CHAPTER 4.5. ESTUARINE PROBABILISTIC MONITORING RESULTS

# **Introduction**

Between 2015 and 2020 DEQ’s Estuarine Probabilistic Monitoring Program (ProbMon) collected water quality, sediment chemistry, sediment toxicity, and benthic community samples at 298 probabilistic stations in tidal waters of the Commonwealth. The annual sampling window runs from July through September. Estuarine ProbMon stations located in the Chesapeake Bay watershed were distributed among the upper tidal reaches of the mainstem James, York, Potomac, and Rappahannock rivers including tidal tributaries and embayments. Sites that were not within the Chesapeake Bay watershed include Atlantic Ocean coastal bays on the Eastern Shore, and Albemarle Sound drainages such as Back Bay and the North Landing River (Table 4.5-1.)

Table 4.5-1 Distribution of ProbMon monitoring stations 2015-2020

|  |  |  |
| --- | --- | --- |
| **Drainage** | **Stations** | **Percentage** |
| Atlantic Bays | 56 | 18.79 ± 4.45 |
| Chesapeake Bay | 219 | 73.49 ± 5.03 |
| North Landing-Back Bay | 23 | 7.72 ± 3.04 |
| **Total** | **298** |  |

If duplicate samples were collected for Quality Assurance (QA) only the primary samples (S1) were included in this report. Likewise, monitoring stations that were sampled more than once per season on different days (i.e. National Coastal Condition Assessment revisit sites *n*=4) include only data from the first visit. Targeted sites revisited during the assessment window, as follow-ups to previously observed sediment contamination were also excluded. Two probabilistic sites in 2016 were not sampled because of late season weather and time restrictions; the defined sampling window for benthic index calculation had expired. One additional site in 2016 could not be sampled for sediment and benthics because the bottom of the entire site consisted of a continuous oyster reef. Water column samples and hydrographic profiles, however, were collected at the site. Consequently, in the following characterizations, 298 sites were evaluated for water column attributes and only 297 sites were evaluated for sediment and benthic attributes.

The salinity regimes at estuarine ProbMon sites are characterized by near-bottom salinities at the time of sampling, because bottom salinity defines habitat types for benthic communities. Table 4.5-2 summarizes the salinity ranges and percentage distributions. The relative frequencies (proportions) of sites in the various salinity classes do not represent Virginia’s estuarine waters as a whole, since the Commonwealth’s survey design does not include the Chesapeake Bay mainstem or the lower tidal mainstems of major tributaries. The Chesapeake Bay and major tributary mainstems are, however, included in the NCCA design, which was integrated into the overall sampling in 2015 and 2020. If mainstem Bay sampling were to be included in all years, the proportions of mesohaline and polyhaline waters would increase substantially, and the percentages of tidal fresh, oligohaline, and euhaline waters would decline proportionally. Euhaline waters were observed to occur primarily along the Atlantic Coast of the Delmarva Peninsula, where oceanic waters have a greater influence.

Table 4.5- 2 Salinity ranges of near bottom salinity during sample collection, 2015-2020. Thresholds follow the Venice System (Venice System, 1958)

| **Salinity Regime** | **Salinity Range** | **Stations** | **Percentage** |
| --- | --- | --- | --- |
| Tidal Freshwater | < 0.5‰ | 32 | 10.74 ± 3.53 |
| Oligohaline | >0.5 - 5‰ | 35 | 11.74 ± 3.67 |
| Low mesohaline | >5 - 12‰ | 30 | 10.07 ± 3.43 |
| High mesohaline | >12 - 18‰ | 68 | 22.82 ± 4.78 |
| Polyhaline | >18 - 30‰ | 88 | 29.53 ± 5.2 |
| Euhaline | >30-40‰ | 45 | 15.1 ± 4.08 |
| **Total** |  | **298** |  |

# **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 Coastal Condition Assessment (NCCA) program. Water Quality, Sediment Quality and Benthic data are collected at each of the ProbMon sites. It is important to note that the water quality parameters (*e.g.*, nutrients, bacteria, 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 results are used in the evaluation of the Sediment Quality Triad (Long and Chapman, 1985; Chapman et al., 1986; Chapman et al., 1987) 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 community condition are summarized below.

# **Water Quality**

DEQ’s Coastal Monitoring Program uses the following five water column parameters to characterize estuarine water quality: (1) near-surface dissolved inorganic Phosphorus concentration (DIP in mg/L), (2) near-surface dissolved inorganic Nitrogen concentration (DIN in mg/L), (3) near-surface chlorophyll-a concentration (Chl-a in µg/L), near-bottom dissolved Oxygen concentration (DO in mg/L), and (5) water clarity, expressed as percent of incident photosynthetically active radiation (PAR) available at a standardized depth of 1.0 meter (percent PAR @ 1.0 m). These five parameters are subsequently integrated into a single water quality index (WQI) for the site. Total Alkalinity and Algal Toxins were added as new parameters during the 2020 season and collected only at NCCA stations.

**Near-surface dissolved inorganic Phosphorus (DIP):** Dissolved inorganic Phosphorus is also known as dissolved orthophosphate (PO**43-**) or soluble reactive Phosphorus (SRP). It is the most available form of Phosphorus for uptake by biological organisms and, along with dissolved inorganic Nitrogen, is an essential natural nutrient required for the growth of algae, the base of the food web in estuarine waters. An excess of these nutrients, however, can result in accelerated eutrophication, characterized by large undesirable algal blooms, increased chlorophyll-a concentrations, reduced water clarity, and lower concentrations of dissolved Oxygen.

