drainages they may be significantly thicker, up to 90 feet thick. The cross section shown on Figure 6-3 shows an example of those fine-grained Holocene deposits. The peat and organic mud is typically found within the paleo-drainages, underlying the soft clay deposits and is approximately 10 to 30 feet thick. The sequence found below the Tail of the Horseshoe shoal in Figure 6-3, includes 15 feet of sand, 18 feet of sandy clay, 20 feet of soft organic sandy clay, and 10 feet of peat.
Proposed Newport News/Suffolk Test Sites

The 1970s borings along the MMMBT alignment encountered soft alluvial Holocene clay of variable thickness. The clay sediments are about 5 to 20 feet thick near the Newport News approach, and about 20 to 25 feet thick beneath the Suffolk/Portsmouth approach of the MMMBT. The soft clay thickens where the marine deposits infilled deeper fluvial incisions near the center of the modern channel of the James River. In the thickest areas, the soft clay is approximately 100 feet thick which corresponds to a basal elevation of about El. -120 feet. The transition zone of soft clay from 20 to about 75 feet thick projects southwest of the proposed Suffolk test sites, thus suggesting that the clay beneath the proposed sites could be more than 50 feet thick.

Three borings (V78B-167 through -169) near the Suffolk/Portsmouth approach encountered primarily sandy sediments and the clay was interpreted to be less than 5-feet thick or absent (Figure 6-4). The basal elevation of this unit near the Suffolk approach was approximately El. -30 to -38 feet and in one localized area (boring V78B-170) it was nearly El. -50 feet. The base of the Holocene deposits is interpreted to be shallower along the Newport News approach is between about El. -28 to -35 feet.

Seismic reflection data along Fugro boomer line 415 displays Holocene deposits (Units 1a, 1b, and 1c) that are bounded below by an erosional surface, reflector H50 (Figure 6-11a). Unit 1a likely consists of fine-grained, clayey sediments, approximately 15 to 25 feet thick, and is characterized by low amplitude, broad, channel-like reflectors. Unit 1b, approximately 20 feet thick (where present) contains contrasting high-amplitude reflectors dipping toward the navigation channel. Unit 1b is likely sand to interbedded sand channel infill sediments. Unit 1c underlies Unit 1a and is bounded above by reflector H30 and below by the erosive reflector H50. Unit 1c of the Holocene deposits contains high-amplitude and highly channelized internal reflectors believed to be sandy to interbedded fluvial sediments.

Pleistocene Age Sequence

At least four major glacial cycles occurred during the Quaternary. During Pleistocene glacial stages, the continental shelf was subjected to subaerial erosion and to deposition during and subsequent to the periods of rising sea level. The result has been the working and reworking of the pre-Quaternary sediments that underlie the Pleistocene, and the working and reworking in turn of the glacial and interglacial sequences that were subsequently deposited. In some instances, individual Pleistocene units were entirely eroded. In other instances, several units of the Pleistocene lay one above the other. The complex stratification corresponding to each interglacial stage will probably never be sorted out satisfactorily. The distinction between the Holocene and the underlying Pleistocene on the other hand, is less complex. The surface between the Holocene sediments and Pleistocene sediments represents an erosional or ravinement surface that has deeply incised the subaqueous surface of the Pleistocene sediments through fluvial processes.

Proposed Chesapeake Bay Bridge-Tunnel Test Site

Much of the Pleistocene section along the CBBT alignment is interpreted to be eroded away. Small localized areas (e.g. near the Thimble Shoal Channel) contain sections of the Pleistocene deposits. Beneath the shore crossings of the CBBT the Pleistocene section is
between 50 to 110 feet thick. As previously mentioned, erosion during sea level lowstands and tidal flushing across the constrained bay mouth likely resulted in stripping away much of the Pleistocene deposits and non-deposition. However, surveys farther seaward (e.g. in the Thimble Shoal and Atlantic Ocean channels) encountered Pleistocene sediments that are 10s of feet thick.

**Proposed Newport News/Suffolk Test Sites**

Due to the complex nature of the subaerial erosion and submerged deposition, the thickness on the continental shelf of the Pleistocene sequence is poorly known and is likely variable. Boring data at the Monitor Merrimac Bay Bridge-Tunnel (Figure 7-6) indicate the Pleistocene section is only on the order of 15 to 40 feet thick at the Suffolk approach and 70 to 120 feet thick at the Newport News approach. Elevation decreases to about -100 feet at the bridge center. Erosion has stripped away the majority of the Pleistocene at the bay mouth (Figure 6-3) and deposited Holocene sediments directly on the Tertiary in most areas.

The subsurface at the proposed Newport News/Suffolk site is interpreted to contain the Sedgefield Member and the Lynnhaven Member of the Pleistocene Tabb Formation. The Tabb Formation is a terrace deposit that is bounded landside by the Suffolk Scarp and has variable thickness beneath Todd's flat (Figure 4-1). It is a fining upward sequence, sub-divided into three members of different lithology. In order of decreasing age and surface elevation, the members are the Sedgefield, the Lynnhaven, and the Poquoson. The Sedgefield Member is a clayey to shelly sand deposited under lagoonal-marsh conditions with pebbles and boulders present at the base from a fluvial-beach environment. The Lynnhaven Member is characterized by clayey sand and sandy clay or silt deposited as beach and nearshore-marine sediments. The Poquoson Member, deposited on a series of beaches as sea level fell is characterized by silty and clayey sand with scattered thin gravelly sand lenses. The Tabb Formation is considered to be of Late Pleistocene age based on fossils found within the Sedgefield Member (Johnson, 1976).

