CHAPTER 4.5 ESTUARINE PROBABILISTIC MONITORING RESULTS

Introduction

Each year, DEQ's Estuarine Probabilistic Monitoring Program[1] collects samples at 50 estuarine sites, randomly selected by computer from designated non-oceanic tidal waters. Designated waters include the narrow upper tidal reaches (transitional and tidal freshwaters), tidal tributaries and embayments of the James, York, Rappahannock and Potomac Rivers. Tidal tributaries and embayments of Coastal Delmarva and the Back Bay – North Landing River region are also included.[2] In the state design, the only preference applied in the process of selection is the requirement that 70% (N = 35) of the annual sites be from inland tidal waters of the Chesapeake Bay and North Landing River watersheds, and 30% (N = 15) of the sites be from the coastal Delmarva peninsula and Back Bay. At five-year intervals (2010, 2015, 2020, etc.) DEQ's Estuarine ProbMon Program is integrated with the National Aquatic Resources Survey (NARS) / National Coastal Condition Assessment (NCCA) Program, the design of which may include a varying number of sites within the Chesapeake, James, York and Rappahannock mainstems. The number of Virginia estuarine sites selected for NARS surveys varies from cycle to cycle, but is usually between 20 and 25. During NCCA years, DEQ complements the national design with enough stations from the state design to complete a total of 50 sites, although the exact 70% / 30% division between inland and coastal tidal waters may not be maintained.

The six-year assessment window (2009 – 2014) encompassed by the 2016 Integrated Report (IR or Report) includes 273 sets of estuarine samples collected from 273 sites. The sliding, six-year assessment windows included in sequential Reports result in considerable overlap in the monitoring data included. Approximately 67% of the data included in each IR were also assessed and included in the previous Report. Consequently, most of the following sections have changed little from those in the 2014 IR.

The geographic distribution and salinities of the 273 probabilistic estuarine sites visited during the six-year period are illustrated in the map of Figure 4.5-1. The salinities classified here represent the near-bottom salinities at the time of sampling, associated with the contemporary benthic community samples collected at the same sites. The color-coded symbols on the map indicate the salinity zone of each site, as summarized in Table 4.5-1 below. The percentages and confidence intervals listed in the table represent the percentages among the 273 sites with measured salinity values, and are not representative of Virginia's estuarine waters as a whole. If the area of the entire Chesapeake Bay mainstem and the lower tidal portions of the James, York, and Rappahannock Rivers were to be included in the Commonwealth's sampling design, the tidal freshwater and oligohaline percentages would be much reduced, and the saltwater percentage would be much greater. All 50 euhaline sites (salinity > 30.0‰) were located adjacent to oceanic waters along the Delmarva coast.

[1] A more detailed description of probabilistic monitoring can be found on the DEQ Webpages at: http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityMonitoring/ProbabilisticMonitoring.aspx

[2] The Chesapeake Bay mainstem and the broad tidal tributary mainstems of the lower James, York and Rappahannock Rivers are excluded from the state designation because they are sufficiently characterized by the Chesapeake Bay Tidal Water Quality Monitoring and Assessment Program.

Table 4.5-1 Numbers and Proportions of Estuarine ProbMon Sites Occurring in Various Salinity Zones.

Salinity Class	Salinity Range (ppt)	Stations	Percentage	
TF - Tidal Freshwater	< 0.5 ‰	30	10.99 ± 3.73%	Fresh and Transitional 64 (23.44 ± 5.05%)
OH - Oligohaline - Transitional	0.5 - 5.0 ‰	34	12.45 ± 3.43%	
MH - Mesohaline	> 5.0 - 18.0 ‰	85	31.14 ± 5.52%	Saltwater 209 (76.56 ± 5.05%)
PH - Polyhaline	>18.0 - 30.0 ‰	74	27.11 ± 5.30%	
UH - Euhaline	> 30.0 ‰	50	18.32 ± 4.61%	

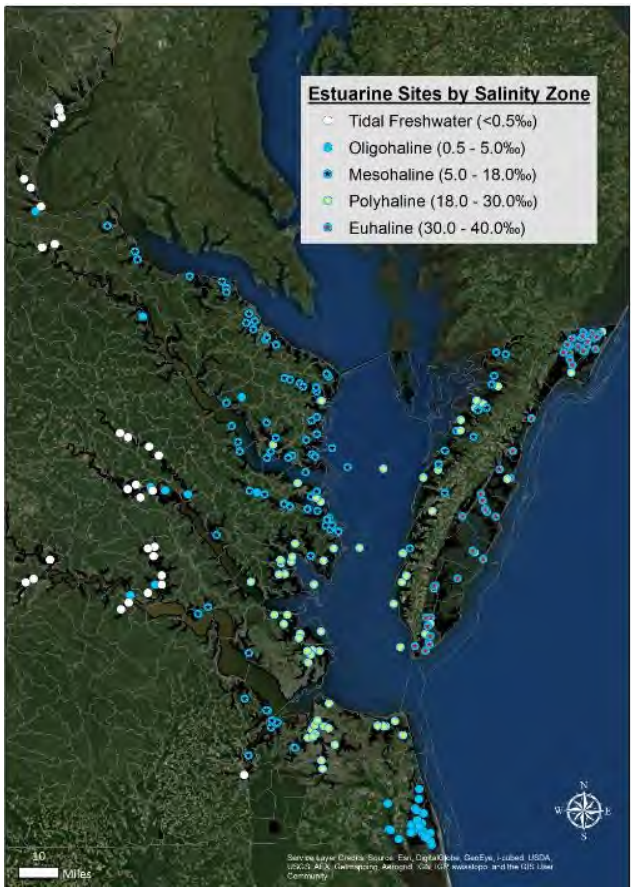


Figure 4.5-1 Geographic distribution of the 273 Estuarine ProbMon Sites Sampled in Tidal Virginia Waters between 2009 and 2014, with their Respective Salinity Zones.

Parameters Measured and Results

DEQ's Estuarine ProbMon Program adheres closely to the same selection of water quality and sediment quality parameters as identified in the national (NCCA) program. Water Quality, Sediment Quality and Benthic data are collected at each of the probmon sites. It's important to note that the water quality parameters (*e.g.*, nutrients, bacteria, dissolved metals, DO, temperature, pH, *etc*.) that are measured at probabilistic sites are considered to be isolated instantaneous observations and are insufficient for assessment purposes because the intensity and duration of such stressors are unknown. However, sediment chemistry, sediment toxicity, and benthic community wellbeing results are used to conduct Weight-of-Evidence assessments at each individual site for Aquatic Life Use (ALU). All three of these measures are considered to be temporally integrative, providing an assessment of environmental conditions experienced by the benthic community during the period prior to the time of sampling. The results of water quality, sediment quality and benthic data are summarized below.

Water Quality

The NCCA Program has traditionally[3] used five parameters to characterize estuarine water quality: near-surface (1) dissolved inorganic Nitrogen (mg/L DIN), (2) dissolved inorganic Phosphorus (mg/L DIP), and (3) chlorophyll-a (µg/L Chl-a), plus (4) water clarity, expressed as the percent of available PAR reaching a specified 1.0 meter depth, and (5) near-bottom dissolved Oxygen (mg/L DO). A classification ("Good", "Fair", or "Poor") based on each of these parameters was subsequently integrated into an overall Water Quality Index (WQI) characterization for the site. The observed values of several of these same parameters are also included for consideration in site-specific weight-of-evidence assessments for the aquatic life designated use (ALU) to be discussed later in this chapter.

On a national scale, the threshold concentrations of these five parameters, differentiating among "Good", "Fair", and "Poor" water quality classes, vary regionally. The final thresholds that were applied for evaluation of individual sites in the 2015 NCCA Report V are summarized in Table 4.5-2a, below. Guidelines for characterizing restricted regions or areas based on their distributions of individual site scores are summarized in Table 4.5-2b. The following discussion of water quality in Virginia's estuaries is based primarily on these thresholds, except where specifically indicated otherwise.

Table 4.5-2a National Coastal Condition Report Water Quality Indicators and Site Specific Thresholds for the Northeast Coastal Region (USEPA 2016)**.**

Estuarine Water Quality Thresholds				
	Region	**Good**	**Fair**	**Poor**
Surface Concentrations of Dissolved Inorganic Nitrogen (DIN) in Estuaries	**Northeast Region**	**< 0.1 mg/L**	**0.1 - 0.5 mg/L**	**> 0.5 mg/L**
Surface Concentrations of Dissolved Inorganic Phosphorus (DIP) in Estuaries	**Northeast Region**	**< 0.01 mg/L**	**0.01 - 0.05 mg/L**	**> 0.05 mg/L**
Surface Concentrations of Chlorophyll a in Estuaries	**Northeast Region**	**< 5.0 µg/L**	**5.0 - 20.0 µg/L**	**> 20 µg/L**
Water Clarity (percent of photosynthetically active radiation [PAR] available at a depth of 1.0 meters) in Estuaries	**Waters with naturally high turbidity**	**> 10%**	**5 - 10%**	**< 5%**
	Waters with normal turbidity	**> 20%**	**10 - 20%**	**< 10%**
	Waters that support SAV	**> 40%**	**20 - 40%**	**< 20%**
Bottom Water Concentrations of Dissolved Oxygen in Estuaries	**All Regions**	**> 5.0 mg/L**	**2.0 - 5.0 mg/L**	**< 2.0 mg/L**

[3] NCC Reports I - V, USEPA, 2001, 2004, 2008, 2012, 2015

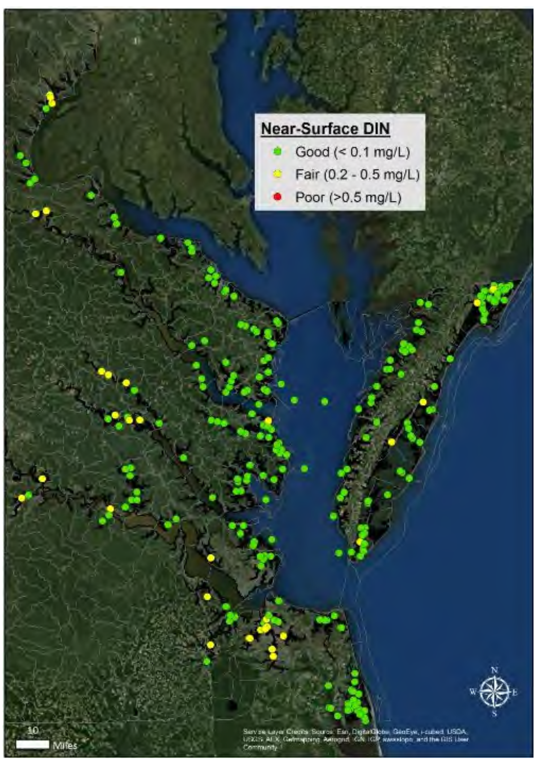
Table 4.5-2b ***Guidelines for Characterizing Regions Based on the Distributions of Individual Site Scores.*** (USEPA 2016)

Regional Rating	Cutpoints
Good	**Less than ten percent of the coastal area is in "Poor" Condition, and more than 50 percent of the coastal area is in "Good" condition.**
Fair	**Ten to 20 percent of the coastal area is in "Poor" condition, or 50 percent or less of the coastal area is in "Good condition.**
Poor	**More than 20 percent of the coastal area is in "Poor" condition.**

Near-Surface Dissolved Inorganic Nitrogen (DIN): Concentrations of near-surface dissolved inorganic Nitrogen were measured in samples from 273 sites. DIN was calculated as the sum of the concentrations of dissolved nitrate (NO_3^-), dissolved nitrite (NO_2^-) and dissolved ammonium (NH_4^+) ions. Among the 273 samples, 240 (87.91 ± 3.88%) were classified as "Good" for DIN, 33 (12.09 ± 3.88%) were classified as "Fair", and zero were classified as "Poor".

