CHAPTER 4.8 2010 NEAR-SHORE OCEANIC SURVEY

Introduction

Prior to 2006, DEQ related its monitoring efforts to "6th-order hydrologic units (14-digit watersheds)" that had been delineated by the Virginia Department of Conservation and Recreation (DCR) in conjunction the Natural Resources Conservation Service (NRCS) of the US Department of Agriculture. That delineation was first completed in 1990 and then revised in 1995 following new delineation standards. Coastal oceanic hydrologic units in those delineations terminated at the toe of the shore face. In 2001, various federal agencies and national committees, along with input from the states, created a new set of "Federal Standards for Delineation of Hydrologic Unit Boundaries." The new guidelines redefined 5th and 6th-order hydrologic units as 10- and 12-digit units, respectively, and extended the coverage in the Atlantic Ocean out to the three-nautical-mile state territorial limit. Completed in July of 2006, Virginia's coverage within the "National Watershed Boundary Dataset" (NWBD) thus included oceanic hydrologic units that had not been incorporated into previous monitoring efforts. In keeping with the agency's goal of collecting surface water quality data within every 6th-order (12-digit) watershed in Virginia, DEQ in collaboration with Tony Olsen at EPA's Western Ecology Division (Corvallis, OR), developed a probabilistic survey design to monitor the new oceanic watersheds in 2010. (Monitoring data have now been collected in nearly 99% of all Virginia 6th-order watersheds since 2002.)

From August 15-18 of 2010, DEQ conducted its first ever probabilistic survey of marine water quality, sediment quality, and benthic community conditions in the Commonwealth's near-shore oceanic waters. DEQ field personnel, with logistical support provided by the US EPA Oceanic Survey Vessel, the OSV Bold (Figure 4.8-1) and its crew, along with field staff from EPA Headquarters and EPA Region 3, collected samples from 50 randomly selected sites between the Commonwealth's barrier beaches and the three-nautical-mile state territorial limit, from the Maryland state line to the North Carolina state line.

Figure 4.8-1 EPA's 224 foot Oceanic Survey Vessel, the OSV Bold, berthed at the NOAA Pier, Norfolk, VA. 14 August 2010

The Study Area

The study area consisted of eleven 6th-order oceanic "sub-watersheds" that encompass 440.75 square (statute) miles of Virginia's Atlantic coast, from the Maryland state line in the north to the North Carolina state line in the south. The map of Figure 4.8-2 illustrates the distribution of the 50 probabilistic sites, as well as the boundaries of the individual watersheds. Initial evaluations resulted in the rejection of a number of tentative sites because they were on land or were in shallow waters subjected to heavy surf. Virginia guidelines for the NWBD delineation indicate that the effects of wave action along the mid-Atlantic coast extend to a depth of 30 feet, which also defines the limiting isobath for the delineation of shore-front watersheds (http://www.dcr.virginia.gov/stormwater_management/hu.shtml). The elimination of sites with less than 30 foot depth would effectively eliminate the frontal watersheds from the sampling frame, so a minimum depth of 15 feet was designated for our sampling; this also corresponded to the nominal draft of the OSV Bold. The limited docking facilities along the coast, the distance between port facilities and the study sites, the requirement for smaller vessels to return to port each night, and general safety precautions precluded the use of smaller vessels for oceanic sampling. Additional logistical considerations related to the daily pick-up of samples along the Delmarva coast and overnight delivery to the Department of General Services, Division of Consolidated Laboratory Services (DCLS) in Richmond resulted in the decision to limit all sampling to the platform provided by the OSV Bold. Facilities aboard the Bold provided for the immediate processing of bacterial samples using the Enterolert System, the quick freezing of filtered chlorophyll and nutrient samples, and the refrigeration of other samples as required for preservation.

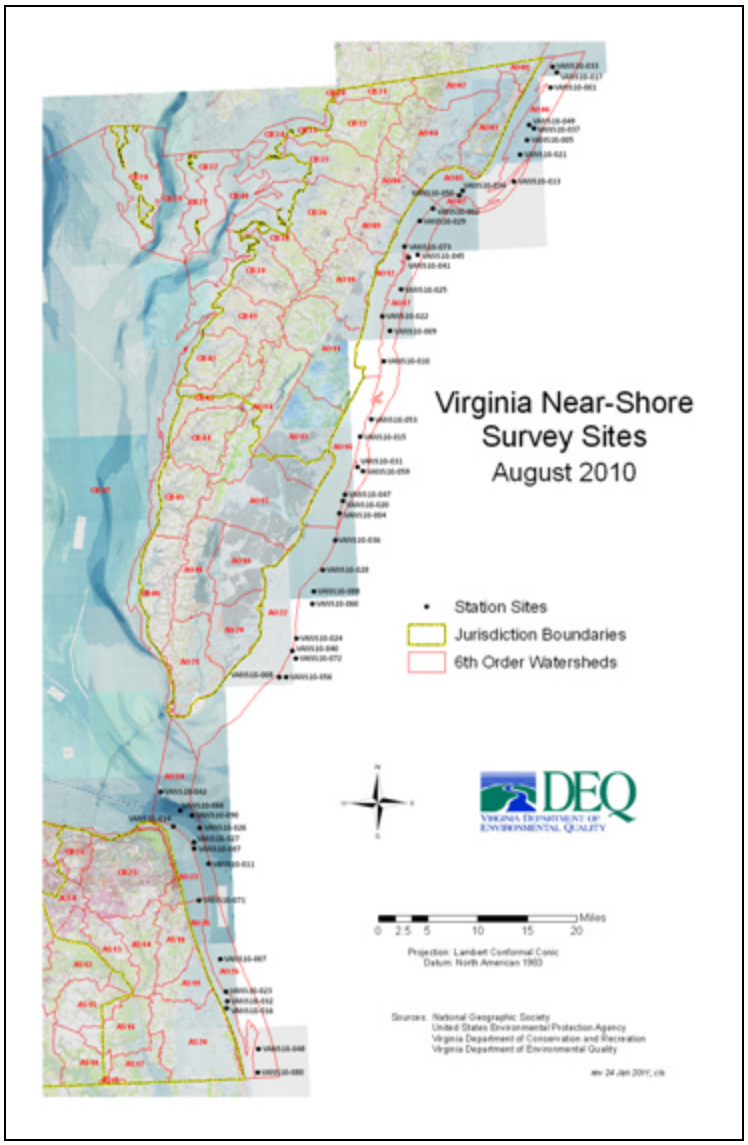
The final evaluation of prospective sites rejected all those with depths less than 15 feet, with the caveat that the Bold should approach each remaining site from due east. If depth became critical in the opinion of the pilot, the Bold should stop and DEQ would accept the coordinates of that point as an alternate site. In reality, the critical minimal depth for the Bold varied considerably with wind velocity, wave amplitude, and pilot discretion. The minimum depth sampled was 27.8 feet (8.5 meters), and the final distribution of sites is illustrated in Figure 4.8-2 and in "Appendix 1 - Station Metadata Table" at the end of this chapter. Although the sampling was limited within the shore-front watersheds, the near-shore oceanic water mass was continuous and in constant motion, and water quality would not be expected to differ significantly except in much shallower waters where continental contributions were more prevalent and wave action would suspend additional fine materials.

Sampling Methods

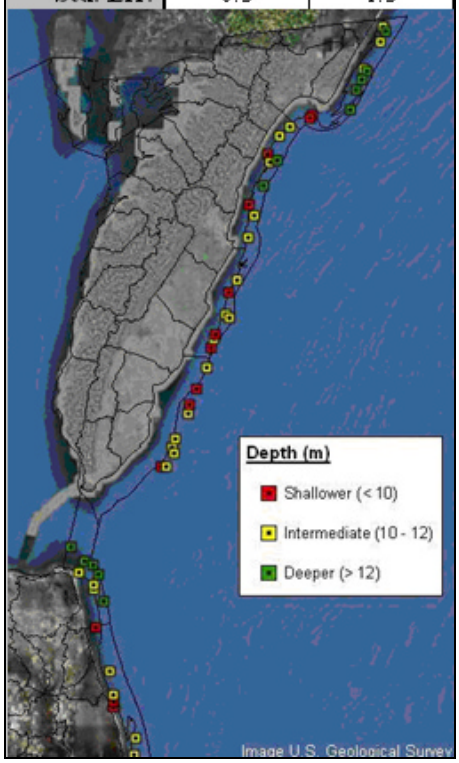
Vertical profiles of water temperature, dissolved oxygen, pH, conductivity/salinity and turbidity were continuously recorded at each site during descending and ascending casts of a Sea-Bird® CTD (Conductivity, Temperature, and Depth) water profiler. Physical samples were collected from the near surface water column for bacteria, dissolved polycyclic aromatic hydrocarbons (PAHs), clean dissolved and total metals, chlorophyll, and nutrients. Metals and PAH samples were collected directly into pre-cleaned containers at an approximate depth of 0.5 m. Bacterial samples were collected in sterile bottles attached to the exterior of a weighted stainless steel bucket used to submerge the glass containers for PAH sampling. Water samples for chlorophyll and nutrient analyses were collected at a depth of 1.0 m using a rosette of Niskin bottles attached to the Sea-Bird CTD. Sediment samples for the determination of particle size and total organic carbon (TOC), for the analysis of chemical contaminants (metals and organics), and for sediment toxicity testing were sub-sampled and homogenized from the top 2.0 cm of sediment collected with a large (1.0 m^2) stainless steel grab. Benthic organisms were collected to evaluate the composition and condition of the bottom dwelling invertebrate community using a standard Young grab (0.044 m^2).

With the exception of bacteria, that were incubated and analyzed on board the Bold, all water column samples, and sediment particle size / TOC samples were analyzed at the Virginia Department of General Services, Division of Consolidated Laboratory Services (DCLS), in Richmond. Sediment chemistry and toxicity samples were submitted to EPA-contracted laboratories associated with the National Aquatic Resource Survey (NARS), National Coastal Condition Assessment (NCCA) Program. Benthic samples

Figure 4.8-2 Final geographic distribution of the 50 probabilistic sites sampled during DEQ's 2010 near-shore oceanic survey (15-18 August 2010). Site depths varied from 27.9 to 84.6 feet (8.5 to 25.8 m). The 6th Order oceanic watersheds AO05, AO06, AO07, AO12, AO16, AO17, AO22, AO23, AO24, AO25, and AO26 were included in the study. Metadata (coordinates, etc.) for the 50 sites can be found in Appendix 1 – "VA Near-Shore Station Metadata."



Attributes	Station Depth (m)	Station Depth (ft)
N	50	50
Max	25.8	84.6
90th %	14.0	45.8
75th %	12.2	40.0
UL 95% CI	11.8	38.6
Median	11.3	37.1
LL 95% CI	10.8	35.5
25th %	10.1	33.0
10th %	9.3	30.5
Min	8.5	27.9
Mean	11.9	39.1
Std. Dev.	3.3	10.9
Std. Err.	0.5	1.5



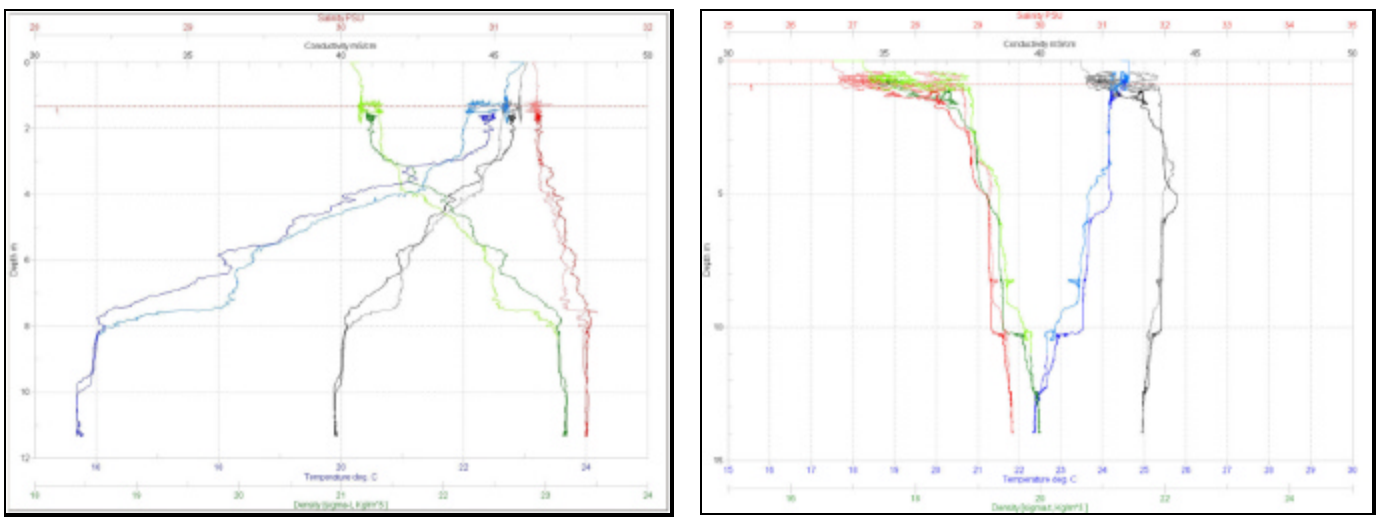
were processed at the Benthic Ecology Laboratory (BEL) at Old Dominion University (ODU). Benthic results included a taxonomic list with enumeration of individual taxa, as well as a general characterization of community structure, function and condition. The integrated analytical results from this study now provide sufficient data for a generalized characterization of present environmental conditions, including background levels of dissolved hydrocarbons and trace elements, in Virginia's eleven 6th-order Atlantic Ocean watersheds.

Results

Water Column

Field Parameters: Hydrographic profiles of temperature, pH, specific conductance/salinity, and dissolved oxygen revealed little evidence of distinct stratification at any of the 50 near-shore sites. Although surface to bottom gradients did exist at many sites (Figure 4.8-3-A), few well-defined thermo-clines or pycnoclines were observed in the water column. There was some evidence of weak stratification near the Chesapeake Bay mouth, where warmer, less saline waters exited the Bay above cooler more saline oceanic waters (Figure 4.8-3-B).

Figure 4.8-3 Temperature and salinity gradients without distinct thermo- or pycnoclines (A - VANS10-001 [7C-AO05-10-001] far north near Maryland line), and with weak thermal and saline stratification (B - VANS10-042 [7C-AO24-10-042] just south of the Chesapeake Bay mouth). Salinity = red trace; Temperature = blue trace. Both descending and ascending casts of the CTD are illustrated.



A **B**

In order to contrast surface and bottom conditions for each field parameter, the arithmetic means were calculated for all values from depths of 0.1 through 1.0 meters (near-surface) and from all values within the last meter of the hydrographic profile (near-bottom) at each site. Temperature differentials between surface and bottom waters varied from a minimum of 0.14 to a maximum of 10.69 ^{o}C. The maximum differentials (= 10.0 ^{o}C) occurred in relatively deep channels near the Chesapeake Bay mouth, but high differentials (= 4.5 ^{o}C) occurred throughout the near-shore area (Figure 4.8-4). Salinity differentials between surface and bottom waters varied from a minimum of 0.00 PSU to a maximum of 6.14 PSU. Once again, the greatest differentials (= 3.0 PSU) were found associated with the area around the Bay mouth (with others distributed to the south). Salinity differentials along the northern and central reaches of Virginia's Delmarva coast seldom exceeded 0.5 PSU (Figure 4.8-5).

Figure 4.8-4 Geographic distribution of surface temperature (A) and temperature differentials (B) [surface temperature – bottom temperature, in °C] among the 50 near-shore probabilistic sites.

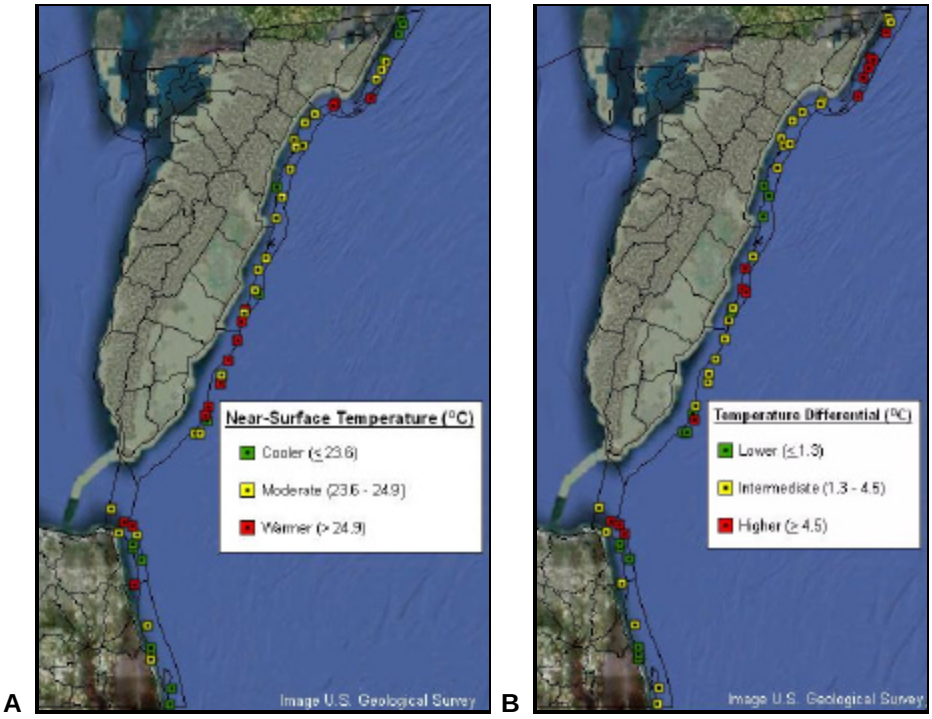
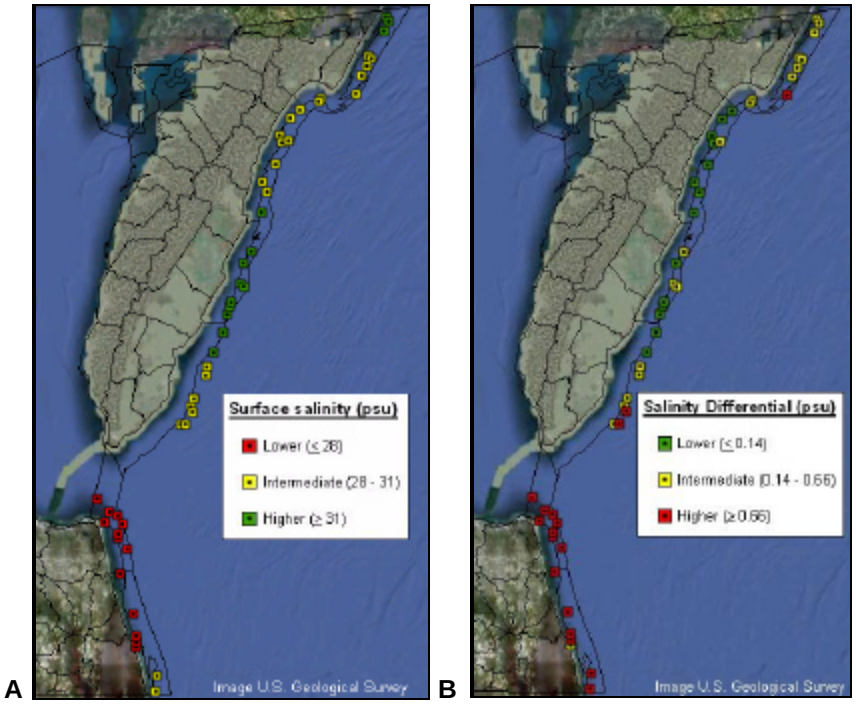
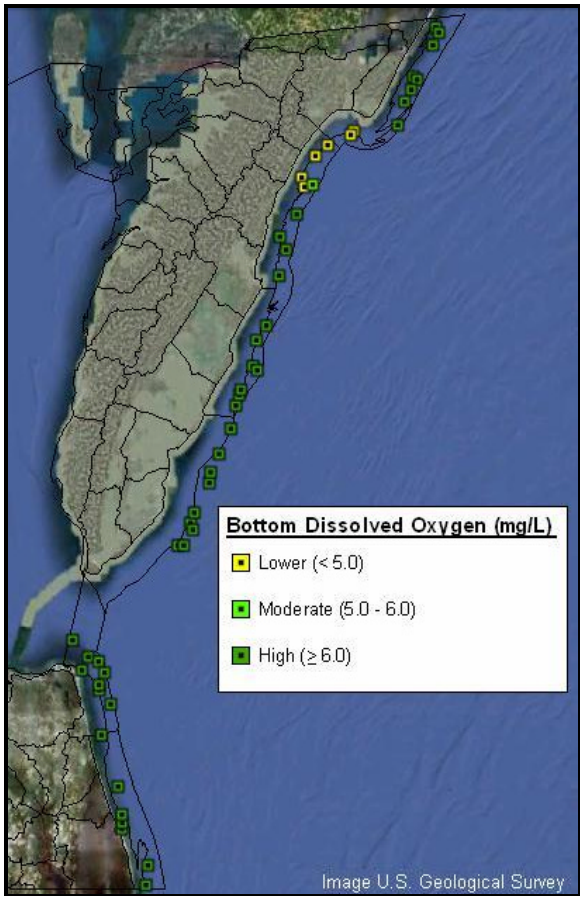


Figure 4.8-5 Geographic distribution of surface salinity (A) and salinity differentials (B) [bottom salinity – surface salinity, in psu] among the 50 near-shore probabilistic sites.



Virginia's water quality standards for field parameters in open oceanic waters include only pH (range 6.0 to 9.0 units) and dissolved oxygen (5.0 mg/L instantaneous minimum). During this study, observed pH values varied from a minimum of 7.8 to a maximum of 8.3 among all sites and depths. No geographic gradient in pH was evident. Surface DO concentrations varied from a minimum of 5.9 to a maximum of 8.0 mg/L. Bottom DO concentrations varied from a minimum of 4.1 to a maximum of 8.1 mg/L. Bottom dissolved oxygen concentrations fell below the 5.0 mg/L oceanic water quality standard at six (12.0 ± 9.2%) of the 50 sites, but no DO measurements fell below 4.1 mg/L. Differentials in DO concentrations (surface – bottom) varied from -0.86 to 3.43 mg/L. The six largest differentials in DO concentration (2.13 – 3.43 mg/L) corresponded to the six lowest bottom concentrations (4.16 - 4.73 mg/L), all located in shallow to moderate depths along the Delmarva coast (Figure 4.8-6).

Figure 4.8-6 Geographic distribution of bottom dissolved oxygen concentrations among the 50 near-shore probabilistic sites. Virginia's water quality standard for dissolved oxygen in transitional and saltwater is an instantaneous minimum of 5.0 mg/L.



Attributes	Near Bottom DO (mg/L)
N	50
Max	8.08
90th %	7.56
75th %	7.32
UL 95%	7.29
Median	7.07
LL 95 %	6.85
25th %	6.33
10th %	4.71
Min	4.17
Mean	6.68
Std. Dev.	0.98
Std. Err.	0.14

General Water Quality: Over the past decade the National Coastal Condition Assessment Program (U.S.EPA. 2001, 2004, 2008b) has developed a general water quality index for the characterization of estuarine waters based on the observed values of five water column parameters: near-surface concentrations of dissolved inorganic forms of nitrogen (DIN) and phosphorus (DIP), near-surface chlorophyll-a (Chl-a) concentration, near-bottom dissolved oxygen (DO) concentration, and water clarity. Although the same five parameters should be appropriate for the characterization of marine water quality, the quantitative estuarine threshold values used to separate "Good", "Fair", and "Poor" ratings of most of

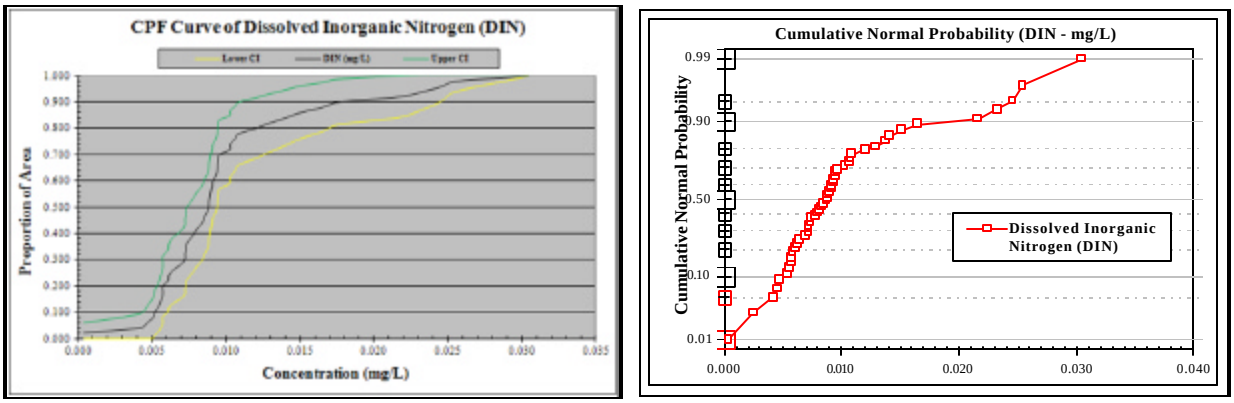
these parameters are probably not appropriate for oceanic waters. In the discussions that follow, wherever published numerical criteria or water quality standards (WQS) for oceanic waters were available they were used; otherwise, the upper quartile (= the 75th percentile), lower quartile (= 25th percentile), and inter-quartile ranges were used to qualitatively identify sites where the relative values/conditions of individual parameters were "more desirable", "moderate", or "less desirable." An integrated Water Quality Index (WQI) was subsequently derived from the results of the same five variables without using specific thresholds.

Near-Surface Dissolved Inorganic Nitrogen (DIN): Near-surface dissolved inorganic nitrogen concentrations, calculated as the sum of dissolved nitrate, nitrite, and ammonium concentrations, varied from a minimum of 0.0004 to a maximum of 0.0304 mg/L. The average DIN concentration of approximately 0.0100 mg/L was well below the 0.1 mg/L threshold used to classify water quality as "Good" in southeastern US estuaries, where photosynthesis and potential eutrophication is generally phosphorus limited. (The maximum DIN concentration observed in this study would still have been considered "Good" by estuarine standards.) Figure 4.8-7A summarizes the numerical distribution of DIN values observed in this study (see explanation below and in the legend of the figure), and Figure 4.8-7B illustrates the geographic distribution of "Higher" (>0.01 mg/L), "Intermediate" (0.007 - 0.010 mg/L), and "Lower" (<0.007 mg/L) DIN values. The upper quartile value, selected as the lower limit of "Higher" DIN concentrations, also corresponds to an apparent breakpoint in the CPF curve of DIN concentrations (Fig. 4.8-7A). Although the higher range of observed DIN values may or may not be stressful to the ecosystem, their geographic distribution is of interest. One cluster, off Cape Henry at the Chesapeake Bay mouth, is not a surprise, since the enriched nutrient status of the Bay is well documented and a Bay-wide nutrient TMDL has already been developed. A second cluster of sites with higher DIN concentrations occurs between Chincoteague Inlet and the northern end of Metompkin Bay. This suggests the possibility of a higher input from the mainland in this region, since the tidal wetland buffer between continental agriculture and oceanic waters is much less extensive there than further south. Further north, the coastal bays and their barrier islands funnel dissolved nutrients southward to the mouth of Chincoteague Bay. A tidal plume from Chincoteague may also contribute to the higher DIN values to the immediate south.