The seismic reflection data shown on Figure 6-11a presents two seismic packages characterized by parallel to sub-parallel reflectors that likely correlate with the Lynnhaven and Sedgefield Members of the Tabb Formation. Unit 2 is interpreted to consist of sandy sediments, likely of the Lynnhaven Member. Unit 2 is of variable thickness and bounded above by an erosive surface (labeled H50) that causes the section to be absent in some areas. Underlying Unit 2, at an approximate elevation of -70 feet, is a strong reflector labeled H60. Reflector H60 caps Unit 3, the Sedgefield Member. Unit 3 is approximately 50 feet thick and contains high-amplitude internal reflectors in the upper section.

The Poquoson Member is not prevalent in the study area and is presumed to be eroded completely. The Lynnhaven Member is interpreted to outcrop in Virginia Beach at the southern portion of the CBBT (Figure 6-3) where it is about 10 feet thick and also underlies the Holocene clay at the Newport News approach of the MMMBT (Figure 6-5) where it is about 40 feet thick.

The gravel and sandy Pleistocene sediments are expected to have greater penetration resistances than the overlying Holocene sediments. Fine-grained sediments (e.g. clay) were likely subaerially exposed during sea level lowstands, possibly had thicker overlying sediments that were subsequently removed by erosion; thus, meaning the clays will likely be slightly to moderately overconsolidated.
Pre-Quaternary Sequence

Tertiary and Miocene age sediments underlie the Quaternary deposits to an elevation of about -200 feet, MLLW. The Tertiary deposits underlying the Quaternary deposits in the study area generally consist of the Yorktown Formation. The Yorktown Formation is an extensive nearshore marine deposit of sandy shelly clay that grades upward to quartzose silty sand. The bedding is massive and compact with discontinuous layers of shell, up to 2 feet thick, and thin lenses of clayey silt. The clay content decreases upward in the deposit, while the shelly beds become more abundant. Within the Hampton Roads area, the Yorktown Formation is a common end-bearing stratum for pilings that support waterfront structures, bridges, and buildings.

The Eastover and St. Mary’s Formations underlie the Yorktown Formation found in the project area and are identified as Miocene age. The Miocene is characterized by long periods of marine transgression with constant sedimentation bounded by short regression periods causing the formations to become unconformably bounded.

The Eastover Formation generally underlies the Yorktown Formation and is divided into two members. The Cobham Bay member is comprised of shelly, well-sorted sand that overlies the Claremont member, a silt clay to clayey sand with clean sand at the base. The St. Mary’s Formation commonly underlies the Eastover Formation in the study area. It is the first post-impact-crater unit that extends across the region. The St. Mary’s formation is characterized by stiff to hard, well sorted, greenish gray to dark gray, very fine sandy clay with scattered shells.

Proposed Chesapeake Bay Bridge-Tunnel Site

At the mouth of the bay, Tertiary deposits are typically found directly below the recent Holocene deposits bounded by a fluvial erosional surface. Most of the Pleistocene strata were removed through the constant erosion and reworking of sediments at the mouth of the bay during glacial-interglacial cycles. Locally, Quaternary sediments may be absent and the Yorktown Formation may outcrop at the bay-floor as seen in cross section CBBT-CBBT’ at Thimble Shoal Channel (Figure 6-3). The Yorktown thickness is highly variable in the area and can range from 10 to 100 feet. Pleistocene channels possibly cut through to the Miocene sediments in some areas the Yorktown may be absent.

A structural contour map of the erosional surface at the base of the Quaternary sediments is provided in Figure 6-9. This map is based on seismic reflection data as well as geotechnical boring data (Meisburger, 1972). Contours shown on Figure 6-9 reveal two, large paleochannels (denoted as Channels A and B). Channel A, north of the proposed test turbine site coincides with the mapped Cape Charles paleochannel. The proposed east WTG site is located along the flank of Channel A where the base of the Quaternary deposits is mapped at a depth of 90 to 100 feet below MLW. Channel B may contain 20 to 60 feet of soft organic clay beneath the sandy bay-mouth deposits. Clay thickness within paleochannels at the entrance to the Chesapeake Bay could have future implications on foundation designs.

Available geotechnical information in the bay mouth does not penetrate to the Miocene sediments. However, Meisburger (1972) mapped a “prominent reflecting surface” within the Tertiary strata. This surface, approximately -180 ft, MLLW, is shown on cross section CBBT-CBBT’ (Figure 6-3) and is possibly the surface of Miocene age sediments in the project area.
The seismic character is described as an evenly bedded with multiple parallel reflectors below the key reflector. This key reflector dips below the seismic record coverage in the south and is difficult to map. The general structural trend of the unit is illustrated in Figure 6-10.