The map presented in Figure 4.5-2 illustrates the geographic distribution of the 273 sites evaluated, classified, and color coded by their near-surface dissolved inorganic nitrogen concentrations. Virginia's estuaries would earn an overall rating of "Good" because the proportion of Good site characterizations was well above 50% and there were no sites characterized as Poor.

DIN Class	Range	Stations	Percentage
Good	< 0.1 mg/L	240	87.91 ± 3.88%
Fair	0.1 - 0.5 mg/L	33	12.09 ± 3.88%
Poor	> 0.5 mg/L	0	0.00%
Missing	N/A	0	0.00%
	Total	273	100.00%



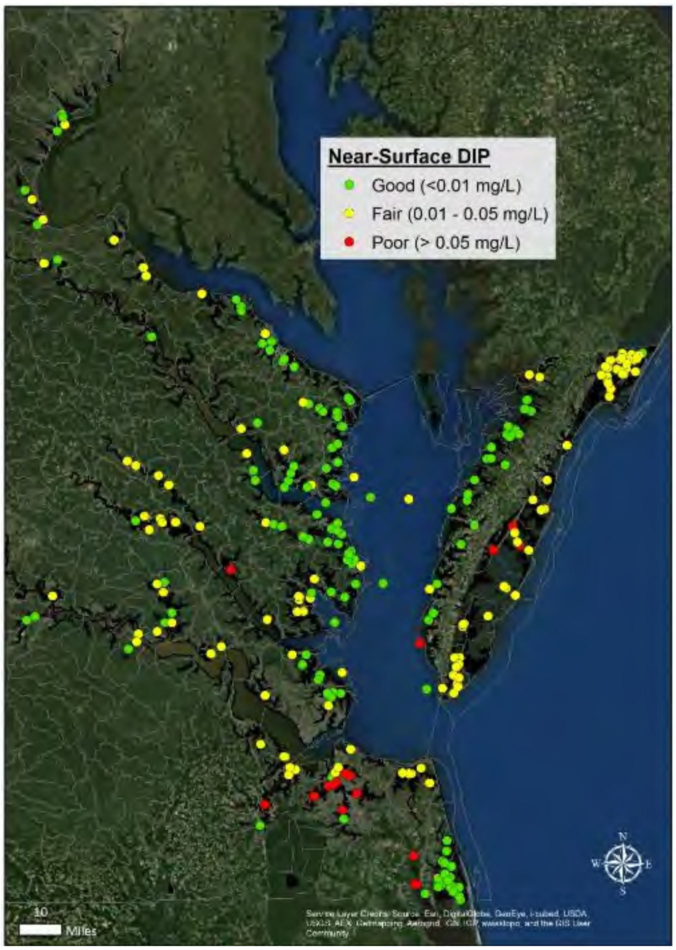
Dissolved Inorganic Nitrogen (DIN) mg/L	
N	273
Maximum	0.347
99th %tile	0.344
90th %tile	0.119
75th %tile	0.034
UL 95% Median	0.018
Median	**0.016**
LL 95% Median	0.014
25th %tile	0.008
10th %tile	0.004
5th %tile	0.002
1st %tile	0.001
Minimum	0.000
Average	**0.042**
Std. Dev.	0.070
Std. Err.	0.004

Figure 4.5-2 Geographic and Statistical Distributions and Characterizations of Dissolved Inorganic Nitrogen (DIN) Samples Collected at 273 Estuarine Sites from 2009 – 2014.

Near-Surface Dissolved Inorganic Phosphorus (DIP): Near-surface dissolved inorganic Phosphorus (also known as phosphate - PO_4^{-3}, orthophosphate, or soluble reactive phosphorus - SRP) concentrations were also measured in samples from 273 sites. The geographic and statistical distributions of DIP characterizations are illustrated in the map and graphs of Figure 4.5-3. One hundred thirty-two (48.35 ± 5.95%) of the 273 samples were classified as “Good,” 122 (44.69 ± 5.92%) were classified as “Fair”, and 19 (6.95 ± 3.03%) were classified as “Poor.”

Virginia’s estuaries earn an overall “Fair” classification for DIP in regional waters, since less than 10% of sites scored “Poor” and 48.35% of the sites scored “Good”. The threshold for a “Good” regional rating is 50%. The Elizabeth River system would be scored as “Poor” on a more limited regional basis.

DIP Class	Range	Stations	Percentage
Good	< 0.01 mg/L	132	48.35 ± 5.95%
Fair	0.01 - 0.05 mg/L	122	44.69 ± 5.92%
Poor	> 0.05 mg/L	19	6.96 ± 3.06%
Missing	N/A	0	0.00 ± 0.00%
	Total	273	100.00%



Dissolved Inorganic Phosphorus (DIP) mg/L	
N	273
Maximum	0.157
99th %tile	0.108
90th %tile	0.043
75th %tile	0.025
UL 95% Median	0.013
Median	**0.011**
LL 95% Median	0.009
25th %tile	0.004
10th %tile	0.002
5th %tile	0.001
1st %tile	0.000
Minimum	0.000
Average	**0.018**
Std. Dev.	0.023
Std. Err.	0.001

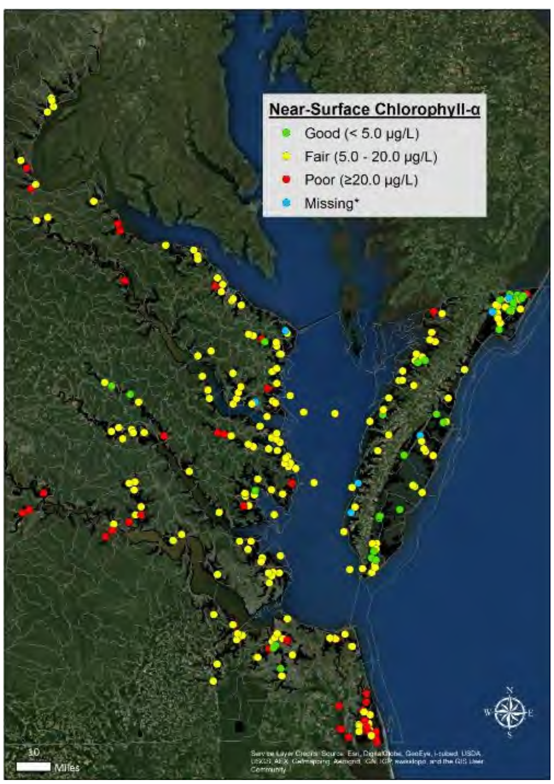
Figure 4.5-3 Geographic and Statistical Distributions and Characterizations of 273 Probabilistic Sites based upon Near-Surface Dissolved Inorganic Phosphorus (DIP) Concentrations (2009 – 2014).

Near-surface Chlorophyll-a: Chlorophyll-a (Chl-a) is used as an indirect measure of the quantity of phytoplankton (algae) in the water column. High values of chlorophyll-a, characteristic of excessive numbers of phytoplankton, are generally interpreted to result from nutrient enrichment or eutrophication of the associated water body.

Near-surface chlorophyll-a concentrations were analyzed from 266 of 273 samples from probabilistic estuarine sites (completeness = 97.44%). The missing seven samples (2.56 ± 1.88%) were mostly lost in the laboratory when their glass extraction tubes broke during centrifugation. On occasion, field-filtered Chl-a samples were rejected by the laboratory if they appeared to be contaminated (*e.g.*, if water had leaked into the filter container). Of the total 273 samples collected, 34 (12.45 ± 3.93%) were characterized as “Good” (< 5.0 µg/L Chl-a) using the chlorophyll-a thresholds in Table 4.5-2a, 191 sites (69.96 ± 5.46%) were classified as “Fair” and 41 (15.02 ± 4.26%) were classified as “Poor” (>20.0 µg/L Chl-a). The geographic, numerical, and statistical distributions of sites by chlorophyll-a class and the corresponding class thresholds are summarized in the map and tables of Figure 4.5-4.

Based on the NCCA thresholds for regional characterizations, Virginia’s estuarine waters would receive an overall score of “Fair” for chlorophyll-a (less than 20% of sites score “Poor” and less than 50% score “Good”). The Chesapeake Bay mainstem and coastal Delmarva waters would also receive localized ratings of “Fair”. Locally restricted tidal fresh and oligohaline waters of minor tributaries would be characterized as “Poor”.

Chlorophyll Class	Range	Stations	Percentage
Good	< 5.0 µg/L	34	12.45 ± 3.93%
Fair	5.0 - 20.0 µg/L	191	69.96 ± 5.46%
Poor	≥ 20.0 µg/L	41	15.02 ± 4.26%
Missing	N/A	7	2.56 ± 1.88%
	Total	273	100.00%



Chlorophyll a (µg/L)	
N	266
Maximum	81.100
99th %tile	54.120
90th %tile	23.700
75th %tile	15.875
UL 95% Median	11.713
Median	**10.850**
LL 95% Median	9.987
25th %tile	6.908
10th %tile	4.735
5th %tile	3.883
1st %tile	1.500
Minimum	1.210
Average	**13.375**
Std. Dev.	10.557
Std. Err.	0.647

Figure 4.5-4 Geographic & Statistical Distributions and Characterizations of 273 Probabilistic Estuarine Sites Based upon Near-Surface Chlorophyll-a Values – µg/L (2009 – 2014).