The "CPF Distribution" illustrated in Figure 4.8-7A and in many of the subsequent figures represents the "Cumulative Probability Function" of the variable. For any value of the variable found along the black CPF curve, the proportion of the total study area expected to have an equal or lower concentration can be read from the "Proportion of Total Area" scale to the left. This expected "Proportion" is a statistical estimate subject to sampling error. The upper and lower CI curves (green and yellow, respectively, in Figure 4.8-7A) represent the limits on an approximate 95% confidence interval for the true proportion. We expect the actual proportion of the study area with equal or lower concentrations to be somewhere near the center of this interval, and have a confidence of 95% that its true value lies between the green and yellow lines. In Figure 4.8-7A, for example, a DIN concentration of 0.010 mg/L corresponds to a Proportion of Total Area value of approximately 0.72. Approximately 72% of the study area is expected to have DIN concentrations equal to or less than 0.010 mg/L. The lower and upper confidence limits for the DIN concentration of 0.010 mg/L correspond to proportions of approximately 0.60 and 0.84, respectively, so we have a confidence of 95% that the real proportion of the study area that has DIN concentrations of = 0.010 mg/L is between 60% and 84%. The Cumulative Normal Probability plot in the figure uses the same data as the CPF curve, but the vertical axis has been transformed to produce a straight line for a normal or Gaussian bell-shaped curve. This facilitates the identification and interpretation of real breakpoints in the distribution.

Near-Surface Dissolved Inorganic Phosphorus (DIP): Dissolved inorganic phosphorus is also at times called dissolved orthophosphate (o-P) or soluble reactive phosphorus (SRP). Near-surface concentrations of DIP in this study varied from 0.0090 to 0.0187 mg/L. Both the average DIP concentration of 0.0132 mg/L and the maximum of 0.0190 mg/L would be considered "Fair" under estuarine conditions, where nitrogen is more abundant and phosphorus often limits photosynthesis. In coastal waters, where phosphorus is generally more available from deep oceanic sources and photosynthesis is nitrogen limited, phosphorus thresholds should probably be higher. Figure 4.8-8A

Figure 4.8-7 Numerical (A) and geographical (B) distributions of dissolved inorganic nitrogen (DIN) concentrations among the 50 near-shore probabilistic sites. Interpretation of the Attribute Table in this and subsequent figures is N = number of observations; Max = maximum observed value; 90th %, 75th %, etc. = corresponding percentiles of the observed distribution; UL 95% and LL 95% = upper and lower 95% confidence limits, respectively, for the median; Median = 50th percentile; Min = minimum observed value; Mean = arithmetic average of observed values; Std. Dev. = standard deviation of observed values; Std. Err. = standard error of observed values.



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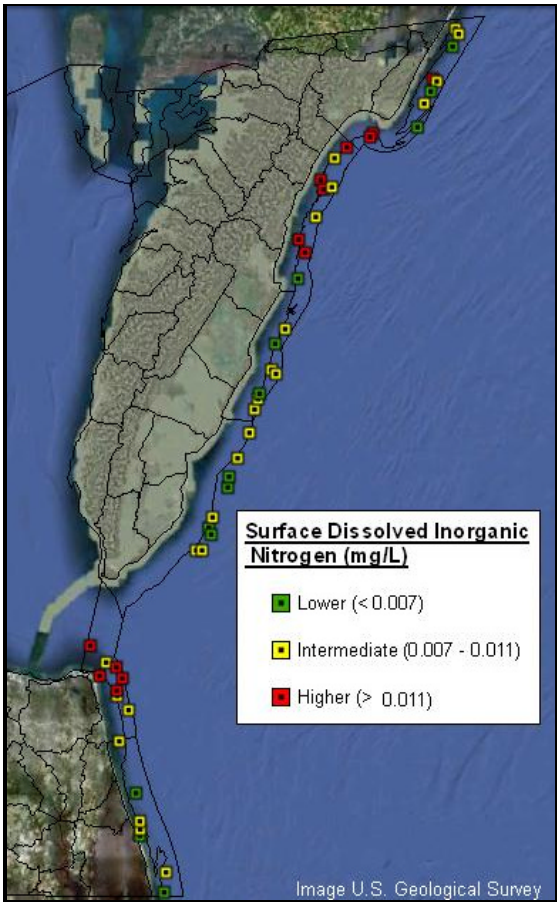


Attribute	DIN (mg/L)
N	50
Max	0.0305
90th %	0.0180
75th %	0.0105
UL 95%	0.0100
Median	**0.0091**
LL 95 %	0.0082
25th %	0.0066
10th %	0.0054
Min	0.0004
Mean	**0.0102**
Std. Dev.	0.0060
Std. Err.	0.0008

B

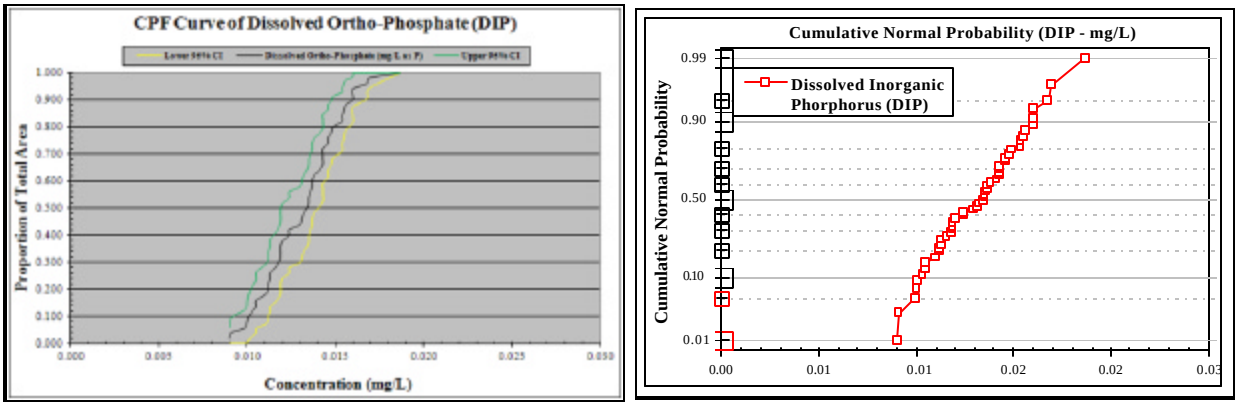
summarizes the numerical distribution of DIP values observed in this study, and Figure 4.8-8B illustrates the geographic distribution of “Higher”, “Intermediate”, and “Lower” DIP values.

In these oceanic waters, the “Higher” range of DIP values observed during the study does not necessarily indicate nutrient enriched or eutrophic sites. Unlike the CPF curve for DIN, the CPF for DIP has no obvious breakpoints. The smooth, relatively straight distribution suggests a symmetrical more-or-less normal distribution around the average DIP concentration of 0.013 mg/L. Sites with DIP in the “Higher” range are scattered all along the coast, with the notable exception of southern Delmarva below Quinby Inlet, where all DIP values are in the “Lower” range.

Nitrogen/Phosphorus balance - the “Redfield Ratio”: Independent evaluations of DIN (Figure 4.8-7) and DIP (Figure 4.8-8) indicated where the relative concentrations of these dissolved inorganic nutrients are higher, intermediate, or lower within Virginia’s near-shore Atlantic waters. It is debatable whether the higher concentrations of either nutrient can or should be considered excessive. One potential way to answer that question is to evaluate the molecular ratio of total nitrogen to total phosphorus in the system. Redfield (1958), based upon earlier works that reported the C:N:P ratio within phytoplankton to be 106:16:1 and that inorganic C:N:P in deeper marine waters varied in the proportions of 105:15:1, suggested that a relatively stable N:P ratio existed within the phytoplankton biomass and nutrient concentrations in marine waters (cited in Geider and La Roche, 2002). The relationship became known as “Redfield’s Ratio” and the molecular ratio of N:P = 16:1 has often been used as a reference value against which to gauge nutrient imbalance in marine systems; a lower ratio (< 16) supposedly would indicate a nitrogen limited system and a higher ratio (> 16) would indicate a phosphorus limited system in which nitrogen was in excess. More recent work (Geider and La Roche, 2002) has revealed that under optimal growth conditions the cellular molecular N:P ratio is much more variable, ranging from 5 to 19, and that “the critical N:P that marks the transition between N- and P-limitation of phytoplankton growth lies in the range of 20-50 mol N:mol P…”

In the present study, dissolved and particulate nutrients were sampled and analyzed separately, the particulate components of C, N, and P, primarily in the form of phytoplankton, were collected during field filtration of whole water samples. On the average, the particulate portions of N and P represented 36.8% of the total nitrogen (TN) and 44.6% of the total phosphorus (TP), respectively. TN and TP in mg/L were calculated as the sum of particulate and total dissolved portions of each nutrient. These values were subsequently converted to molar concentrations, and the molecular N:P (Redfield) ratio was calculated for each site. The numerical distributions of the mol N:mol P ratio are presented in Figure 4.8-9A and the geographic distribution in Figure 4.8-9B. Ratios varied from a minimum of 11.97 to a maximum of 23.84, with median (16.61) and arithmetic mean (16.81) both near the “ideal” Redfield ratio. The CPF curve is smooth, symmetrical, and fairly straight for ratios between the minimum and a value of approximately 19.5, where an apparent breakpoint occurs in the distribution. An N:P ratio of 19.0 was consequently used as a tentative threshold for higher values where nitrogen was potentially in excess. No lower threshold was defined because the lowest N:P ratios, of approximately 12.0, were still well above the lower optimal growth ratios described by Geider and La Roche (2002). The geographic distribution of the sites with higher, potentially “Extra” nitrogen was arrayed both north and south of the Chesapeake Bay mouth, at least suggesting the possibility of a “diffusive estuarine outflow plume” from the Bay. As described by Filippino (2008), however, such plumes would not extend so far to the north, even under the influence of southerly winds. It is more likely that the higher N:P ratios observed north of the Bay mouth result simply from the fact that phosphorus concentrations are lower in that region (Figure 4.8-8B, DIP).

Figure 4.8-8 Numerical (A) and geographical (B) distributions of dissolved inorganic phosphorus (DIP) concentrations among the 50 near-shore probabilistic sites.



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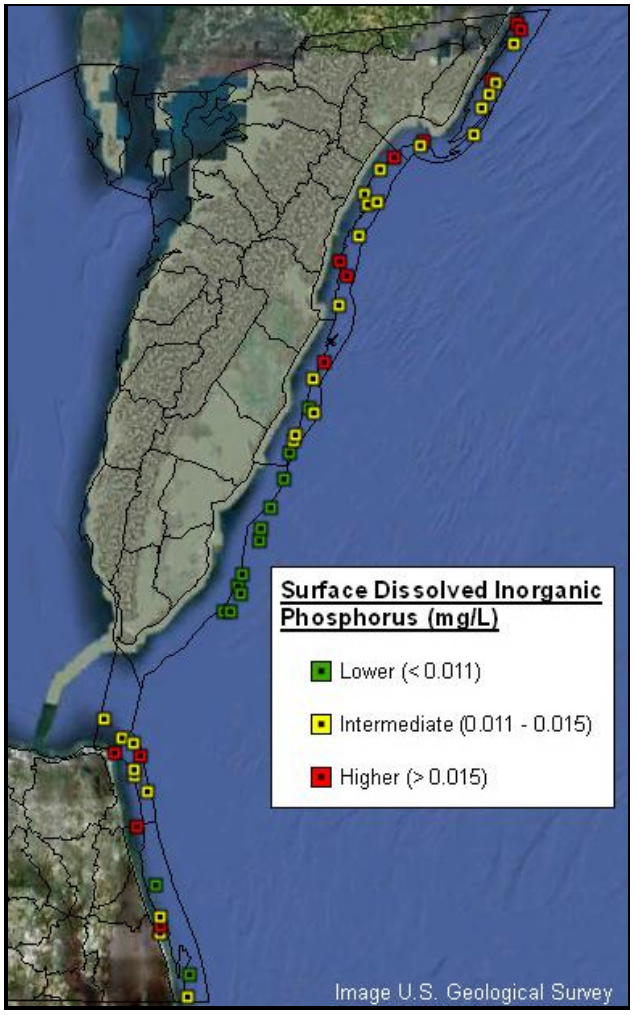
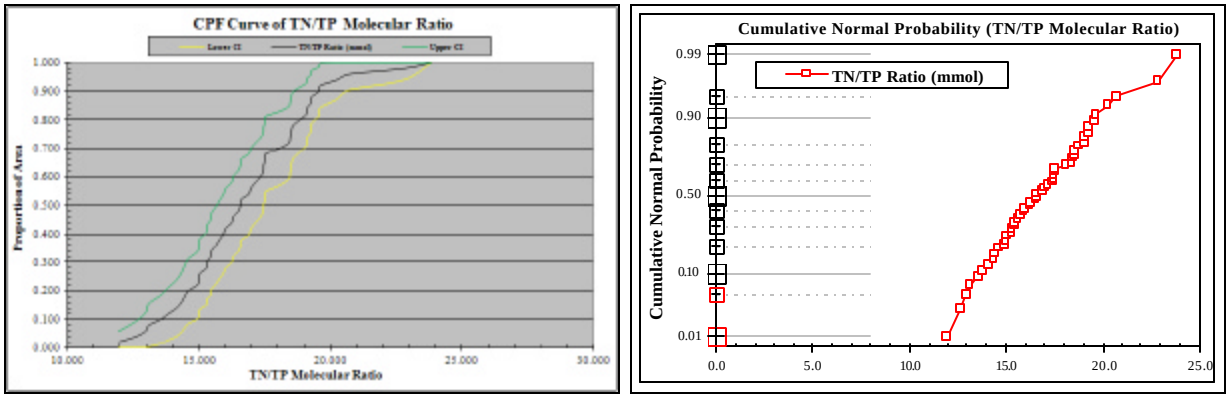


Attribute	DIP (mg/L)
N	50
Max	0.019
90th %	0.016
75th %	0.015
UL 95 %	0.014
Median	**0.013**
LL 95 %	0.013
25th %	0.012
10th %	0.010
Min	0.009
Mean	**0.013**
Std. Dev.	0.002
Std. Err.	0.000

B

Figure 4.8-9 Numerical (A) and geographical (B) distributions of molecular TN/TP ratios among the 50 near-shore probabilistic sites. A *balanced* "Redfield Ratio" has traditionally been considered to be approximately 16 but has more recently been shown to vary from 5 to 19 under optimal growth conditions for phytoplankton (Geider and La Roche, 2002).



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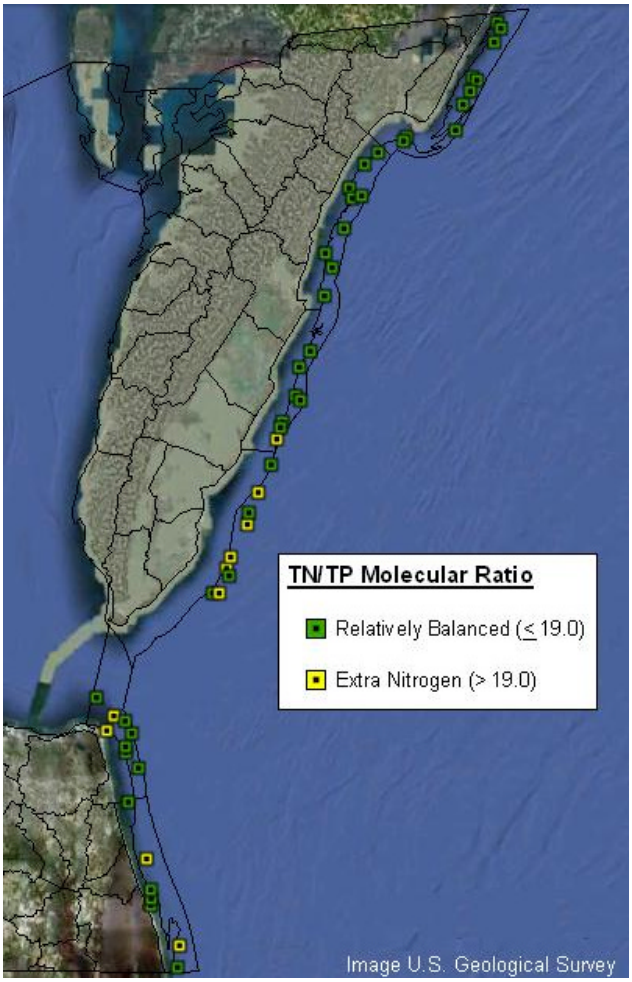


Attributes	TN/TP Ratio (mmol)
N	50
Max	23.84
90th %	19.57
75th %	18.51
UL 95 %	17.37
Median	16.61
LL 95 %	15.85
25th %	15.09
10th %	13.81
Min	11.97
Mean	16.81
Std. Dev.	2.49
Std. Err.	0.35

B

Near-Surface Chlorophyll-a (Chl-a): Chlorophyll concentrations were measured by two different methods during this study. A WETStar® fluorometer attached to the Sea-Bird® CTD of the Bold measured and recorded the fluorescence of chlorophyll-containing phytoplankton continuously during the deployment of the CTD. Average near-surface chlorophyll concentrations measured by the fluorometer were calculated as described above for temperature, pH, salinity, and DO. Physical near-surface water samples were also collected and immediately field-filtered and frozen for later extraction and analysis of Chl-a in the laboratory, using methodologies approved by the NCCA and EPA's Interstate Chesapeake Bay Program. Although the results from the two methods were highly correlated (Figure 4.8-10), the relationship was not linear and the fluorometer results were consistently higher than those derived from laboratory analyses. Only the results from the laboratory analyzed, field-filtered chlorophyll samples were used in the following discussions.

Near-surface chlorophyll-a values observed in this study varied from a minimum of 0.53 to a maximum of 7.44 µg/L. The average observed chlorophyll concentration of 2.55 µg/L would be classified as "Good" and the maximum observed value of 7.44 µg/L as "Fair" by estuarine standards. Figure 4.8-11A summarizes the numerical distribution of Chl-a values observed in this study, and Figure 4.8-11B illustrates the geographic distribution of "Higher", "Intermediate", and "Lower" Chl-a values. A breakpoint in the CPF curve at a Chl-a concentration of approximately 3.0 µg/L suggests a possible upper threshold value but, once again, "Higher" is used only in a relative sense, and does not necessarily indicate an undesirably high rate of primary production. Clusters of sites with higher Chl-a values occur near and to the south of the Chesapeake Bay mouth (not unexpected; Filippino, 2008) and in northern Delmarva from Assateague Island to Kegotank Bay. The occurrence of higher Chl-a values north of Chincoteague Inlet, along the oceanic side of Assateague Island, suggest that the higher Chl-a (and possibly DIN, Fig. 4.8-7) concentrations south of the Inlet may result from oceanic influence as well as from a Chincoteague Bay plume and terrestrial contributions.

Figure 4.8-10 Comparison of near-surface chlorophyll concentrations estimated from the laboratory extraction and analysis by DCLS of field-filtered, frozen chlorophyll samples and values resulting from the *in situ* measurement of fluorescing phytoplankton using a WETStar® fluorometer.

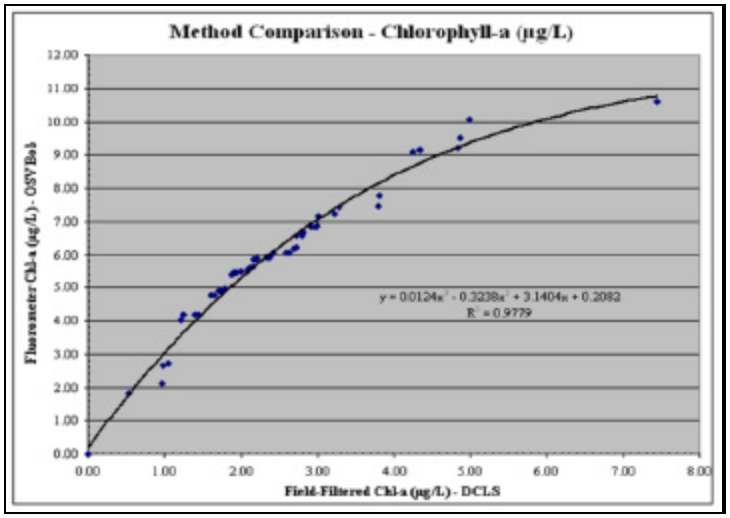
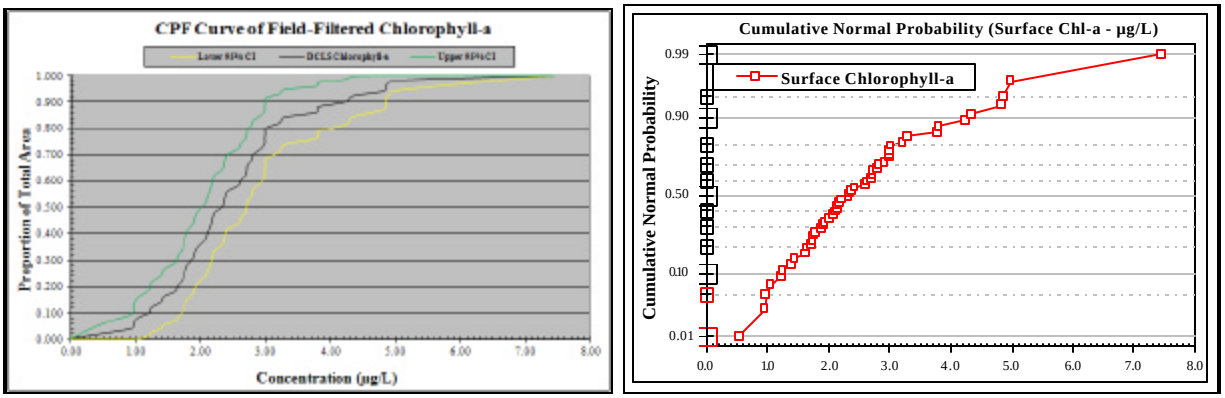


Figure 4.8-11 Numerical (A) and geographical (B) distributions of chlorophyll-a (Chl-a) concentrations among the 50 near-shore probabilistic sites.



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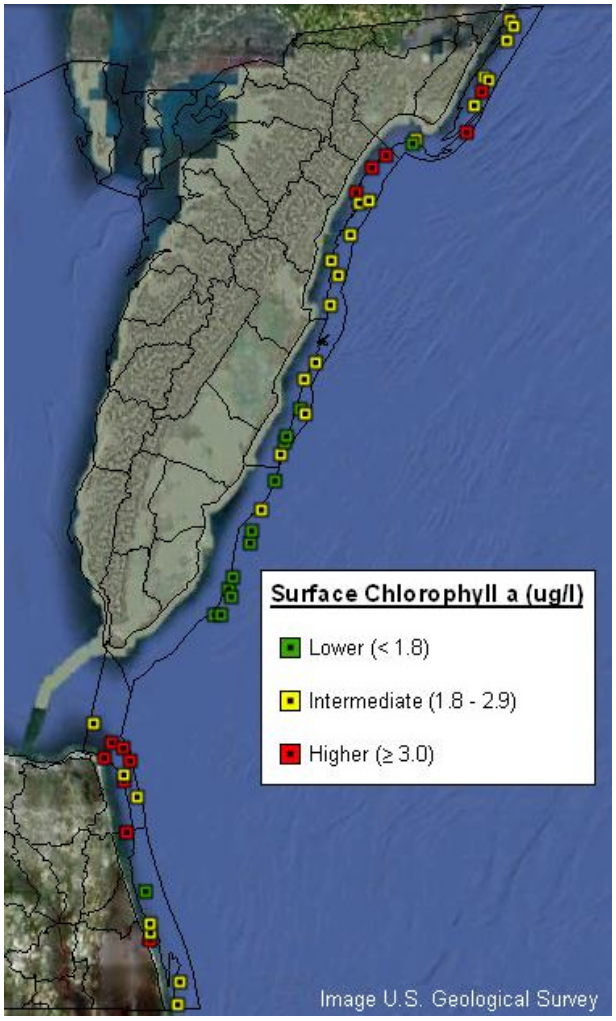


Attributes	Field-Filtered Chl-a (µg/L)
N	50
Max	7.44
90th %	4.26
75th %	2.99
UL 95%	2.90
Median	2.63
LL 95 %	2.36
25th %	1.78
10th %	1.25
Min	0.53
Mean	2.51
Std. Dev.	1.25
Std. Err.	0.18

B

Although lower chlorophyll concentrations are almost universally considered more desirable, it seems that some degree of primary production among phytoplankton must be desirable, even in open oceanic environments. Consequently, there must be some lower Chl-a threshold below which an environment would be considered "Barren" as opposed to "Desirably Productive", but such a criterion has seldom been considered.

Near-Surface Water Clarity (Turb): During most estuarine and many oceanic studies water clarity is measured using a Secchi disk and/or with surface and submerged sensors (*e.g.*, LI-COR® sensor, *LI-COR* Biosciences) that measure available photosynthetically active radiation (PAR), which is subsequently expressed as percent of incident light (at the surface) that is still available at a specified depth. During the Bold expedition, however, environmental sampling was carried out on a 24-hour, round-the-clock schedule. Neither Secchi disk nor PAR sensors provide comparable water clarity data during nighttime measurements with artificial lighting. Consequently, measurements from a Seapoint ® turbidity meter attached to the Sea-Bird® CTD were used to measure water clarity for this survey.

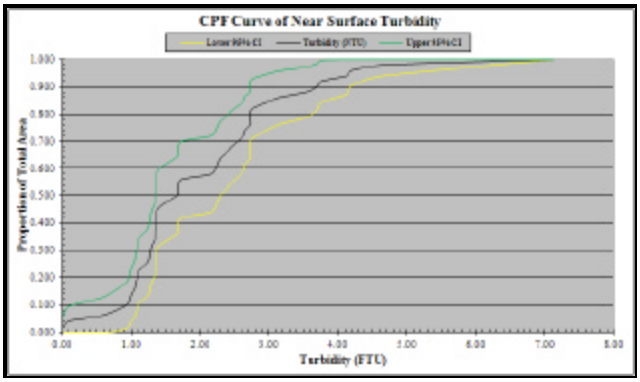
Average near-surface water clarity, in Formazin Turbidity Units (FTU), was calculated as described above for temperature, pH, salinity, and DO. Although turbidity units and percent availability of light (PAR) are inversely related (high light availability corresponds to low turbidity), the relationship is not well defined and varies geographically as well as with chlorophyll and salinity variations, at least within the Chesapeake Bay estuary (U.S. EPA, 2007, 2008a). All further discussion of water clarity in this report will be expressed in FTU. In any case, NCCA estuarine thresholds for water clarity, expressed in percent availability of PAR, would not be appropriate for open, near-shore oceanic waters.