Table 4.5-3 summarizes the ranges of DIP concentrations that the NCCA has established as thresholds for water quality classes in estuarine waters of the northeastern United States, the number of Virginia probabilistic stations during the 2015 to 2020 sampling window falling within each class, and the estimated proportions (with 95 percent confidence intervals) of estuarine waters falling within each class.

Table 4.5- 3 Dissolved Inorganic Phosphorus (DIP) results compared to NCCA 2015 thresholds, 2015-2020

|  |  |  |  |
| --- | --- | --- | --- |
| DIP Quality | DIP Range (mg/L) | Stations | Percentage |
| Good | <0.01 | 157 | 52.68 ± 5.69 |
| Fair | >0.01 and < 0.05 | 122 | 40.94 ± 5.61 |
| Poor | >0.05 | 19 | 6.38 ± 2.79 |
| **Total** |  | **298** |  |

**Near-surface Dissolved Inorganic Nitrogen (DIN):** Dissolved inorganic Nitrogen concentrations are the sum of dissolved nitrate (NO**3-**) Nitrogen, nitrite (NO**2-**) Nitrogen, and ammonia (NH**4+**) Nitrogen. DIN plays a similar role to DIP, in that it is an essential natural nutrient for algal growth, and when in excess can accelerate eutrophication. Table 4.5-4 summarizes the ranges of DIN concentrations that the NCCA has established as thresholds for water quality classes in estuarine waters of the northeastern United States, the number of Virginia probabilistic stations falling within each class, and the estimated proportions (with 95 percent confidence intervals) of estuarine waters falling within each class.

Table 4.5- 4 Dissolved Inorganic Nitrogen (DIN) results compared to NCCA 2015 thresholds, 2015-2020

|  |  |  |  |
| --- | --- | --- | --- |
| DIN Quality | DIN Range (mg/L) | Stations | Percentage |
| Good | <0.1 | 266 | 89.26 ± 3.53 |
| Fair | > 0.1 and < 0.5 | 29 | 9.73 ± 3.38 |
| Poor | >0.5 | 3 | 1.01 ± 1.14 |
| **Total** |  | **298** |  |

**Near-surface chlorophyll-a (Chl-a):** Chlorophyll-a concentrations in surface waters are an indication of the quantity of algae in the water. High concentrations of chlorophyll-a, often caused by nutrient enrichment, can indicate the presence of undesirable algal blooms, which may further reduce water quality by increasing pH and decreasing water clarity. Also, the die-off of excess algae can result in insufficient amounts of dissolved oxygen for fish and other aquatic life.

Table 4.5-5 summarizes the ranges of chlorophyll-a concentrations that the NCCA has established as thresholds for water quality classes in estuarine waters of the northeastern United States, the number of Virginia probabilistic stations falling within each class, and the estimated proportions (with 95 percent confidence intervals) of estuarine waters falling within each class.

Table 4.5- 5 Surface Chlorophyll-a results compared to NCCA 2015 thresholds, 2015-2020

|  |  |  |  |
| --- | --- | --- | --- |
| Chlorophyll-a Quality | Chlorophyll-a Range (µg/L) | Stations | Percentage |
| Good | < 5 µg/L | 44 | 14.77 ± 4.04 |
| Fair | >5 and < 20 µg/L | 216 | 72.48 ± 5.09 |
| Poor | >20 µg/L | 38 | 12.75 ± 3.8 |
| **Total** |  | **298** |  |

**Near-bottom dissolved oxygen (DO):** Acceptable dissolved oxygen concentrations are crucial for the survival of all aquatic organisms. Near bottom dissolved Oxygen concentrations are considered critical for two reasons. First, near-bottom concentrations are almost always the minimum concentrations in the DO surface-to-bottom profile, and second, they represent the Oxygen available to the community of relatively sessile benthic organisms which are often used for further characterizations of the ecological condition of aquatic sites.

Table 4.5-6 summarizes the ranges of bottom DO concentrations that the NCCA has established as thresholds for water quality classes in estuarine waters of the northeastern United States, the number of Virginia probabilistic stations falling within each class, and the estimated proportions (with 95 percent confidence intervals) of estuarine waters falling within each class.

Table 4.5- 6 Near bottom Dissolved Oxygen (DO) results compared to NCCA 2015 thresholds, 2015-2020

|  |  |  |  |
| --- | --- | --- | --- |
| DO Quality | DO Range | Stations | Percentage |
| Good | > 5 mg/L | 243 | 81.54 ± 4.42 |
| Fair | > 2 and < 5 mg/L | 48 | 16.11 ± 4.19 |
| Poor | < 2 mg/L | 7 | 2.35 ± 1.73 |
| **Total** |  | **298** |  |

**Water Clarity (PAR):** Water clarity is considered an important element of water quality for several reasons. The availability of adequate photosynthetically active radiation (PAR), to a depth of at least 2.0 meters, is a necessity for the survival and growth of submerged aquatic vegetation (SAV), which provides shelter and food for numerous aquatic organisms. Also, a lack of water clarity may indicate excessive suspended sediment and/or excessive algal blooms in the water column. Table 4.5-7 provides a summary of NCCA thresholds for the generalized water clarity classes.

| **Water Class** | **% Transmittance @ 1.0 meter\*** | | **Kd = c/Secchi Depth\*\*** |
| --- | --- | --- | --- |
| **Threshold 1**  Poor vs. Fair | **Threshold 2**  Fair vs. Good | Value of c |
| **Naturally Turbid** | 5% | 10% | 1.0 |
| **Normal Turbidity** | 10% | 20% | 1.4 |
| **SAV Growth and Restoration** | 20% | 40% | 1.7 |

Table 4.5-7. NCCA water clarity thresholds for generalized estuarine water classes.