Water Clarity: Water clarity is considered an important element of water quality, but its inclusion in an integrated Water Quality Index (WQI) is somewhat complex. Part of this complexity stems from assigning thresholds to a very broad classification of coastal waters. Coastal waters are categorized as follows: (1) coastal waters with naturally high turbidity (Alabama, Louisiana, Mississippi, South Carolina, Georgia, and Delaware Bay), (2) coastal waters with normal turbidity (most of the United States), and (3) coastal waters that support SAV beds or have active programs for SAV restoration (Laguna Madre; the Big Bend region of Florida; the region from Tampa Bay to Florida Bay; the Indian River Lagoon; portions of Chesapeake Bay; Hawaii; American Samoa; Guam; Puerto Rico; and the U.S. Virgin Islands) (USEPA, 2012). The rationale for classifying such broad geographic areas into a uniform or homogeneous expectation of water clarity is open to question. Clearly, the expectation of water clarity and the presence or absence of SAV would not be the same for local areas with disparate depths, exposure to high wave activity, with strong tidal currents, areas of varying bottom substrates, or in estuaries fed by tannin-stained blackwater streams. Shallower waters, more subject to wind and wave action and the re-suspension of bottom sediment, would be expected to have higher turbidities (lower clarity) than deeper nearby waters.

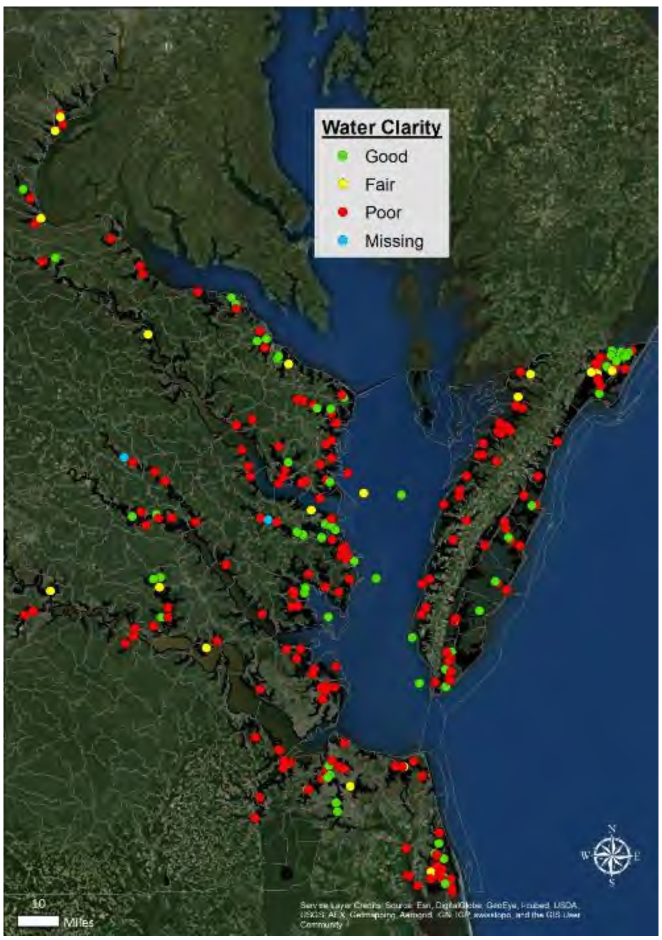
Water clarity is also a function of the density of phytoplankton in the water column, and in this sense is a redundant characteristic that may be highly and inversely correlated with chlorophyll and nutrient concentrations in the water column. Its accurate measurement is also susceptible to variations in ambient light conditions – diffused light on cloudy or overcast days versus direct sunlight, and the angle of incident light at the water's surface. In addition, water clarity is extremely difficult to measure accurately at shallow sites.

EPA's Chesapeake Bay Program (CBP) has defined SAV zones for numerous segments within the Bay watershed as that portion of the segment extending from the shoreline out to a depth contour (isobath) of 2.0 meters, relative to mean low water (MLW) level, excluding certain segments where SAV was not expected to grow (Kemp et al., 2000). Water quality criteria (e.g., water clarity) related to SAV growth and survival are only applied within these defined areas and during defined seasons. "For several SAV species (notably Myriophyllum spicatum and Hydrilla verticillata), maximum depth penetration might be greater than two meters, but it was felt that this would be an exception…" (Kemp et al., 2000). Criteria for excluding certain areas from the maps were based primarily on known historical SAV distributions, and on habitat areas exposed to high wave energy and/or that have undergone physical modifications that prevented them from supporting SAV growth. Ironically, the same shallow water areas that potentially support SAV are the most susceptible to shoreline erosion and to the re-suspension of sediment by wave action. The presence of SAV in such shallow areas improves water clarity (and consequently water quality) by buffering wave action, thus enhancing the precipitation of suspended material, and reducing shoreline erosion and the re-suspension of previously deposited sediment. SAV and water clarity consequently interact with a positive feedback mechanism – the presence of SAV improves water clarity, improved water clarity enhances the growth of SAV, etc.

The water clarity criteria established by the CBP for areas of SAV within Virginia's Chesapeake Bay watershed are published in Virginia's Water Quality Standards 9VAC25-260-185. In the following characterization, the scientifically derived CBP light availability (clarity) habitat types have been extended geographically, equated with local habitat types, and integrated with NCCA criteria where appropriate. This provided the application of similar criteria to define potential SAV areas in estuarine waters of coastal Delmarva and to the oligohaline waters of the Back Bay / North Landing River region (tributaries to Currituck Sound, NC) as were applied within the Chesapeake Bay watershed. Within the Bay watershed, sites that were within the designated SAV areas and had a depth equal to or less than 2.0 meters at the time of sampling were evaluated using the CBP criteria for defined SAV areas. Elsewhere, sites with depths less than or equal to 2.0 meters were considered potential SAV areas and were evaluated with the NCCA SAV criteria, unless they were impacted by strong wave action or strong tidal currents. Such determinations were made using map reconnaissance, comments from site field sheets, and the evaluation of substrate structure. Sandy substrates with very low fine particle concentrations (*e.g.*, ≥ 95% sand) were considered to be characteristic of such impacted sites. Sites with deeper waters (>2.0 m) were evaluated as areas of normal turbidity, although why coastal Delmarva waters of Virginia should be considered less turbid (normal) than coastal South Carolina and Georgia waters (naturally high) is a valid and unanswered question.

The geographic distribution and characterization of the 273 sites, based on the integrated, mixed water clarity criteria described above, are illustrated in the map of Figure 4.5-5. The statistical distribution of "Percent PAR @ 1.0 m depth" in the table of Figure 4.5-5 is not classified or color-coded because thresholds for characterizations ("Good", "Fair", "Poor") vary with location, salinity, depth, etc. The majority of the highest water clarity sites occur in the Chesapeake Bay mainstem and its larger embayments.

Virginia's estuarine waters received an overall score of "Poor" for water clarity because more than 20% of the individual sites were scored as "Poor". This score may be worse than warranted, because many sites that were individually scored as "Poor" actually fell within CBP SAV segments that, based on several years of ambient monitoring, were evaluated as meeting SAV growth goals for DEQ's 2014 Integrated Report (DEQ-WQA. 2014). This was especially evident in the upper tidal Potomac River, the Rappahannock, Mattaponi and Pamunkey Rivers, and tributaries to the lower tidal James River (refer to Figure 4.5-5). An additional factor is that DEQ's state probabilistic design targets smaller tributaries and embayments (generally shallower waters) where sediment laden storm runoff waters are more prevalent and re-suspension of existing sediment is more common, and the program normally excludes the open bay and lower, broader major tidal tributary mainstems where water clarity would generally be better.



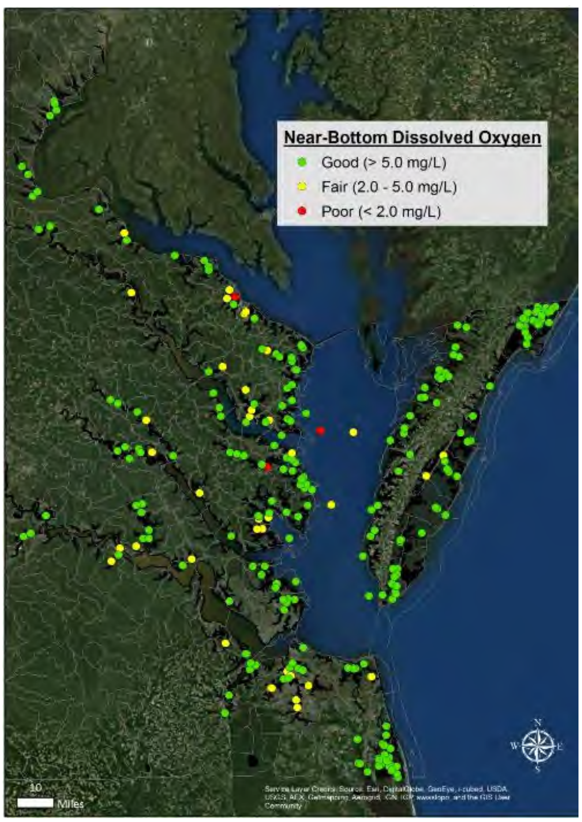
Water Clarity % Transmission @ Application Depth	
N	270
Maximum	57.57%
99th %tile	50.30%
90th %tile	28.17%
75th %tile	18.53%
UL 95% Median	10.39%
Median	**8.87%**
LL 95% Median	7.36%
25th %tile	2.67%
10th %tile	0.56%
5th %tile	0.19%
1st %tile	0.0014%
Minimum	0.0000%
Average	**12.01%**
Std. Dev.	11.57%
Std. Err.	0.70%

Figure 4.5-5 Geographic and Statistical Distributions of 273 Probabilistic Sites based on Water Clarity.

Near-Bottom Dissolved Oxygen: Dissolved Oxygen (DO) profiles from near-surface (0.5 m) to near-bottom (0.5 m above sediment) were recorded during all 275 site visits. Near-bottom DO concentrations are summarized here as one element in the NCCA Water Quality Index (WQI) for site characterizations. They are also utilized in the Weight-of-Evidence (WOE) site assessment for Aquatic Life Designated Use (ALU), to be described later in this chapter. Of the 273 bottom DO measures evaluated here, 232 (84.98 ± 1.88%) were classified as “Good” based on NCCA criteria. An additional 38 sites (13.92 ± 4.12%) were classified as “Fair” and only 3 sites (1.10 ± 1.24%) were classified as “Poor.”