*Proposed Newport News/Suffolk Sites*

Cross sections SS-SS' and NN-NN' show the Tertiary and Miocene sediments underlie the present Pleistocene deposits (Figure 6-4 and 6-5). The Tertiary consists of the Yorktown Formation and is generally 30 to 100 feet thick. In this area it is characterized by intermixed sandy clay and silt to silty sand. The Eastover Formation is interpreted below the Yorktown at an elevation -150 to -180 feet, MLLW. It is characterized by silty sand grading upward to compact fine sand.

Four borings along the MMBBT are interpreted to penetrate the St. Mary's Formation. Where samples have been obtained, the deposits are described as green, silty clay with trace amounts of shell. The surface is mapped at an average elevation of -200 feet, but the total thickness is unknown.

The seismic reflection data along boomer line 415 in Figure 6-11a and 6-11b displays a package, approximately 50 feet thick, of flat-lying parallel reflectors that are interpreted to be shallow marine deposits, likely of the Yorktown Formation.

The reflection data also shows two deep, strong reflectors, interpreted at elevations around -165 feet and -200 feet. The reflectors, labeled H90 and H100 in Figure 6-11a, can be mapped laterally into the project area to align with the interpreted surfaces of the Eastover and St. Mary's Formation respectively.

**VARIABILITY OF MATERIALS**

The primary geologic features that create subsurface variability and that may potentially affect the foundation design of wind turbine test structures are paleochannels within the subsurface. Paleochannel features may cause considerable horizontal and vertical variation of material types and strength. The paleochannel infill may include soft, fine-grained sediments; coarse granular (sand + gravel) sediments; and/or coarse basal lag gravels that fine upwards in sequence. Figures 4-4, 4-5, and 4-7 present examples of how the channels formed, are infilled, and subsequently buried.

Various paleodrainages are mapped in the Chesapeake Bay region and are presented in this report. Figure 6-9 displays the depth to the base of the erosional surface at the CBBT site and a schematic of the subsurface strata underlying the CBBT is presented in Figure 6-3. Profiles along the MMBBT are shown in Figures 6-4 and 6-5. Fine-grained material of Holocene age is interpreted to fill an incised channel in the James River to an elevation of -120 feet.

Figure 4-6 show the locations of Quaternary paleochannels interpreted by various studies. The inferred location of the Cape Charles channel projects north of the proposed wind turbine test sites at the mouth of the Chesapeake Bay. Several studies in the area have mapped smaller scale channels at the mouth and within the tributaries of the Bay. Therefore, it is likely that a network of drainages underlie the study area, and has not yet been mapped.
INFERRED ENGINEERING CHARACTERISTICS OF SUBSURFACE SEDIMENTS

From the mouth of the bay to the James River, the engineering character of the soils underlying the area varies over a considerable range as suggested by the geologic model. It is not possible, nor is it advisable to attempt to assign quantitative engineering properties to different soils. Even for a given soil stratum, the properties can vary significantly in both vertical and lateral directions. The following is an attempt to provide a qualitative and preliminary evaluation of the anticipated engineering characteristics of soils in the study area, postulated on the basis of limited boring and test data and the proposed geologic model.

The Holocene clays and silts within most of the study region are probably normally consolidated with low to medium strengths. Some of the Pleistocene and older deposits may be overconsolidated and therefore relatively stronger than they would be in a normally consolidated state. The state of overconsolidation probably resulted from subaerial desiccation and shrinkage during low sea levels and to a lesser degree, erosion of former materials that once overlaid the sediments. However, the extent of any such strengthening depends upon the duration and intensity of exposure.

The Mid- and Early-Pleistocene stratigraphy is likely complex. There may be one, two, three or four sequences of Pleistocene sediments that correspond to the major sea level fluctuations, or in some areas the Pleistocene sediments may be absent entirely.

The depth and width of paleochannels also will be highly variable. The size will reflect whether they are primary, secondary, tertiary, etc. tributaries with the former paleodrainage network. Figure 4-7 illustrates how successive channels could possibly be of similar width and depth, yet differing age and compaction.

Based on available blow count data, the Tertiary and Miocene sediments are likely medium dense to dense/stiff to hard. If shell and gravel-size particles contained in the fine to medium sand contributed to the observed high penetration resistance in some of the borings, density evaluations based only on penetration resistance may be misleading. The relatively dense condition of the near-surface fine to medium sands is probably a result of reworking by ocean currents and wave action. In areas where fine to medium sand is intermixed with silts and clays, densities are probably lower.