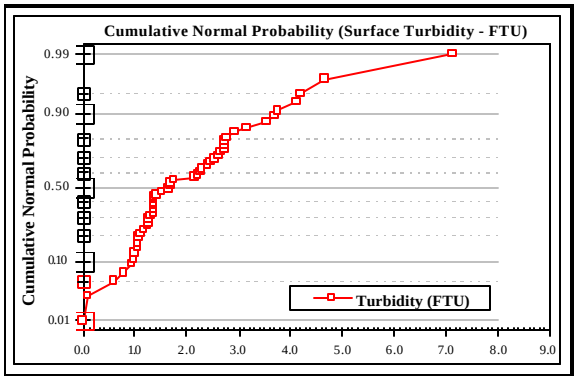
Near-surface turbidity values observed in this study varied from a minimum of 0.01 to a maximum of 7.12 FTU. The average observed turbidity was 2.05 FTU. Figure 4.8-12A summarizes the numerical distribution of turbidity values observed in this study, and Figure 4.8-12B illustrates the geographic distribution of "Lower" more desirable, "Intermediate", and "Higher" less desirable turbidity values. No well defined geographic clustering was observed. At some shallower sites with finer substrate particles, the sampling process itself may have artificially elevated the surface turbidity. The Bold maintained its position on station using directional horizontal thrusters that often suspended fine sediment in the water column.

NOAA, in summaries of various surveys of the Mid- and South Atlantic Bite conducted between 2000 and 2006 (Balthis, et al., 2009; Cooksey et al., 2010), did not measure nor discuss water clarity or turbidity in relation to marine waters. There is no criterion available to suggest that turbidities classified as "Higher" (less desirable) in this study are in fact stressful to the near-shore oceanic ecosystem.

Near-Bottom Dissolved Oxygen (DO): In general, dissolved oxygen concentrations are lower and most stressful to aquatic organisms near the bottom of the water column. As mentioned above, near-bottom DO concentrations varied from a minimum of 4.1 to a maximum of 8.1 mg/L during this study. Estuarine thresholds classify DO concentrations as "Good" when above 5.0 mg/L and as "Poor" when below 2.0 mg/L, but marine organisms may be less tolerant of low DO concentrations than estuarine organisms. Virginia's oceanic water quality standard (WQS) for DO is an instantaneous minimum of 5.0 mg/L. Bottom dissolved oxygen concentrations did fall below the 5.0 mg/L WQS at six sites (12.0 ± 9.2%), but no DO measurements were observed below 4.1 mg/L. The thresholds used for the classification of DO values in this study are "High" = 6.0 mg/L, "Moderate" 5.0 - 6.0 mg/L, and "Low" < 5.0 mg/L. The numerical distribution of near-bottom DO concentrations is summarized in Figure 4.8-13. The geographic distribution of near-bottom DO concentrations was illustrated above in Figure 4.8-6. Although bottom DO concentrations in the 4.0 to 4.9 mg/L range may not be highly stressful to benthic communities, they do fall below the Virginia instantaneous WQS of 5.0 mg/L. It is also significant that all seven sites with lower to moderate bottom DO concentrations are clustered within the region off Wallops and Assawoman Islands, between Chincoteague Inlet and Kegotank Bay.

Figure 4.8-12 Numerical (A) and geographical (B) distributions of turbidity (Turb - FTU) concentrations among the 50 near-shore probabilistic sites.





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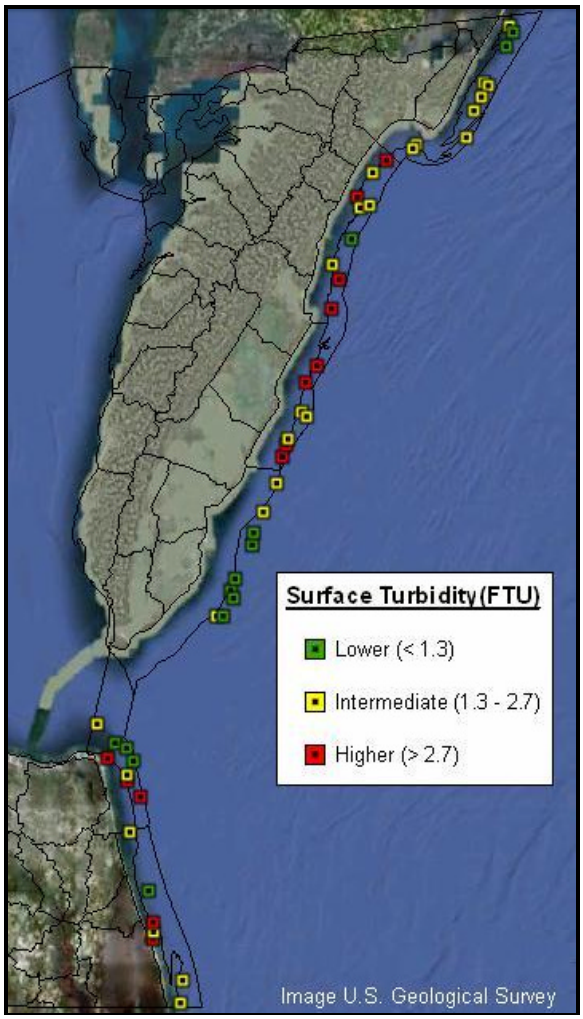
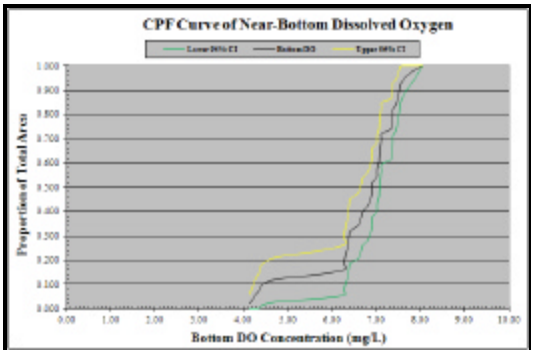
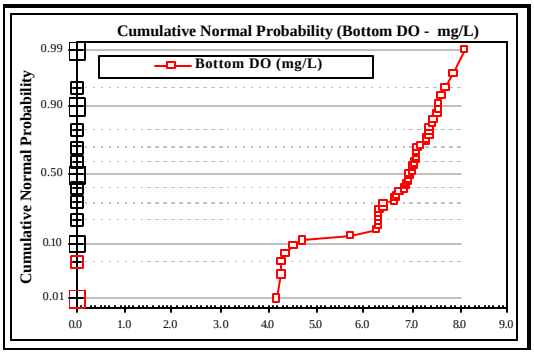


Attributes	Surface Turbidity (FTU)
N	50
Max	7.12
90th %	3.70
75th %	2.71
UL 95%	1.98
Median	1.67
LL 95%	1.35
25th %	1.28
10th %	0.97
Min	0.01
Average	2.05
Std. Dev.	1.28
Std. Err.	0.18

B

Figure 4.8-13 Numerical distribution of near-bottom dissolved oxygen concentrations (DO – mg/L) among the 50 probabilistic near-shore sites. Refer to Figure 4.8-6 for the geographical distribution of near bottom DO concentrations.





Attributes	Near Bottom DO (mg/L)
N	50
Max	8.08
90th %	7.56
75th %	7.32
UL 95%	7.29
Median	7.07
LL 95 %	6.85
25th %	6.33
10th %	4.71
Min	4.17
Mean	6.68
Std. Dev.	0.98
Std. Err.	0.14

Integrated Water Quality Index (WQI): Classifications based on the upper and lower quartile thresholds were arbitrary for most of the parameters integrated into the WQI, and evaluating the number of "Good", "Fair", and "Poor" classifications of the component variables, as is done in the NCCA Program, would not be a reliable way to classify water quality. Consequently, a procedure was utilized to standardize the absolute values of each of the five parameters into relative values on a common scale prior to integrating them into a WQI. The procedure employed, sometimes described as the "ranging" of values, serves to compress the range of each variable into a scale that extends from 0.000 through 1.000. To accomplish this, each value of a variable was transformed in the following manner, such that the most desirable observed value was assigned a value of 1.000 and the least desirable a value of 0.000.

For those parameters for which higher values are more desirable (*i.e.*, DO),

$$X_i'_{(ranged)} = (X_i - X_{min}) / (X_{max} - X_{min}).$$

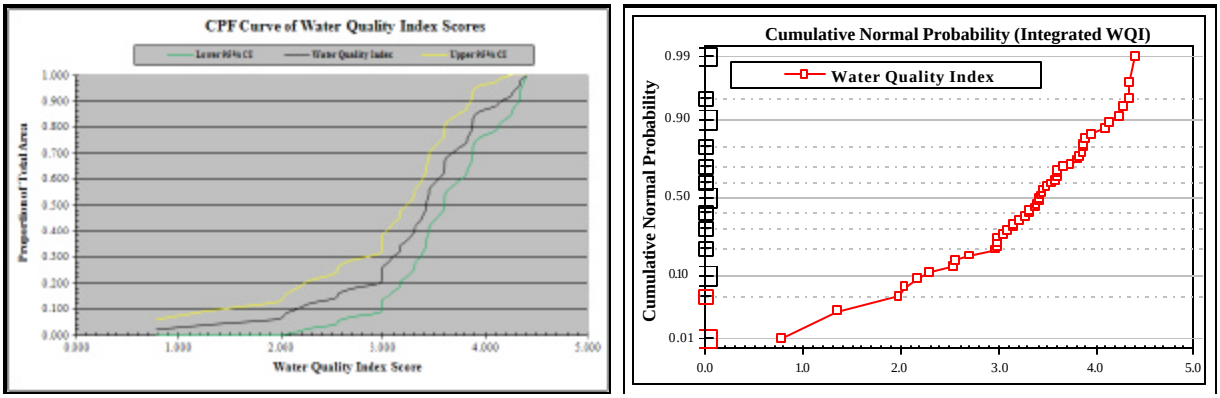
And for those for which lower values are more desirable (*i.e.*, DIN, DIP, Chl-a, and Turb),

$$X_i'_{(ranged)} = 1.000 - [(X_i - X_{min}) / (X_{max} - X_{min})].$$

Subsequently, the WQI score for each site was calculated as the sum of the ranged scores of the five component variables. Thus, if a site had the most desirable observed values across all five variables, its WQI score would be 5.000, if it had the least desirable observed values across all five variables it would have a WQI score of 0.000, and if it had median values across all five variables, its WQI score would be 2.500. The numerical and geographic distributions of WQI scores calculated in this way are summarized in Figures 4.8-14A and 4.8-14B, respectively. WQI scores varied from a minimum of 0.781 to a maximum of 4.406, with a median of 3.431 and an average of 3.315. The distribution of the scores as illustrated in the CPF curve of Figure 4.8-14A, appears to have "break points" near the upper and lower quartiles, at values of approximately 3.01(near the 25th percentile) and 3.83. The classification thresholds for "Higher", "Moderate", and "Lower" water quality scores were arbitrarily assigned these values; "Higher - 13 sites (26.0 ± 12.5%), "Intermediate - 24 sites (48.0 ± 14.2%), and Lower - 13 sites (26.0 ± 12.5%).

At this point it should again be emphasized that this is only an ordinal classification, and that an observed value of "Lower" water quality does not necessarily indicate environmental degradation. Among the five variables integrated into the WQI, only dissolved oxygen has an approved marine water quality standard against which to assess degradation. Sites with lower to intermediate WQI scores were clustered just south of the mouth of Chesapeake Bay and from Chincoteague Inlet to Wachapreague Inlet.

Figure 4.8-14 Numerical (A) and geographical (B) distributions of the Water Quality Index (WQI) scores among the 50 near-shore probabilistic sites.



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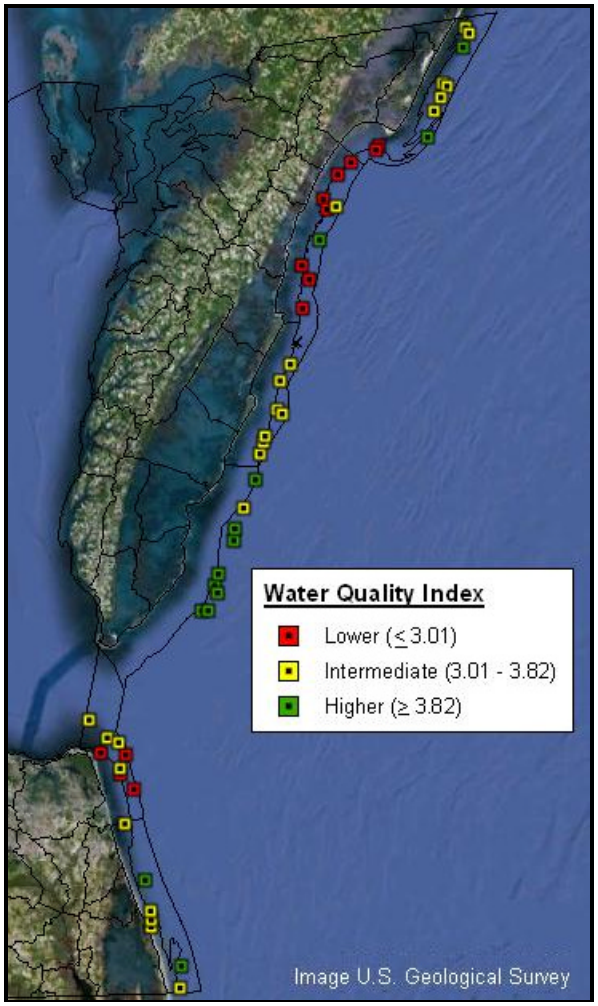


Attribute	Water Quality Index
N	50
Max	4.406
90th %	4.152
75th %	3.828
UCI 95%	3.612
Median	**3.431**
LCI 95%	3.250
25th %	3.013
10th %	2.282
Min	0.781
Average	**3.315**
Std. Dev.	0.750
Std. Err.	0.106

B

Near-surface Bacteria (*Enterococcus*): Virginia's primary contact recreational use bacterial water quality standards for transitional and saltwater are… "Enterococci bacteria shall not exceed a monthly geometric mean of 35 cfu/100 ml in transition and saltwater… If there are insufficient data to calculate monthly geometric means in transition and saltwater, no more than 10% of the total samples in the assessment period shall exceed enterococci 104 cfu/100 ml."

Near-surface bacterial samples were collected at all 50 sites, but two samples (4.0% missing) were lost during handling and processing aboard the Bold. Of the remaining 48 sites, 41 (85.42 ± 10.25%) had no detectable enterococci and seven (15.58 ± 10.25%) had from 1 to 16 cfu of enterococci / 100 mL. No individual site exceeded the instantaneous WQS and the geometric mean among all 48 samples was 0.6 cfu. The numerical and geographic distributions of enterococci counts among the 50 near-shore sites are summarized in Figures 4.8-15A and 15B, respectively. Sites positive for *Enterococcus* bacteria were scattered along the Delmarva coast from the Maryland state line to near the mouth of Chesapeake Bay.

Near-Surface Trace Metals: Near-surface water samples for the determination of dissolved and total trace metals were collected at all 50 sites using clean-handling procedures. At present, all of Virginia's water quality standards for toxic trace metals are based upon dissolved concentrations. Total metal results from this study are available as reference values and for other uses, but the discussion here will be restricted to dissolved metals in the water column.

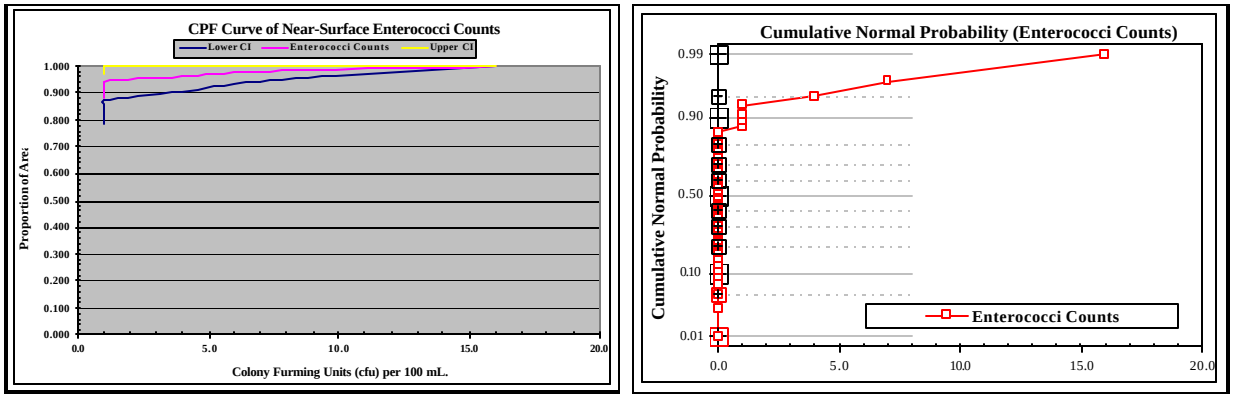
For saltwater, Virginia has established both acute and chronic aquatic life use (ALU) standards for ten trace metals. Silver is the only metal for which an acute saltwater standard has been defined without an accompanying chronic standard. Comparison of the concentrations of dissolved metals observed during this survey with the established ALU standards provides a useful characterization of this aquatic resource class relative to stresses resulting from dissolved toxic metals in the water column.

Table 4.8-1 summarizes all the dissolved metals analyzed during this study, as well as several additional metals for which saltwater standards have been defined. Only comparisons with chronic ALU standards are summarized in the table. The lower chronic criteria are more protective of the aquatic biota, and since none of them were exceeded no comparisons with acute standards were required. The average concentrations listed for each metal in the table are biased slightly above the true values because the values of the reporting limits were used for those samples where no metal was detected.

Of the eleven dissolved metals, metal valence states, and metal compounds for which the Commonwealth has acute and/or chronic ALU saltwater quality standards, eight are included for analysis in DEQ's saltwater clean dissolved metals parameter group code (DCMETS1). Of the 400 comparisons that were made between observed dissolved metals concentrations and established chronic saltwater ALU standards, not a single concentration exceeded its respective chronic standard.

The closest any dissolved metal came to exceeding a chronic ALU standard was the copper concentration of 5.8 µg/L observed at station 7C-AO05-10-034, 1.8 nautical miles southwest of the southern tip of Assateague Island. The second highest copper concentration, of 3.3 µg/L, barely more than half of the 6.0 µg/L chronic standard for aquatic life use, was observed at site 7C-AO06-10-005, 2.40 nautical miles east of Assateague Island Beach. In fact, of the ten observed copper concentrations = 2.0 µg/L, six occurred offshore from Assateague Island, between the Maryland state line in the north and Wallops Island to the south. Elsewhere, dissolved copper concentrations were between the method detection limit of 0.3 µg/L and the reporting limit of 1.0 µg/L at 32 (64.00 ± 13.69%) of the 50 sites (see Figure 4.8-16, below).

Figure 4.8-15 Numerical (A) and geographical (B) distributions of *Enterococcus* colony forming unit counts among the 50 near-shore probabilistic sites. No site exceeded the instantaneous maximum Enterococci standard of 104 cfu/100 mL.



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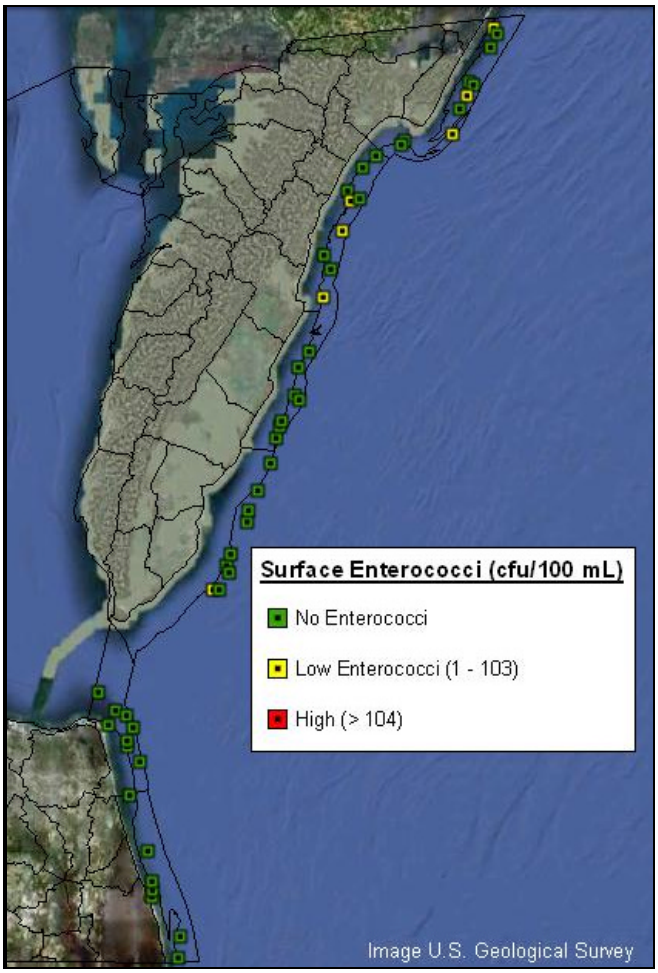


Attribute	Near-surface Enterococci (cfu/100ml)
N	48
Max	16
90th %	1
75th %	0.0
UL 95%	0.0
Median	**0.0**
LL 95 %	0.0
25th %	0.0
10th %	0.0
Min	0.0
Mean	**0.6**
Std. Dev.	2.5
Std. Err.	0.4

B

Table 4.8-1 The results of near-surface clean dissolved metals analyses at 50 probabilistic near-shore oceanic sites.

Summary of Saltwater Aquatic Life Use Standards and Observed Values for Dissoloved Metals
Virginia Near-shore Oceanic Survey - August 2010

Analyte [1]	Form	Matrix	Units	MDL	Acute Standard	Chronic Standard	Minimum Value Observed	Average Value Observed	Maximum Value Observed	Number Exceeding Chronic Standard	Percent Non-detects
Aluminum (Al)	Dissolved	Saltwater	µg/L	2.0	N/A	N/A	2.0	5.13	15.4	N/A	52.7
Antimony (Sb)	Dissolved	Saltwater	µg/L	0.2	N/A	N/A	0.2	0.20	0.2	N/A	98.2
Arsenic (As)	Dissolved	Saltwater	µg/L	0.2	69	36	0.5	0.79	1.1	0	0.0
Cadmium (Cd)	Dissolved	Saltwater	µg/L	1.0	40	8.8	1.0	1.00	1.0	0	100.0
Calcium (Ca)	Dissolved	Saltwater	mg/L	0.5	N/A	N/A	42.9	323.00	366.0	N/A	0.0
Chromium III (Cr)	Dissolved	Saltwater	µg/L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Chromium VI (Cr)	Dissolved	Saltwater	µg/L	N/A	1,100	50	N/A	N/A	N/A	N/A	N/A
Copper (Cu)	Dissolved	Saltwater	µg/L	1.0	9.3	6	1.0	1.44	5.80	0	64.5
Iron (Fe)	Dissolved	Saltwater	µg/L	N/A	N/A	N/A	200.0	200.00	200.0	N/A	100.0
Lead (Pb)	Dissolved	Saltwater	µg/L	1.0	240	9.3	1.0	1.00	1.0	N/A	100.0
Magnesium (Mg)	Dissolved	Saltwater	mg/L	0.5	N/A	N/A	87.6	1011.32	1150.0	N/A	0.0
Manganese (Mn)	Dissolved	Saltwater	µg/L	1.0	N/A	N/A	1.0	1.96	12.2	N/A	70.9
Mercury (Hg)	Dissolved	Saltwater	ng/L	1.5	1,800 ng/L	940 ng/L	1.5	1.50	1.5	0	100.0
Nickel (Ni)	Dissolved	Saltwater	µg/L	1.0	74	8.2	1.0	1.49	3.2	0	65.5
Potassium	Dissolved	Saltwater	mg/L	1.0	N/A	N/A	30.2	306.77	341.0	N/A	0.0
Selenium (Se)	Dissolved	Saltwater	µg/L	0.2	290	71	0.2	0.20	0.2	0	100.0
Sodium (Na)	Dissolved	Saltwater	mg/L	1.0	N/A	N/A	742.0	8448.40	9430.0	N/A	0.0
Silver (Ag)	Dissolved	Saltwater	µg/L	N/A	1.9	N/A	N/A	N/A	N/A	N/A	N/A
(Tributyltin) [2] TBT	Dissolved	Saltwater	µg/L	N/A	0.42	0.0074	N/A	N/A	N/A	N/A	N/A
Vanadium (V)	Dissolved	Saltwater	µg/L	2.0	N/A	N/A	2.0	2.02	2.2	N/A	80.0
Zinc (Zn)	Dissolved	Saltwater	µg/L	2.0	90	81	2.0	2.70	13.9	0	78.2

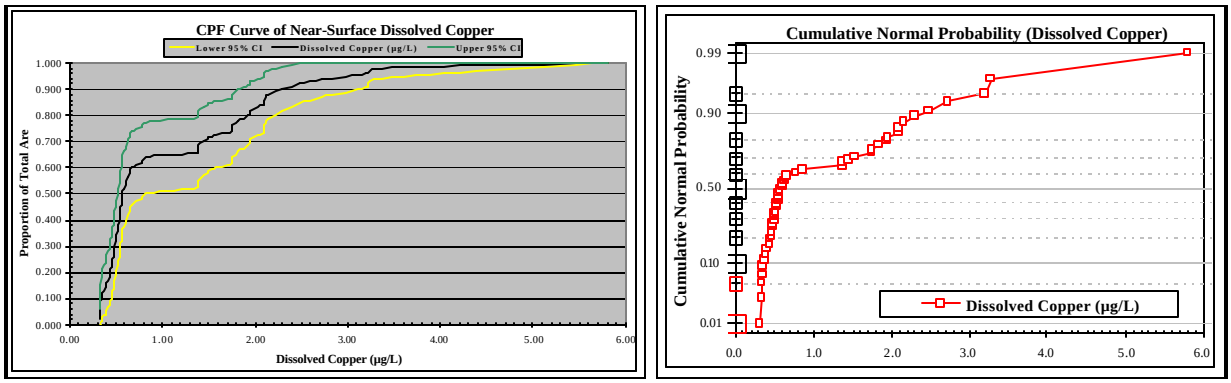
[1] Analytes in bold font are included in the saltwater dissolved clean metals Parameter Group Code DMETS1.

[2] Tributyltin is the only organo-metalic compound for which the Commonealth has saltwater criteria.

Acute aquatic life standard **Chronic aquatic life standard**
All observed values < chronic standard

In contrast, among dissolved metals samples collected at eleven probabilistic sites within Chincoteague Bay and Chincoteague Channel in 2008 and 2009, only two copper values attained or exceeded the reporting limit for the analytical method utilized - one of 1.0 µg/L and another of 1.54 µg/L. The dissolved copper observed at the off-shore sites apparently does not originate from the adjacent mainland or embayments, but is being carried southward by oceanic currents from sources further to the north. In fact, several other dissolved metals reveal a similar pattern. Although only present at low concentrations, lead (Pb), cadmium (Cd), nickel (Ni), selenium (Se), several major cations (Ca, K, Na) and other metals (Al, Mg, Fe, Mn) also reveal declining concentration gradients from the northernmost sub-watersheds AO05 and AO06, through AO12, AO16 and AO17 to the south. Sub-watershed AO22, from Great Machipongo Inlet to the mouth of Chesapeake Bay (CB), exhibits only background levels of these dissolved metals. Waters from the CB mainstem that exit to AO24 at the south end of AO22 exhibit low concentrations of these metals, but higher levels of antimony (Sb), zinc (Zn), arsenic (As), and vanadium (V).