**\*** Transmittance (Trans) is calculated from the PAR attenuation coefficient (K**d**): Trans = exp(-K**d**\*depth m)

**\*\*** If not directly measured, K**d** is estimated from Secchi Depth: K**d** = c / Secchi Depth (m)

The Chesapeake Bay Program (CBP) has developed more detailed water clarity criteria for shallow water, bay grass designated use habitats, based on salinity regime, season, and application depth. The CBP criteria were used to classify all of the tidal-fresh, oligohaline and mesohaline sites; however, the temporal application periods listed in Table 4.5-8 indicate that for polyhaline sites, only those sampled in September should be classified using the CBP criteria. Therefore, shallow water polyhaline clarity measurements that were collected outside the CBP temporal application period were classified using the NCCA thresholds for normal turbidity water in Table 4.5-7. Table 4.5-8 summarizes the habitats, criteria and seasonal applications of CBP shallow water clarity criteria.

| **Salinity Regime** | **Water Clarity Criteria\***  (% PAR through water) | **Temporal Application Period** |
| --- | --- | --- |
| **Tidal-fresh** | 13% | 1 April - 31 October |
| **Oligohaline** | 13% | 1 April - 31 October |
| **Mesohaline** | 22% | 1 April - 31 October |
| **Polyhaline** | 22% | 1 March - 31 May  1 September - 30 November |

Table 4.5-8. CBP criteria for water clarity in shallow water, bay grass designated use habitats within the tidal waters of the Chesapeake Bay drainage.

**\*** The CBP uses the "c" value of 1.45 for the Secchi depth conversion to K**d:** K**d** = 1.45 / Secchi depth (m)

Photosynthetically active radiation (PAR) was measured using LI-1400 dataLOGGER units from LI-COR Biosciences. One sensor on each device measured PAR intensity (Iz) underwater at depths z (m), and a second sensor remained in the air measuring PAR intensity (Io) of ambient light. At each site, Kd for each measurement is calculated as the natural log of the negative slope of the regression with ln(Iz/Io) on the y-axis vs. depth(m) on the x-axis using the downcast measurements. Percent transmittance is equal to e-Kd\*100. In cases where LI-COR devices were not used (*n*=15) K**d** was calculated using Secchi depth and a c-value, using the formula:

K**d** = c-value / Secchi Depth (m).

The c-value is a conversion constant, which is set to 1.4 for normal habitat (i.e. habitat not expected to support SAV) or 1.7 for SAV habitat (i.e. habitat with the potential to support SAV). The c-value constant changes based on habitat type, as discussed in the NCCA 2015 Technical Support Document. At 6 stations both secchi measurements and LI-COR data were not available and therefore no water clarity classifications were made

Table 4.5- 9 PAR quality following NCCA 2015 thresholds for normal habitat or CBP thresholds for stations sampled in habitat with potential to support SAV, 2015-2020

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Habitat** | **PAR Quality** | **PAR Range (%)** | **Stations** | **c-values** | **Percentage** |
| Normal | Good | > 20 | 85 | 1.4 | 50.6 ± 7.62 | |
| Fair | < 20 & > 10 | 32 | 19.05 ± 5.98 | |
| Poor | < 10 | 46 | 27.38 ± 6.79 | |
| Missing | ------ | 5 | 2.98 ± 2.59 | |
| SAV | Good | > 40 | 7 | 1.7 | 5.38 ± 3.92 | |
| Fair | < 40 & > CBP Criteria | 21 | 16.15 ± 6.39 | |
| Poor | < CBP Criteria | 101 | 77.69 ± 7.22 | |
| Missing | ------ | 1 | 0.77 ± 1.52 | |
|  | **Total** |  | **298** |  |  | |
|  |  |  |  |  |  | |

1Stations that met CBP SAV criteria were compared to respective values in Table 4.5-8.

**Water Quality Index (WQI):** The five individual elements of water quality evaluated above may not always agree in their separate characterizations of water quality. For example, a decrease in dissolved nutrients (DIP and DIN) might be interpreted as an improvement of water quality, but if the decrease was caused by the rapid uptake of nutrients by an expanding population of algae (a bloom), an increase in chlorophyll-a (Chl-a) and a decrease in water clarity (PAR) would result. Both of the latter (as well as an algal bloom) would be considered degradations of water quality. Increased photosynthesis by an algal bloom would improve local (surface) DO concentrations during the day, but nighttime metabolism by algae might greatly depress DO concentrations. Also, the decomposition of dying algae, later in the bloom, would further depress DO concentrations, especially deeper in the water column. Consequently, all five water quality elements discussed above (DIP, DIN, Chl-a, DO, and PAR) are integrated into a single WQI to provide a general characterization of water quality at each site. This integration is performed by evaluating the observed class of each of the five elements and combining them using the thresholds described in Table 4.5-10.