7.0 – GEOHAZARDS

SEDIMENT TRANSPORT AND SCOUR

Significance of Sediment Transport and Scour

Sediment transport and scour are potentially one of the most significant geohazards for future offshore wind structures. Ocean currents and waves, as shown in Figure 7-1, are expected to be capable of transporting sediments up to tens of miles into the Chesapeake Bay. Migration of seabed waves (e.g. dunes and sand waves) and scour around wind turbine structures (Figure 7-2) and cable trenches has been a significant geohazard for some European wind farms. At some European wind farms, mitigating scour has been costly and difficult. In the extreme, scour has locally created unexpected risk for the structural performance of wind turbines or compromised the delivery of energy through inner array and export cables.
The study area is in an area prone to bottom currents and tidal variations that are expected to be capable of transporting sediments and causing scour at wind turbine sites. Evaluation of the data in this study reveals the presence of morphologic features that support that inference. Figure 5-1 and 5-2 shows features created by bottom currents, from both tidal and net transport into the bay mouth. Nor’easter events can amplify sediment transport processes in the project areas.

Sediment transport processes may result in net erosion or deposition. Erosion processes may be problematic for structures if scour occurs at the base of the structure (Figure 7-2). Removal of material can reduce skin friction, reduce lateral resistance, soften the load-response of the foundation, and/or modify the resonance of the turbine structure. Sediment transport is based on an interrelationship between seabed sediment type and bottom flow conditions. Figure 8-3 presents a relationship between those properties.

The bay-floor and seafloor morphology revealed in the bathymetry data suggest that the mouth of the Bay is a hydrodynamically complex area influenced by tidal and wave conditions. The morphology reveals areas that are ebb and flood tide dominated as discussed previously (i.e. Figure 5-1). The bedforms also illuminate areas subjected to higher versus lower bottom current speeds. Assuming that sediment type and water depth are constant, local scour depth around a pile will be greater in areas where bottom current speeds increase.

**SHALLOW GAS HAZARDS**

We reviewed Fugro geotechnical, site characterization, and geophysical survey reports of various projects within the Chesapeake Bay region to provide insight into the potential for shallow gas hazards. Biogenic gas is present in the Quaternary sediments within the Bay area. Gas is interpreted in seismic records and documented on geotechnical logs during exploration surveys. The gas likely accumulates as organics in lagoonal, paleo-channel infill, and fluvial-estuarine deposits decay and then accumulates in overlying sandy deposits. Shallow hazard surveys can be conducted to evaluate the potential for shallow gas hazards prior to drilling or installation.

**TSUNAMI**

A tsunami is a series of sea waves generated by rapid displacement of a large volume of sea water. The rapid displacement of water may result from vertical warping of the seabed, large scale submarine or coastal landslides, or volcanic eruptions in or near ocean basins. Tsunami waves are generally produced by displacement of the seafloor during an earthquake. Uplift of the seafloor elevates the sea surface upwards, while subsidence of the seafloor produces a drawdown of the sea surface. Tsunami waves may also be triggered by offshore landslides. Tsunamis are usually described as local- or distant-sourced. The potential for significant, local-sourced tsunamis is probably small, but distant-sourced tsunamis may have a higher potential. Distance-sourced tsunami areas may include earthquakes generated in the Caribbean region, Azores region, or New Foundland area. Although areas on the US Atlantic continental slope may be considered potentially unstable, the potential for tsunamis generated from submarine landslides on the slope that could reach the Hampton Roads coastline are considered to be very low.
In the open ocean, distant-source tsunami waves have a very long period and wavelength and can travel at speeds of greater than 300 miles (500 km) per hour. As a tsunami moves into shallow water, the wave height increases, and the wavelength and speed decreases. Historical records indicate that the character of tsunami waves varies greatly depending on factors such as the shape of the coastline, coastal seafloor topography, the existence of offshore islands, and the direction of the incoming waves.

There are no tsunami run-up heights documented within 50 nautical miles of the project area. The closest documented tsunami waves are along the Maryland eastern shoreline (Figure 7-5). A run-up height of 0.3 m was documented in Ocean City, Maryland in 1929. Two more waves reached the shore further south near Chincoteague Island in 1821, but no run-up heights are available. Other run-up locations in the Mid-Atlantic region are labeled in Figure 7-5 including one in South Carolina that reached Charleston in 1929 with a height of 0.12 m.

The likely most significant affects of a tsunami would be an increased rate of scour around the base of a turbine to erode sediments and expose buried cables. Loading affects on a turbine structure would not be considered to be significant.

8.0 – CONCLUSIONS AND IMPLICATIONS

SITE AND SUBSURFACE CONDITIONS

Bay-Floor Topography

The water depth in the three potential VOWTS development areas are as follows: 1) CBBT - 20 to 30 feet, 2) Newport News site adjacent to MMBBT - 12 feet, and 3) Suffolk site adjacent to MMBBT - <5 to 15 feet.

The bay-floor bathymetry is relatively flat and gentle in the Newport News and Suffolk sites areas adjacent to the MMBBT. In contrast, the potential VOWTS site adjacent to the CBBT is underlain by more complex bay-floor topography that results from the highly dynamic oceanographic conditions at the bay mouth. The dynamics are created by tidal processes, littoral drift, and wave conditions, and their interrelations.

The very shallow water at the Craney Flats site to the east of the MMBBT off Suffolk may limit access of large marine plant required to install offshore-scale wind turbine generators and their associated foundations and towers.

Ocean Conditions

The oceanographic conditions, such as tidal currents and storm-generated bottom currents are anticipated to be greater and of more significance to the VOWTS development at the CBBT than at either of the MMBBT sites. Scour is anticipated to be a significant design consideration at the CBBT site.