Figure 4.8-16 Numerical (A) and geographical (B) distributions of near-surface dissolved copper concentrations among the 50 near-shore probabilistic sites. Virginia's chronic saltwater standard for copper is 6.0 µg/L.



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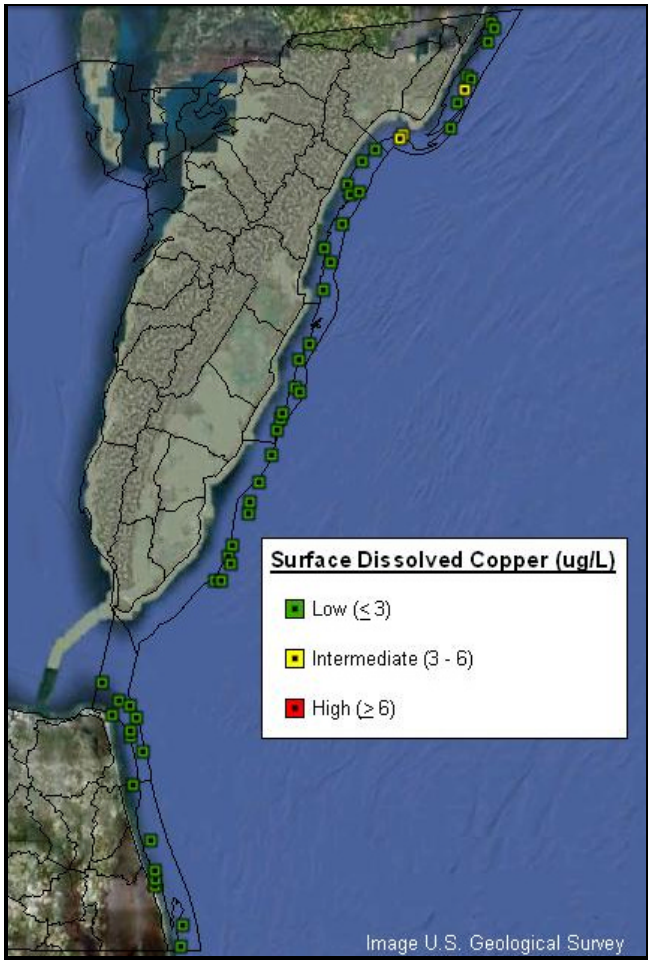


Attributes	Dissolved Copper (µg/L)
N	50
Max	5.80
90th %	2.32
75th %	1.75
UL 95%	0.87
Median	0.58
LL 95%	0.30
25th %	0.47
10th %	0.36
Min	0.32
Average	1.15
Std. Dev.	1.06
Std. Err.	0.15

B

In Figure 4.8-17, the 50 near-shore sites are arrayed by their latitudes, from north to south, along with their mean near-surface salinities (numerically on the left and graphically on the right). Five quality assurance sites in the table include replicate dissolved metals results; they can be identified by the red font of their Site IDs and the fact that the two replicates are represented by a single salinity value. The latitudes on the graphical salinity scale to the right do not correspond exactly with the sites to their left, but the scale serves to illustrate that the surface salinities remain essentially constant (31.0 – 31.4 psu) from 38.00^{o} N southward to 37.20^{o} N, where effects of the tidal plume from Chesapeake Bay begin to influence surface salinity. Immediately south of the Bay mouth antimony (Sb), zinc (Zn), arsenic (As), and vanadium (V) become more prevalent.

With the exception of copper, none of the other evaluated dissolved metals with saltwater ALU criteria even approached the concentration of their respective chronic standards. The only additional metal that merits discussion is Vanadium. Vanadium was added to the saltwater parameter group code at the time of DEQ's near-shore oceanic survey because it is a potential indicator of petroleum contamination. The agency was not only concerned about possible impact from the BP Gulf oil spill in the spring and summer of 2010, but also wanted to establish baseline reference values prior to potential future offshore exploration, extraction, and transport of petroleum in Virginia. The Commonwealth of Virginia has no saltwater standards for vanadium. In response to the Deep Horizon spill in the Gulf of Mexico in the spring of 2010, however, EPA posted a chronic saltwater aquatic life benchmark of 50 µg/L for vanadium.

Only eleven (20.0 ± 11.4%) of the 55 samples (including five QA replicate samples) attained or exceeded vanadium's reporting limit of 2.0 µg/L. The concentrations observed varied from a minimum of < 2.0 µg/L to a maximum of 2.2 µg/L, with an average value of 2.08 µg/L among the 11 samples with measurable concentrations.

Near-Surface Polycyclic Aromatic Hydrocarbons (PAHs): Evaluations of near-surface PAHs were added to the survey for two reasons: (1) because of concern about potential Gulf Stream-borne petroleum contamination resulting from the Gulf of Mexico oil spill from the British Petroleum Deep Horizon platform during the spring and summer of 2010, and (2) to provide baseline reference values in the event of future releases/spills during potential exploration, extraction, and transport of petroleum in Virginia's off-shore waters. Among the 19 petroleum-related PAHs evaluated at each of the 50 sites, every result was non-detect, *i.e.*, well below the reporting limit of 0.1 µg/L. Table 4.8-2 provides a summary of the near-surface dissolved PAH analytes, the Virginia water quality standards of those for which they exist, and EPA's water quality PAH benchmarks for aquatic life. The non-detect results for dissolved PAHs in this study did not permit calculating an integrated PAH benchmark. If all the analytes had been at their reporting limit thresholds, however, the resultant chronic benchmark would have been 1.93, indicating a potential risk of toxicity to aquatic organisms.

Near-Shore Sediment Quality

Particle Size Distribution and Total Organic Carbon: Near-shore oceanic sediments within the three-nautical-mile territorial limit were predominantly sandy. The percentage sand (particles = 0.0625 mm) varied from 31.9% to 98.3% by dry weight among the fifty sites sampled, with an average of 85.9% ± 2.5% (mean ± SE). Only four of the 50 sites (8.0 ± 7.7%) had what could be considered "muddy" substrate following estuarine (Chesapeake Bay Program) criteria (*i.e.*, < 60% sand). Figures 4.8-18A and 4.8-18B summarize the numerical and geographic distributions, respectively, of sandy vs. muddy substrates. Most of the sites with muddy substrate are clustered in the Wallops Island area. Note that there appears to be a distinct break-point at approximately 93% sand in the CPF distribution. This may indicate a break between predominantly oceanic substrates (68.0 ± 13.3% of sites) and those receiving significant amounts of continental contribution in the form of "fine" particles (32.0 ± 13.3% of sites), perhaps a more significant threshold for oceanic sediments than the estuarine "Sand" versus "Mud" criterion of 60% sand.

Figure 4.8-17 Relative near-surface concentrations of dissolved metals in relation to the north-south latitudinal gradient, near surface salinity, and discharge from the mouth of Chesapeake Bay. Quality Assurance sites with replicate dissolved metals results are identified with red font in the Site_ID field.

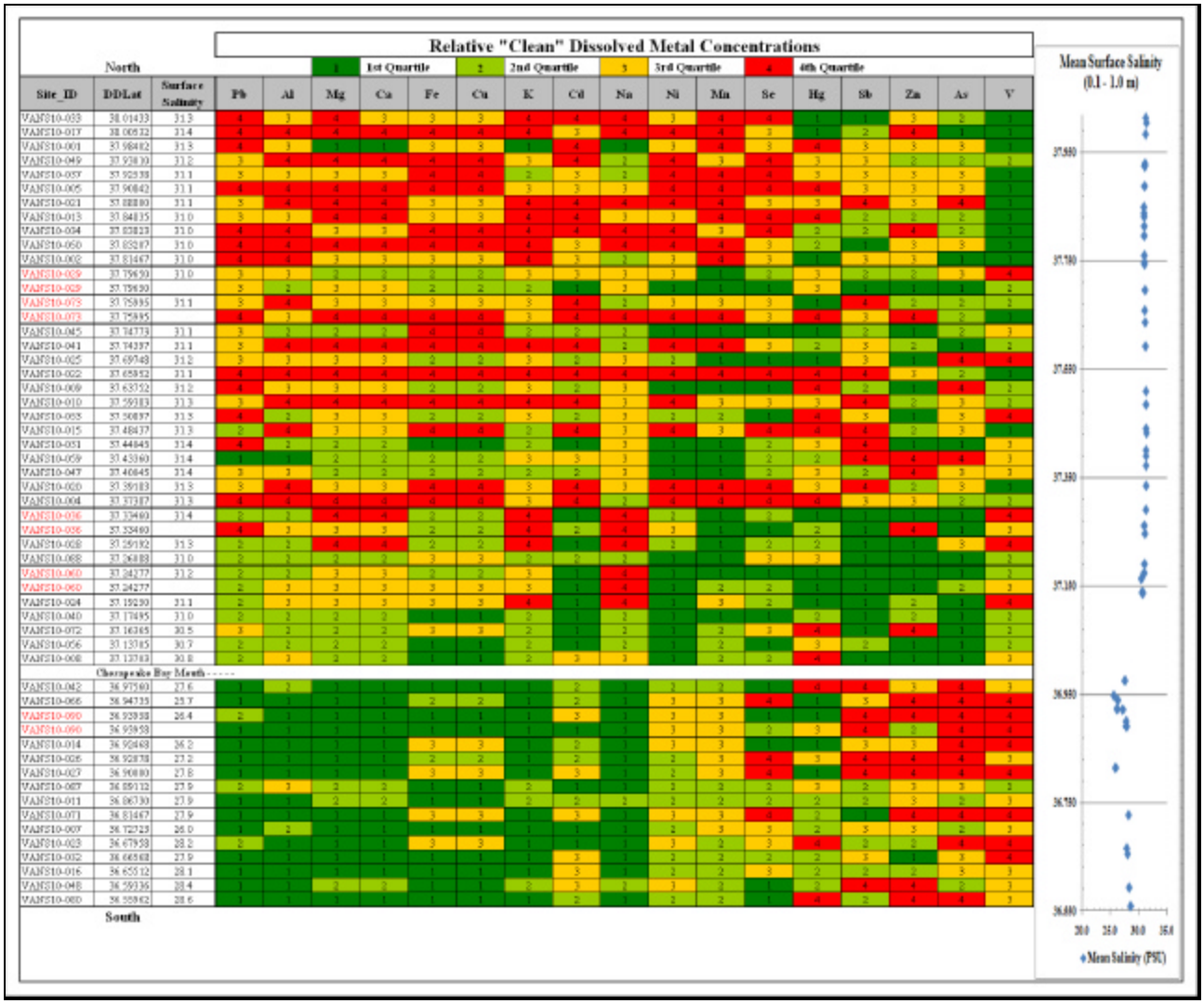
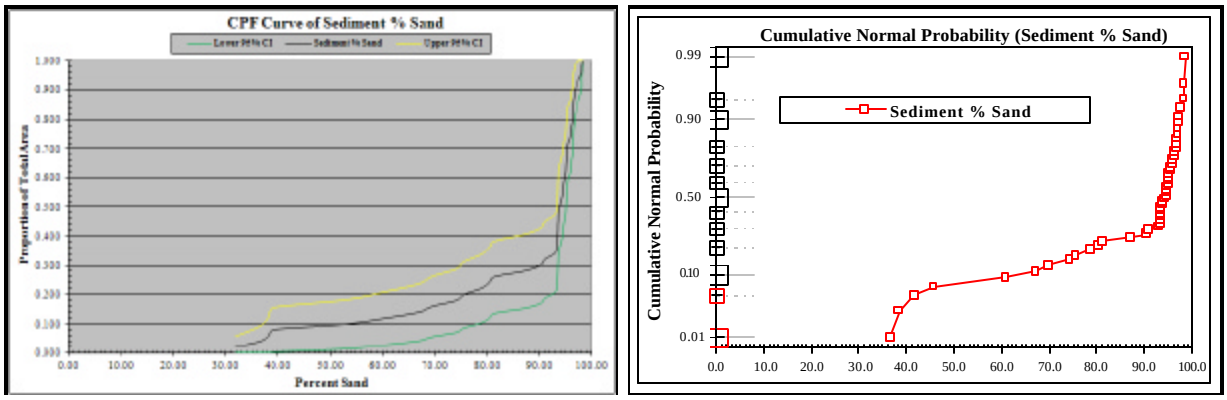


Table 4.8-2 Near-surface PAH analytes, Virginia water quality standards, and EPA Water Quality PAH Benchmarks for Aquatic Life. (http://www.epa.gov/bpspill/water-benchmarks.html)

		Aquatic Life Use		Human Health		EPA Water Quality PAH Benchmarks for Aquatic Life [1]			
		Saltwater		Public Water Supply	All Other Surface Waters	Acute Potency Divider[1]	Chronic Potency Divider[1]	Alkylation Multiplier [1]	Maximum Observed Concentration
Analyte	Units	Acute	Chronic						
1-Methylnaphthalene	µg/L	-	-	-	-	340	81.7	1	< 0.1 µg/L
2-Methylnaphthalene	µg/L	-	-	-	-	340	81.7	1	< 0.1 µg/L
Acenaphthene	µg/L	-	-	670	990	232	55.8	1	< 0.1 µg/L
Acenaphthylene	µg/L	-	-	-	-	1280	307	1	< 0.1 µg/L
Anthracene	µg/L	-	-	8,300	40,000	86.1	20.7	1	< 0.1 µg/L
Benzo(a)anthracene	µg/L	-	-	0.038	0.18	9.28	2.23	1	< 0.1 µg/L
Benzo(b)fluoranthene	µg/L	-	-	0.038	0.18	2.82	0.677	1	< 0.1 µg/L
Benzo(k)fluoranthene	µg/L	-	-	0.038	0.18	2.67	0.642	1	< 0.1 µg/L
Benzo(a)pyrene	µg/L	-	-	0.038	0.18	3.98	0.957	1	< 0.1 µg/L
Benzo(e)pyrene	µg/L	-	-	-	-	3.75	0.901	1	< 0.1 µg/L
Benzo(ghi)perylene	µg/L	-	-	-	-	1.83	0.439	1	< 0.1 µg/L
Chrysene	µg/L	-	-	0.0038	0.018	8.49	2.04	5	< 0.1 µg/L
Dibenz(a,h)anthracene	µg/L	-	-	0.038	0.18	1.17	0.282	1	< 0.1 µg/L
Fluoranthene	µg/L	-	-	130	140	29.6	7.11	1	< 0.1 µg/L
Fluorene	µg/L	-	-	1,100	5,300	164	39.3	14	< 0.1 µg/L
Indeno(1,2,3-cd)pyrene	µg/L	-	-	0.038	0.18	1.14	0.275	1	< 0.1 µg/L
Naphthalene	µg/L	-	-	-	-	803	193	120	< 0.1 µg/L
Phenanthrene	µg/L	-	-	-	-	79.7	19.1	6.8	< 0.1 µg/L
Pyrene	µg/L	-	-	830	4,000	42.0	10.1	2.1	< 0.1 µg/L

[1] Oil-related organic compounds are assessed jointly through a mixture approach because they all have the same type of effect on aquatic organisms. Potency divisors are not chemical-specific benchmarks, but are intermediates used in calculating the aggregate toxicity of the mixture. To assess the potential hazard to aquatic organisms, the sum of the calculated values is compared to a hazard index of 1. A value greater than 1 (>1) indicates that the sample has the potential to cause an acute or chronic effect on aquatic life like fish, crabs, and clams.
http://www.epa.gov/bpspill/water/explanation-of-pah-benchmark-calculations-20100622.pdf

Figure 4.8-18 Numerical (A) and geographical (B) distributions of percent sand in sediment among the 50 near-shore probabilistic sites. The illustrated classification threshold between "Mud" and "Sand" substrates is the estuarine criterion of 60% sand sized particles. The cumulative normal distribution suggests that a threshold of 93% sand may be characteristic of oceanic sediments and that any lower sand content indicates the addition of continental fines!



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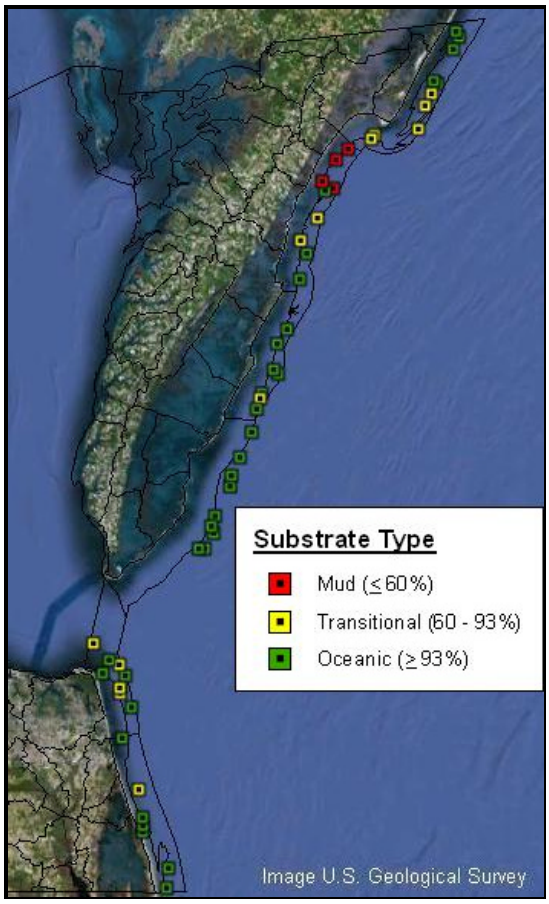


Attribute	Sediment Sand (%)
N	50
Max	98.32
90th %	96.81
75th %	95.96
UL 95 %	96.85
Median	93.91
LL 95 %	90.96
25th %	82.68
10th %	60.00
Min	31.92
Mean	85.90
Std. Dev.	17.84
Std. Err.	2.52

B

Total organic carbon varied from a minimum of 0.03% to a maximum of 1.43% by weight. A single sample exceeded the 1.0% threshold above which risk of reduced species richness from organic loading and associated stressors in sediment is considered medium (Table 4.8-3, Hyland et al., 2005). The maximum concentration observed (1.43%) was still considerably below the 3.5% (35 mg/g) threshold indicative of high risk to benthic richness as defined in the table. The single site (7C-AO17-10-029) that exceeded the 1% TOC threshold was a muddy site with a depth of 10.2 m, approximately 1.74 nautical miles due east of Assawoman Island at Kegotank Bay.

Table 4.8-3 Relative risk to benthic taxonomic richness in response to ranges in Total Organic Carbon (TOC) content of marine sediment.

Relative Risk to Taxonomic Richness	TOC mg/kg (% by weight)
Low	< 10 mg/kg (< 1.0%)
Medium	10 - 35 mg/kg (1.0 - 3.5%)
High	> 35 mg/kg (> 3.5%)
Marine Sediment TOC Ranges (Hyland et al., 2005)	

Chemical Contamination:

Individual Metals: Near-shore oceanic sediment samples were analyzed for 23 metals. Marine Effects Range Median (ERM) and Effects Range Low (ERL) sediment screening values were available for nine of these (Buchman, 1999), and each of the metals was evaluated individually. An ERM or ERL quotient (ERMq or ERLq) for each was calculated by dividing the observed concentration of a metal in the sediment by its respective screening value. If a quotient exceeded 1.0 in value, the associated sediment exceeded its corresponding screening value. None of the metals exceeded their ERM values at any of the 50 sites (*i.e.*, all ERMq's were < 1.0). Arsenic was the only metal to exceed its ERL value. Three sites (6.00 ± 6.75%) along the Delmarva coast between Wallops Island and the Metompkin Islands, with depths of 9.5 to 10.4 meters, had arsenic ERLq's of 1.110, 1.152, and 1.207. Although ambient arsenic may be derived from natural mineral deposits, elevated arsenic levels in freshwater and marine sediments are often associated with runoff from poultry rearing and processing facilities. Arsenic is often included in poultry feed as an antihelminthic to prevent or treat parasitic worm infestations, and elevated concentrations are often passed in poultry feces. Table 4.8-4 summarizes the comparisons of individual metals in the sediment with their respective ERM and ERL screening values.

Table 4.8-4 Summary of Effects Range Median (ERM) and Effects Range Low (ERL) sediment screening value comparisons for individual metals among the 50 near-score oceanic sites.

Metal	Units	ERM	Maximum ERMq	Average ERMq	Number ≥ ERM	ERL	Maximum ERLq	Number ≥ ERL
Arsenic (As)	mg/Kg	70	0.141	0.052	0	8.2	1.207	3
Cadmium (Cd)	mg/Kg	9.60	0.083	0.010	0	1.2	0.667	0
Chromium (Cr)	mg/Kg	370	0.141	0.058	0	81	0.646	0
Copper (Cu)	mg/Kg	270	0.039	0.013	0	34	0.306	0
Lead (Pb)	mg/Kg	218	0.077	0.039	0	46.7	0.360	0
Mercury (Hg)	mg/Kg	0.71	0.063	0.012	0	0.15	0.300	0
Nickel (Ni)	mg/Kg	51.6	0.343	0.136	0	20.9	0.847	0
Silver (Ag)	mg/Kg	3.7	0.054	0.026	0	1	0.200	0
Zinc (Zn)	mg/Kg	410	0.160	0.074	0	150	0.439	0

Individual Organics: Near-shore oceanic sediment samples were analyzed for 25 polycyclic aromatic hydrocarbons (PAHs) and other semi-volatile compounds, 28 chlorinated pesticides and/or associated isomers or metabolites, and 56 polychlorinated biphenyls (PCBs). The samples were individually evaluated for each of the compounds or classes of compounds for which ERM and ERL sediment screening values were available. No ERM or ERL was reached or exceeded by any of the organics at any of the 50 sites (see Table 4.8-5, below). The entire suite of organic parameters was below detection limits in the sediment at 24 sites (48.0 ± 14.2%). No chlorinated pesticides or associated products were detected at any site. PCBs were only detected at two sites (4.0 ± 5.6%) and the maximum ERLq for total PCBs was 0.618. PAHs were the predominant organic contaminant among those examined, reaching detectable concentrations in the sediment at 25 (50.0 ± 14.2%) of the 50 sites. High molecular weight PAHs were more frequently observed than low molecular weight PAHs, occurring at 25 sites (50.0 ± 14.2%) in comparison with only 10 sites (20.0 ± 11.4%) for those of low molecular weight. The maximum ERLq observed among the 13 individual PAHs and three PAH classes was 0.136 for the high molecular weight PAH class.

Table 4.8-5 Summary of ERM and ERL sediment screening value comparisons for individual and categorical organic compounds among the 50 near-score oceanic sites.

Organic Compounds	Units	ERM	Max ERMq	Mean ERMq	Number = ERM	ERL	Max ERLq	Mean ERLq	Number = ERL	Number > 0.000
Polychlorinated Biphenyls (PCBs)										
Total PCBs	µg/Kg	180	0.078	0.002		22.7	0.618	0.018	0	2
Chlorinated Pesticides										
Chlordane	µg/Kg	6	0.000	0.000	0	0.5	0.000	0.000	0	0
p,p'-DDD	µg/Kg	20	0.000	0.000	0	2	0.000	0.000	0	0
p,p'-DDE	µg/Kg	27	0.000	0.000	0	2.2	0.000	0.000	0	0
p,p'-DDT	µg/Kg	7	0.000	0.000	0	1	0.000	0.000	0	0
DDT, Total	µg/Kg	46.1	0.000	0.000	0	1.58	0.000	0.000	0	0
Dieldrin	µg/Kg	8	0.000	0.000	0	0.02	0.000	0.000	0	0
Polycyclic Aromatic Hydrobarbons (PAHs)										
2-Methylnaphthalene	µg/Kg	670	0.000	0.000	0	70	0.000	0.000	0	0
Acenaphthene	µg/Kg	500	0.000	0.000	0	16	0.000	0.000	0	0
Acenaphthylene	µg/Kg	640	0.000	0.000	0	44	0.000	0.000	0	0
Anthracene	µg/Kg	1,100	0.002	0.000087	0	85.3	0.023	0.001	0	4
Benzo(a)anthracene	µg/Kg	1,600	0.013	0.000422	0	261	0.080	0.003	0	7
Benzo(a)pyrene	µg/Kg	1,600	0.018	0.001	0	430	0.067	0.002	0	8
Chrysene	µg/Kg	2,800	0.008	0.000	0	384	0.056	0.002	0	8
Dibenz(a,h)anthracene	µg/Kg	260	0.015	0.001	0	63.4	0.060	0.002	0	5
Fluoranthene	µg/Kg	5,100	0.007	0.000301	0	600	0.062	0.003	0	17
Fluorene	µg/Kg	540	0.000	0.000	0	19	0.000	0.000	0	0
Naphthalene	µg/Kg	2,100	0.001	0.000062	0	160	0.015	0.001	0	4
Phenanthrene	µg/Kg	1,500	0.004	0.000301	0	240	0.025	0.002	0	10
Pyrene	µg/Kg	2,600	0.014	0.001	0	665	0.054	0.002	0	15
Low Molecular Weight PAHs	µg/Kg	3,160	0.004	0.000222	0	552	0.021	0.001	0	10
High Moleculary Weight PAHs	µg/Kg	9,600	0.024	0.001	0	1,700	0.136	0.005	0	25
Total PAHs	µg/Kg	44,792	0.005	0.000218	0	4,022	0.061	0.002	0	25

Integrated Organics - Equilibrium Partitioning Sediment Benchmarks (ESBs) for PAH Mixtures: The U.S. EPA has published several procedures for the derivation of contaminant equilibrium partitioning sediment benchmarks (ESBs) for the protection of benthic organisms. Such benchmarks consider the potential cumulative (additive) effects of multiple related contaminants (*e.g.*, metals, PAHs, etc.) within the same sediment sample. The ESB calculations for PAH mixtures (U.S. EPA, 2000) were originally derived for a mixture of 34 individual compounds and subclasses of PAHs, based upon their toxicities to benthic organisms, and their equilibrium partitioning between sediment, its total organic carbon (TOC) content,

and the water in the sediment's interstitial spaces where most benthic organisms reside. The final calculation in deriving the Total ESB_{34} score for a sediment sample is to sum the scores for the 34 individual analytes. Freshwater or saltwater sediments in which the Total ESP_{34} Score is = 1.0 for the mixture of the 34 PAHs are acceptable for the protection of benthic organisms, and if the Total ESB_{34} is greater than 1.0, sensitive benthic organisms may be unacceptably affected.