The geographic and statistical distributions of bottom DO measurements, evaluated by the NCCA criteria, are summarized in the map and table of Figure 4.5-6. There is no indication that any strong regional or local influence depressed bottom dissolved oxygen concentrations within the estuarine area sampled under the Virginia state survey design. Virginia’s estuarine waters would earn an overall score of “Good” under the most protective Virginia standard of 4.0 mg/L, under the less protective CBP DO standard of 3.2 mg/L, or under the least protective NCCA criterion (2.0 mg/L), since under all three the proportion of “Poor” sites was less than 10% of the total and considerably more than 50% of the sites were in “Good” condition.

Bottom Dissolved Oxygen Class	Range (NCCA Criteria)	Stations	Percentage
Good	> 5.0 mg/L	232	84.98 ± 4.26%
Fair	2.0 - 5.0 mg/L	38	13.92 ± 4.12%
Poor	< 2.0 mg/L	3	1.10 ± 1.24%
Missing	N/A	0	0.00%
	Total	273	100.00%



Dissolved Oxygen (DO) at the bottom - mg/L	
N	273
Maximum	10.780
99th %tile	9.143
90th %tile	7.900
75th %tile	7.200
UL 95% Median	6.432
Median	**6.270**
LL 95% Median	6.108
25th %tile	5.500
10th %tile	4.468
5th %tile	3.760
1st %tile	2.071
Minimum	0.800
Average	**6.249**
Std. Dev.	1.433
Std. Err.	0.087

Figure 4.5-6 Geographic Distribution and Classification of 273 Probabilistic Estuarine Sites Based upon Near-Bottom Dissolved Oxygen Concentrations (2009 - 2014).

Water Quality Index (WQI): The five water quality metrics discussed above are integrated into a general Water Quality Index (WQI) for site characteizations. Discussions early in 2013, related to the Fifth NCCA Report ("Progress Update – National Webinar – National Coastal Condition Assessment." U.S. Environmental Protection Agency - 14 January 2013), raised the question of whether or not the water clarity metric should be included in this index, not only because of the difficulty in establishing appropriate local criteria, but also because water clarity is such an ephemeral characteristic of the local water bodies (*i.e.*, varies from hour to hour, minute to minute). For this reason, calculations of the Water Quality Index in the current chapter have been carried out both including and excluding the Water Clarity metric. Table 4.5-3 summarizes the criteria used for both indices.

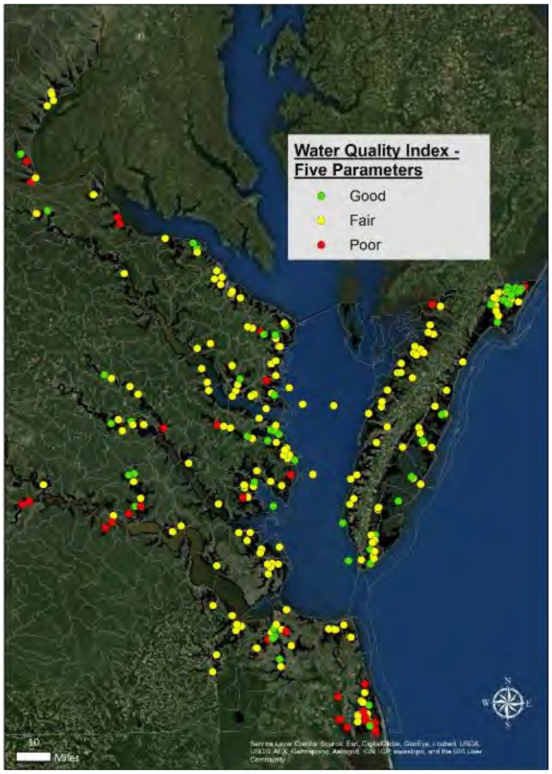
Table 4.5-3 Criteria for Characterizing the Site-specific Integrated Water Quality Index (WQI) based on Five (WQI_5) or Four (WQI_4) Water Quality Parameters. The four parameter WQI used for the Great Lakes in NCCA Report V (USEPA 2015) employed the same thresholds as the five parameter estuarine WQI.

Rating	Thresholds
Good	A maximum of one indictor is rated fair, and no indicators are rated poor
Fair	One of the indicators is rated poor, or two or more are rated fair
Poor	Two or more of the indicators are rated as poor
Missing	Two component indicators are missing, and the available indicators do not suggest a fair or poor rating

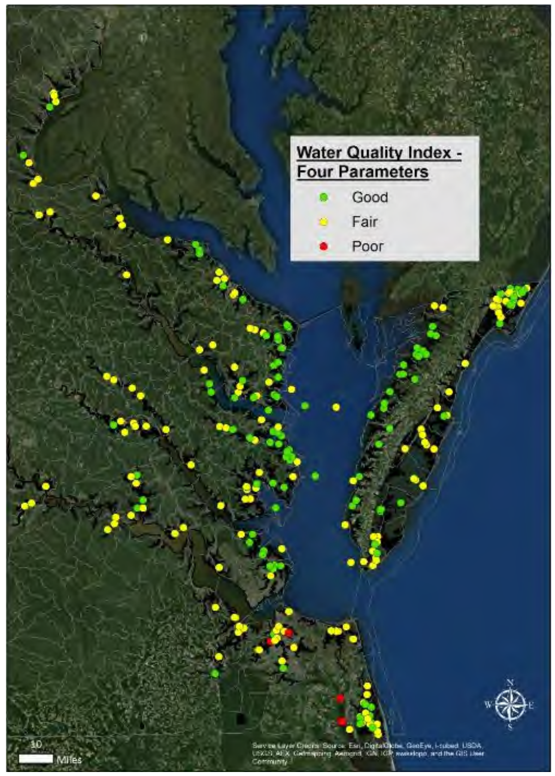
The tables in Figure 4.5-7 summarize site-specific WQI characterizations including the integrated, mixed criteria water clarity metric (A – WQI_5) and excluding the water clarity metric (B – WQI_4). It is evident from comparison of the two tables that the the contribution of the water clarity metric has an overwhelming influence on individual site characterizations. Removal of the single water clarity metric increased the number of "Good" characterizations for sites from 57 (20.88 ± 4.84%) to 113 (41.39 ± 5.87%) and decreased the number of "Fair" characterizations from 182 (66.67 ± 5.62%) to 155 (56.78 ± 5.90%). The number of "Poor" characterizations was reduced from 34 (12.45 ± 3.93%) to 5 (1.83 ± 1.60%), but was insufficient to change Virginia's "Fair" regional characterization based on the WQI because the proportion of sites characterized as "Good" was less than 50% under both five-metric and four-metric indices. Refer to Table 4.5-2b for scoring cutpoints of WQI regional characterizations.

Five Parameter Water Quality Index (WQI_5)	Stations	Percentage
Good	57	20.88 ± 4.84%
Fair	182	66.67 ± 5.62%
Poor	34	12.45 ± 3.93%
Missing	0	0.00 ± 0.00%
Total	273	100.00%

Four Parameter Water Quality Index (WQI_4)	Stations	Percentage
Good	113	41.39 ± 5.87%
Fair	155	56.78 ± 5.90%
Poor	5	1.83 ± 1.60%
Missing	0	0.00 ± 0.00%
Total	273	100.00%



A – With Clarity



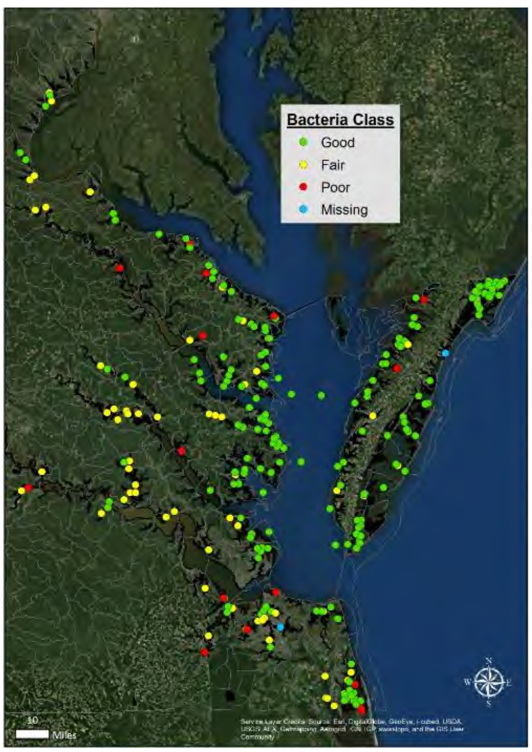
B – Without Clarity

Figure 4.5-7 Geographic Distribution and Characterizations of 273 Probabilistic Estuarine Sites based on the Water Quality Index (WQI), A - Calculated with five metrics, including the Integrated, Mixed Criteria Water Clarity Metric and B - with four metrics, excluding the Integrated, Mixed Criteria Water Clarity Metric.

Other Water Quality Measures: In DEQ's state design Estuarine Probabilistic Monitoring Program the agency added on several water column parameters that have not traditionally been required for NCCA surveys. The first of these consisted of near-surface bacterial monitoring and the second (2008 – 2011) consisted of the near-surface sampling and subsequent analysis of trace metals (both dissolved and total). The results from these efforts are discussed in the following sections.

Bacteria: Virginia Code specifies instantaneous maximum Water Quality Standards for primary contact recreational use of freshwater (including tidal fresh) of 235 cfu/dL of *E. coli* and for transitional and saltwater of 104 cfu/dL of enterococci. For scoring individual sites on the basis of bacterial contamination, the salinity at the time of sampling was used to classify the site salinity zone, and then the measured concentration of the appropriate bacterial group was evaluated (*E. coli* in tidal fresh and enterococci in oligohaline, mesohaline, polyhaline and euhaline). If the appropriate bacterial group was below detection limits the site was characterized as "Good". If the appropriate bacterial group was at or in excess of the corresponding instantaneous maximum standard concentration, the site was characterized as "Poor". If the appropriate bacterial concentration was measurable (*i.e.*, above zero) and was below the corresponding standard the site was characterized as "Fair".

The majority of the 273 sites (190 = 69.60 ± 5.48%) were characterized as "Good", and only 16 (5.86 ± 2.80%) were characterized as "Poor" for bacterial contamination. The geographic distribution and characterizations of the sites are illustrated in the map of Figure 4.5-8[4].