Subsurface Stratigraphy and Conditions

The subsurface conditions in the three potential VOWTS development areas are summarized as follows:

- The CBBT location is in an area adjacent to both navigation and natural channels. Some of the area may be underlain by relatively soft clay paleochannel infill. The
potential for laterally varying subsurface condition is significant. If the test WTG location is underlain by relatively soft clay paleochannel infill, a deeper and larger foundation will be required than if the WTG is located outside of a paleochannel.

- The Newport News site at the north end of the MMBT is anticipated to be underlain by relatively competent sediments.
- In contrast, it is probable that the Suffolk site near the south end of the MMBT is underlain by about 50 to 75 feet of soft clay. Nearby (along the axis of the eroded fluvial channel) the clay thickens to as much as 100 feet. The locations of the ancestral James River and Nansemond River channels relative to the proposed Suffolk test sites are uncertain. Based on our review of subsurface information within the vicinity, the surficial alluvial soft clay transitions from 20 to about 75 feet thick. The transition zone projects to the southwest of the proposed sites, thus suggesting that the clay beneath the proposed sites is about 50 to 75 feet thick. Deeper and larger foundations may be required for a WTG at the Suffolk site than at the Newport News site.

We note that the potential presence of thick soft clays in the proposed CBBT and Suffolk development areas may provide the opportunity for constructing a more flexible WTG foundation (as compared to a site not underlain by soft clay) that will, to some extent, emulate deeper water conditions underlain by competent soils.

**IMPLICATIONS OF PROJECT SITE AND SUBSURFACE CONDITIONS**

**European Lessons Learned**

The last decade of offshore wind development in Europe has provided the following lessons learned (McNeilan and Hodgson, 2011):

- All offshore wind projects pay for a quality ground investigation, whether one is conducted – or not.
- Scour can develop quickly around foundations (particularly large diameter monopiles) and in areas of ground disturbance created by WTG and cable installation. The scour tends to be most significant in areas of shallow water, variable seafloor topography, and significant tidal flow.
- Slippage across the tower-transition structure-foundation interface on monopiles has required costly remediation after several years of repeated cyclic loads.
- Monopile foundations may currently be being used for larger (and heavier) WTGs and in deeper waters than is optimal. The induced stresses across the transition structure grout interface from bending loads in the foundations may have contributed to grout slippage.

How the expected seafloor and subsurface conditions at the proposed VOWTS locations may relate to those lessons learned are discussed below.

**Quality Ground Investigations**

Many of the initial offshore wind projects in Europe suffered from untimely, inadequate and/or poor quality ground investigations. The untimely, poor quality or limited scope
geotechnical data led to bad assumptions, poor designs, and installation difficulties, which caused delays and cost over runs.

It is therefore important that the ground conditions under potential WTG test locations be investigated using appropriate offshore drilling, sampling, and in situ testing methods, such as are required by the U.S. Department of Interior’s Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE, 2009, 2010, 2011) for offshore energy structures. While the VOWTS will not be located in an area regulated by BOEMRE the use of traditional land-based drilling and sampling methods and the resulting sub-standard data will: 1) add uncertainty to (and potentially either unconservative or overly conservative) foundation design, and 2) reduce the potential to measure and calibrate structure performance to subsurface conditions and soil-structure interaction effects.

Scour

Scour is anticipated to be a potentially significant geohazard at the CBBT location. Scour should be thoroughly evaluated based on quantitative bottom current measurements and characterization of the bay-floor sediments. Mitigation and contingency remediation measures should be included in the project development process. In addition to the potential that scour around the WTG foundation could change the performance character of the WTG foundation and its soil-structure interaction, the potential for scour to undermine the WTG’s power cable (particularly at the exit from the WTG J-lube and adjacent to a CBBT pier) should be considered.

Scour hazards at the MMBT sites are anticipated to be less severe, but should nevertheless be considered in the design and monitored.

Transition Piece Grout Slippage

While the design of the grout at the tower-transition structure-foundation connection is a structural detail (as opposed to a geoscience consideration), we draw the attention to the importance of the design detail.

Monopile Foundation Considerations

Monopiles are comparatively short and large diameter foundations, as compared to foundation piles supporting jacket (or similar) structures. Thus, whereas, the piles supporting a jacket structure transfer significant load as axial load, monopiles transfer load as lateral load. Because monopiles are relatively short, they are relatively stiff and rotate relative to a point of fixity. Large numbers of large cyclic loads can reduce the soil stiffness and increase the pile-head deflection and change the foundation’s period of vibration. If scour occurs around the monopole, the point of fixity is translated deeper and the pile-head deflection will increase. Care should be exercised during design to evaluate such phenomena.

OTHER CONSIDERATIONS

Offshore -size WTGs are very large and heavy structures. The operations of a 5+ MW WTG has been compared to mounting and rotating a Boeing 747 at the top of a 100+-meter-long pole.
Installation of the foundation, tower and nacelle for a large offshore wind WTG requires large, marine construction equipment. The design of a WTG and associated tower and substructure/foundation should consider the availability (or lack thereof) of appropriately-sized marine plant.