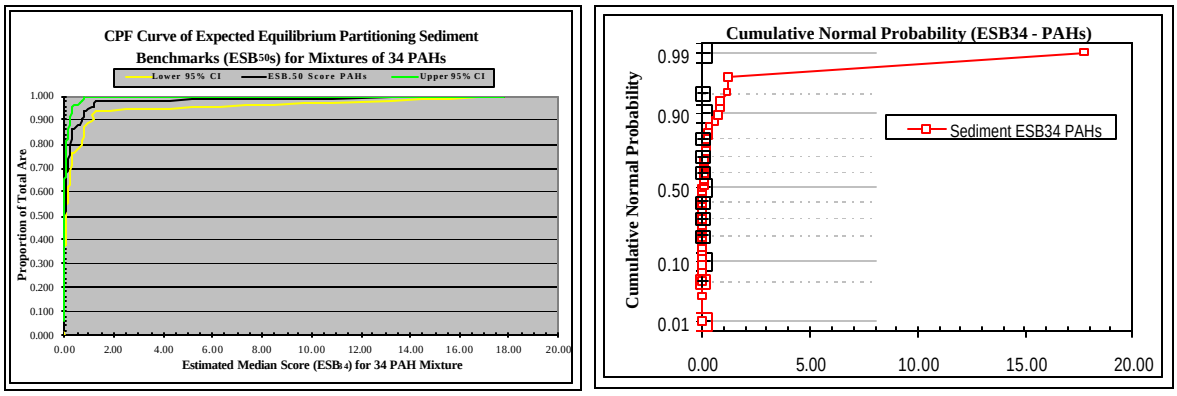
Only 23 of the PAHs included in the original ESB derivations were among the suite of PAH analytes included in this study, but the EPA publication cited above also provides correction factors to estimate the reliability of predicting a score for the total suite based on the results from these 23 analytes. Multiplying the total score derived from summing the 23 analytes (ESB_{23}) by a correction factor of 1.64 provides an estimate of the expected median score for the ESB_{34} among the N = 2001 reference samples originally used to derive the ESB relationship. When this correction factor was applied to the results from the 50 near-shore probabilistic sites, 94% had expected ESB_{34} scores = 1.0. Only three sites (6.00 ± 6.75%) had expected ESB_{34} scores greater than 1.0, and only one exceeded 1.3 (see Figure 4.8-19). The maximum expected ESB_{34} of 17.810, predicting a very high risk of benthic effects, occurred at site VANS10-020 in watershed AO16 on the Delmarva coast, off the southern end of Hog Island just north of Great Machipongo Inlet. Although this site had a high expectation of significant PAH-related effects on the benthos, an independent evaluation based upon integrated metal and organic contaminants (mean ERM-Quotient, see below) predicted only low risk of benthic degradation. Amphipod survivorship during sediment toxicity tests was rated as good (86.7% survivorship), and the benthic community there was evaluated as being well above average (see discussion in the section on benthic communities)!

Integrated Metals and Organics – Mean ERM Quotients (mean ERMq's): When the concentrations of nine metal and 23 organic analytes were compared with their individual sediment screening values (ERMs and ERLs), not a single analyte concentration exceeded its ERM value, and only one analyte (arsenic) slightly exceeded its ERL value at three sites (Tables 4.8-4 and 4.8-5). It was evident from the analytical results, however, that complex low-level mixtures of contaminants existed in the sediment at many of the sites. Various studies in the southeastern U.S. and elsewhere over the past 14 years have demonstrated that the additive (or synergistic) effects of low-level contaminants can have adverse effects on benthic communities (Hyland et al., 1998; Hyland et al., 1999; Hyland et al., 2003; Ingersoll et al., 2005; Winning et al., 2005). One method of estimating the integrated effects of multiple contaminants is to compare their average ERM quotient to observed benthic effects at a wide variety of marine sites. Hyland and others (2003) used this approach in estuaries along the U.S. Atlantic and Gulf of Mexico coasts to identify ranges of mean ERMq values that were associated with relative levels of benthic degradation (Table 4.8-6 – for the Virginian Maritime Province). The standard procedure is to calculate the arithmetic average of the ERMq values across eight metals (As, Cd, Cr, Cu, Pb, Hg, Ag, and Zn, excluding Ni), total PCBs, 4,4'-DDE, Total DDT, and the 13 individual PAHs for which ERM values have been established. The numerical and geographic distributions of mean ERMq values among the 50 near-shore oceanic sites in this study are summarized in Figure 4.8-20A and Figure 4.8-20B, respectively. No sites were observed to have high risk of benthic degradation, and the four with medium risk were clustered south of Chincoteague Inlet (3) and at the mouth of Chesapeake Bay (1). The maximum mean ERMq value observed (0.030) was well below the midpoint of the medium effects class. The three sites with the highest mean ERM quotients were the same as those with ERL exceedances for arsenic.

Table 4.8-6 Relative risk of benthic degradation in response to ranges of mean ERM quotients (Hyland et al., 2003) among 50 probabilistic near-shore sites in the Virginian Maritime Province.

Relative risk of benthic degradation	Mean ERMq	Site Count	Percent
Low	= 0.022	46	92.00 ± 7.71%
Medium	> 0.022 - 0.098	4	8.00 ± 7.71%
High	> 0.098 - 0.473	0	0.0%
Very High	> 0.473	0	0.0%

Figure 4.8-19 Numerical (A) and geographical (B) distributions of expected median Equilibrium Partitioning Sediment Benchmarks (ESB_{34}) values for mixtures of 34 PAHs in sediment among the 50 probabilistic near-shore sites. Estimates are based upon the 23 PAH analytes evaluated in the current study.



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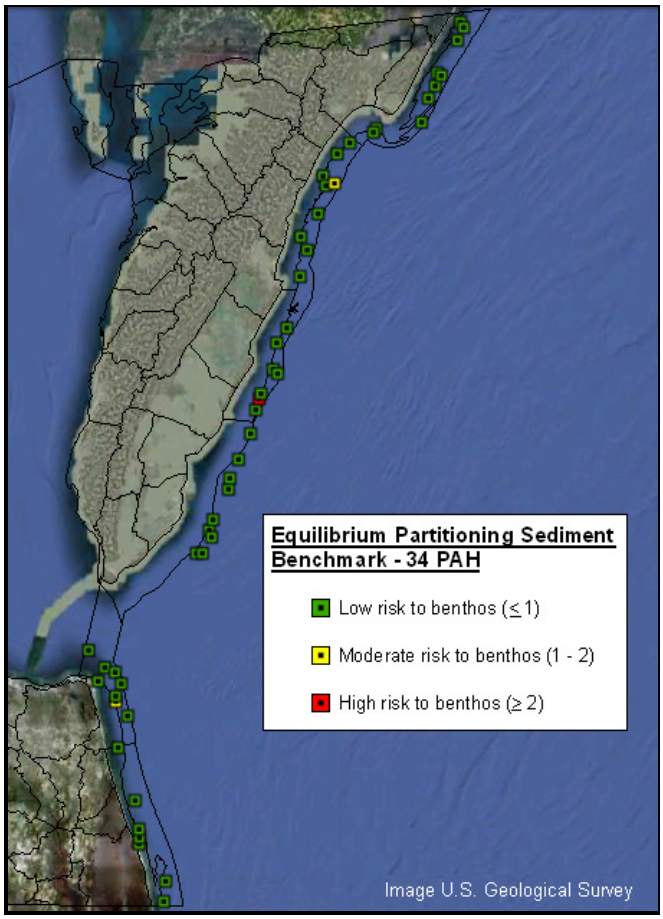
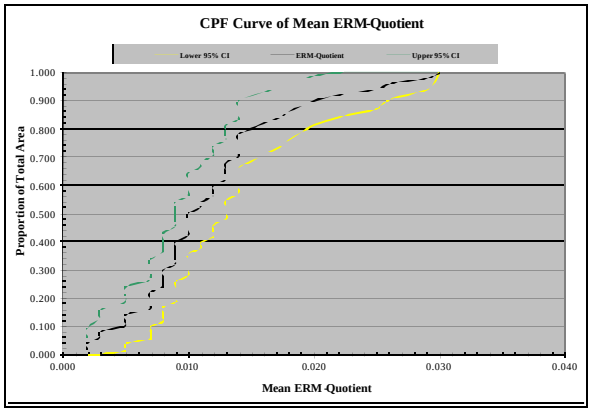
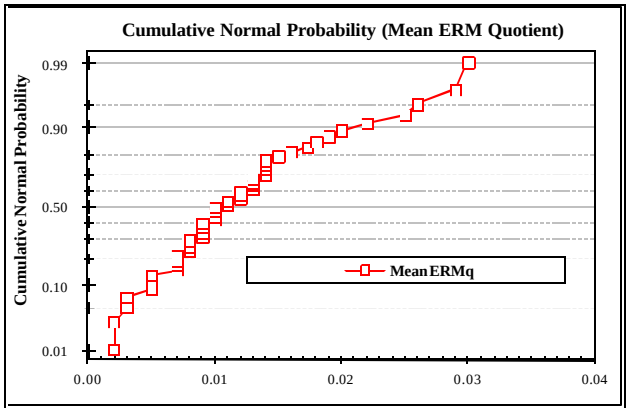


Attribute	ESB.50s 34 PAH Mixture
N	50
Max	17.810
90th %	0.759
75th %	0.188
UL 95%	0.060
Median	0.018
LL 95%	-0.024
25th %	0.000
10th %	0.000
Min	0.000
Mean	0.517
Std. Dev.	2.514

B

Figure 4.8-20 Numerical (A) and geographical (B) distributions of mean ERM Quotient (mean ERMq) values for mixtures of metallic and organic contaminants in sediment among the 50 probabilistic near-shore sites.





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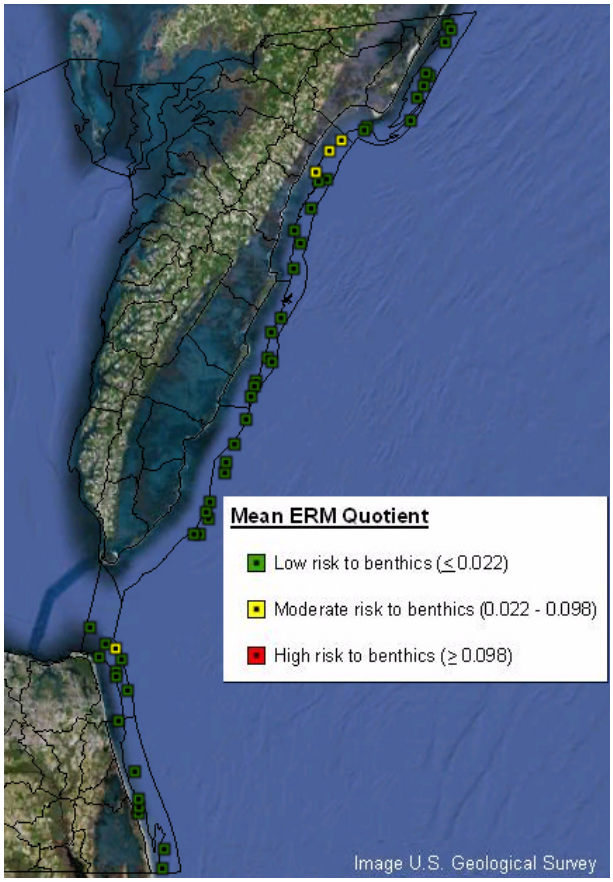


Attribute	Mean ERM Quotient
N	50
Max	0.030
90th %	0.020
75th %	0.014
UL 95%	0.012
Median	0.011
LL 95%	0.009
25th %	0.008
10th %	0.005
Min	0.002
Mean	0.012
Std. Dev.	0.006
Std. Err.	0.001

B

Sediment Toxicity: Sediment toxicity was evaluated with ten-day, static acute toxicity tests employing the estuarine amphipod *Leptocheirus plumulosus* as the test organism. All tests were performed by an EPA-contracted laboratory under auspices of the NARS/NCCA Program. Much of the ancillary data, such as test vessel temperature, pH, DO, ammonia, etc. have not yet been provided. Consequently, the classification provided here should be considered preliminary.

Leptocheirus survival, even in apparently non-contaminated oceanic sediments, appeared to be lower in this near shore oceanic study than in most of Virginia's estuarine sediments tested at the same lab during the 2010 NARS/NCCA Program. Although *Leptocheirus plumulosus* is apparently less sensitive to variations in sediment particle size than *Ampelisca abdita* (U.S EPA, 1996), an additional consideration is that the near-shore oceanic sediments were predominantly sandy - only five of the 50 sites (10.0 ± 8.5%) had what could be considered "muddy" substrate by estuarine standards (*i.e.*, < 60% sand). It is possible that the high sand component in these sediments adversely influenced the amphipod toxicity test results, as was observed with *A. abdita* in Guam and reported in National Coastal Condition Report IV (U.S. EPA, 2012 – Dec 2010 Draft). Seventy-two percent of the sites in this near-shore oceanic survey exceeded 90% sand in their sediments. Emery et al. (1997), in the development of chronic sublethal sediment bioassay protocols using *L. plumulosus*, reported reduced amphipod survivorship in sediments greater than 75% sand. With all other parameters being controlled, the 28-day survivorship of *Leptocheirus* in their study was less than 70% when tested in a 100% sand substrate.

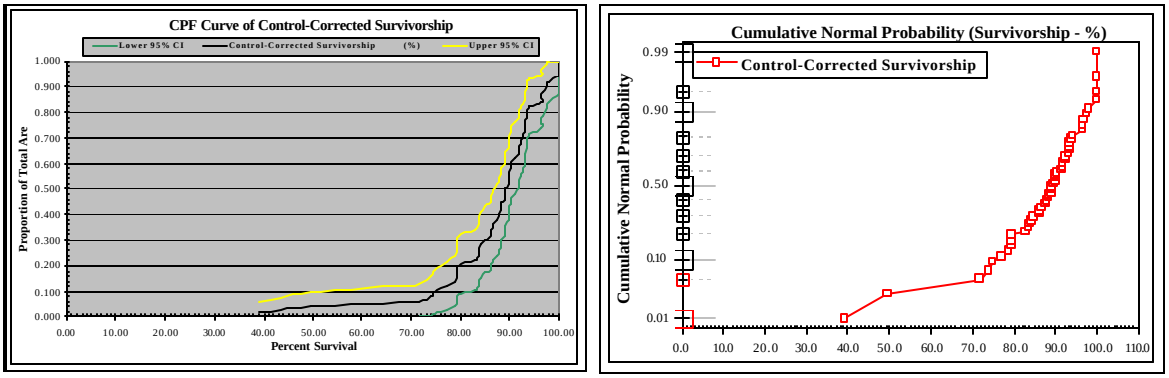
Previous classifications of sediment toxicity test results for National Coastal Condition Reports (U.S. EPA.. 2001, 2004, 2008b) have identified sites with control-corrected survivorship = 80% as good, and those with survivorship < 80% as poor, based on the ecological significance of 20% mortality to a breeding population. In reality, considering the structure of the ten-day acute toxicity tests, 80% survivorship (20% mortality) is well below the approximate limit at which statistical significance can be confirmed at the 95% confidence level. Toxicity test survivorship as high as 90% at times can be shown to be statistically different from controls with this level of confidence, while control-corrected survivorship less that 80% is almost universally statistically significant. In other words, statistically significant results may not be ecologically significant, but ecologically significant results are almost always statistically significant. Considering the potential of particle size effects in this study, the following tentative classification has been used: sites with control-corrected survivorship = 80.0% will be classified as "Good", those with survivorship < 70.0% will be classified as "Poor", and those between 70% and 80% will be classified as "Fair", with the caveat that the "Fair" classification may result from contamination or from the effects of particle size distribution.

Figure 4.8-21 summarizes the numerical (Fig. 4.8-21A) and geographical (Fig. 4.8-21B) distributions of sediment toxicity results. Among the 50 sites in the survey, 80.0 ± 11.4% were classified as "Good" for sediment toxicity, 16.0 ± 10.4% were classified as "Fair", and 4.0 ± 5.6% were classified as "Poor." Both "Poor" sites and half of the "Fair" sites were distributed along the Delmarva coast from Assateague Island to Wachapreague Inlet. Four additional "Fair" sites were located near or south of the Chesapeake Bay mouth.

Integrated Sediment Quality Index (SQI)

All four National Coastal Condition Reports (U.S. EPA 2001, 2004, 2008b, 2012) have included an integrated Sediment Quality Index based on three components: (1) sediment toxicity rated as "Good" or "Poor" based upon % survivorship = 80% or < 80% respectively, (2) sediment contamination rated as "Good", "Fair", or "Poor" based upon number of ERM and/or ERL exceedances, and (3) sediment TOC concentrations rated as "Good", "Fair", or "Poor" based upon < 2.0%, 2.0%-5.0%, and > 5.0% by weight, respectively. In this report different components of sediment quality have been evaluated, with different thresholds, either specified in the literature or chosen arbitrarily based upon observed variable distributions. Consequently, in this study an integrated Sediment Quality Index (SQI) has been derived using standardized variable ranges as described above for the WQI.

Figure 4.8-21 Numerical (A) and geographical (B) distributions of control-corrected survivorship in ten-day, static acute sediment toxicity tests with *Leptocheirus plumulosus* among the 50 probabilistic near-shore sites.



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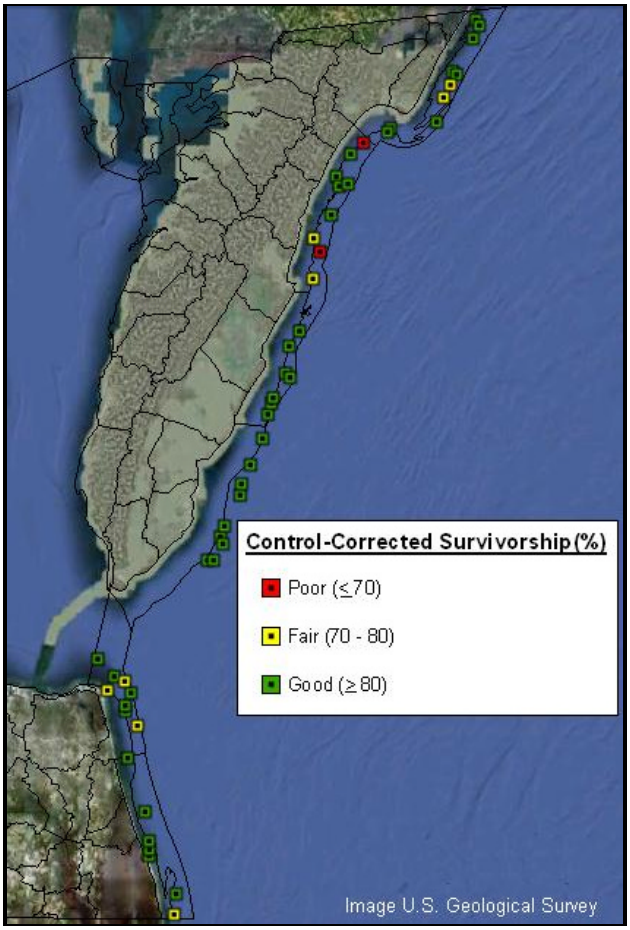


Attribute	Control-Corrected Survivorship (%)
N	50
Max	100.00%
90th %	97.78%
75th %	93.33%
UL 95%	91.47%
Median	89.39%
LL 95%	87.32%
25th %	84.00%
10th %	76.82%
Min	39.08%
Mean	87.29%
Std. Dev.	11.49%
Std. Err.	1.62%

B

Components of the SQI include sediment TOC concentrations (ranged between 0.0% and the 3.5% threshold for high risk of benthic degradation - Hyland et al., 2005), mean ERM quotients (ranged between 0.000 and the 0.474 threshold for very high risk of benthic degradation (Hyland et al., 2003), sediment ESBs for PAH mixes (ranged between observed minimum [0.000] and maximum values), and sediment toxicity (ranged between observed minimum and maximum values of control-corrected survivorship). The site SQI was subsequently calculated as the sum of ranged variable values across the four components; the sum was then multiplied by 1.25 to create a total SQI scale which could vary between 0.000 and 5.000. Tentative breakpoints were identified in the CPF curve at values of approximately 4.300 and 3.900. Based on these tentative thresholds, sites with SQI scores > 4.300 (86.0 ± 9.9% of the sites) were classified as being of "Higher" sediment quality, those with scores < 3.900 (6.0 ± 6.8%) as being of "Lower" sediment quality, and those with scores from 3.900 to 4.300 (8.0 ± 7.7%) as being of "Moderate" sediment quality. The numeric and geographic distributions of the SQI scores are summarized in Figures 4.8-22A and 4.8-22B, respectively. The three sites with "Lower" SQI scores correspond to the two sites with the lowest survivorship in sediment toxicity testing and the site with the highest ESB_{34} score for PAH mixtures in sediment.

Benthic Communities: The three benthic indices normally used for the evaluation of estuarine benthic communities in Virginia waters are not considered reliable for the assessment of benthic communities at marine sites. The Chesapeake Bay Program's Benthic Index of Biotic Integrity (CBP B-IBI, Weisberg et al., 1997) is intended for and only appropriate in tidal waters within the Bay drainage; it is the best index available for those waters. The mid-Atlantic B-IBI (Llansó et al., 2002) and the EMAP Virginia Province Index of Estuarine Condition (VP-IEC - Paul et al., 2001) are both appropriate for all of Virginia's estuarine waters (Bay and coastal estuarine), but not for marine ecosystems. All three of these indices were still calculated and evaluated for the benthic samples from off-shore oceanic sites, with the understanding that the threshold values normally used to determine the relative state of degradation (non-degraded, marginal, slightly or severely degraded) were not reliable for marine samples. It was assumed, however, that the relative values of each index would still differentiate more degraded from less degraded communities along a gradient of stressors, and that if all three indices agreed in their classifications it was a relatively good indication of the degree of stress the benthic community had experienced.

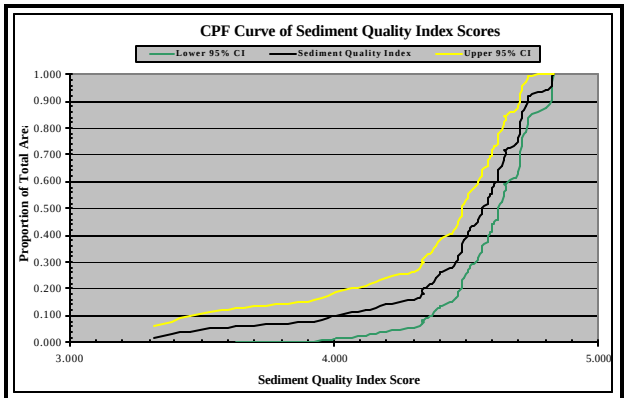
Several additional metrics, including some that were incorporated into one or more of the estuarine indices, were assumed to be appropriate for ranking benthic communities in general. These metrics were calculated for each of the marine samples. The distribution of values of each metric was then evaluated and scores were assigned to the ranges that were considered more desirable (score 5), less desirable (score 1), or intermediate (score 3).

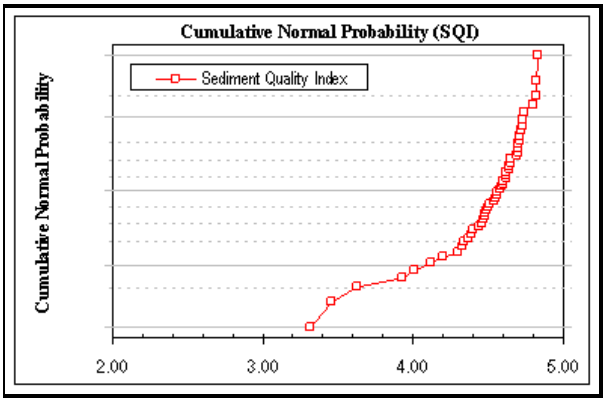
The individual metrics and their corresponding threshold values are summarized in the paragraphs below and in Table 4.8-7. A site benthic score was subsequently calculated as the arithmetic mean score across all metrics for each individual site. This final score was used as an additional benthic index for evaluation of the 50 sites. Arbitrary thresholds were estimated to divide the range of values into "Less Desirable", "Intermediate" and "More Desirable" classes (see discussion below), but these scores were used primarily to rank the sites and not to define impaired (degraded) as opposed to non-impaired (non-degraded) benthic communities!

<u>Individual Metrics</u>

Abundance (total number of individual organisms) - Both extremes of abundance, i.e. either too few or too many organisms, were considered indicative of a stressed community. The most extreme 25 % of the abundance values were scored as 1 (the lowest 12.5 % and the highest 12.5 %), the central 25 % of the abundance values were scored as 5 (between the 37.5 and 62.5 percentiles), and intermediate abundances were scored as 3 (see Table 4.8-7 for threshold values).

Figure 4.8-22 Numerical (A) and geographical (B) distributions of the Sediment Quality Index (SQI) scores among the 50 probabilistic near-shore sites.





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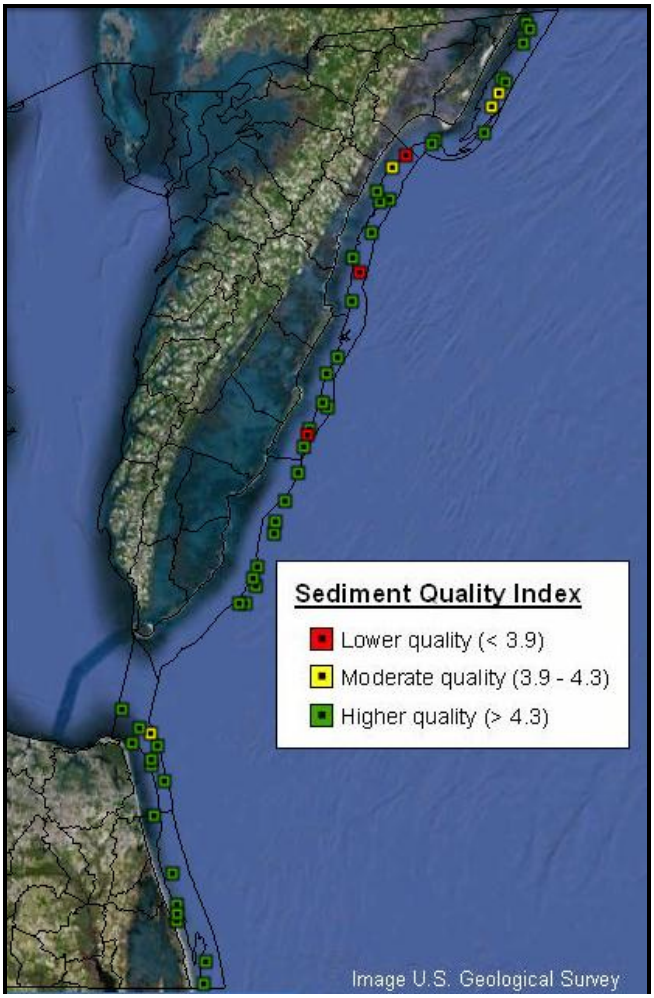


Attribute	Sediment Quality Index
N	50
Max	4.831
90th %	4.735
75th %	4.697
UCI 95%	4.635
Median	4.572
LCI 95%	4.508
25th %	4.411
10th %	4.109
Min	3.316
Average	4.481
Std. Dev.	0.326
Std. Err.	0.046

B

Table 4.8-7 Threshold Values for Scoring Individual Benthic Metrics and Classifying Marine Benthic Samples.