Bacteria	Range (cfu/dL) Fresh / Salt	Stations	Percentage
Good	0 / 0	190	69.60 ± 5.48%
Fair	1 - 235 / 1 - 104	65	23.81 ± 5.07%
Poor	> 235 / > 104	16	5.86 ± 2.80%
Missing	N/A	2	0.73 ± 1.02%
	Total	273	100.00%

Figure 4.5-8 Geographic Distributions and Characterizations of 273 Probabilistic Estuarine Sites based on Bacterial Contamination (2009 – 2014).

[4] No statistical summaries are presented for bacteria, because the bacterial counts constitute a discontinuous variable with varying intervals between values. Also, the integrated results are from two different groups of bacteria in different habitats, each with different water quality standards and threshold criteria.

EPA's National Coastal Condition Assessment Reports (U.S. EPA 2001, 2004a, 2008, 2012) do not provide criteria for site characterizations based on bacterial contamination, nor are thresholds available for regional characterizations. Best professional judgment would suggest that because almost 70% of the samples contained no detectable bacteria of interest ("Good"), and bacterial water quality standards were exceeded in less than 10% of the samples ("Poor"), the overall condition of Virginia's estuarine waters based on bacterial contamination was "Good".

Dissolved Trace Metals in the Water Column: Between 2008 and 2011, DEQ's Estuarine Probabilistic Monitoring (ProbMon) Program collected clean dissolved and total trace metals samples from near surface waters (0.3 m depth) at 182 probabilistic estuarine sites. Results from the entire 2008 – 2011 period were reported in the 2014 IR and no additional clean dissolved metals samples were collected in 2013 or 2014. Please refer to the 2014 Report for a complete discussion of the clean dissolved metals results and the justification for discontinuing this monitoring effort. The clean dissolved metals results are included in the summary table of site attributes and stressor prevalence at the end of this chapter.

Sediment Quality

Integrated Sediment Chemistry Index: Prior to the 2010 survey, the NCCA Program had considered three sediment characteristics important in the evaluation of sediment quality: (1) sediment chemical contamination, (2) sediment toxicity, and (3) sediment total organic carbon (TOC) content. Each of these characteristics had been evaluated separately in earlier NCCA Reports, and the three evaluations were subsequently integrated into a single Sediment Quality Index (SQI). Sediment TOC was removed from the SQI for the 2010 NCCA Survey (USEPA 2015) and the previously applied characterization of sediment chemical contamination was replaced with two new measures, the mean Effects Range Median Quotient (mERM-Q)[5] and the Logistic Regression Model (LRM)[6] (including the concept of utilizing the maximum probability (P_{max}) of acute toxic effects among the sediment contaminant analytes to characterize the ecological condition of a site). EPA used the P_{max} value in conjunction with the mERM-Q to characterize individual sites in relation to their ecological condition. In order to be classified as "Good" a site was required to have a mean ERM Quotient less than 0.1 and a Logistic Regression Model P_{max} < 0.5. The NCCA threshold criteria for characterizing sediment chemical contaminants and toxicity are summarized in Table 4.5-4, and the general criteria are summarized in Table 4.5-5, below. In summary, if both indicators (mERM-Q and P_{max}) are rated "Good" or if the mERM-Q is rated as "Good" and P_{max} is rated "Fair", the site is characterized as "Good" for sediment chemistry.

Table 4.5-4 NCCA 2010 Guidelines for Characterizing Sediment Contamination by Site.

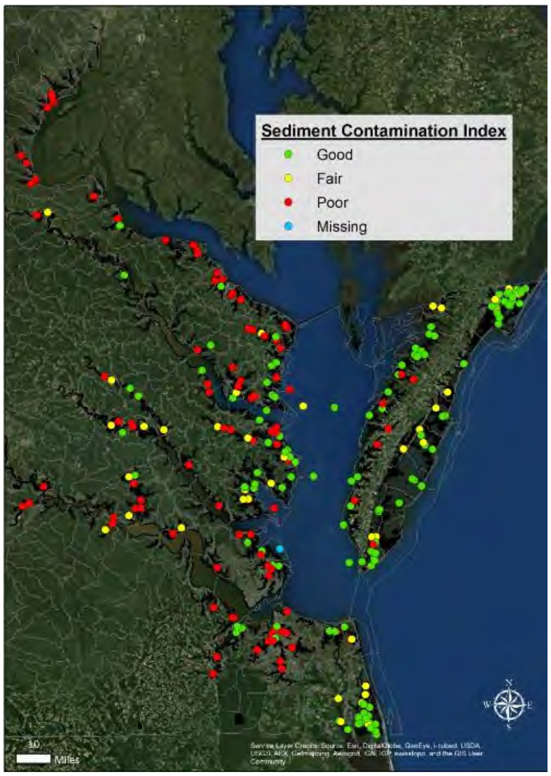
NCCA Site Characterization Guidelines for Estuarine Sediment Contaminantion			
	Good	**Fair**	**Poor**
Sediment Contaminants	**mean ERM-Q < 0.1 <u>and</u> LRM $P_{max} \leq 0.5$**	**mean ERM-Q > 0.1 and < 0.5 <u>or</u> LRM P_{max} > 0.5 but < 0.75**	**mean ERM-Q $\geq$ 0.5 <u>or</u> LRM P_{max} ≥ .75**
Sediment Toxicity: Test results	**Not significantly less than control (p > 0.05) <u>and</u> control-corrected survivorship ≥ 80%**	**Significantly < control (p < 0.05) and contol-corrected survival ≥ 80% <u>or</u> not significantly less than control (p > 0.0) and control-corrected survival > 80%**	**Significantly less than control (p < 0.05) and control-corrected survival < 80%**

[5] The mean Effects Range Median (ERM) Quotient (mERM-Q) is described by Hyland et al. (1999, 2003).
[6] The Logistic Regression Model was included in the 2010 Technical Report (USEPA 2016) and also described in earlier publications (LRM - Field et al., 1999; Field et al., 2002).

Table 4.5-5 Site Characterization Guidelines for the Integrated Sediment Chemistry Index based on the mERM-Q and LRM P_{max} Indicators.

Sediment Chemical Contamination Class	Site characterization Guidelines for the Integrated (mERM-Q and LRM P_{avg}) Sediment Chemistry Index (SCI)
Good	If both indicators are rated as Good or only P_{avg} is rated as "Fair"
Fair	If both indicators are rated as "Fair" or mERM-Q is "Fair" and P_{avg} is "Good"
Poor	If either indicator is rated as "Poor"
Missing	If both indicators are missing

The geographic distribution and characterization of sites by the Integrated SCI are summarized in Figure 4.5-9.



Sediment Chemical Contamination Class	Stations	Percentage
Good	131	47.99 ± 5.95%
Fair	42	15.38 ± 4.30%
Poor	99	36.26 ± 5.73%
Missing	1	0.37 ± 0.72%
Total	273	100.00%

Figure 4.5-9 Sediment Chemical Contamination Index (SCI) Integrating the Results from the mERM-Q and the LRM P_{max} Characterizations. No color-coded percentile distribution is possible because the index is derived from the characterization classes ("Good", "Fair", "Poor") of the two individual chemical contamination indices (mERM-Q and LRM P_{max}).

Equilibrium Partitioning Sediment Benchmark (ESB) 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 and/or synergistic) effects of multiple related contaminants (e.g., various metals or various PAHs, etc.) within the same sediment sample. DEQ uses the ESB for PAH mixtures as an additional line of information in its weight-of-evidence assessments for aquatic life use, but it is not included in the Integrated Sediment Chemistry Index discussed above.[7]

This study includes 23 of the 34 PAH analytes. EPA's publication cited above provides correction factors to estimate the reliability of predicting a contaminant equilibrium partitioning sediment benchmark score for the total suite (34 analytes, ESP34) based on the results from these 23 analytes (ESB23). Multiplying the total score derived from summing the 23 analytes by a correction factor of 1.64 provides an estimate of the expected median score for the ESP34 among the N = 2001 reference samples initially used to derive the original ESB relationship. A Microsoft Excel ® spreadsheet that carries out these calculations automatically for individual site assessments based on the Sediment Quality Triad is provided in DEQ's Weight-of-Evidence workbooks. The Weight-of-Evidence assessment procedure and the associated Excel workbooks are described in DEQ's 2014 Assessment Guidance Manual (DEQ-WMA 2014).

When the ESB_{23} to ESB_{34} correction factor was applied to the results from the 272 estuarine sediment samples in this study, estimated ESB_{34} scores varied from 0.000 to 4.474. Two hundred sixty-eight (98.17 ± 1.60%) of the samples had expected ESB_{34} scores < 1.000, indicating that undesirable effects from dissolved PAHs would not be expected to impact the benthos. Sites with estimated ESB_{34} scores < 1.000 were consequently characterized as being of "Low" risk to benthic communities ("Good"). Sites with estimated ESB_{34} scores greater than 1.000 and less than or equal to 2.000 (N = 3; 1.10 ± 1.24%) were characterized as being of "Medium" risk to benthic communities ("Fair"), because a marginal rather than a severe impact would be expected. Estimated ESB_{34} scores greater than 2.000 and less than or equal to 5.000 (N = 1; 0.37 ± 0.72%) were characterized as being of "High" risk to benthic communities ("Poor"), and no sites had ESB_{34} scores exceeding 5.000, which would be characterized as being of "Very High" risk to benthic communities ("Very Poor"). The ranges of estimated ESB_{34} (adjusted ESB_{23}) scores, the resultant characterizations, and the numeric distribution of the results are summarized in Figure 4.5-12, below. The single "Poor" site was in the Elizabeth River, Southern Branch (ESB_{34} = 4.47). The three "Fair" sites were in Stoakes Creek (south of Gwynn Island – ESB_{34} = 1.78), White House Cove (Poquoson - ESB_{34} = 1.63) and the lower Appomattox River (just above Hopewell – ESB_{34} = 1.00).

As previously indicated, the ESB_{34} provides an estimated benthic risk factor from dissolved PAHs in the interstitial water. It is useful in inferring a possible cause and pathway for benthic impairment at a site, but a high ESB_{34} score does not necessarily mean that PAHs are an unimportant contaminant. PAHs bound to TOC in organic detritus may be ingested by benthic organisms and consequently result in degradation much more severe than would be indicated by the ESB_{34} itself.