We discourage the use of non traditional foundations for the test WTGs. WTG system interactions (i.e. nacelle-tower-substructure/foundation interactions) and soil-structure interactions effects may be different for non traditional foundations than for traditional substructure foundations.
9.0 - REFERENCES


_________ (2007b) "Chesapeake Bay Entrance," Nautical Chart 12221, 79th edition, scale is 1:80,000, June.

_________ (2008a) "Cape Charles to Norfolk Harbor," Nautical Chart 12222, 50th edition, scale is 1:40,000, September.


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PROJECT LOCATION MAP
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

LEGEND
- Virginia Interstate Highway
- Major Road/Route

Proposed Test Turbine Sites
- East
- Alternate

CBBT = Chesapeake Bay Bridge-Tunnel
HRBT = Hampton Roads Bridge-Tunnel
MMMBT = Monitor Merrimac Memorial Bridge-Tunnel
ER = Elizabeth River

FIGURE 1-1
Typical water depth ranges are depicted above for various foundations installed to date. Modified from Musial et al. (2006) and Lang et al. (2009).

Note: Illustrations are not to scale.

TYPICAL WATER DEPTH TRANSITIONS
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia
REGIONAL BATHYMETRY
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

Source: NOAA (2007)
LEGEND
Bathymetry

- 5-Foot Contour Interval
- Bathymetry - Feet (MLLW)
- -150

Source: NOAA (2007)

STUDY AREA BATHYMETRY
Proposed Chesapeake Bay Bridge-Tunnel Site
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

Proposed Test Turbine Sites
- East
Approximate Location of
Proposed 50' Wide Cable Route
+ Coordinate Grid, WGS 84

FIGURE 3-3
LEGEND
Bathymetry

6-Foot Contour Interval

Bathymetry - Feet (MLLW)

BATHYMETRY
Proposed Newport News and Suffolk Sites
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

Proposed Test Turbine Sites

○ East

○ Alternate

+ Coordinate Grid, WGS 84


FIGURE 3-5
Figure 4-1. A generalized profile along the James-York Peninsula from the vicinity of Richmond to Chesapeake Bay depicting the landform and underlying stratigraphy. Although the approximate vertical scale is indicated, the horizontal dimension is not to scale.
Note: Borehole locations shown on map represent the 16 borings displayed on profile B-B’. A total of 139 regional borings are included in Powers and Bruce, 1999, Appendix 1A.

LEGEND

- Virginia Interstate Highway
- Major Road/Route

Structural Features

- Suffolk Scarp
- Norfolk Arch

Borehole Location shown on Profile B-B’

Proposed Test Turbine Sites
- East
- Alternate

CHESAPEAKE BAY IMPACT CRATER
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 4-2
Schematic profile of B-B' showing the subsurface structure impacted by the Eocene Chesapeake Bay Impact Crater. Borehole locations shown as sticks penetrating the units referenced in the logs, found in Appendix 1A of Powers and Bruce (1999). Location of boreholes and B-B' shown on Figure 4-2.

**PROFILE B-B' ACROSS CHESAPEAKE BAY IMPACT CRATER**

Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 4-3
A. Schematic diagram illustrating the relationship between depositional systems, growth increments, and the dispersal system of the Nassawadox spit. The pattern of progradational growth depicted in this model of the Nassawadox paleospit can be applied to the Holocene growth of Fisherman Island at the tip of the Delmarva Peninsula. Fisherman shoal (Figure 5-1) is prograding obliquely up the shoreface of Fisherman Island and will continue as long as sediment transport by littoral drift overrides the removal from tidal transport.

B. Schematic perspective view of the Nassawadox Formation, showing relationship between the depositional systems of the Butlers Bluff Member and the sequence Stratigraphic elements of the formation.

Source: Parsons et al. (2003)
The portion of the global eustatic curve displayed in each cartoon is marked with a red outline.

**A.**

SEA LEVEL LOWSTANDS
During Sea Level Lowstands (e.g. Wisconsin – Last Glacial Maximum ~25-15.7 kya), drainage systems developed on the subaerially exposed Continental Shelf.

**B.**

MARINE TRANSGRESSION
As sea level rose, the shoreline transgressed across the shelf which resulted in: 1) fluvial channels transitioning to estuarine environments, and 2) drowning, infilling, and burial of channels; channels infilled with upward deepening succession of lagoonal and estuarine muds.

**C.**

CONDITIONS TODAY
Following transgression, Holocene-age marine sediments mask the location of channels and the materials that infill them. Conditions also underlie barrier spit prograding deposits along the Delmarva Peninsula.

Source: Nordfjord et al. (2005)

**CHANNEL INCISION AND BURIAL EXAMPLE**
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 4-5
Regional Paleochannels
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 4-6
Diagrammatic cross sections of the Chesapeake Bay and the Delmarva Peninsula. This image shows the evolution of the bay through one interglacial-glacial cycle. Remnant deposits of previous highstands (R) and fluvial terraces (T) are rarely preserved in the underlying stratigraphic section from intermediate sea level fluctuations (modified from Colman et al., 1988).