Threshold Values for Scoring Individual Benthic Metrics and Classifying Standardized Marine Benthic Samples (0.04 m^2)			
Class > Score >	Less Desirable (1)	Intermediate (3)	More Desirable (5)
Total Abundance (Number of Individuals)	< 113 or > 1315	113 to 186 or 578 to 1315	186 - 578
Number of Taxa	< 20	20 - 26	= 27
% Dominance of Two Most Abundant Taxa	> 77%	46% - 77%	< 46%
Shannon-Weiner H' (Log_2)	< 2.271	2.271 - 3.403	> 3.403
Gleason D	< 3.345	3.345 - 4.572	> 4.572
Pielou J' - Evenness (Log_2)	< 0.476	0.467 - 0.770	> 0.770
Number of Tubificidae	> 11	5 - 11	< 5
Number of Spionidae	< 10 or > 74	37 to 74 or 10 to 21	21 - 37
% Abundance - Pollution Indicative Taxa	> 3.53%	1.18% - 3.53%	= 1.18%
% Abundance - Pollution Sensitive Taxa	< 21.98	22.00% - 46.99%	> 47.00%
% Abundance - Bivalve Taxa	< 3.76%	3.76% - 14.56%	> 14.56%
% Abundance - Deep-Feeding Taxa	< 5.96%	5.96% - 47.23%	> 47.23%
Skewness of Log_e Taxon Abundance Distribution	> 1.309	0.727 - 1.309	< 0.727
Kurtosis of Log_e Taxon Abundance Distribution	< -0.180 or > +2.985	-0.180 to -0.457 or +0.265 to +2.985	-0.457 to +0.265
Final Site Benthic Score Threshold Values	< 2.43 (14.8%)	2.44 - 2.99 (16.6%)	= 3.00 (68.6%)

Note: The Site Benthic Score serves only to rank sites from more perturbed to less perturbed on a benthic community gradient. The threshold values defined here are not intended to distinguish impaired (significantly degraded sites) from non-impaired (non-degraded) sites!

Taxonomic Richness (total number of taxa) - In general, a community that is rich with many types of organisms is considered more healthy and ecologically stable than one that has few types of organisms. The communities with the highest numbers of taxa (upper quartile or 25%) were scored as 5, those with the lowest numbers were scored as 1 (lower quartile or 25%), and communities with intermediate richness (inter-quartile range) were scored as 3. Refer to Table 4.8-7 for threshold values.

Dominance (percent of total abundance included in one or more dominant taxa) - Dominance was expressed as the percent of the total number of individual organisms that was included in the two most abundant taxa (identical to one metric in the mid-Atlantic B-IBI). High dominance by a few taxa was considered undesirable – communities in the upper quartile were scored as 1 ("Less Desirable") and those in the lower quartile were scored as 5 ("More Desirable"). Communities in the inter-quartile range were scored as 3 ("Intermediate").

Diversity measures (an integrated measure of taxonomic richness and evenness) - Two indices of diversity were included in the site benthic score calculation.

The Shannon diversity index (H', also known as the Shannon-Weiner Index) is one component of both the CBP B-IBI and the mid-Atlantic B-IBI. It is calculated as:

$$H' = S_{i = 1, S}\ p_i \log_2 (p_i)$$

Where S = taxonomic richness (number of taxa),
p_i = proportion of total abundance included in taxon *i,*
$\log_2$ = logarithm base 2

The Gleason diversity index (D) is a component of the EMAP index of estuarine condition. It is calculated as:

$$D = S / \ln(N)$$

Where S = taxonomic richness (number of taxa)
$\ln(N)$ = natural logarithm of total number of individuals in the sample

High values of diversity are considered indicative of stable healthy communities. Values in the upper quartile of both diversity indices were scored as 5 ("More Desirable"), values in the lower quartile were scored as 1 ("Less Desirable"), and values in the inter-quartile range were scored as 3 ("Intermediate").

Evenness (a measure of the equitability of abundances among the taxa in a community) - Pielou's index of evenness (J') is a common measure of equitability and was included as a candidate metric in the EMAP index of estuarine condition. J' can theoretically vary from 0.00 to 1.00, and is calculated as:

$$J' = H' / H'_{max}$$

Where **H'** = the Shannon diversity index (above)

H'_{max} = the theoretical maximum value of H', when all taxa contain the same number of individuals, which is calculated as:

$$H'_{max} = Log_2 (S)$$

Where ***S*** = taxonomic richness (number of taxa),

log_2 = logarithm base 2 (because H' was calculated using log_2)

High evenness is considered desirable (upper quartile was scored as 5) and low evenness undesirable (lower quartile was scored as 1). Intermediate values were scored as 3 (Table 4.8-7).

Abundance of Tubificid Oligochaetes (Tubificidae) – Oligochaetes of the family Tubificidae are often abundant at eutrophic freshwater and estuarine sites and tubificid abundance was included as one metric of the EMAP index. A relatively high number of tubificids is considered indicative of degradation. Among the off-shore sites over half of the benthic communities were devoid of tubificids; 75% of the samples contained 5 or fewer. Because of the highly skewed distribution, all sites with 5 or fewer tubificids (below 75th percentile) were scored as 5 ("More Desirable"), and only those with 12 or more (90th percentile) were scored as "Less Desirable".

Abundance of Spionid Polychaetes (Spionidae) – An abundance of polychaetes of the family Spionidae is considered indicative of degraded communities in estuarine waters; they are pollution tolerant species. However, the genera of spionids characteristic of the mid-Atlantic continental shelf differ from the estuarine genera and are probably less tolerant of pollution (A. Rodi, 2011). Most near-shore sites had a relative abundance of spionids (inter-quartile range 13 to 50, with a median of 31) in comparison with estuarine waters. Consequently, for marine waters both extremes were considered undesirable and the scoring was similar to that of the total abundance measure: the most extreme 25% of the values were scored as 1 (the lowest 12.5% and the highest 12.5%), the central 25% of the values were scored as 5 (between the 37.5 and 62.5 percentiles), and intermediate values were scored as 3 (see Table 4.8-7 for threshold values).

Percent abundance of pollution indicative taxa – A relatively high abundance of pollution tolerant organisms is considered indicative of a stressed community. Many near-shore sites (40%) were devoid of species classified as pollution indicative in estuarine waters; the median percent abundance was 1.18%. Because of the highly skewed distribution, all sites at or below the median value were scored as 5 ("More Desirable") and sites in the upper quartile were scored as 1 ("Less Desirable"); the 25% between the median and the 75th percentile were scored as 3 ("Intermediate").

Percent abundance of pollution sensitive taxa - An abundance of pollution sensitive organisms is considered indicative of a non-stressed community. Values in the upper quartile were scored as 5 ("More Desirable"), values in the lower quartile were scored as 1 ("Less Desirable"), and values in the inter-quartile range were scored as 3 ("Intermediate").

Percent abundance of bivalve taxa – A relatively high abundance of bivalve organisms is considered indicative of a healthy environment (mid-Atlantic B-IBI). Values in the upper quartile were scored as 5

("More Desirable"), values in the lower quartile were scored as 1 ("Less Desirable"), and values in the inter-quartile range were scored as 3 ("Intermediate"). (See Table 4.8-7 for threshold values.)

Percent abundance of deep-feeding taxa - An abundance of deep-feeding organisms is considered indicative of a non-contaminated substrate. Values in the upper quartile were scored as 5 ("More Desirable"), values in the lower quartile were scored as 1 ("Less Desirable"), and values in the inter-quartile range were scored as 3 ("Intermediate"). (See Table 4.8-7 for threshold values.)

The log-normal distribution - The species abundance distribution of large samples collected from stable, near-climax communities is often described as being approximately log-normal in form. Smaller samples are assumed to be truncated on the left (missing rare species), inducing a positive asymmetry.[1] Perturbed communities are assumed to deviate further from this distribution than stable, non-perturbed communities. In perturbed communities, opportunistic taxa often become extremely abundant, causing a severe positive asymmetry in the abundance curve. Two characteristics of the normal distribution were utilized to score relative departures of samples from the log-normal; skewness - a measure of asymmetry, and kurtosis - a measure of the relative grouping of values near the mean. Both statistics were calculated for the distribution of natural logarithms of taxon abundances.

Skewness, or asymmetry, of normal distributions is zero; large positive departures would indicate a relative excess of extremely abundant taxa.

$$skewness = \frac{\sum_{i=1}^{N}(Y_i - \bar{Y})^3}{(N-1)s^3}$$

Where Y_i = the log abundance of an individual taxon,

$\bar{Y}$ = the arithmetic mean of all log abundances,

s = the standard deviation, and

N = the number of taxa

Samples in the upper quartile (most positive asymmetry) were scored as 1 ("Less Desirable"), those is the lowest quartile (near zero or negative asymmetry) were scored as 5 ("More Desirable"), and those in the inter-quartile range were scored as 3 ("Intermediate").

The basic equation for kurtosis is:

(1)

$$kurtosis = \frac{\sum_{i=1}^{N}(Y_i - \bar{Y})^4}{(N-1)s^4}$$

Where $\bar{Y}$, $\mathbf{Y_i}$, **s**, and **N** are the same as above.

Using equation (1) the kurtosis of a normal distribution is three. For this reason, the following definition of kurtosis (often referred to as "excess kurtosis") was used, so that a log-normal distribution of abundance would have a kurtosis of zero.

[1] Preston's veil line, in: Preston, F.W. 1948. The Commonness, and Rarity of Species. Ecology 29 (3): 254–283.

(2)

$$kurtosis = \frac{\sum_{i=1}^{N}(Y_i - Y)^4}{(N-1)s^4} - 3$$

Applying equation (2) a positive kurtosis indicates a more peaked distribution than normal, with more values near the center than expected in a normal distribution, and a negative kurtosis indicates a flatter than normal distribution. The most extreme values of kurtosis, both positive and negative, were considered least desirable and were scored 1, while those near zero were considered most desirable and were scored 5. Intermediate values were scored as 3 (see Table 4.8-7 for threshold values). Table 4.8-8 summarizes the cumulative distributions of each of the 14 individual metrics and of the final benthic scores among the 50 sites.

Site Benthic Scores (SBS) - Individual site benthic scores were calculated as the arithmetic mean of the 14 previously described metrics at each site. The resultant distribution of site scores was positively correlated with each of the three estuarine benthic indices, having a maximum r^2 value of 0.699 with the mid-Atlantic B-IBI, with which it shared the most metrics. The final choice of thresholds for the "More Desirable", "Intermediate", and "Less Desirable" classes of the SBS was based on three considerations: (1) agreement with the classification by the three estuarine indices, (2) degree of chemical contamination observed in the sediment at the site, and (3) results of toxicity tests of the sediment at the site.

Table 4.8-8 Distributions of the 14 Individual Metrics and of the Final Site Benthic Scores among the 50 Sites.

Distributional Attributes	Total Abundance	Taxonomic Richness	% Dominance of Two Most Abundant Taxa	Shannon-Weiner H' (Log2)	Gleason D	Pielou J' Evenness (Log2)	Number of Tubificidae	Number of Spionidae	% Abundance Pollution Indicative Taxa	% Abundance Pollution Sensitive Taxa	% Abundance Bivalve Taxa	% Abundance Deep Feeding Taxa	Skewness of Log. Taxon Abundance Distribution	Kurtosis of Log. Taxon Abundance Distribution	Site Benthic Score
Maximum Value	3580.0	38.0	98.4	4.120	7.390	0.879	273.0	168.0	23.3	86.6	31.8	92.4	2.678	8.005	4.143
95th Percentile	1948.0	34.3	90.9	3.697	5.480	0.839	32.6	87.6	9.3	79.3	28.2	84.2	1.924	3.432	4.000
90th Percentile	1492.0	31.6	85.1	3.623	5.146	0.802	12.6	78.8	7.4	75.6	24.7	77.8	1.719	3.137	3.857
87.5th Percentile	1315.0	30.3	84.5	3.610	5.058	0.801	11.3	74.0	6.1	72.1	22.4	75.1	1.697	2.985	3.857
75th Percentile	986.0	27.0	77.1	3.403	4.572	0.770	5.0	50.5	3.532	46.996	14.569	47.2316	1.309	1.136	3.429
62.5th Percentile	578.8	25.0	58.9	3.110	4.357	0.715	2.0	37.5	2.1	41.4	11.7	33.7	1.070	0.265	3.286
50th Percentile (Median)	322.0	23.0	53.4	2.972	4.117	0.652	0.0	31.0	1.180	34.9	9.1	21.8	0.959	-0.096	3.143
37.5th Percentile	186.5	22.0	49.8	2.664	3.744	0.584	0.0	21.8	0.0	29.3	5.4	12.7	0.822	-0.457	3.000
25th Percentile	147.0	20.5	46.2	2.271	3.435	0.476	0.0	13.0	0.0	21.981	3.759	5.9645	0.727	-0.677	2.643
12.5th Percentile	113.0	17.8	38.4	1.601	3.239	0.348	0.0	9.8	0.0	16.0	2.4	3.9	0.527	-0.810	2.429
10th Percentile	104.6	17.0	35.3	1.532	3.123	0.333	0.0	7.8	0.0	15.1	2.3	3.7	0.432	-0.994	2.429
5th Percentile	89.1	16.7	32.5	1.292	2.903	0.269	0.0	5.7	0.0	9.0	0.9	1.7	0.292	-1.205	2.286
Minimum Value	70.0	12.0	29.5	0.286	2.228	0.070	0.0	1.0	0.0	1.8	0.2	0.0	-0.231	-1.642	1.571
Mean	638.4	23.9	58.5	2.740	4.101	0.607	9.5	38.1	2.8	38.3	10.7	31.4	1.022	0.510	3.119
Std.Dev.	722.1	5.6	18.9	0.847	0.903	0.194	37.4	33.1	4.6	22.0	8.6	28.5	0.526	1.829	0.545
Std. Err.	97.4	0.8	2.5	0.114	0.122	0.026	5.0	4.5	0.6	3.0	1.2	3.8	0.071	0.247	0.073

1 Less Desirable 3 Intermediate 5 More Desirable

(1) In general, the oceanic sites scored fairly well when classified by either of the estuarine B-IBIs - 50% of the sites scored non-degraded (= 3.00) with the CBP B-IBI and 75% of the sites scored non-degraded (= 3.00) with the mid-Atlantic B-IBI. The EMAP Virginia Province Index of Estuarine Condition scored 47% of the sites as non-degraded.

(2) No Effects Range Median (ERM) exceedances were observed at any site and a single analyte, arsenic (As), slightly exceeded its Effects Range Low (ERL) value at three sites. Mean ERM quotients varied from a minimum of 0.002 to a maximum of 0.030. Forty-six (92.0 ± 7.7%) of the sites had low risk of benthic degradation due to observed sediment contamination (Hyland et al., 2003). Four sites (8.0 ± 7.7%) exceeded the threshold of 0.022 for medium risk of benthic degradation, but the maximum ERMq observed (0.030) was well below the midpoint of the medium risk range defined in Table 4.8-6. The evaluation of equilibrium partitioning sediment benchmarks (ESBs) for PAHs in the sediment suggested that only three sites (6.0 ± 6.7%) revealed any significant risk of benthic degradation from the additive effects of PAHs. The site with the maximum estimated ESB_{34} value of 17.810 (VANS10-020 in watershed

AO16) was still classified as meeting goals by the CBP and mid-Atlantic estuarine B-IBIs and as "Higher" (more desirable) with the near-shore Site Benthic Score.

(3) Tentative classification of the 50 sites in the survey based on sediment toxicity test results indicated that 80.0 ± 11.4% were classified as "Good" for sediment toxicity, 16.0 ± 10.4% were classified as "Fair", and 4.0 ± 5.6% were classified as "Poor." The results (control-corrected survivorship) from the ten-day, static, acute sediment toxicity tests with the marine amphipod *Leptocheirus plumulosus* were not significantly correlated with average ERM quotients (r^2 = 0.007), with PAH ESB_{34} expectations (r^2 = 0.013), or with any of the established benthic indices (r^2 = 0.047 inversely with CBP B-IBI, r^2 = 0.011 with mid-Atlantic B-IBI; r^2 = 0.047 with EMAP IEC). Two sites at which highly significant mortality occurred during sediment toxicity tests (50.6% and 60.9% mortality) scored non-degraded on three of the four benthic indices! Of nine sites at which control-corrected survivorship was between 70% and 80% (Moderate), one was classified as "Less Desirable", four were classified as "Intermediate", and four were classified as "More Desirable" based on their site benthic scores. Eight of the nine sites were classified as "Meets Goals" by the CBP B-IBI (one "Degraded). Of the same nine sites, four were classified as "Meets Goals" and five as "Degraded" by the mid-Atlantic B-IBI. This lack of relationship between estimated toxicity and the degree of chemical contamination and associated benthic scores, as well as other uncertainties about the 2010 toxicity test data currently available, suggest that these toxicity results should be considered tentative, at best.

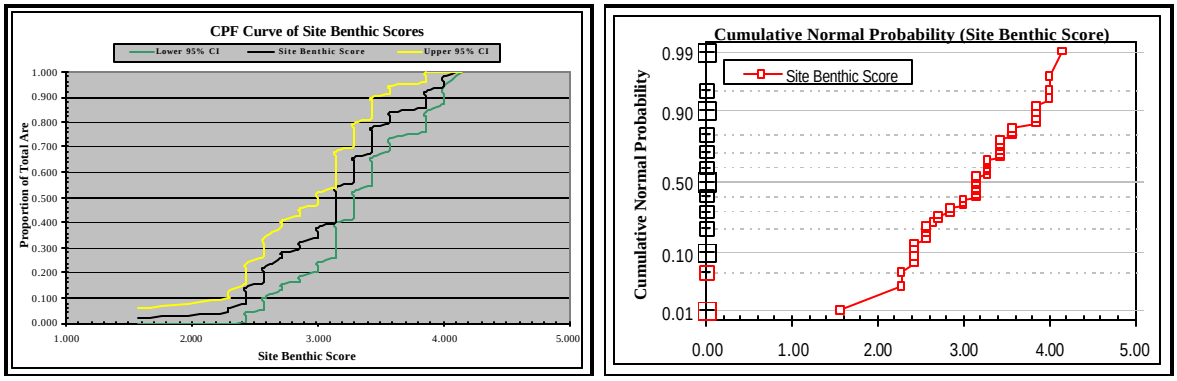
Based on the three sources of information described above, tentative threshold values for the SBS were set as = 3.0 = "Higher Benthic Score", = 2.5 = "Lower Benthic Score", and the intermediate values as "Intermediate" or "Moderate" Benthic Score." The numerical distributions of classifications using all three estuarine indices and the near-shore "Site Benthic Score" (SBS) are summarized in Table 4.8-9, and the numerical and geographic distributions of the Site Benthic Scores for the 50 near-shore sites can be found in Figure 4.8-23.

Table 4.8-9 Score distributions of the three estuarine benthic indices and of the near-shore Site Benthic Score among the 50 near-shore oceanic sites. The classification thresholds of the estuarine indices are not considered appropriate for oceanic sites, but the two B-IBIs still provide reasonable estimates of the proportion of sites in each class. These descriptive statistics were calculated based a total of 55 scores, including five QA duplicate samples.

Distributional Attributes of Near-shore Benthic Communities	Chesapeake Bay Program B-IBI	mid-Atlantic B-IBI	EMAP Index of Estuarine Condition	Near-shore Oceanic Site Benthic Score
N	55	55	55	55
Maximum Value	4.00	5.00	1.814	4.14
90th Percentile	3.33	5.00	0.518	3.86
75th Percentile	3.33	4.50	0.289	3.43
UL 95% CI Median	3.15	4.33	0.122	3.32
50th Percentile (Median)	3.00	4.00	-0.019	3.14
LL 95% CI Median	2.85	3.67	-0.160	2.97
25th Percentile	2.67	3.00	-0.346	2.64
10th Percentile	2.33	2.50	-0.666	2.43
Minimum Value	2.00	1.50	-1.362	1.57
Mean	2.94	3.69	-0.047	3.12
Std.Dev.	0.43	0.97	0.540	0.54
Std. Err.	0.06	0.13	0.073	0.07

Meets Goals / Non-Degraded / More Desirable
Marginal / Intermediate
Degraded / Less Desirable

Figure 4.8-23 Numerical (A) and geographical (B) distributions of Site Benthic Scores among the 50 near-shore oceanic sites. For these statistics, the five quality assurance sites were represented by the median score of their two replicate samples.



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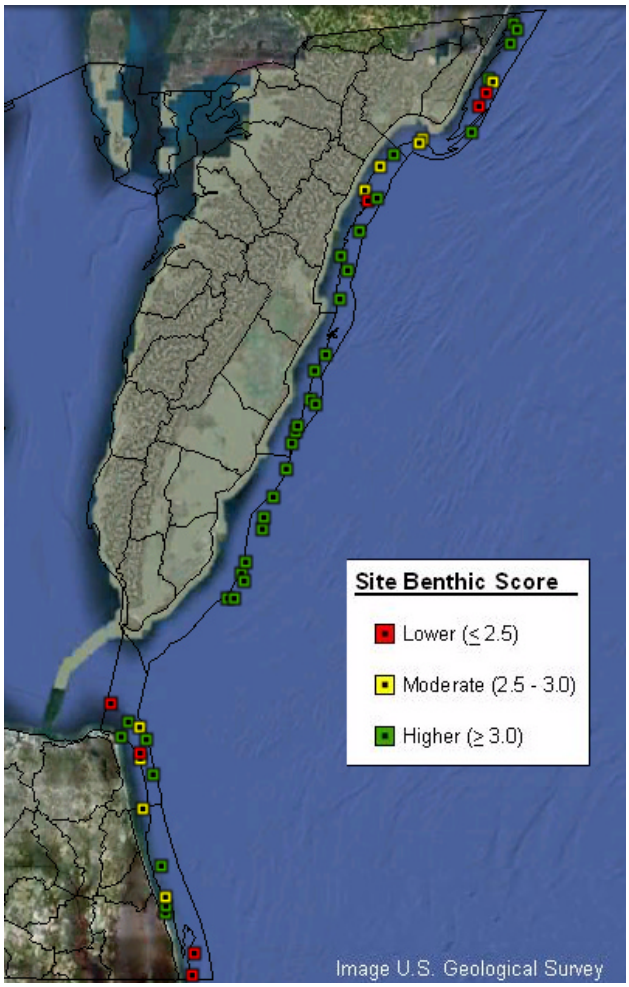


Attribute	Site Benthic Scores
N	50
Max	4.143
90th %	3.857
75th %	3.429
UCI 95%	3.301
Median	3.143
LCI 95%	2.984
25th %	2.714
10th %	2.429
Min	1.571
Average	3.133
Std. Dev.	0.545
Std. Err.	0.077

B

The CPF curve for the Site Benthic Score is not as smooth as for the other classification variables, because its values are discrete rather than continuous. Natural breakpoints in its distribution are consequently not so easily identified. Arbitrary classification thresholds were subsequently established for the results, as described above, with SBS values = 3.00 classified as "Higher" (68.0 ± 13.3% of all sites); this value coincides with the "Non-Degraded"/"Meets Goals" thresholds of the CBP and Mid-Atlantic B-IBIs. Sites with SBS values = 2.50 were classified as "Lower" (14.0 ± 9.9% of all sites); this value approximates the B-IBI thresholds between "Marginal" and "Degraded". Sites with intermediate SBS values were classified as "Moderate" (18.0 ± 10.2% of all sites). As noted in Table 4.8-7 above, this classification serves only to rank sites from less perturbed (more desirable) to more perturbed (less desirable) on a benthic community gradient. The threshold values defined are not intended to distinguish impaired (significantly degraded sites) from non-impaired (non-degraded) sites!

Integrated Site Score (ISS): An Integrated Site Score (ISS) was calculated for each site as the arithmetic average of the WQI, SQI, and SBS, the first two of which were originally expressed on a scale of 0.00 to 5.00, and the latter on a scale of 1.00 to 5.00. ISS values varied from a minimum of 2.461 to a maximum of 4.392, with a median value of 3.735 (Figure 4.8-24A). Weak breakpoints were observed in the CPF distribution at values of approximately 3.700 and 3.100. These were used as tentative thresholds for classifying sites with "Higher" site scores (29 sites – 58.0 ± 14.0%), "Moderate" site scores (14 sites – 28.0 ± 12.8%), or "Lower" site scores (7 sites – 14.0 ± 9.9%). The geographic distribution of Integrated Site Scores is illustrated in Figure 4.8-24B.

Weight of Evidence Characterizations: Individual weight-of-evidence (WOE) characterizations based on the sediment quality triad were performed on each of the 50 near-shore sites to evaluate attainment of (benthic) aquatic life designated use (ALU). This WOE procedure is normally carried out for all estuarine probabilistic sites as well, because all three components of the sediment quality triad - sediment contamination, sediment toxicity, and benthic community composition - are considered temporally integrated, in contrast with water column measures that are considered grab samples of instantaneous parameter values. The primary difference between the normal estuarine WOE assessments and those performed in this study is that validated benthic indices are available for estuarine waters. Without a validated benthic index for mid-Atlantic oceanic waters the current WOE results should be considered more of a characterization than a formal assessment. Based on the results of these evaluations, each of the near-shore sites was tentatively assigned to one of three EPA/Virginia assessment categories and subcategories.