Table 4.5- 10 Water Quality Index (WQI) scores based on individual site characterizations of near-surface DIP, DIN, and Chl-a, near-bottom DO, and water clarity, 2015-2020. Class Attributes and thresholds are from the NCCA 2015 Technical Report.

|  |  |  |  |
| --- | --- | --- | --- |
| WQI Score | Class Attributes | Stations | Percentages |
| Good | 0 Poor and ≤ 1 Fair | 42 | 14.09 ± 3.97 |
| Fair | 1 Poor or > 2 Fair | 225 | 75.5 ± 4.9 |
| Poor | ≥ 2 Poor | 31 | 10.4 ± 3.48 |
| Missing | ≥ 2 elements missing | 0 | 0 |
| **Total** |  | **298** |  |

**Generalized, Statewide Water Quality Characterization:** In past reports on NCCA surveys EPA has provided guidelines in the Technical Support Document (TSD) for characterizing regional attributes based on the proportions of individual sites that fell into the classes of “Good”, “Fair”, or “Poor” (Table 4.5-11). Virginia’s statewide estuarine waters earn a score of “Fair” for generalized water quality, because more than 10 percent of the sites were classified as “Poor” and fewer than 50 percent of the sites were classified as “Good” on their water quality characterizations.

Table 4.5- 11 Criteria for Regional Water Quality Rating based on NCCA 2015 thresholds, 2015-2020.

|  |  |
| --- | --- |
| **Rating** | **Statewide Water Quality Characterization Criteria** |
| Good | Fewer than 10% of the sites are in "Poor" condition, and more than 50% of the sites are in "Good" Condition |
| Fair | Ten to 20% of the sites are in "Poor" condition, or 50% or fewer of the sites are in "Good" condition. |
| Poor | More than 20% of the sites are in "Poor" condition. |

**Other Water Quality Attributes:** Virginia has established water quality standards for several additional water quality attributes that have not been included among those traditionally evaluated by the NCCA Program. Summaries of the following attributes are presented only for the purpose of characterizing the state’s estuarine waters as a whole, and the single observed values at individual sites are not appropriate for site-specific assessments.

**Acidity-Alkalinity (pH):** Virginia has established a single range of pH values to be acceptable for all classes of fresh and salt waters, except for swamp waters. In normal fresh and salt waters, observed pH values in the range of 6.0 - 9.0 are considered to be acceptable. Any observed pH value below 6.0 or above 9.0 is considered an excursion of the standard. Acidification (lowering of pH) is often associated with acid rain (H**2**SO**4**, HNO**3**, H**2**CO**3**) deposition, especially in freshwater streams, lakes, and reservoirs. Alkalinization (rising pH) may result from eutrophication and excessive algal blooms or as a result of salinization due to the input of salts containing strong bases (Na**+**, Mg**2+**, K**+**).

For the purpose of pH evaluations, all measurements surface to bottom of the hydrographic profile were considered. Among 1,253 pH measurements collected across 298 estuarine sites, only five measurements at three sites exceeded the state pH standard. All exceedances were above pH 9.0, and all sites were in the Potomac River drainage (Sites 1APOM000.11 and 1APOM001.99 in Potomac Creek and 1APOW000.25 in Powells Creek). The Potomac Creek stations had exceedances >9 at two different depth intervals and the Tank Creek site had one violation at 0.5 meters. Table 4.5-12 summarizes the pH excursions observed within Virginia’s estuarine waters.

Table 4.5- 12 Total pH exceedances of >9 or <6 for each depth of the water profile sampled during the downcast, 2015-2020

|  |  |  |
| --- | --- | --- |
| **pH Exceedance Range** | **Stations** | **Percentage** |
| >9 | 5 | 0.4± 0.35 |
| <6 | 0 | 0 |
| No Exceedance | 1248 | 99.6 ± 0.35 |
| **Total** | **1253** |  |

**Bacteria:** High counts of *E. coli* bacteria in a freshwater and e*nterococci* in transitional and saltwaterindicate that there is an elevated human health risk of illness from exposure to pathogenic organisms. Virginia Water Quality Standards for bacteria exposure from recreational use (9VAC25-260-170) include criteria to be applied when multiple bacteria samples are taken:

“In freshwater, E. coli bacteria shall not exceed a geometric mean of 126 counts/100ml and shall not have greater than a 10% excursion frequency of a statistical threshold value (STV) of 410 counts/100 ml, both in an assessment period of up to 90 days. In transition and saltwater, Enterococci bacteria shall not exceed a geometric mean of 35 counts/100ml and shall not have greater than a 10% excursion frequency of a statistical threshold value (STV) of 130 counts/100ml, both in an assessment period of up to 90 days”

Since the Estuarine ProbMon program only collects one bacteria sample per station per year, the geometric mean and STV thresholds in the Water Quality Standards are not applicable to these data and are, therefore, not presented.

# **Sediment Quality**

Sediment quality is important for characterizing probabilistic estuarine sites because the composition of the sediment and the chemical contaminants that it contains may adversely affect ecosystem function and the health of aquatic organisms, as well as the health of humans that use the ecosystem for work, recreation, or food. The NCCA Program has traditionally used two measures of sediment quality - chemical contamination and toxicity - to characterize individual sites. These indicators are subsequently integrated into a single sediment quality index (SQI) to further characterize the site.