The Role and Distribution of Individual Analytes in Sediment Contamination: Individual metals contribute to both the mean ERM Quotient and to the P_{max} statistic of the Logistic Regression Model. Individual PAHs contribute sporadically, although total PAHs seldom approach the Effects Range Median value for this composite group of analytes. Only three metals were observed to exceed their ERM values among the 272 sediment chemistry samples evaluated for this report: Zinc (Zn - 4 exceedances), Cadmium (Cd - 2 exceedances), and Nickel (Ni - 1 exceedance). Various individual PAHs induced high probabilities of toxic effects on benthos, but total PAHs never approached their Effects Range Median threshold, which is relatively high (ERM = 44,792 µg/Kg). Total PAHs did, however exceed their ERL value (ERL = 4,022 µg/Kg) on six occasions. For the purpose of this report, total PAHs are the simple sum of all 23 PAHs analyzed in each sample Both ERL and ERM exceedances by selected metals and total PAHs are summarized in Table 4.5-6.

[7] The procedure for calculating the ESB for PAH mixtures was described in detail in DEQ's 2014 Integrated Report (DEQ WQA, 2014). Unfortunately, following release of the 2014 IR, an error was discovered in the formula calculating the fraction of Total Organic Carbon (TOC) in the sediment and the fraction of TOC, which chemically sequesters PAHs from the water, was greatly underestimated. Consequently the calculated risk factor to benthos from dissolved PAHs in the interstitial water within the sediment was greatly overestimated in the 2014 IR. This error has now been corrected and the results presented in the current IR are more representative than those reported in 2014.

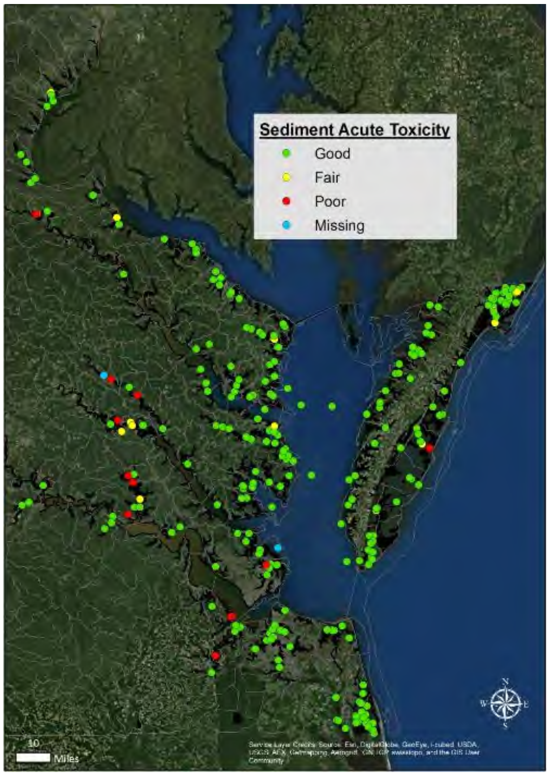
Table 4.5-6 Number of Effects Range Low (ERL) and Effects Range Median (ERM) Exceedances Observed for Selected Metals and Total PAHs.

Analyte	Number of Exceedances among 272 samples: ERL	ERM
Arsenic (As)	85	0
Cadmium (Cd)	46	2
Chromium (Cr)	2	0
Copper (Cu)	41	0
Lead (Pb)	17	0
Mercury (Hg)	19	0
Nickel (Ni)	77	1
Zinc (Zn)	36	4
Total PAHs	6	0

An addendum to this IR chapter, which includes maps of the geographic distributions and summaries of the statistical distributions of selected metals and total PAHs, is available from DEQ upon request. Contact donald.smith@deq.virginia.gov or (804) 698-4429 to request an electronic copy via email.

Sediment Toxicity: Sediment toxicity (SedTox) has been included as one element of sediment quality since the inception of the Coastal 2000 Initiative. In National Coastal Condition Reports I – IV (USEPA, 2001, 2004, 2008, 2012) EPA classified the results of SedTox tests as either “Good” (C-CS ≥ 80%) or “Poor” (C-CS < 80%), with no intermediate class of “Fair” defined. Mortality greater than 20% (C-CS < 80%) was considered to be biologically or ecologically meaningful, without comparisons with controls to evaluate the statistical significance of differences. Beginning with NCCA Report V (USEPA 2015), and in DEQ’s 2014 IR and the current Report, an additional intermediate class of “Fair” has been defined for those sites with transitional results where C-CS ≥ 80% but a one tailed statistical test revealed a significantly ($p \leq 0.05$) lower survivorship than controls, or where C-CS was < 80% but statistically significance difference from controls could not be verified ($p > 0.05$).

The characterizations and geographic distributions of the sites using these criteria are summarized in Figure 4.5-10, below. Applying the current criteria, 244 results from 273 sites (89.38 ± 3.67%) were characterized as “Good” for sediment toxicity, 15 sites (5.49 ± 2.72%) were characterized as “Fair”, and 12 results (4.40 ± 2.44%) were characterized as “Poor.” Two sites were characterized as “Missing” for sediment toxicity results (0.72 ± 1.02% - completeness = 99.28%). No sample was collected at one site because of densely compacted sand substrate, and the results from the second site, 8-MPN028.78 in tidal freshwaters of the Mattaponi River, were discarded because of an excessive bloom of iron-fixing bacteria that killed most of the test organisms. The toxicity of chemical contaminants could not be verified.



Sediment Acute Toxicity Class	Stations	Percentage
Good	244	89.38 ± 3.67%
Fair	15	5.49 ± 2.72%
Poor	12	4.40 ± 2.44%
Missing	2	0.73 ± 1.02%
Total	273	100.00%

Figure 4.5-10 Geographic Distribution and Characterization of 273 Estuarine Probabilistic Sites Based upon Acute Sediment Toxicity (2009 – 2014).

Following the current criteria, Virginia's estuarine waters as a whole would have less than 5% of the sites in "Poor" condition (4.40 ± 2.44%) and almost 90% (89.38 ± 3.67%) in "Good" condition. This would support the choice of a "Good" characterization for the estuarine area as a whole based on sediment toxicity.

It is interesting to note that, as is often the case, we have not observed significant acute mortality in sediment from many of the sites where we have measured significant chemical contamination. This is especially notable in the Elizabeth River system, where sediment contamination by many metals (Zn, Ni, Cu, Cd, and As) and organic compounds (primarily by PAHs and PCBs) is widespread. This may be an indication that the chemical contaminants are in a form not readily available to the benthic community (or toxicity test organism), or that the available concentrations are so low that only chronic effects would be evident. In contrast, significant toxicity is often observed during tests of sediment in which chemical analyses have not revealed a probable cause of the toxicity observed. In the environment, complex mixtures of contaminants of various classes (trace metals, pesticides, PAHs, etc.) even at relatively low concentrations, as well as other unmeasured factors, often have unpredictable and at times severe effects.

Sediment Quality Index (SQI): Once both sediment quality indicators (sediment chemistry and sediment toxicity) were scored for a site, NCCA Report V (USEPA, 2015) calculated an integrated Sediment Quality Index (SQI) to characterize overall sediment quality at the site. Guidelines for determining the SQI are described in Table 4.5-7, below. In the SQI determinations that follow, the Integrated Sediment Chemistry Index (SCI) and Sediment Toxicity were used to characterize sediment contamination. The resultant characterizations and their geographic distribution are summarized in Figure 4.5-11, below.

Based on the NCCA guidelines in Table 4.5-8, below, Virginia's region-wide estuarine sediments would be characterized as "Poor" because the percentage of sites with "Poor" sediment was more than 15%.

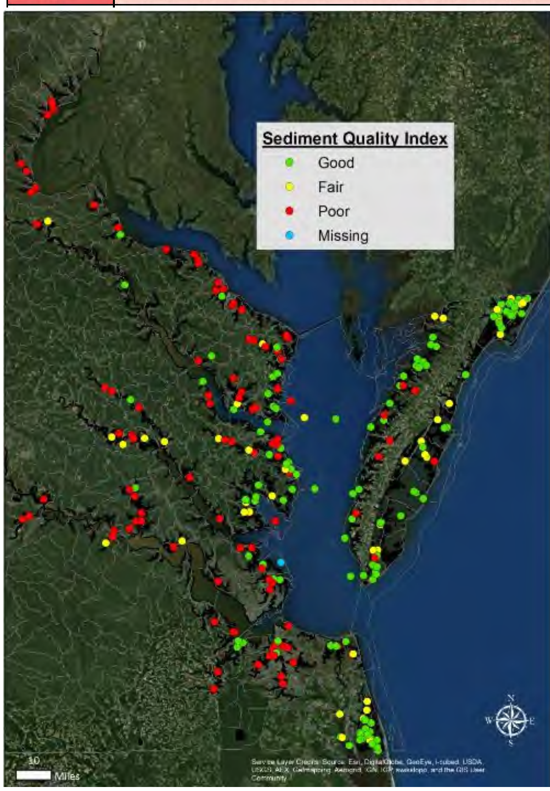
Ecologically, the most representative index of sediment “quality” is the condition of the benthic community that resides in it. Benthic community status is discussed below, and will later be integrated into an overall site score for a characterization of statewide estuarine condition.

Table 4.5-7 Scoring Guidelines for Characterizing Individual Sites using the Sediment Quality Index (SQI). *(Taken from USEPA, 2015) The two indices used in this case were the Integrated Sediment Chemistry Index (SCI) and sediment Toxicity.*

Sediment Quality Index Guidelines		
Good	**Fair**	**Poor**
Both indicators are rated good.	At least one indicator is rated fair and none are rated poor.	At least one indicator is rated poor.

Table 4.5-8 Scoring Guidelines for Characterizing Regions based on the Sediment Quality Index (SQI). (Taken from U.S. EPA, 2012)

Rating	Cutpoints
Good	Less than 5% of the coastal area is in poor condition, and more than 50% of the coastal area is in good condition.
Fair	5% to 15% of the coastal area is in poor condition, or 50% or less of the coastal area is in good condition.
Poor	More than 15% of the coastal area is in poor condition.



Sediment Quality Index	Stations	Percentage
Good	123	45.05 ± 5.93%
Fair	45	16.48 ± 4.42%
Poor	104	38.10 ± 5.79%
Missing	1	0.37 ± 0.72%
Total	273	100.00%

Figure 4.5-11 The Geographic Distribution and Characterizations of 273 Probabilistic Estuarine Sites based on the Sediment Quality Index – SQI (2009 – 2014). The Sediment Quality Index is derived from site characterizations by the Sediment Chemical Contamination Index and Sediment Toxicity.