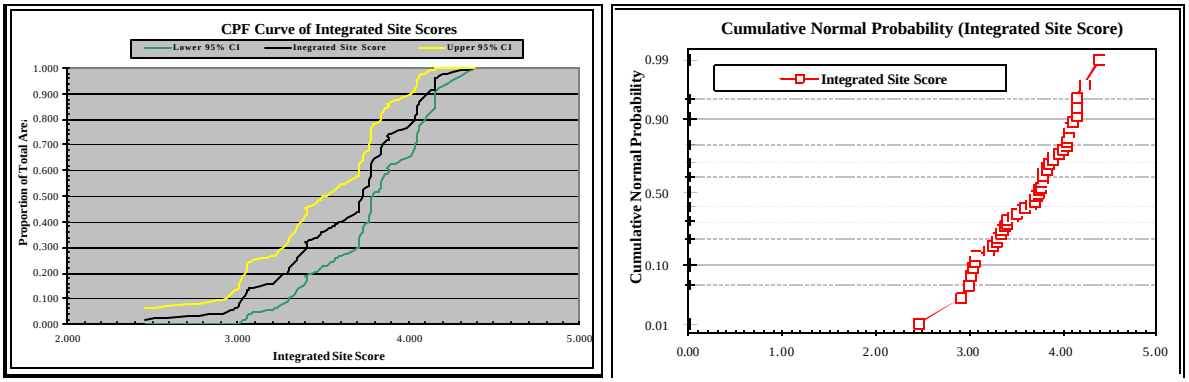
2A - Waters are fully supporting of the use (aquatic life – benthic) for which they were monitored. Benthic community, sediment contaminants, and observed survival during toxicity tests were all good!
27 of 50 sites (54.0 ± 14.2%)

2B - Waters are fully supporting but of concern because a sediment toxicity test resulted in ecologically significant control-corrected mortality. Toxicity results received to date (1 February 2012) do not provide enough information to reach statistically definitive conclusions.
6 of 50 sites (12.0 ± 9.2%)

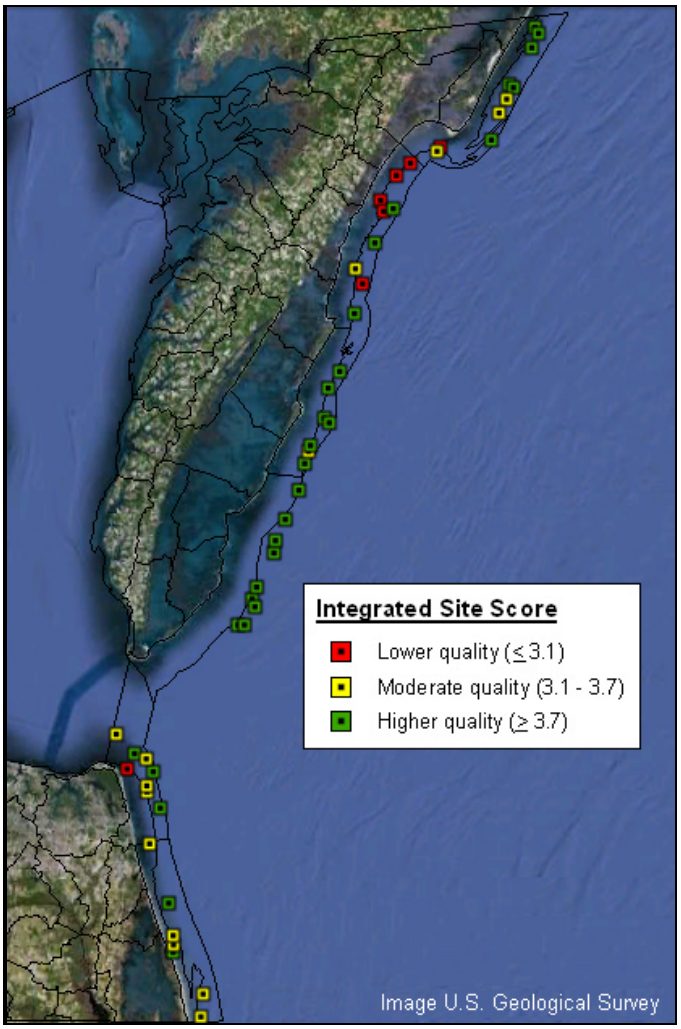
3B[2] - Some data exist but are insufficient to determine support of the monitored designated use. Classification in this subcategory results from a benthic classification of "Marginal" or "Poor" by the majority of the benthic indices and/or an elevated risk of benthic impact as indicated by mean ERM quotients and/or Equilibrium Partitioning Sediment Benchmarks (ESBs) for PAHs.
17 of 50 sites (34.0 ± 13.5%)

[2] Subcategory 3B may include observations of significant sediment toxicity as well, but significant benthic effects accompanied by confirmed sediment contamination take precedence. No validated benthic index is yet available to confirm significant benthic degradation in the marine waters of the mid-Atlantic region.

Figure 4.8-24 Numerical (A) and geographical (B) distributions of Integrated Site Scores among the 50 near-shore oceanic sites.



A

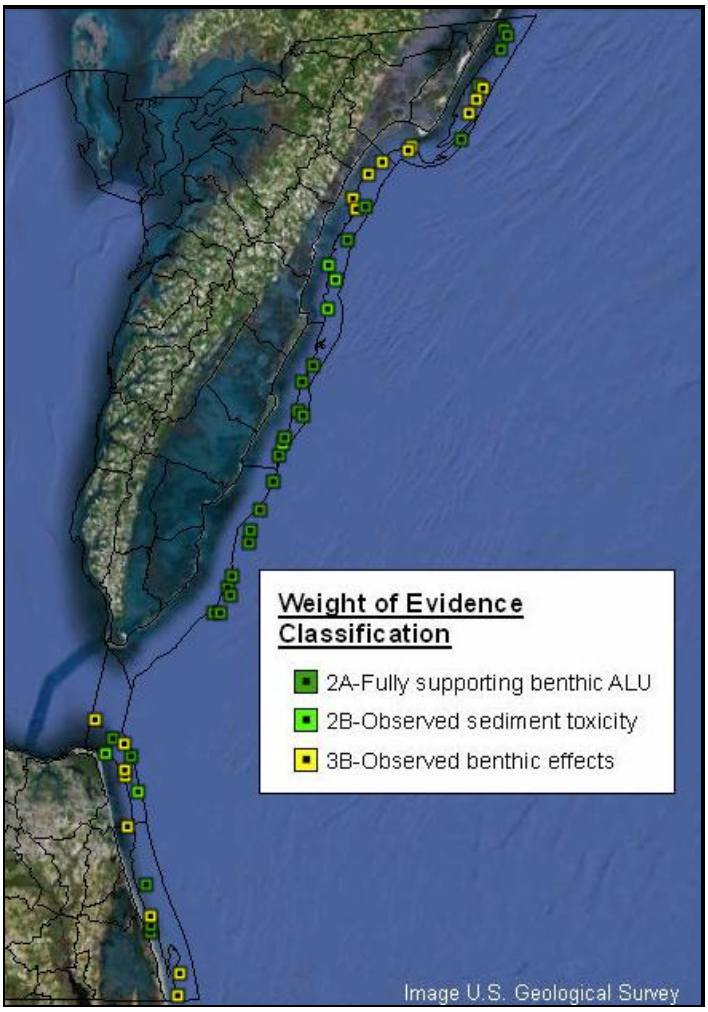


Attribute	Integrated Site Score
N	50
Max	4.392
90th %	4.114
75th %	3.940
UCI 95%	3.864
Median	3.735
LCI 95%	3.605
25th %	3.356
10th %	3.051
Min	2.461
Average	3.643
Std. Dev.	0.408
Std. Err.	0.058

B

The geographic distribution of the sites with their tentative assessment categories and subcategories is illustrated in Figure 4.8-25 and identifies two areas of concern. The first, under the influence of the tidal plume from Chesapeake Bay, extends southward along the coast from Cape Henry to the North Carolina state line. The second extends from the southeastern portion of Assateague Island southward nearly to Wachapreague Inlet.

Figure 4.8-25 Geographic distribution of Weight-of-Evidence (WOE) assessment results of the designated (benthic) aquatic life use among the 50 near-shore probabilistic sites, based on evaluation of the sediment quality triad (sediment contamination, sediment toxicity, benthic community composition).



Although based exclusively on sediment chemical contamination, sediment toxicity and benthic community characterizations, the distribution of sites with observed WOE effects (Subclass 3B) closely parallels that earlier described for several water column parameters - near surface DIN (Fig. 4.8-7) and Chl-a (Fig. 4.8-11), near bottom DO (Fig. 4.8-6), and the integrated WQI (Fig. 4.8-14). Independently derived sediment quality characterizations based on sediment TOC, sediment contamination (ESBs for PAHs - Fig. 4.8-19, and mean ERM quotients – Fig. 4.8-20), and sediment toxicity (Fig. 4.8-21) gave rise to an integrated Sediment Quality Index (SQI – Fig. 4.8-22) that also resembled the geographic

distribution of WOE observed effects sites. Of the individual sediment components evaluated, only substrate type (muddy vs. sandy sediments – Fig. 4.8-18), and sediment toxicity (Fig. 4.8-21) distributions resembled that of the WOE results.

(Note: Soon after the draft of this chapter was submitted for review, Rutgers University posted a report on the Internet (http://marine.rutgers.edu/main/Front-Page-News/Rutgers-Study-Assesses-the-Condition-of-New-Jersey-Coastal-Ocean-Waters.html) describing the development of a provisional oceanic benthic index for soft bottom, near-shore waters of New Jersey. An addendum to this report (Appendix 11) summarizes the process and outcome of applying New Jersey's provisional adaptation of the European AZTI Marine Biotic Index (AMBI - Borja et al., 2000) to the benthic results from Virginia's 2010 Near-shore Oceanic Survey. In general, the results from applying the provisional New Jersey AMBI corroborated the conclusions (both in characterizations and in geographic distributions) arrived at by interpreting the other benthic indices described in the original report.)

General Discussion and Conclusions

A formal assessment of near-shore oceanic sites, especially based on a probabilistic survey, is difficult when marine water quality standards have not been established for many of the parameters of interest. Virginia does not yet have marine water quality standards for the nutrient-related parameters - nitrogen, phosphorus, and chlorophyll - which are currently of such concern in freshwater and estuarine systems. For those water quality standards that do exist (chronic and acute toxicity standards for dissolved metals and organics, primary and secondary contact human health - *Enterococcus*) no violations were observed among the 50 sites surveyed. But even if violations were to be observed, the results of one-time probabilistic sampling of the water column would not satisfy the duration/frequency requirements of chronic toxicity standards, or the 10% violation rate criterion of instantaneous bacterial standards, except on a resource-wide basis. Although the components of the WOE characterizations are considered to be temporally integrated, in Virginia exceedances of sediment screening values have traditionally been considered only as observed effects. They are insufficient for an assessment of impaired unless corroborated by highly significant toxicity and/or significantly degraded benthos. No validated benthic index has yet been developed for oceanic waters of the mid-Atlantic bight, so the severity of benthic degradation is not reliably assessable at present. Efforts are under way, with participation by EPA, various states, and the academic community, to adapt the European AZTI's Marine Biotic Index (AMBI) approach to develop a National Index of Benthic Condition. Major efforts to date have focused on Pacific coastal waters, but southeastern Atlantic and Gulf coast waters are also under consideration.

A pertinent question is how useful such marine water quality and benthic standards would be for formal assessments. General characterization are obviously very useful for identifying stressors and determining the extent of the resultant impacts, but violation of a marine water quality standard would imply an assessment classification of "Impaired" and the necessity of developing and implementing a Total Maximum Daily Load (TMDL). How would this be accomplished locally in an open marine ecosystem other than by evaluating the contributions of locally contributing freshwater and estuarine systems, which are already subject to their own standards and TMDLs? Addressing and controlling contributions from an open oceanic circulation is well beyond the capacity of the individual states and may in fact be beyond that of an individual nation!

In spite of these limitations, the general characterizations made possible by the 2010 survey are very informative and the final product has been well worth the time, effort, and resources invested. Approximately 440 square miles of Virginia's near-shore oceanic waters, never previously assessed, have now been evaluated and tentatively characterized in terms of water quality, sediment quality, and benthic community condition. Even with the relative dearth of specific quantitative criteria for formally assessing these three major components of the near-shore marine ecosystem, it has been possible to evaluate the observed variations in multiple parameters, compare them with reference values from other

sources or identify tentative local quality-related threshold values, and integrate them into a coherent regional portrait of ecological conditions along Virginia's Atlantic coastline.

Those stressors for which Virginia has oceanic water quality standards (WQS), or for which screening values (SV) or quantitative thresholds have been published, are summarized in Table 4.8-10 and Figure 4.8-26. The specific standards or criteria, the relative risk involved with each, and the proportion of the study area considered to be at risk are also summarized there. One prevalent stressor class, as reflected by potential toxicity and mean ERM quotients, is sediment contamination. Ecologically significant sediment toxicity (< 80% survival of test animals) was the highest ranked stressor in relation to proportion of the sites affected (20.0 ± 11.4%), although the data needed to test the statistical difference from control test results has not yet been provided by EPA. Some of the moderate mortality observed may have resulted from the extremely high sand content of oceanic sediment. High risk of toxics effects (< 70% survival) were only observed at two sites (4.0 ± 5.6%). Although no individual ERM values were exceeded, four of the study sites (8.0 ± 7.7%) had sufficient quantities of metals and/or organics (primarily PAHs) in their sediment to be considered at medium risk of benthic degradation because of additive toxic effects (Figure 4.8-20). However, the highest mean ERM quotient observed (0.030) was still in the lower half of the medium effects range (Table 4.8-6). The ERL sediment screening value of one metal - arsenic (As) - was slightly exceeded at three sites (6.0 ± 6.7%), but is not considered a high risk.

Table 4.8-10 Levels of relative risk, threshold criteria, and proportions of the study area affected by stressors for which marine water quality standards and/or published threshold criteria are available.

Stressor - Designated Use	Criterion	Relative Risk	Extent
Weight-of-Evidence Observed Effects - ALU	Varied	Medium Risk	34.0 ± 13.5%
Sediment Toxicity [1] (Control-corrected Survivorship) - ALU	< 80%	Ecological Risk	20.0 ± 11.4%
Dissolved Oxygen - WQS 5.0 mg/L - ALU (near bottom)	4.0 - 5.0 mg/L	Low Risk	12.0 ± 9.2%
Sediment Mean ERM-Quotient - ALU (medium risk to benthos) [2]	= 0.022	Medium Risk	8.0 ± 7.7%
Sediment Equilibrium Partitioning Benchmark (ESB_{34}) for PAHs - ALU	> 1.0	Low to High Risk	6.0 ± 6.7%
Sediment Individual Metals [3] - ERL exceedance - ALU	= 1.0	Low Risk	6.0 ± 6.7%
Sediment Toxicity (Control-corrected Survivorship) - ALU	< 70%	High Risk	4.0 ± 5.6%
Sediment Equilibrium Partitioning Benchmark (ESB_{34}) for PAHs - ALU	> 15.0	Very High Risk	2.0 ± 3.9%
Sediment Total Organic Carbon	> 1.0%	Medium Risk	2.0 ± 3.9%
Dissolved Metals (near-surface) Chronic WQS exceedance - ALU	Varied	Low Risk	0.0 ± 0.0%
Sediment Individual Metals ERM-Quotient - ALU	= 1.0	Low Risk	0.0 ± 0.0%
Sediment Individual Organics ERM-Quotient - ALU	= 1.0	Low Risk	0.0 ± 0.0%
Sediment Individual Organics ERL-Quotient - ALU	= 1.0	Low Risk	0.0 ± 0.0%
Bacteria - Human health primary contact (Enterococcus - near surface)	= 104	Low Risk	0.0 ± 0.0%
Dissolved PAHs (near-surface) ALU, Human health	Varied	Low Risk	0.0 ± 0.0%

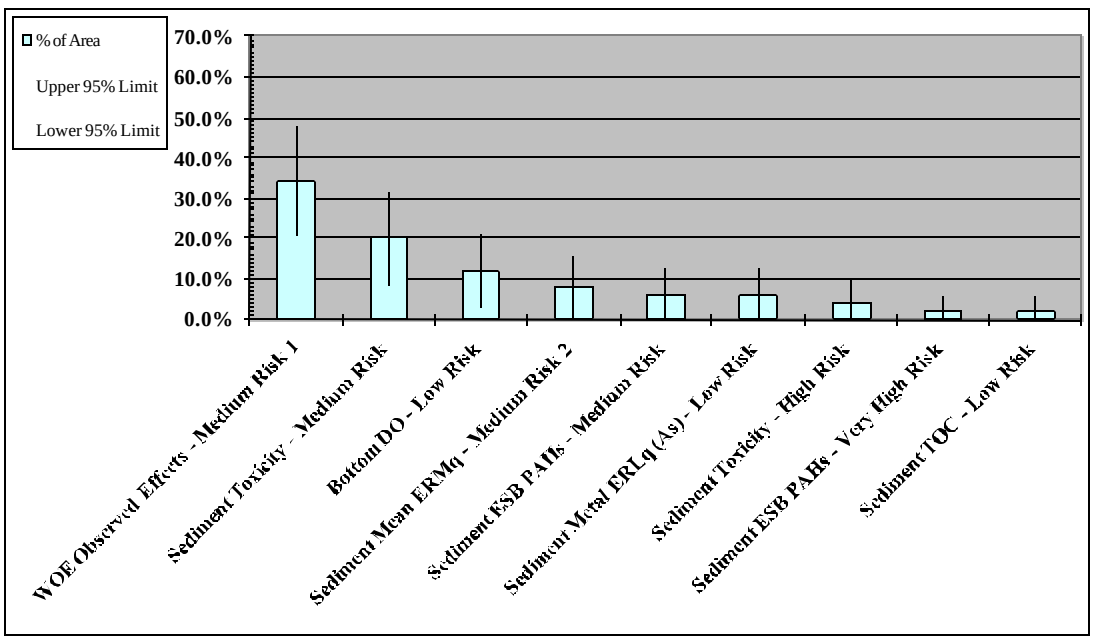
[1] Less than 80% survivorship is considered ecologically significant; however the data for confirming statistical significance are not yet available.
[2] The maximum mean Effects Range Median Quotients (ERMq) observed in this study were in the lower half of the medium risk range for benthic communities in estuarine sediments. ERM values do not consider the organic carbon content of the sediment, and relative risk to the benthos may have been slightly higher in these marine sediments with extremely low total organic carbon concentrations.
[3] Arsenic (As) exceeded its Effects Range Low (ERL) screening value at three sites.

Near bottom dissolved oxygen (DO) concentrations were below the Virginia saltwater standard of 5.0 mg/L at six sites (12.0 ± 9.2%), and constituted the third most prevalent stressor. The minimum bottom DO concentration observed, however, was 4.1 mg/L and the consequent risk to benthic organisms is considered to be low. Additive risks to the benthos from PAHs in the sediment, as evaluated by

Equilibrium Partitioning Sediment Benchmarks (ESBs) for PAH mixtures, were considered probable at three sites (6.0 ± 6.7%) but were only considered to be high at a single site (2.0 ± 3.9%). A single site (2.0 ± 3.9%) had a sediment TOC concentration high enough to fall in the lower portion of the medium risk range for benthic effects (1.43% - Table 4.8-3). It is evident from this discussion that the most pervasive stressors in the near-shore ecosystem are of low to medium risk to aquatic life, and the higher risk stressors effect 4.0% or less of the near-shore region.

When evaluating the results from probabilistic surveys with non-stratified, equal probability sampling, it is customary to consider the simple proportion of measurements of a parameter falling within a specific class (*e.g.*, exceeding a water quality standard, or being of high risk to benthos) to be an estimate of the total proportion of the study area (or aquatic resource) within that class. This does not mean, however, that the sites where such stressful conditions are observed are also randomly distributed. It is clear from the earlier, parameter by parameter discussions, that sites with less desirable characteristics are often grouped in well defined regions of the study area. Low DO (Fig. 4.8-6), elevated DIN (Fig. 4.8-7), elevated Chl-a (Fig. 4.8-11), and the integrated WQI derived from them (Fig. 4.8-14) all indicated lower water quality in the region between the southern tip of Assateague Island and Wachapreague Inlet. With the exception of DO, the same parameters and the WQI indicate a second area of lower water quality stretching southward from the mouth of Chesapeake Bay. These two areas of concern include approximately 25% of the Commonwealth's coastal waters.

Figure 4.8-26 Percentages of the study area exposed to identified stressors and their relative levels of risk to the Aquatic Life Designated Use (ALU). Stressors evaluated for Human Health - Primary Contact Recreation (*Enterococcus*) revealed no risk.



[1] The maximum mean Effects Range Median Quotients (ERMq) fell in the lower half of the medium risk range.
[2] The Weight-of-Evidence toxics characterization, based on the sediment quality triad, is not a stressor; it evaluates the combined influence of several other stressors (contamination, toxicity) in the figure and is included for the purpose of comparison.

The same two regions exhibit greater deposition of fine particulates in their sediment (transitional to muddy substrates - Fig. 4.8-18) and higher sediment toxicity (Fig. 4.8-21). Moderate to low site benthic scores (SBS), representing approximately 14.0% of the coastline, are also more common there and integrated site scores (ISS - Fig. 4.8-24), derived from the WQI, SQI, and SBS, also tend to be moderate or low along the same two stretches of the coastline. And finally, independently performed characterizations using weight-of-evidence (WOE) evaluations of the 50 near-shore sites, based on the sediment quality triad of chemical contamination, toxicity, and benthic community condition, revealed that observed effects on the aquatic life designated use (ALU - benthic) were more common in the same two regions (Fig. 4.8-25), encompassing approximately 34.0% of the study area.

The effects of the tidal plume from the Chesapeake Bay, with its load of nutrients, chlorophyll, suspended sediment, and other potential chemical contaminants, is well documented and continues to be intensively studied. Its effects along the coastline southward from the mouth of the Bay are not a surprise, and hopefully the numerous TMDLs currently under study or already completed, and others already being implemented, both in the Bay itself and in its many tidal and non-tidal tributaries, will bring relief to the southern coastal region of the Commonwealth in the near future.

Identifying, delimiting, and eliminating the source(s) of the observed effects further to the north, along the northeastern Delmarva coastline, will require considerable follow-up efforts. At least three potential sources contributing to the problem are of concern; (1) input from the lower end of the Labrador Current that carries potential pollutants southward along the coasts of Maryland and Delaware, from the Delaware Bay estuary and beyond, (2) the tidal plume from Chincoteague Bay that receives considerable input from Maryland in addition to that from Virginia, and (3) runoff from Virginia's frontal sub-watersheds AO04, AO08, AO09, AO10, and to a lesser extent AO11 (Table 4.8-11), that extend from the mouth of Chincoteague Bay at Chincoteague Inlet southward to Wachapreague Inlet. Only the southern extremity of AO04 and the northern extremity of AO11 contribute directly to oceanic waters. Elsewhere the former drains directly into Chincoteague Bay and the latter drains into Bradford and Swash Bays.

Table 4.8-11 Sixth order frontal sub-watersheds between Chincoteague Inlet and Wachapreague Inlet on the Delmarva coast. AO04 is a component of the Lower Chincoteague Bay watershed (AO-A - 0204030305) and AO08 through AO11 are components of the Burtons Bay-Metompkin Bay watershed (AO-C - 0204030401).

Virginia Sub-Watershed Code	Hydrologic Unit Code	Sub-Watershed Name	Area (Acres)
AO04	020403030503	Chincoteague Bay-Chincoteague Inlet	37811.64
AO08	020403040101	Assawoman Inlet	12942.43
AO09	020403040102	Gargathy Inlet	12117.14
AO10	020403040103	Metomkin Inlet	25295.65
AO11	020403040104	Wachapreague Inlet (northern portion)	38280.76

(1) There is some evidence to indicate that elevated concentrations of nutrients (both DIN - Fig. 4.8-7 and DIP - Fig. 4.8-8) as well as chlorophyll (Fig. 4.8-11) are being carried southward along the Atlantic shores of Assateague Island by oceanic currents. In addition, higher (though not toxic) concentrations of many dissolved metals are also evident there, diminishing in concentrations as the currents move southward along Virginia's Delmarva coast (Fig. 4.8-17). Some particulate deposition (Fig. 4.8-18) and some sediment toxicity (Fig. 4.8-21) were also observed there, giving rise to moderate SQI scores (Fig. 4.8-22). Finally, several site benthic scores (SBS - Fig. 4.8-23) and Integrated Site Scores (ISS - Fig. 4.8-24) were lower there, not to mention the observed ALU effects (Fig. 4.8-25) indicated by the WOE

characterizations. There appears to be insufficient development along Maryland's and Virginia's portions of Assateague Island to precipitate such local effects, so the sources are presumably further to the north.

(2) The tidal plume from Chincoteague Bay undoubtedly contributes to the nutrient problem immediately south of Chincoteague Inlet. The State of Maryland has defined "Biological Thresholds" for total nitrogen (TN - 0.644 mg/L), total phosphorus (TP - 0.037 mg/L), chlorophyll (Chl-a - 15.0 µg/L), and dissolved oxygen (DO –– 5.0 mg/L) for its portion of Chincoteague waters, and is in the process of developing a TMDL to control nutrient inputs into the bay. Probabilistic monitoring carried out within Virginia's portion of Chincoteague Bay during the past eleven summers (July – August, 2001 - 2011) indicates that TN and TP concentrations there frequently exceed the thresholds defined by Maryland and DO measurements fall below the 5.0 mg/L Virginia saltwater standard in 11.8% of the measurements. Summer Chl-a levels in Virginia's Chincoteague waters only exceeded the Maryland criterion on occasion (2.6% of 77 summer samples). In addition, 17 dissolved metals samples collected and analyzed during the same period revealed no problems with metals in the water column; the elevated dissolved metals concentrations observed in nearby oceanic waters apparently do not come from Chincoteague Bay. Among 48 probabilistic sediment samples collected in Chincoteague waters between 2001 and 2011, however, arsenic exceeded its ERL screening value ten times (20.8 ± 11.5% of the sites sampled); so particulate borne arsenic from the bay may be contributing to that in the sediments to the south. As mentioned earlier, the source of this arsenic may be poultry production facilities, which are common on the Delmarva Peninsula and often use arsenic as an antihelminthic dietary additive.

(3) The five frontal sub-watersheds between Chincoteague Inlet and Wachapreague Inlet do not possess such broad expanses of tidal wetlands between their continental headlands and oceanic waters as do the watersheds further to the north and south. Consequently, near-shore oceanic waters in the region may be more susceptible to runoff from the peninsula than are those in other areas of the Delmarva shore, where barrier islands isolate oceanic waters from those of coastal bays and/or wetlands. Consequently, local sources must be considered and evaluated to determine how significant their contributions are to the near-shore observed effects. Several non-tidal streams in this region are already listed for benthic impairments (primarily for low DO) and various estuarine streams are listed for low dissolved oxygen and bacteria (both for shellfish consumption - fecal coliforms, *E. coli*, and primary contact recreation - *Enterococcus*). Although most of these impairments are listed with "source unknown", both low DO and bacterial contamination are consistent with agricultural NPS nutrient and animal waste runoff. Hopefully additional monitoring and the development of TMDLs in this region over the next few years will answer many of the remaining questions and mitigate the stressors causing the effects already observed.

The approximate 35 statute miles of near-shore coastline between Wachapreague Inlet and lower Smith Island also deserve special mention. With the exception of a single observation of elevated PAH concentrations in the sediment, this region consistently scored in the most desirable range for all of the stressors evaluated. The sub-watersheds AO11 (southern portion), AO13, AO15, AO19, AO20, and AO21 (Table 4.8-12), lying between the peninsular headlands and barrier islands to the east, consist almost exclusively of broad shallow bays and tidal wetlands interspersed with small islands. Much of this area, of more than 180,000 acres, is preserved by the U.S. Fish and Wildlife Service, the Virginia Department of Game and Inland Fisheries, and vast Nature Conservancy holdings. The value of these areas in the uptake of nutrients, the filtering of suspended particulates, and the absorption of other pollutants from continental runoff is obvious. The functionality of these wetlands without a doubt contributes to the higher water quality observed along the southern Delmarva coast, but one additional consideration must be included. The broad expanses of shallow waters (< 30 ft) offshore from this region extend out to or beyond the three-nautical-mile territorial limit that defines the outer boundary of Virginia's oceanic watersheds. Survey sampling from the OSV Bold was consequently restricted to near or beyond the outer margins of the delineated sub-watersheds in this region. The better water quality observed there during the survey may have resulted, at least in part, from the fact that the measurements were collected further from shore.

The results of the 2010 Near-shore Oceanic Survey have provided DEQ's first general characterization of Virginia's marine watersheds. This opportunity was a consequence of three concurrent events; (1) the National Aquatic Resources Survey/ National Coastal Condition Assessment (NARS/NCCA) provided

financial resources that covered much of the expenses for sediment chemistry analyses and sediment toxicity testing, (2) EPA's Oceanic Survey Vessel (OSV) Bold and its crew were made available (gratuitously) for logistical support, and (3) Virginia DEQ suspended its own 2010 Estuarine Probabilistic Survey design to provide additional resources for the near-shore survey. EPA Headquarters in Washington, DC, and EPA Region 3 in Philadelphia, PA, also provided field staff that helped the DEQ field crew conduct the survey from the Bold. DEQ would not have been able to conduct the survey without the co-occurrence of all these sources of support. At present, the NARS/NCCA surveys of coastal waters are scheduled to recur every five years (2015, 2020, etc.). If this schedule once again coincides with the availability of the OSV Bold and other sources of logistical, financial, and human support, recurrent near-shore surveys at five- or ten-year intervals would be very informative. This would be especially desirable in the advent of offshore petroleum exploration and the construction of offshore wind farms as is currently proposed.