**Sediment Chemistry:** Sediment used for chemical analyses and toxicity testing was collected from the top 2.0 cm. of bottom substrate, most commonly sampled by DEQ with Petite Ponar grabs. Sediment samples collected in the Chesapeake Bay mainstem from Old Dominion University’s research vessel, the Fay Slover, were normally collected with a larger, standard Young grab. In both cases, a four-liter sample of homogenized sediment was collected and subdivided for analyses of chemistry, toxicity, total organic Carbon (TOC), and particle size. At one site during the 2016 season water quality parameters were collected and sediment was not available due to an oyster reef substrate hence the difference in total water quality collection sites (N=298) and total sediment collection sites (N=297).

Sediment chemistry samples were analyzed for a number of metals, pesticides, and other organic compounds, including polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs), because they are persistent, bioaccumulative and are often associated with acute and chronic effects on aquatic organisms. Table 4.5-13 summarizes the analytes that are quantified in DEQ’s estuarine probabilistic sediment samples. The results of these chemical analyses are evaluated in several different ways, each line of evidence contributing to the final chemical characterization of the sediment.

In recent years, the NCCA Program has utilized two independent methods of evaluating the effects of multiple chemical contaminants in sediment; the “ERM-quotient” method, and the “Logistic Regression” method. Both of these methods are also utilized in DEQ’s Estuarine

ProbMon Program. DEQ also applies EPA’s “Equilibrium Partitioning Sediment Benchmarks for PAH Mixtures” (ESB**PAH**), as a third line of evidence for characterizing sediment chemistry (U.S. EPA, 2003).

Table 4.5- 13 Concentrations of organics are expressed as μg/Kg, of metals as mg/Kg, both on a dry weight basis.

|  |  |  |
| --- | --- | --- |
| **23 Polynuclear Aromatic Hydrocarbons (PAHs)** | **22 Organochlorine Pesticides & Derivatives other than DDT** | **21 Polychlorinated Biphenyl Congeners (PCBs)** |
| 1-methylnaphthalene | Aldrin | PCB # Compound Name |
| 1-methylphenanthrene | Alpha-BHC | 8 2,4'-dichlorobiphenyl |
| 2,3,5-trimethylnaphthalene | Beta BHC | 18 2,2',5-trichlorobiphenyl |
| 2,6-dimethylnaphthalene | Delta-BHC | 28 2,4,4'-trichlorobiphenyl |
| 2-methylnaphthalene | Gamma-BHC (Lindane) | 44 2,2',3,5'-tetrachlorobiphenyl |
| Acenaphthene | Alpha-Chlordane | 52 2,2',5,5'-tetrachlorobiphenyl |
| Acenaphthylene | Gamma-Chlordane | 66 2,3',4,4'-tetrachlorobiphenyl |
| Anthracene | Dieldrin | 77 3,3',4,4'-tetrachlorobiphenyl |
| Benz(a)anthracene | Endosulfan I | 101 2,2',4,5,5'-pentachlorobiphenyl |
| Benzo(b)fluoranthene | Endosulfan II | 105 2,3,3',4,4'-pentachlorobiphenyl |
| Benzo(a)pyrene Benzo(e)pyrene | Endosulfan sulfate | 110 2,3,3',4',6-pentachlorobiphenyl |
| Benzo(g,h,i)perylene | Endrin | 118 2,3,4,4',5-pentachlorobiphenyl |
| Benzo(k)fluoranthene | Endrin Aldehyde | 126 3,3,4,4',5-pentachlorobiphenyl |
| Chrysene | Endrin Ketone | 128 2,2',3,3',4,4'-hexachlorobiphenyl |
| Dibenz(a,h)anthracene | Heptachlor | 138 2,2',3,4,4',5'-hexachlorobiphenyl |
| Fluoranthene | Heptachlor epoxide | 153 2,2',4,4',5,5'-hexachlorobiphenyl |
| Fluorene | Hexachlorobenzene | 170 2,2',3,3',4,4',5 heptachlorobiphenyl |
| Ideno(1,2,3-c,d)pyrene | Mirex | 180 2,2',3,4,4',5,5'-heptachlorobiphenyl |
| Naphthalene | Oxychlordane | 187 2,2',3,4',5,5',6-heptachlorobiphenyl |
| Perylene | Toxaphene | 195 2,2',3,3',4,4',5,6-octachlorobiphenyl |
| Phenanthrene | Cis-Nonachlor | 206 2,2',3,3',4,4',5,5',6-nonachlorobiphenyl |
| Pyrene | Trans-Nonachlor | 209 2,2'3,3',4,4',5,5',6,6'-decachlorobiphenyl |
| **16 Trace Metals** | **2 Semi-volatiles** |  |
| Aluminum | Biphenyl |  |
| Antimony | Dibenzothiophene |  |
| Arsenic | **8 DDT & Derivatives** |  |
| Cadmium | 2,4'-DDD |  |
| Chromium | 4,4'-DDD |  |
| Copper | 2,4'-DDE |  |
| Iron | 4,4'-DDE |  |
| Lead | 2,4'-DDT |  |
| Manganese | 4,4'-DDT |  |
| Mercury | **Other Measurements** |  |
| Nickel | Total organic carbon (mg/Kg dry weight) |  |
| Selenium | Percent moisture |  |
| Silver |  |  |
| Tin |  |  |
| Vanadium |  |  |
| Zinc |  |  |

**Sediment Quality Guidelines (SQGs)** are threshold limits of contaminants used in Ecological Risk assessments to determine the likelihood ofadverse effects from sediment chemistry to biological communities. DEQ applies both consensus-based SQGs (i.e Probable Effects Concentrations PECs, MacDonald et al., 2000) and effects-based screening values known as Effects Range Medians or ERMs (Long et al., 1995). ERM and PEC screening values are published in DEQ’s Water Quality Monitoring and Assessment Guidance Manual. Bottom salinity at time of sample collection dictates which group of the aforementioned screening values are applied. Transitional waters (oligohaline) are compared against whichever screening value is lower Table 4.5-14.