EASTERN SHORE PALEOCHANNEL DEVELOPMENT
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 4-7
LEGEND
Morphological Zones
- Maintained Channel
- Natural Channel
- Bay Deposits
- Shoal Deposits
- Geophysical Data Line (see Figure 5-3)
- Sediment Transport Direction (refer to notes)

MORPHOLOGICAL ZONES
Proposed Chesapeake Bay Bridge-Tunnel Site
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

Notes:
1) Arrows qualitatively indicate regional observations in the general directionality of transport during a normal tidal cycle in the project vicinity.
2) Arrow lengths are not vectors; absolute values are not known. Modified from B. Parsons et al. (2003) and Colman et al. (1989).

Proposed Test Turbine Sites
- East
- Approximate Location of Proposed 50' Wide Cable Route
- Coordinate Grid, WGS 84

FIGURE 5-1
Virginia Offshore Wind Test Site Development
Project No. 04.81110013

MORPHOLOGICAL ZONES
Proposed Newport News and Suffolk Sites
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

Notes:
1) Arrows qualitatively indicate regional observations in the
general directionality of transport
during a normal tidal cycle in the
project vicinity.
2) Arrow lengths are not vectors:
absolute values are not known.
Modified from Cronin et al., (2003)

LEGEND
Morphological Zones
- Maintained Channel
- Natural Channel
- Bay Deposits
- Shoal Deposits
- Craney Flats
- Sediment Transport Direction (refer to notes)

Proposed Test Turbine Sites
- East
- Alternate

+ Coordinate Grid, WGS 84

FIGURE 5-2
A-A'. Side Scan Sonar Image A-A' of an area within the Chesapeake Channel. Arrows showing asymmetric flood-facing meggaripples. Image location shown in image below and Figure 5-1 (modified from Colman et al., 1988).

B. Three dimensional image of the bathymetry shows a complex seafloor in the vicinity of the CBBT. The black arrows indicate generalized flow direction and are not vectors. Noted large scale bedforms listed from high to low flow energy include the ridge-and-swale features, sand waves, and meggaripples. Bedforms in the flood-flow direction are fewer and at a smaller scale than the bedforms developed from ebb-flow indicating increased bottom flow currents during ebb tide.

**BEDFORMS**

*Proposed Chesapeake Bay Bridge-Tunnel Site*

*Offshore Wind Test Site Desktop Study*

*Chesapeake Bay, Virginia*
Exploration Locations

- Borings (Typical penetration depth is between 60 and 150 feet below mudline)
  - 1999 VDOT Boring
  - 1950s and 1960s Moran, Proctor, Mueser & Rubidge Borings
  - CPTs (Typical penetration depth is shallower than 30 feet below mudline)
  - 2007 S&ME MiniCPT
- Vibracores (Typical penetration depth is shallower than 20 feet below mudline)
  - 2010 Fugro Vibracore
  - 2008 Alpine Vibracore
  - 2007 S&ME Vibracore
  - 2006 Moffatt & Nichol Vibracore
  - 2005 Great Lakes Dredging & Dock Co. Vibracore
  - 1990s USACE Vibracore
  - 1980s USACE Vibracore
  - 1980s VIMS Vibracore
  - 1980s VDOT Vibracore
  - 1977 USACE Vibracore
  - 1960s and 1970s Vibracore
  (from Meisburger 1975)

LEGEND

- Proposed Test Turbine Sites
- East
- Approximate Cable Route Loc
- Bathymetry - Feet (MLLW)

GEOTECHNICAL EXPLORATION AND GEOPHYSICAL TRACKLINE LOCATION MAP

Proposed Chesapeake Bay Bridge-Tunnel Site
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

Source: NOAA (2007)

Geophysical Tracklines
- 2006 S&ME Tracklines (CHC)
- 2007 OSI Tracklines (AOC & TSC)

Historical Geophysical Tracklines
- From Swift (2003)
- From Colman et al. (1986)
- From Williams (1997)
**Exploration Locations**

- **Borings (Typical penetration depth is between 60 and 150 feet below mudline)**
  - 2007 Fugro Boring
  - 2007 McCallum Boring
  - 1940s to 2000 USACE Exploration
  - 1970s VDOT Boring
- **CPTs (Typical penetration depth is between 50 and 200 feet below mudline)**
  - 2007 Fugro CPT
  - 2007 S&ME CPT
  - 2007 S&ME Vibracore
- **Tbars (Typical penetration depth is between 40 and 50 feet below mudline)**
  - 2007 Fugro Tbar
- **CPTs (Typical penetration depth is shallower than 30 feet below mudline)**
  - 2007 S&ME MiniCPT
- **Vibracores (Typical penetration depth is shallower than 20 feet below mudline)**
  - 2007 S&ME Vibracore

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**GEOTECHNICAL EXPLORATION AND GEOPHYSICAL TRACKLINE LOCATION MAP**

**Proposed Newport News and Suffolk Sites**

**Offshore Wind Test Site Desktop Study**

**Chesapeake Bay, Virginia**

**FIGURE 6-2**

1. The red highlighted section of Boomer line 415 represents the extent of the seismic reflection data displayed on Figures 6-11a and 6-11b.
SOIL BORING LITHOLOGY WITH SPT BLOW COUNT DATA

SOIL TYPES

- Lean CLAY (CL)
- Silty CLAY (CL-ML)
- Fat CLAY (CH)
- Silt (ML)
- Elastic Silt (MH)
- Poorly-Graded SAND (SP)
- Well-Graded SAND (SW)
- Clayey SAND (SC)
- Silty SAND (SM)
- Well-Graded GRAVEL (GW)
- Poorly-Graded GRAVEL (GP)
- Silty Gravel (GM)
- SILTSTONE
- PEAT
- Fill
- Base Material
- Description illegible on original field log.