Table 4.8-12 Sixth order estuarine sub-watersheds between Wachapreague Inlet and Smith Island on the Delmarva coast. Sub-watersheds AO13 and AO15 are components of the Hog Island Bay-Machipongo River watershed (AO-D - 0204030402), and sub-watersheds AO19, AO20 and AO21 are components of the Cobb Bay-Magothy Bay watershed (AO-E – 0204030403).

Virginia Sub-Watershed Code	Hydrologic Unit Code	Sub-Watershed Name	Area (Acres)
AO11	020403040104	Wachapreague Inlet (southern portion)	38280.76
AO13	020403040201	Quinby Inlet	33068.28
AO15	020403040203	Great Machipongo Inlet	41117.3
AO19	020403040302	Sand Shoal Channel	24824.62
AO20	020403040303	South Bay	20259.19
AO21	020403040304	The Thorofare-Smith Island Inlet	24797.36

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The OSV Bold and its crew
EPA HQ Field team
EPA Region 3 Field Team

Appendix 1 - Station Metadata Table

NARS/NCCA Site ID	DEQ Station ID	Waterbody/Sub-Watershed ID (6th Order NWBD Subwatershed)	Station Description	Lat Deg	Lat Min	Lat Sec	Lon Deg	Lon Min	Lon Sec	DDLat	DDLon	Topo Map Code [1]	USGS 7' Topo Map Name [1]	NOAA Chart ID
VANS10-001	7C-AO05-10-001	ATLANTIC OCEAN-ASSATEAGUE ISLAND	1.51 nm east of Assateague Island beach	37	59	2.46	-75	13	46.14	37.984017	-75.229483			NOAA Chart 12211_1
VANS10-033	7C-AO05-10-033	ATLANTIC OCEAN-ASSATEAGUE ISLAND	1.17 nm SE of Assateague Island Beach	38	0	51.60	-75	13	23.52	38.014333	-75.223200	162C	162C - WHITTINGTON POINT, MD.-VA.	NOAA Chart 12211_1
VANS10-034	7C-AO05-10-034	ATLANTIC OCEAN-ASSATEAGUE ISLAND	3.76 nm east of Wallops Island Beach	37	50	17.64	-75	23	59.28	37.838233	-75.399800	141C	141C - WALLOPS ISLAND, VA.	NOAA Chart 12210_1
VANS10-050	7C-AO05-10-050	ATLANTIC OCEAN-ASSATEAGUE ISLAND	2.88 nm SE of Wallops Island Beach	37	49	55.44	-75	24	21.78	37.832067	-75.406050	141C	141C - WALLOPS ISLAND, VA.	NOAA Chart 12210_1
VANS10-005	7C-AO06-10-005	ATL. OCEAN DEEP-ASSATEAGUE ISLAND	2.21 nm ESE of Assateague Is. Beach	37	54	30.30	-75	16	34.92	37.908417	-75.276367	141A	141A - CHINCOTEAGUE EAST, VA.	NOAA Chart 12210_1
VANS10-017	7C-AO06-10-017	ATL. OCEAN DEEP - ASSATEAGUE ISLAND	1.74 nm SE of Assateague Island Beach	38	0	19.14	-75	12	59.40	38.005317	-75.216500	162C	162C - WHITTINGTON POINT, MD.-VA.	NOAA Chart 12211_1
VANS10-021	7C-AO06-10-021	ATL. OCEAN DEEP-ASSATEAGUE ISLAND	2.40 nm E of Chincoteague Is. Beach	37	53	16.80	-75	17	25.98	37.888000	-75.290550	141A	141A - CHINCOTEAGUE EAST, VA.	NOAA Chart 12210_1
VANS10-037	7C-AO06-10-037	ATL. OCEAN DEEP-ASSATEAGUE ISLAND	2.31 nm SE of Chincoteague Island Beach	37	55	31.38	-75	15	49.20	37.925383	-75.263667	141A	141A - CHINCOTEAGUE EAST, VA.	NOAA Chart 12210_1
VANS10-049	7C-AO06-10-049	ATL. OCEAN DEEP - ASSATEAGUE ISLAND	1.85 nm SE of Chincoteague Is. Beach	37	55	48.36	-75	16	18.30	37.930100	-75.271750	141A	141A - CHINCOTEAGUE EAST, VA.	NOAA Chart 12211_1
VANS10-013	7C-AO07-10-013	ATL. OCEAN DEEP-CHINCOTEAGUE INLET	2.60 nm se of Assateague Island beach	37	50	54.06	-75	18	18.24	37.848350	-75.305067			NOAA Chart 12210_1
VANS10-010	7C-AO12-10-010	ATLANTIC OCEAN-METOMPKIN ISLAND	1.30 nm east of Cedar Is. Beach	37	35	37.80	-75	33	33.72	37.593833	-75.559367			NOAA Chart 12210_1
VANS10-022	7C-AO12-10-022	ATLANTIC OCEAN-METOMPKIN ISLAND	1413 m E of Cedar Island Beach	37	39	34.26	-75	33	27.84	37.659517	-75.557733	120A	120A - METOMKIN INLET, VA.	NOAA Chart 12210_1
VANS10-041	7C-AO12-10-041	ATLANTIC OCEAN-METOMPKIN ISLAND	1.13 nm E of Metompkin Is. Beach	37	44	38.28	-75	30	19.32	37.743967	-75.505367	120A	120A - METOMKIN INLET, VA.	NOAA Chart 12210_1
VANS10-073	7C-AO12-10-073	ATLANTIC OCEAN-METOMPKIN ISLAND	879 m east of Gargathy Beach	37	45	35.82	-75	30	40.68	37.759950	-75.511300	142D	142D - BLOXOM, VA.	NOAA Chart 12210_1
VANS10-004	7C-AO16-10-004	ATLANTIC OCEAN-PARRAMORE ISLAND	1.83 nm E of Hog Island Beach	37	22	25.92	-75	39	4.80	37.373867	-75.651333	092C	092C - GREAT MACHIPONGO INLET, VA.	NOAA Chart 12210_1
VANS10-015	7C-AO16-10-015	ATLANTIC OCEAN-PARRAMORE ISLAND	1.03 nm E of Paramore Is. Beach (south)	37	29	3.72	-75	36	28.08	37.484367	-75.607800	092B	092B - QUINBY INLET, VA.	NOAA Chart 12210_1
VANS10-020	7C-AO16-10-020	ATLANTIC OCEAN-PARRAMORE ISLAND	2.42 nm E of Hog Island Beach	37	23	30.60	-75	38	38.88	37.391833	-75.644133	092B	092B - QUINBY INLET, VA.	NOAA Chart 12210_1
VANS10-002	7C-AO17-10-002	ATL. OCEAN DEEP-PARRAMORE ISLAND	2.15 nm E of Assawoman Is & Inlet Beach	37	48	52.80	-75	27	20.22	37.814667	-75.455617	141C	141C - WALLOPS ISLAND, VA.	NOAA Chart 12210_1
VANS10-009	7C-AO17-10-009	ATL. OCEAN DEEP-PARRAMORE ISLAND	2.51 nm E of Cedar Island Beach	37	38	15.06	-75	32	40.02	37.637517	-75.544450	120A	120A - METOMKIN INLET, VA.	NOAA Chart 12210_1
VANS10-025	7C-AO17-10-025	ATL. OCEAN DEEP-PARRAMORE ISLAND	2.83 nm E of beach N of Metompkin Inlet	37	41	50.94	-75	31	17.94	37.697483	-75.521650	120A	120A - METOMKIN INLET, VA.	NOAA Chart 12210_1
VANS10-029	7C-AO17-10-029	ATL. OCEAN DEEP-PARRAMORE ISLAND	1.72 nm E of Assawoman Island Beach	37	47	47.40	-75	28	54.48	37.796500	-75.481800	141C	141C - WALLOPS ISLAND, VA.	NOAA Chart 12210_1
VANS10-031	7C-AO17-10-031	ATL. OCEAN DEEP-PARRAMORE ISLAND	2.25 nm E of Hog Island Beach	37	26	25.62	-75	36	55.02	37.440450	-75.615283			NOAA Chart 12210_1
VANS10-045	7C-AO17-10-045	ATL. OCEAN DEEP-PARRAMORE ISLAND	2.89 nm E of Metompkin Islands Beach	37	44	51.84	-75	29	14.88	37.747733	-75.487467			NOAA Chart 12210_1
VANS10-047	7C-AO17-10-047	ATL. OCEAN DEEP-PARRAMORE ISLAND	2.76 nm east of Hog Island Beach	37	24	1.62	-75	38	26.10	37.400450	-75.640583	092B	092B - QUINBY INLET, VA.	NOAA Chart 12210_1
VANS10-053	7C-AO17-10-053	ATL. OCEAN DEEP-PARRAMORE ISLAND	2.5 nm E of Hog Island Beach - Alt-038	37	30	32.28	-75	35	12.00	37.508967	-75.586667			NOAA Chart 12210_1
VANS10-059	7C-AO17-10-059	ATLANTIC OCEAN-METOMPKIN ISLAND	3.24 mi E of Hog Island	37	26	0.96	-75	36	21.30	37.433600	-75.605917			NOAA Chart 12210_1
VANS10-008	7C-AO22-10-008	ATL. OCEAN-LOWER EASTERN SHORE	1.31 nm east of Smith Island Beach	37	8	13.32	-75	46	28.26	37.137033	-75.774517	063A	063A - SHIP SHOAL INLET, VA.	NOAA Chart 12221_1
VANS10-024	7C-AO22-10-024	ATL. OCEAN-LOWER EASTERN SHORE	2.01 nm east of Myrtle Island Beach	37	11	33.00	-75	44	23.82	37.192500	-75.739950	063A	063A - SHIP SHOAL INLET, VA.	NOAA Chart 12221_1
VANS10-028	7C-AO22-10-028	ATL. OCEAN-LOWER EASTERN SHORE	4.69 nm east of Wreck Island	37	17	30.90	-75	41	13.50	37.291917	-75.687083	092C	092C - GREAT MACHIPONGO INLET, VA.	NOAA Chart 12221_1
VANS10-036	7C-AO22-10-036	ATL. OCEAN-LOWER EASTERN SHORE	2.76 nm east of Cobb Island Beach	37	20	4.56	-75	39	43.62	37.334600	-75.662117	092C	092C - GREAT MACHIPONGO INLET, VA.	NOAA Chart 12221_1
VANS10-040	7C-AO22-10-040	ATL. OCEAN-LOWER EASTERN SHORE	1438 m east of Smith Island Beach	37	10	29.82	-75	44	52.68	37.174950	-75.747967	063A	063A - SHIP SHOAL INLET, VA.	NOAA Chart 12221_1
VANS10-056	7C-AO22-10-056	ATL. OCEAN-LOWER EASTERN SHORE	3.47 nm east of Smith Island Beach	37	8	13.38	-75	45	43.98	37.137050	-75.762217	063A	063A - SHIP SHOAL INLET, VA.	NOAA Chart 12221_1
VANS10-060	7C-AO22-10-060	ATL. OCEAN-LOWER EASTERN SHORE	2.75 nm east of New Inlet	37	14	33.96	-75	42	28.44	37.242767	-75.707900			NOAA Chart 12221_1
VANS10-072	7C-AO22-10-072	ATLANTIC OCEAN-LOWER EASTERN SHORE	2.93 mi E of Smith Island Beach	37	9	49.14	-75	44	34.74	37.163650	-75.742983	063A	063A - SHIP SHOAL INLET, VA.	NOAA Chart 12221_1
VANS10-088	7C-AO22-10-088	ATL. OCEAN-LOWER EASTERN SHORE	2.94 mi E of Wreck Island	37	15	39.18	-75	42	18.66	37.260883	-75.705183	092C	092C - GREAT MACHIPONGO INLET, VA.	NOAA Chart 12221_1
VANS10-087	7C-AO23-10-087	ATLANTIC OCEAN-RUDEE INLET	1037 m E of 65-St, Virginia Beach	36	53	28.02	-75	56	30.42	36.891117	-75.941783	033B	033B - NORTH VIRGINIA BEACH, VA.	NOAA Chart 12221_1
VANS10-011	7C-AO24-10-011	ATL.OCEAN DEEP-CHESAPEAKE BAY INLET	2.96 nm E of 39th Street, Virginia Beach	36	52	2.28	-75	55	2.52	36.867300	-75.917367	033C	033C - VIRGINIA BEACH, VA.	NOAA Chart 12221_1
VANS10-014	7C-AO24-10-014	ATL.OCEAN DEEP-CHESAPEAKE BAY INLET	1797 m east of beach at Cape Henry	36	55	28.86	-75	58	43.50	36.924683	-75.978750	033B	033B - NORTH VIRGINIA BEACH, VA.	NOAA Chart 12221_1
VANS10-026	7C-AO24-10-026	ATL.OCEAN DEEP-CHESAPEAKE BAY INLET	3.09 nm east of beach at Cape Henry	36	55	14.82	-75	55	49.86	36.920783	-75.930517	033B	033B - NORTH VIRGINIA BEACH, VA.	NOAA Chart 12221_1
VANS10-027	7C-AO24-10-027	ATL.OCEAN DEEP-CHESAPEAKE BAY INLET	2.20 nm east 75th Street, Virginia Beach	36	54	0.00	-75	56	32.35	36.900000	-75.942319	033B	033B - NORTH VIRGINIA BEACH, VA.	NOAA Chart 12221_1
VANS10-042	7C-AO24-10-042	ATL.OCEAN DEEP-CHESAPEAKE BAY INLET	3.30 nm north of Cape Henry Lighthouse	36	58	32.16	-75	59	55.20	36.975600	-75.998667	034A	034A - CAPE HENRY, VA.	NOAA Chart 12221_1
VANS10-058	7C-AO24-10-058	ATL.OCEAN DEEP-CHESAPEAKE BAY INLET	2.30 mi NNE Cape Henry	36	57	47.79	-76	0	15.60	36.963275	-76.004333	034A	034A - CAPE HENRY, VA.	NOAA Chart 12221_1
VANS10-066	7C-AO24-10-066	ATL.OCEAN DEEP-CHESAPEAKE BAY INLET	2.48 mi ENE of Cape Henry	36	56	50.46	-75	57	54.18	36.947350	-75.965050	033B	033B - NORTH VIRGINIA BEACH, VA.	NOAA Chart 12221_1
VANS10-090	7C-AO24-10-090	ATLANTIC OCEAN-020403040502	3.16 mi ENE of Cape Henry	36	56	22.50	-75	56	36.06	36.939583	-75.943350	033B	033B - NORTH VIRGINIA BEACH, VA.	NOAA Chart 12221_1
VANS10-016	7D-AO25-10-016	ATLANTIC OCEAN-SAND RIDGE	659 m E of Sand Ridge - Wash Flats	36	39	18.42	-75	53	37.68	36.655117	-75.893800	001B	001B - NORTH BAY, VA.	NOAA Chart 122071_1
VANS10-032	7D-AO25-10-032	ATLANTIC OCEAN-SAND RIDGE	1340 m E of Sand Ridge@ Bush Isl. Cove	36	39	56.46	-75	53	34.86	36.665683	-75.893017	001B	001B - NORTH BAY, VA.	NOAA Chart 122071_1
VANS10-071	7D-AO25-10-071	ATLANTIC OCEAN-SAND RIDGE	1.39 nm east of US Naval Amphibious Base	36	48	52.80	-75	56	13.44	36.814667	-75.937067	033C	033C - VIRGINIA BEACH, VA.	NOAA Chart 122071_1
VANS10-080	7D-AO25-10-080	Atlantic Ocean	390m offshore 1.21km north of VA-NC Line	36	33	34.62	-75	50	34.44	36.559617	-75.842900			NOAA Chart 122071_1
VANS10-007	7D-AO26-10-007	ATLANTIC OCEAN DEEP-SAND RIDGE	1.67 nm east of beach at Sandbridge	36	43	38.04	-75	54	6.78	36.727233	-75.901883	001B	001B - NORTH BAY, VA.	NOAA Chart 122071_1
VANS10-023	7D-AO26-10-023	ATLANTIC OCEAN DEEP-SAND RIDGE	1.03 nm E of Sand Ridge beach	36	40	46.50	-75	53	37.62	36.679583	-75.893783	001B	001B - NORTH BAY, VA.	NOAA Chart 122071_1
VANS10-048	7D-AO26-10-048	ATLANTIC OCEAN DEEP-SAND RIDGE	1.82 nm E of beach @ False Cape Landing	36	35	36.10	-75	50	19.75	36.593361	-75.838819			NOAA Chart 122071_1

Appendix 1 - Station Metadata Table (continued)

NARS/NCCA Site ID	DEQ Station ID	Hydrologic Unit Code (8-digit HUC)	County FIPS Code	Comment
VANS10-001	7C-AO05-10-001	02040303	001	2010 Offshore SS; HUC 02040303 - Chincoteague; Watershed AO05 - Atlantic Ocean-Assateague Island; NOAA Chart 12211_1
VANS10-033	7C-AO05-10-033	02040303	001	2010 Offshore SS; HUC 02040303 - Chincoteague; Watershed AO05 - Atlantic Ocean-Assateague Island; NOAA Chart 12211_1
VANS10-034	7C-AO05-10-034	02040303	001	2010 Offshore SS; HUC 02040303 - Chincoteague; Watershed AO05 - Atlantic Ocean-Assateague Island; NOAA Chart 12210_1
VANS10-050	7C-AO05-10-050	02040303	001	2010 Offshore SS; HUC 02040303 - Chincoteague; Watershed AO05 - Atlantic Ocean-Assateague Island; NOAA Chart 12210_1
VANS10-005	7C-AO06-10-005	02040303	001	2010 Offshore SS; HUC 02040303 - Chincoteague; Watershed AO06 - Atlantic Ocean Deep-Assateague Island; NOAA Chart 12210_1
VANS10-017	7C-AO06-10-017	02070008	001	2010 Offshore SS; HUC 02040303 - Chincoteague; Watershed AO06 - Atlantic Ocean Deep-Assateague Island; NOAA Chart 12211_1
VANS10-021	7C-AO06-10-021	02040303	001	2010 Offshore SS; HUC 02040303 - Chincoteague; Watershed AO06 - Atlantic Ocean Deep-Assateague Island; NOAA Chart 12210_1
VANS10-037	7C-AO06-10-037	02040303	001	2010 Offshore SS; HUC 02040303 - Chincoteague; Watershed AO06 - Atlantic Ocean Deep-Assateague Island; NOAA Chart 12210_1
VANS10-049	7C-AO06-10-049	02040303	001	2010 Offshore SS; HUC 02040303 - Chincoteague; Watershed AO06 - Atlantic Ocean Deep-Assateague Island; NOAA Chart 12211_1
VANS10-013	7C-AO07-10-013	02040303	001	2010 Offshore SS; HUC 02040303 - Chincoteague; Watershed AO07 - Atlantic Ocean Deep-Chincoteague Inlet; NOAA Chart 12210_1
VANS10-010	7C-AO12-10-010	02040304	001	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO12 - Atlantic Ocean-Metompkin Island; NOAA Chart 12210_1
VANS10-022	7C-AO12-10-022	02040304	001	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO12 - Atlantic Ocean-Metompkin Island; NOAA Chart 12210_1
VANS10-041	7C-AO12-10-041	02040304	001	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO12 - Atlantic Ocean-Metompkin Island; NOAA Chart 12210_1
VANS10-073	7C-AO12-10-073	02040304	001	2010 Offshore SS - QA Site; HUC 02040304 - Eastern Lower Delmarva; Watershed AO12 - Atlantic Ocean-Metompkin Island; NOAA Chart 12210_1; Alternate for VANS10-006
VANS10-004	7C-AO16-10-004	02040304	131	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO16 - Atlantic Ocean-Parramore Island; NOAA Chart 12210_1
VANS10-015	7C-AO16-10-015	02040304	001	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO16 - Atlantic Ocean-Parramore Island; NOAA Chart 12210_1
VANS10-020	7C-AO16-10-020	02040304	131	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO16 - Atlantic Ocean-Parramore Island; NOAA Chart 12210_1
VANS10-002	7C-AO17-10-002	02040304	001	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO17 - Atlantic Ocean Deep-Parramore Island; NOAA Chart 12210_1
VANS10-009	7C-AO17-10-009	02040304	001	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO17 - Atlantic Ocean Deep-Parramore Island; NOAA Chart 12210_1
VANS10-025	7C-AO17-10-025	02040304	001	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO17 - Atlantic Ocean Deep-Parramore Island; NOAA Chart 12210_1
VANS10-029	7C-AO17-10-029	02040304	001	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO17 - Atlantic Ocean Deep-Parramore Island; NOAA Chart 12210_1
VANS10-031	7C-AO17-10-031	02040304	131	2010 Offshore SS; HUC 02040304 - Lower Coastal Delmarva; Watershed AO17 - Atlantic Ocean Deep-Parramore Island; NOAA Chart 12210_1
VANS10-045	7C-AO17-10-045	02040304	001	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO17 - Atlantic Ocean Deep-Parramore Island; NOAA Chart 12210_1
VANS10-047	7C-AO17-10-047	02040304	131	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO17 - Atlantic Ocean Deep-Parramore Island; NOAA Chart 12210_1
VANS10-053	7C-AO17-10-053	02040304	001	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO17 - Atlantic Ocean Deep-Parramore Island; NOAA Chart 12210_1; Alternate for VANS10-038
VANS10-059	7C-AO17-10-059	02040304	131	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO12 - Atlantic Ocean-Metompkin Island; Alternate for VANS10-018; NOAA Chart 12210_1
VANS10-008	7C-AO22-10-008	02040304	131	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO22 - Atlantic Ocean-Lower Eastern Shore; NOAA Chart 12221_1
VANS10-024	7C-AO22-10-024	02040304	131	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO22 - Atlantic Ocean-Lower Eastern Shore; NOAA Chart 12221_1
VANS10-028	7C-AO22-10-028	02040304	131	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO22 - Atlantic Ocean-Lower Eastern Shore; NOAA Chart 12221_1
VANS10-036	7C-AO22-10-036	02040304	131	2010 Offshore SS - QA Site; HUC 02040304 - Eastern Lower Delmarva; Watershed AO22 - Atlantic Ocean-Lower Eastern Shore; NOAA Chart 12221_1
VANS10-040	7C-AO22-10-040	02040304	131	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO22 - Atlantic Ocean-Lower Eastern Shore; NOAA Chart 12221_1
VANS10-056	7C-AO22-10-056	02040304	131	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO22 - Atlantic Ocean-Lower Eastern Shore; NOAA Chart 12221_1; Alternate for VANS10-019
VANS10-060	7C-AO22-10-060	02040304	131	2010 Offshore SS - QA Site; HUC 02040304 - Eastern Lower Delmarva; Watershed AO22 - Atlantic Ocean-Lower Eastern Shore; NOAA Chart 12221_1; Alternate for VANS10-04
VANS10-072	7C-AO22-10-072	02040304	131	2010 Offshore SS; HUC 02040304 - Atlantic Ocean-Lower Eastern Shore; alternate for VANS10-003; NOAA Chart 12221_1; Alternate for VANS10-003
VANS10-088	7C-AO22-10-088	02040304	131	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO22 - Atlantic Ocean-Lower Eastern Shore; Alternate for VANS10-012; NOAA Chart 12221_1
VANS10-087	7C-AO23-10-087	02040304	810	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO23 - Atlantic Ocean-Rudee Inlet; NOAA Chart 12221_1
VANS10-011	7C-AO24-10-011	02040304	810	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO24 - Atlantic Ocean Deep-Chesapeake Bay Inlet; NOAA Chart 12221_1
VANS10-014	7C-AO24-10-014	02040304	810	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO24 - Atlantic Ocean Deep-Chesapeake Bay Inlet; NOAA Chart 12221_1
VANS10-026	7C-AO24-10-026	02040304	810	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO24 - Atlantic Ocean Deep-Chesapeake Bay Inlet; NOAA Chart 12221_1
VANS10-027	7C-AO24-10-027	02040304	810	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO24 - Atlantic Ocean Deep-Chesapeake Bay Inlet; NOAA Chart 12221_1
VANS10-042	7C-AO24-10-042	02040304	810	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO24 - Atlantic Ocean Deep-Chesapeake Bay Inlet; NOAA Chart 12221_1
VANS10-058	7C-AO24-10-058	02040304	810	2010 Offshore SS; HUC 02040304 - Eastern Lower Delmarva; Watershed AO24 - Atlantic Ocean Deep-Chesapeake Bay Inlet; NOAA Chart 12221_1
VANS10-066	7C-AO24-10-066	02040304	810	2010 Offshore SS; HUC 02040304 - Coastal Delmarva; Watershed AO24 - Atlantic Ocean-020403040502; Alternate for VANS10-030; NOAA Chart 12221_1
VANS10-090	7C-AO24-10-090	02040304	810	2010 Offshore SS; HUV 02040304 - Coastal Delmarva; Watershed AO24 - ATLANTIC OCEAN-020403040502; Alternate for VANS10-046; NOAA Chart 12221_1
VANS10-016	7D-AO25-10-016	03010205	810	2010 Offshore SS; HUC 03010205 - Albemarle; Watershed AO25 - Atlantic Ocean-Sand Ridge; NOAA Chart 122071_1
VANS10-032	7D-AO25-10-032	03010205	810	2010 Offshore SS; HUC 03010205 - Albemarle; Watershed AO25 - Atlantic Ocean-Sand Ridge; NOAA Chart 122071_1
VANS10-071	7D-AO25-10-071	03010205	810	2010 Offshore SS; HUC 03010205 - Albemarle; Watershed AO25 - Atlantic Ocean-Sand Ridge; NOAA Chart 122071_1; Alternate for VANS10-035
VANS10-080	7D-AO25-10-080	03010205	810	2010 Offshore SS; HUC 03010205 - Albemarle; Watershed AO25 - Atlantic Ocean-Sand Ridge; NOAA Chart 122071_1; Alternate for VANS10-043
VANS10-007	7D-AO26-10-007	03010205	810	2010 Offshore SS; HUC 03010205 - Albemarle; Watershed AO26 - Atlantic Ocean Deep-Sand Ridge; NOAA Chart 122071_1
VANS10-023	7D-AO26-10-023	03010205	810	2010 Offshore SS; HUC 03010205 - Albemarle; Watershed AO26 - Atlantic Ocean Deep-Sand Ridge; NOAA Chart 122071_1
VANS10-048	7D-AO26-10-048	03010205	810	2010 Offshore SS; HUC 03010205 - Albemarle; Watershed AO26 - Atlantic Ocean Deep-Sand Ridge; NOAA Chart 122071_1

[1] Not all offshore sites will be located within USGS 7' Topographic Map Quadrangles (TopoQuad). Many are outside the range of continental mapping.

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