Table 4.5- 14 Applied Sediment Quality Guideline (SQG) screening values based on salinity regime

|  |  |
| --- | --- |
| **Salinity Regime** | **Screening Value** |
| Tidal Freshwater | Probable Effects Concentration (PEC) |
| Oligohaline | lowest value: Effects Range Median (ERM) or Probable Effects Concentration (PEC) |
| Low mesohaline | Effects Range Medians (ERM) |
| High mesohaline |
| Polyhaline |
| Euhaline |

For each station, quotients were derived by dividing the measured concentration of each contaminant by its corresponding PEC or ERM screening value. Quotients greater than 1 indicate the measured concentration exceeded its screening value and adverse effects from that contaminant are “probable”. To predict the toxicity for mixtures of multiple contaminants in sediments, the mean from an ecologically relevant subset of contaminant quotients (mean Sediment Quality Guidelines Quotient or mSQGq) is used. DEQ’s saltwater sites incorporate the same contaminant subset used to calculate the mean Effects-Range Median quotient (mERM-Q) from Long et al. 1995 and the NCCA 2015 Technical Support Document. Freshwater and transitional sites adhere to the subset of contaminant quotients used when calculating the mean Probable Effects Concentrations quotient (mPEC-Q) (Hyland et al. 2003; MacDonald et al. 2000; Ingersoll et al. 2001). The larger the value of mSQGq, the higher the risk of adverse effects to aquatic life Table 4.5-15.

Table 4.5- 15 Scores and threshold limits of Mean Sediment Quality Guideline Quotients (mSQGq), 2015-2020

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **mSQGq Score** | | **mSQGq Score Range** | **Stations** | **Percentage** |
| Good | < 0.022 | | 127 | 42.76 ± 5.65 |
| Fair | > 0.022 and < 0.098 | | 141 | 47.47 ± 5.7 |
| Poor | > 0.098 and < 0.473 | | 29 | 9.76 ± 3.39 |
| Very Poor | >0.473 | | 0 | 0 |
| **Total** |  | | **297** |  |

**Logistic Regression Model (LRM):** NCCA introduced the Logistic Regression Model for sediment characterizations in the report on the 2010 National Survey (US EPA, 2015, 2016). Tabled logistic regression coefficients from Field et al. (2002) were presented for 10 metals, 21 PAHs, biphenyl, total PCBs, and 4 pesticides. The observed concentration of each tabled analyte is used in the LRM to calculate the estimated probability of significant acute mortality to amphipod crustaceans. NCCA subsequently used the maximum probability of toxicity (P**max**) among all analytes to characterize sediment chemistry at the site (US EPA, 2015, 2016). Table 4.5-16 summarizes the NCCA P**max** thresholds and the consequent distribution of sediment characterizations in Virginia’s estuarine waters.

Table 4.5- 16 Logistic Regression Pmax scores and ranges based on NCCA 2015 thresholds, 2015-2020

|  |  |  |  |
| --- | --- | --- | --- |
| **pmax Score** | **pmax Range** | **Stations** | **Percentage** |
| Good | Pmax < 0.5 | 291 | 97.98 ± 1.61 |
| Fair | Pmax > 0.5 and < 0.75 | 3 | 1.01 ± 1.14 |
| Poor | Pmax > 0.75 | 3 | 1.01 ± 1.14 |
| Very Poor |  | 0 | 0 |
| **Total** |  | **297** |  |

**Equilibrium Partitioning Sediment Benchmark for PAH Mixtures (ESBPAH):** The ESB for PAH mixtures is the only one of the three sediment chemical contamination indices utilized in this report that adjusts the risk of benthic effects for the sediment concentration of total organic Carbon, which binds PAHs (and other organic contaminants) and reduces their availability to benthic organisms. EPA has published guidelines for estimating the effects of mixtures of PAHs in sediments on the resident benthic communities (US EPA, 2003). The Virginia DEQ uses this method to provide a third line of evidence for the characterization of sediment contamination in estuarine waters. In summary, the observed sediment concentrations of 23 individual PAHs are multiplied by their respective toxicity coefficients and adjusted for the total organic Carbon concentration in the sediment. The resultant values are then summed across all 23 PAHs, and the sum is subsequently compared to an EPA-defined critical value. The EPA critical value divides the results into two classes: values ≤ 1.0 - low probability of benthic effects, and values > 1.0 - elevated probability of benthic effects. To further refine the degree of benthic risk and for the sake of comparability with other sediment contamination indices in this report, the elevated probability range of ESB values was subdivided Table 4.5-17. Only 4 of the 297 sites did not score as “Good”. In the Lower Chesapeake Bay 3 sites scored as “Fair” and the only site scoring “Poor” was in the Southern Branch of the Elisabeth River-Deep Creek.