KEY TO CROSS SECTIONS
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 6-6
BASE OF HOLOCENE BAY-MOUTH SHOAL DEPOSIT
Proposed Chesapeake Bay Bridge-Tunnel Site
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 6-7
ISOPACH (THICKNESS) OF HOLOCENE BAY-MOUTH SHOAL DEPOSIT
Proposed Chesapeake Bay Bridge-Tunnel Site
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 6-8
EROSIONAL BASE OF QUaternary DEPOSITS
Proposed Chesapeake Bay Bridge-Tunnel Site
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 6-9
DEPTH TO INFERRED MIOCENE SURFACE
Proposed Chesapeake Bay Bridge-Tunnel Site
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 6-10
Diagram above shows (a) the bottom flows that mobilize sediments and cause sediment transport (i.e., waves and/or currents), and (b) the different types of sediment transport (i.e., bedload transport and suspended transport).

Mobilized sediments can either move along seafloor or be suspended into the water column. For these sediments to be transported, either on the sea bed (bedload transport) or within the water column (suspended load transport), ultimately depends on the characteristics of the bottom flow (e.g., velocity) and physical characteristics of the sediments (e.g., density) and water (i.e., viscosity and density).

Figure is modified from Soulsby (1997).
According to Sumer and Fredsøe (2002), the key element in the scour process is the horseshoe vortex. This vortex can erode a significant amount of sediment away from the vicinity of the pile. As shown above, the horseshoe vortex is a result of flow encountering the pile and being directed downward into the seafloor causing a rotation of the flow. The turbulent flow then moves around the pile and decelerates (wake vortex) until it stabilizes with the surrounding flow.

As a result of the turbulent flow around the base of the pile, a truncated cone-shaped scour hole will form (left). In the up-flow direction, the scour hole is more or less equal to the angle of internal friction, whereas in the down-flow direction, the slope is flatter. The characteristic scour pattern (right) is deep scour in the direction of the flow, and a shallow, broad scour on the lee-side. Often an area of deposition is observed as the flow velocity decreases and sediments settle. The overall depth and lateral extent of this scour hole will depend on the diameter (D) of the pile, sediment characteristics (grain size, sediment gradation), and flow velocity (direction with respect to the pile and magnitude).

Note: Diagrams are not to scale.
Notes:
1. Storm tracklines are from NOAA (2011). Tracklines are based on 6-hourly center locations and contain storms from 1851 through 2011. These data are only intended for regional display and/or analysis purposes.
2. Only storms categorized as hurricanes or tropical storms are shown. Also, only post-1950 hurricanes are labeled with the storm name and year.

LEGEND
- Offshore Wind Test Site Development Area
- Tropical Storm Tracklines
  - Category 4 Hurricane
  - Category 3 Hurricane
  - Category 2 Hurricane
  - Category 1 Hurricane
  - Tropical Storm

MID-ATLANTIC TROPICAL STORM TRACKS
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 7-3
Notes:
1. Storm tracklines are from NOAA (2011). Tracklines are based on 6-hourly center locations and contain storms from 1851 through 2011. These data are only intended for regional display and/or analysis purposes.
2. Only post-1950 hurricanes are labeled with the storm name and year.
3. The extratropical storm classification indicates that a cyclone has lost its tropical characteristics in terms of intensity and that it has moved out of the tropics.

LEGEND
Tropical Storm Tracklines
- Category 2 Hurricane
- Category 1 Hurricane
- Tropical Storm
- Subtropical Depression
- Extratropical Storm

Proposed Test Turbine Sites
- East
- Alternate

MID-ATLANTIC TROPICAL STORM TRACKS WITHIN PROJECT VICINITY
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 7-4
Virginia Offshore Wind Test Site Development
Project No. 04.81110013

LEGEND
- US East Coast Tsunami Run-up Location
  Date and run-up height (m) are labeled for
  Mid-Atlantic region. If no run-up height is
  labeled, run-up height is unknown.
- NGDC Tsunamis Data Location: 1884-2011
- Offshore Wind Test Site Development Area

Source: NGDC Global
Historical Tsunami Events
& Run-up Database:
<http://www.ngdc.noaa.gov/
hazard/tau_db.shtml>

RECORDED TSUNAMI RUN-UP LOCATIONS
Offshore Wind Test Site Desktop Study
Chesapeake Bay, Virginia

FIGURE 7-5