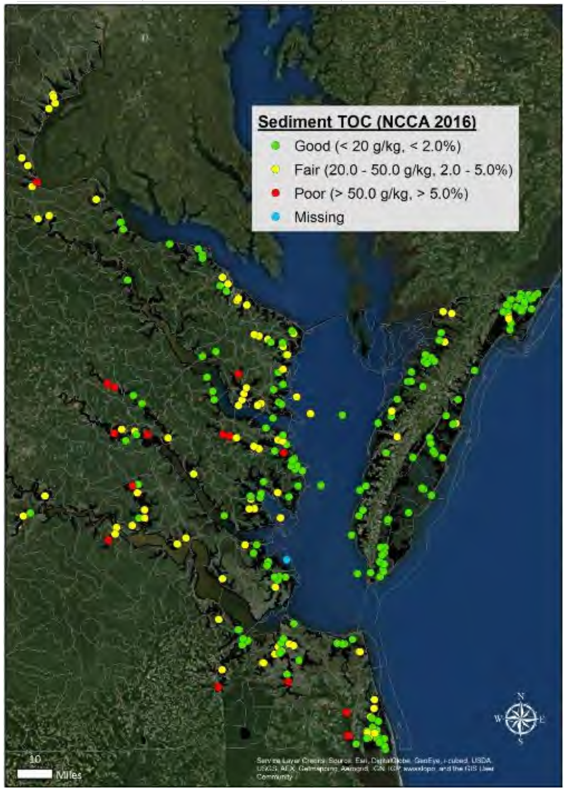
Sediment Total Organic Carbon (TOC): The NCCA Program has traditionally included total organic carbon (TOC) as one element of its Sediment Quality Index (SQI) for an integrated characterization of sediment. TOC, as both a component of and a degradation product from vegetal and animal detritus, is a natural constituent of freshwater and estuarine bottom deposits. TOC in the sediment may chemically bind both organic and inorganic pollutants and reduce their availability in dissolved form to benthic organisms. Changes in temperature and water chemistry (e.g., pH and dissolved oxygen), however, may result in the release of previously bound contaminants. TOC also provides food for many benthic organisms, in which case bound toxic contaminants would also be ingested. Excessive concentrations of TOC in local sediment deposits, regardless of degree of contamination, may alter the composition of benthic communities, and promote the dominance of pollution-tolerant species. High concentrations of TOC may also indicate local foci of sediment deposition where available pollutants may accumulate. Because of the difficulty in interpreting these potentially contradictory effects of TOC in the sediment, it was removed as a component indicator of the SQI for the fifth NCCA Report. It is still utilized in conjunction with percent fine particles (silt/clay) in the sediment to interpret other sediment quality results.

The TOC ranges utilized for characterizations here come from two sources: (1) NCCA Report IV (U.S. EPA, 2012) and (2) Hyland et al, 2005. Under the NCCA classification, 171 sites (62.64 ± 5.76%) were characterized as "Good" (TOC < 2.0%), 85 sites (31.14 ± 5.52%) were characterized as "Fair" (TOC 2.0% – 5.0%), and only 16 sites (5.86 ± 2.80%) were characterized as "Poor" (TOC > 5.0%) for sediment TOC composition. A single site lacked a sediment TOC sample because the substrate was too compacted to sample successfully. Following the guidelines provided in NCCA Report IV, Virginia's estuarine waters would earn a "Good" overall rating based on sediment TOC, because the percentage of estuarine sites with a "Poor" characterization is well below 10% and "Good" characterizations exceeded 50%. Characterizations following the criteria of Hyland et al. (2005) resulted in 121 "Good" sites (44.32 ± 5.92%), 92 "Fair" sites (33.70 ± 5.63%), and 59 "Poor" sites (21.61 ± 4.90%). An overall rating based on these results would characterize Virginia's estuarine waters as "Poor" because more than 20% of the sites were in this category.

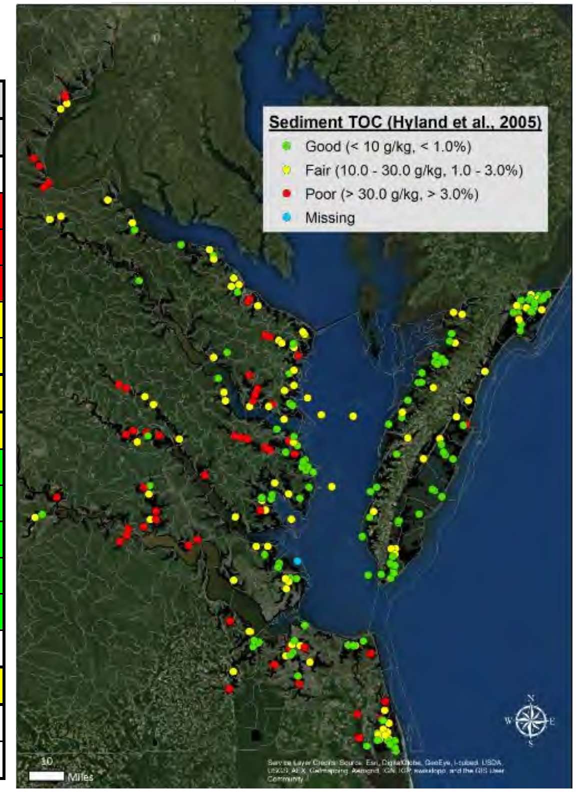
The geographical and statistical distributions of sites based on their sediment TOC characterizations are summarized in Figure 4.5-12. The sites with the highest sediment TOC concentrations were found in low gradient, coastal plain streams such as the North Landing River (17.7% TOC), the Chickahominy River (12.9% TOC), Upper Chippokes Creek (9.5% TOC), and the Piankatank River (8.8% TOC), while those with the lowest TOC concentrations (< 0.02% TOC) were generally from channels and inlets of coastal Delmarva.

Sediment TOC (NCCA 2010)	Range	Stations	Percentage
Good	< 20 g/Kg (< 2.0%)	171	62.64 ± 5.76%
Fair	20.0 - 50.0 g/Kg (2.0 - 5.0%)	85	31.14 ± 5.52%
Poor	> 50.0 g/Kg (> 5.0%)	16	5.86 ± 2.80%
Missing	N/A	1	0.37 ± 0.72%
	Total	273	100.00%

Sediment TOC (Hyland et al., 2003)	Range	Stations	Percentage
Good	< 10 g/Kg (< 1.0%)	121	44.32 ± 5.92%
Fair	10.0 - 30.0 g/Kg (1.0 - 3.0%)	92	33.70 ± 5.63%
Poor	> 30.0 g/Kg (> 3.0%)	59	21.61 ± 4.90%
Missing	N/A	1	0.37 ± 0.72%
	Total	273	100.00%



	Sediment TOC (%)	
	NCCA	Hyland
N	272	272
Maximum	23.10	23.10
99th %tile	10.51	10.51
90th %tile	3.99	3.99
75th %tile	2.70	2.70
UL 95% Median	1.49	1.49
Median	**1.26**	**1.26**
LL 95% Median	1.03	1.03
25th %tile	0.28	0.28
10th %tile	0.15	0.15
5th %tile	0.07	0.07
1st %tile	0.03	0.03
Minimum	0.00	0.00
Average	**1.90**	**1.90**
Std. Dev.	2.45	2.45
Std. Err.	0.15	0.15



A – NCCA (2016)

B – Hyland et al. (2005)

Figure 4.5-12 Geographic Distribution and Characterizations of 273 Probabilistic Estuarine Sites based on Sediment Total Organic Carbon (TOC) Concentrations: A – with criteria from NCCA Report V (2016) and B - Calculated with criteria of Hyland et al. (2005).

Benthic Community

Benthic Quality Index: A benthic index, also commonly referred to as a Benthic Index of Biological Integrity or B-IBI, is a scientific tool used to identify, classify, and interpret the structure and function of benthic communities, often in relation to environmental stressors such as water pollution. Such indices are generally derived from the results of local or regional benthic surveys, and are consequently geographically restricted in their application. There are three commonly applied regional benthic indices that are appropriate for use in Virginia's estuarine waters, the Chesapeake Bay Program B-IBI (CBP B-IBI - Weisberg et al., 1997), the Mid-Atlantic B-IBI (MAIA B-IBI - Llansó et al., 2002a, 2002b) and the EMAP Index of Estuarine Condition for the Virginian Biogeographic Province (EMAP VP-IEC – Paul et al., 2001).

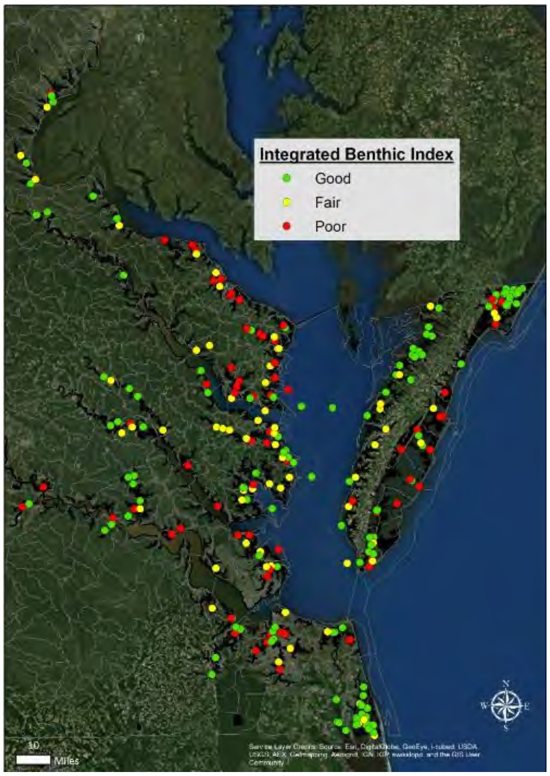
The CBP B-IBI was developed specifically for estuarine waters of the Chesapeake Bay watershed and it is the most appropriate for use in those waters. The MAIA B-IBI was developed for waters of the Mid-Atlantic Region, which includes the estuarine waters of the Delaware Bay and Chesapeake Bay watersheds, the coastal bays of the Delmarva Peninsula, and the Albemarle-Pamlico estuarine system of southeastern Virginia and northeastern North Carolina. It is the only one of the three indices that is appropriate in all of Virginia's estuarine waters. The EMAP VP-IEC was developed for the Virginian Biogeographic Province, which extends from Cape Cod to the mouth of Chesapeake Bay, but excludes the southeastern Virginia coastal area. All three indices were calculated for the benthic data from each site in this study, but most weight was given to the interpretation of CBP B-IBI within the Chesapeake watershed, and to the interpretation of the MAIA B-IBI in coastal waters of Delmarva and the Back Bay/North Landing River portion of the Pamlico Sound system.