Table 4.5- 17 Scores and ranges of Equilibrium Partitioning Sediment Benchmarks (ESBs) for PAH mixtures based on NCCA 2015 thresholds.

|  |  |  |  |
| --- | --- | --- | --- |
| **ESB Score** | **ESB Range** | **Stations** | **Percentage** |
| Good | ESB < 1.000 | 293 | 98.65 ± 1.32 |
| Fair | ESB > 1.000 to 1.100 | 3 | 1.01 ± 1.14 |
| Poor | ESB > 1.100 to 5.001 | 0 | 0.34 ± 0.65 |
| Very Poor | ESB > 5.0001 | 0 | 0 |
| **Total** |  | **297** |  |

**Integrated Sediment Chemistry Index (SCI):** DEQ’s Integrated SCI is derived from characterizations of sediment chemistry based on mean Sediment Quality Guideline Quotient (mSQG-Q or mERM-Q), the Pmax statistic of the Logistic Regression Model (LRM-Pmax), and the Equilibrium Partitioning Sediment Benchmark for PAH Mixtures (ESBPAH). This is a slight deviation from the NCCA SCI which does not include the ESBPAH .The ESBPAH incorporates reduced PAH bioavailability from Total Organic Carbon sequestration and is pertinent to include in the SCI. Based on the percentage distributions of the SCI characterization among classes, Virginia’s estuarine waters earn a statewide characterization of “Fair” for sediment chemical contamination Table 4.5- 18.

Table 4.5- 18 Integrated Sediment Chemistry Index (SCI) scores and thresholds

|  |  |  |  |
| --- | --- | --- | --- |
| **SCI Score** | **SCI Range** | **Stations** | **Percentage** |
| Good | All three elements Good | 127 | 42.76 ± 5.65 |
| Fair | No Poor, and at least one element Fair | 138 | 46.46 ± 5.7 |
| Poor | One or two elements Poor or Very Poor | 32 | 10.77 ± 3.54 |
| Very Poor | Two or more elements Very Poor | 0 | 0 |
| **Total** |  | **297** |  |

**Sediment Toxicity (SedTox):** In addition to sediment chemistry, sediment toxicity is considered to be another important attribute of sediment quality. The acute toxicity of sediment was measured by performing 10-day, static acute toxicity tests with two species of amphipod crustaceans: *Leptocheirus plumulosus* tests in tidal waters were usually complemented with *Hyalella azteca* tests in tidal freshwaters. The utilization of complementary *Hyalella* tests was initiated in 2013, after significant blooms of Iron-fixing bacteria were observed on freshwater sediment following normalization of overlying water to 20.0‰ for standardized *Leptocheirus* saltwater toxicity tests. The bacterial blooms caused a precipitous drop in pH and elevated ammonia concentrations in the test chambers, and induced a significant mortality of test organisms that was not a direct result of sediment contamination by toxics. The complementary freshwater tests of sediment from the same site with *Hyalella* seldom resulted in such high mortality. If multiple tests were conducted, results from both *Leptocheirus* and *Hyalella* tests were integrated into a single classification per site.

Table 4.5-19 summarizes the characterization estuarine sites where sediment was collected (N=297) based upon the results of ten-day, static acute sediment toxicity tests. Toxicity test endpoints were mortality of test organisms, expressed as percent control-corrected survival. Statistically significant difference from controls was tested at α = 0.05 level; ecological effect was considered significant if control-corrected survival was less than 80.0 percent. In some cases, significant amphipod mortality may not be attributed directly to chemical contamination of the sediment. Particle size distributions within the sediment (> 95.0 percent sand) were a probable cause for observed mortality. These circumstances were discussed and evaluated during weight-of-evidence assessments. Virginia’s estuarine waters earn an overall characterization of “Good” for sediment toxicity, because fewer than 10 percent of the sites were rates as “Poor” and more than 50 percent of the sites were rated as “Good” Table 4.5-19.

Table 4.5- 19 Sediment toxicity testing scores and threshold ranges following NCCA 2015 benchmarks

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Toxicity Score** | **Toxicity Range** | **Stations** | | **Percentage** |
| Good | Results not significantly different from controls  (p > 0.05) and > 80% control-corrected survival | | 244 | 82.15 ± 4.37 |
| Fair | Results significantly less than controls (p < 0.05) and > 80% control-corrected survival or not significantly different from controls (p > 0.05) and < 80% control-corrected survival | | 50 | 16.84 ± 4.27 |
| Poor | Results significantly less than controls (p < 0.05) and  < 80% control-corrected survival | | 3 | 1.01 ± 1.14 |
| **Total** |  | | **297** |  |

**Sediment Quality Index (SQI):** The NCCA has traditionally integrated the sediment chemical contamination index (SCI) and the sediment toxicity results into a single index of sediment quality, to evaluate whether the sediment at a site is “highly likely or not likely to cause adverse effects to benthic organisms” (US EPA, 2016). The classes of the SQI, the attributes of each class, and the sediment quality characterizations of Virginia probabilistic estuarine sites sampled between 2015 and 2020 are summarized in Table 4.5-19. Virginia’s statewide estuarine waters earn a score of “Fair” because fewer than 50 percent of the sites are rated “Good” as presented in Table 4.5-20.