The structures, similarities and dissimilarities, scoring and site characterizations using all three benthic indices were discussed in detail in DEQ's 2014 IR. All three benthic indices were calculated for benthic samples from each of the sites characterized herein. During testing and calibrating the Pavg statistic of the Linear Regression Model, described earlier in this report, it was noted that the EMAP-IEC was as capable of discriminating between lightly and severely contaminated sediments as were either of the multimetric B-IBIs mentioned above (Smith, 2016). Consequently, all three indices were integrated into a single average benthic class. Each site was first scored as "Good", "Fair", or "Poor" by each of the benthic indices. The results for each index are summarized in Table 4.5-9. If all three indices agreed in their characterizations, the common characterization was assigned to the integrated index: all three "Good" – 100 sites = 36.63% ± 5.74%, all three poor – 52 sites = 19.05% ± 4.68%. No sites were characterized as "Fair" by all three indices. The sites where all three indices did not agree were evaluated using best professional judgement. Within the Chesapeake Bay watershed the CBP B-IBI was given higher weight, elsewhere the MAIA B-IBI was given higher weight, but the overall evaluation of the site considered all three indices. If the MAIA and EMAP indices agreed in giving a Chesapeake Bay site a "Poor" rating while the CBP index indicated "Good", a "Fair" characterization was assigned. Likewise, if the CBP and EMAP indices agreed in contradicting the MAIA rating for a coastal Delmarva site, an intermediate characterization was assigned.

Table 4.5-9 Site Characterizations of 273 Probabilistic Estuarine Sites (2009 – 2014) by the Three Independent Benthic Indices utilized in the Present Report: The Chesapeake Bay Program (CBP) B-IBI, The Mid-Atlantic (MAIA) B-IBI, and the national Environmental Monitoring and Assessment Program (EMAP) Index of Estuarine Condition for the Virginian Biogeographic Province (VP-IEC).

► Benthic Index ►	CBP B-IBI		MAI B-IBI		EMAP IEC	
▼ Class ▼	Count	Percentage	Count	Percentage	Count	Percentage
Good	127	46.52 ± 5.94%	196	71.79 ± 5.36%	159	58.24 ± 5.88%
Fair	28	10.26 ± 3.61%	2	0.73 ± 1.02%	14	5.13 ± 2.63%
Poor	118	43.22 ± 5.90%	75	27.47 ± 5.32%	100	36.63 ± 5.74%
Missing	0	0.00%	0	0.00%	0	0.00%
Total	273	100.00%	273	100.00%	273	100.00%

The final geographic and statistical distributions for integrated benthic characterizations are summarized in Figure 4.5-13. Following the NCCA guidelines in Table 4.5-2b, Virginia's estuarine waters would be given an overall rating of "Poor" for benthos, since more than 20% of the individual sites were characterized as "Poor", even though nearly 50% of the sites were characterized as "Good".



Integrated Benthic Class	Stations	Percentage
Good	128	46.89 ± 5.95%
Fair	71	26.01 ± 5.23%
Poor	74	27.11 ± 5.30%
Missing	0	0.00%
Total	273	100.00%

Figure 4.5-13 Geographic Distribution and Characterizations of 273 Probabilistic Estuarine Sites based on the Integrated Benthic Index (2009 – 2014).

Weight-of-Evidence (WOE) Assessment

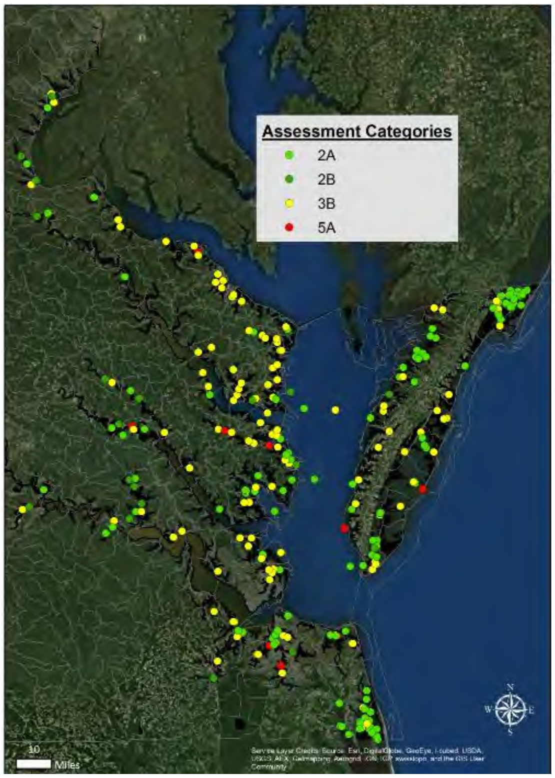
Weight-of-Evidence assessments of each individual site for Aquatic Life Use (ALU) were carried out based primarily upon the Sediment Quality Triad (SQT) of sediment chemistry, sediment toxicity, and benthic community wellbeing. All three of these measures are considered to be temporally integrative, providing an assessment of environmental conditions experienced by the benthic community during the period prior to the time of sampling. The other water quality parameters (*e.g.*, nutrients, bacteria, dissolved metals, DO, temperature, pH, *etc*.) that are measured at probabilistic sites are considered to be isolated instantaneous observations and are insufficient for assessment purposes because the intensity and duration of such stressors are unknown. The evaluation and interpretation of the SQT is carried out with the use of an analytical matrix (Chapman et al., 1986, 1987) that is described in DEQ's Water Quality Assessment Guidance Manual for the 2016 305(b)/303(d) Integrated Water Quality Report (DEQ-WQA, 2016).

The criteria used in this WOE assessment and the Microsoft Excel® workbooks used for the process are also described in the Water Quality Assessment Guidance Manual (*Ibid*.). The site characterizations that are integrated into the WOE assessments have been discussed individually earlier in this report. They include counts of ERM and ERL exceedances (criteria from previous NCCA Reports), the Mean ERM Quotient, the Logistic Regression Model, the Equilibrium Partitioning Sediment Benchmark for PAH mixtures (ESB_{PAHs} or ESB_{34}), the results of sediment toxicity tests, and taxonomic richness, diversity, and evenness along with the evaluation of benthic community health and function using benthic indices (B-IBIs).

If elevated chemical contamination and/or sediment acute toxicity is observed in conjunction with a degraded or severely degraded benthic community, an assessment of "5A – Impaired" (by toxics) is assigned. If a degraded or severely degraded benthic community is observed without chemical or toxicological corroboration, an assessment of "3B - observed effects with insufficient information" is assigned, even though ancillary information may suggest a possible cause other than toxics. A "3B" assessment is also assigned if sediment contamination exceeds sediment quality guidelines specified in the Guidance Manual, but benthic scores are still acceptable. Statistically and ecologically significant sediment toxicity, without chemical corroboration or benthic degradation, is assigned assessment category "2B - waters are of concern to the state but no Water Quality Standard exists for a specific pollutant, or the water exceeds a state screening value. If no benthic degradation, sediment chemical contamination, or sediment toxicity are observed, an assessment category of "2A" is assigned "- waters are attaining all of the uses for which they are monitored (based on the data in the WOE workbook) and there is insufficient data to document the attainment of all [other] uses." Assessments of "2A" or "2B" are characterized as "Good", assessments of "3B" are characterized as "Fair", and assessments of "5A" are characterized as "Poor." Because the assessment category of "5A – Impaired" for ALU is only assigned in cases where benthic degradation is corroborated by sediment chemical contamination and/or sediment acute toxicity, the proportion of sites in this category is less than that observed for many other individual parameters or indices.

Weight-of-Evidence assessments categorized 142 sites (52.01 ± 5.95%) as "Good" (2A or 2B), 122 sites (44.69 ± 5.92%) as "Fair" (3B), and 9 sites (3.30 ± 2.13%) were assessed as "Poor" (5A – Impaired for ALU by toxics). It must be kept in mind that the low number of 5A – Impaired sites (3.30 ± 2.13%) in comparison with the number of degraded or severely degraded benthic community sites (44.7 ± 5.9%) results from the fact that the WOE assessment is specifically directed at toxics. If benthic degradation by toxics was not substantiated within the sediment quality triad, the WOE assessment was a Category 3B – "Observed effects", with insufficient data to assign a cause, and the site was prioritized for follow-up monitoring. The NCCA Reports provide no thresholds for evaluating weight-of-evidence assessments with the sediment quality triad. The fact that the results contained fewer than 20% "Poor" characterizations and the percentage of "Good" characterizations did not significantly exceed 50% (95% Confidence Interval extends downward to 46.06%) Virginia's estuaries should probably be characterized as "Fair" on the whole for toxics-induced ALU impairment (based on regional thresholds defined in Table 4.5-2b),

The geographic distribution of these results is illustrated in the map of Figure 4.5-14.



Assessment Class	Stations	Percentage	
2A	120	43.96 ± 5.91%	52.01 ± 5.95%
2B	22	8.06 ± 3.24%	
3B	122	44.69 ± 5.92%	
5A	9	3.30 ± 2.13%	
Total	273	100.00%	

Figure 4.5-14 Weight-of-Evidence Assessment Results from 273 Probabilistic Estuarine Sites Sampled between 1 January 2009 and 31 December 2014.

Conclusion

DEQ's estuarine probabilistic monitoring program sampled 273 estuarine sites during the 2009-2014 assessment period. The vast majority of the sites fell within the minor tidal tributaries and embayments of the Chesapeake Bay watershed or in the estuarine waters of coastal Delmarva and the Back Bay / North Landing River region of southeastern Virginia. These sites are categorized using thresholds developed by EPA's National Coastal Condition Assessment Program. On the basis of the four water quality parameters sampled at each site, 41% sites were rated as "good", 57% were rated as "fair", and 2% were rated as "poor". On the basis of sediment chemistry and acute toxicity, 45% of sites were rated as "good", 17% were rated as "fair", and 38% were rated as "poor". Sediment contamination was identified as the second most prevalent stressor. Most of the sites (73%) had benthic communities that were classified as "good" or "fair" according to the Integrated Benthic Index. Hopefully, as the National Coastal Condition Assessment Program continues to refine its thresholds to reflect improvements in scientific understanding, DEQ will be able to improve its ability to detect, identify the source(s) of, and remediate problems in the Commonwealth's estuarine waters.

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