Table 4.5- 20 Sediment Quality Index (SQI) scores based on sediment chemical contamination index (SCI) and the sediment toxicity results. Thresholds follow NCCA 2015 benchmarks

|  |  |  |  |
| --- | --- | --- | --- |
| **SQI Score** | **SQI Range** | **Stations** | **Percentage** |
| Good | Toxicity and Chemistry = Good | 111 | 37.37 ± 5.52 |
| Fair | Toxicity and/or Chemistry = Fair | 152 | 51.18 ± 5.71 |
| Poor | Toxicity and/or Chemistry = Poor | 34 | 11.45 ± 3.64 |
| **Total** |  | **297** |  |

# **Benthic Community**

**Benthic Community Characterizations:** A benthic index, certain types of which are 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 several 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). A fourth benthic index, the US M-AMBI, has recently been adapted by EPA from a well-established European benthic index (Pelletier et al., 2018). It was first evaluated by DEQ for potential inclusion in future weight-of-evidence assessments in 2018. The US M-AMBI was eventually included as a fourth benthic index assimilated into the 2019 and 2020 weight-of-evidence assessments**.** Each of the benthic indices currently employed has its own published scale of values and thresholds for benthic characterizations. DEQ uses slightly modified scales of threshold values for MAIA, EMAP and M-AMBI indices in order to better delineate between “Poor” and “Very Poor”, and to make comparisons between all indices more uniform. Modified threshold values were guided by summary statistics (e.g. percentiles, minimums, and maximums) using a decade of historic data at over 600 sites. The threshold values and scores for each benthic index applied during this assessment is below Table 4.5-21.

Table 4.5- 21 Modified values of each benthic index compared to the originally published scale values.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Index Values** | **Benthic Index Score** | **CBP B-IBI** | **MAIA B-IBI** | **EMAP VP-IEC** | **M-AMBI** |
| Modified | Good | ≥ 3.0 | ≥ 3.0 | > 0.1 | ≥ 0.53 |
| Fair | 2.7 to 2.9 | 2.7 to 2.9 | 0.1 to -0.1 | > 0.39 and < 0.53 |
| Poor | 2.1 to 2.6 | 2.1 to 2.6 | < -0.1 to -1.0 | 0.20 to 0.39 |
| Very Poor | ≤ 2.0 | ≤ 2.0 | < -1.0 | < 0.20 |
| Original | Good | ≥ 3.0 | ≥ 3.0 | > 0.0 | ≥ 0.53 |
| Fair | 2.7 to 2.9 | - | - | ≥ 0.39 and < 0.53 |
| Poor | 2.1 to 2.6 | < 3.0 | ≤ 0.0 | < 0.39 |
| Very Poor | ≤ 2.0 | - | - | - |

The CBP B-IBI was the most conservative of the indices, resulting in fewer “Good” (35.3 percent) and more “Poor” (18.5 percent) characterizations among all estuarine sites. The MAIA B-IBI was the least conservative of the indices, resulting in more “Good” (75.1 percent) and fewer “Poor” (12.1 percent) characterizations than any other index, across all estuarine waters. The benthic indices may not all characterize the same site in the same class, but they tend to agree more often at the extremities of the scale (Good or Very Poor) than near the center (“Fair”). The site distributions among the classifications (“Good”, “Fair”, “Poor”, “Very Poor”), for each of the indices is summarized in Table 4.5-22.

Table 4.5- 22 Scores of benthic condition using Chesapeake Bay Program B-IBI, MAIA, EMAP, and M-AMBI indices. Total stations for M-AMBI (N=100) are lower because it was only integrated in 2019 and 2020 assessments. All other indices include stations from 2015-2020 (N=297)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Score** | **CBP B-IBI** | | **MAIA** | | **EMAP** | | **M-AMBI** | |
| Stations | Percentage | Stations | Percentage | Stations | Percentage | Stations | Percentage |
| Good | 105 | 35.35 ± 5.46 | 223 | 75.08 ± 4.94 | 185 | 62.29 ± 5.53 | 39 | 39 ± 9.68 |
| Fair | 35 | 11.78 ± 3.68 | 0 | 0 | 21 | 7.07 ± 2.93 | 33 | 33 ± 9.33 |
| Poor | 55 | 18.52 ± 4.44 | 36 | 12.12 ± 3.73 | 64 | 21.55 ± 4.7 | 24 | 24 ± 8.47 |
| Very Poor | 102 | 34.34 ± 5.42 | 38 | 12.79 ± 3.81 | 27 | 9.09 ± 3.28 | 4 | 4 ± 3.89 |
| **Total** | **297** |  | **297** |  | **297** |  | **100** |  |

For the purpose of the weight-of-evidence assessment for Aquatic Life designated Use (ALU), to be discussed later in this chapter, each benthic index was expressed in terms of its relative degree of degradation following guidelines provided in Chapman et al. (1987) Table 4.5-23.

Table 4.5- 23 Numeric degradation scores associated with each class of benthic well-being.

| **Benthic Class** | **Degradation Score** |
| --- | --- |
| Good (Meets Goals) | 0 |
| Fair (Marginal) | 1 |
| Poor (Degraded) | 2 |
| Very Poor (Severely Degraded) | 3 |

A weighted average across all indices was then calculated to determine an Integrated Benthic Score (IBS) for each site. At stations within the Chesapeake Bay drainage, the CBP B-IBI carries twice the weight. Likewise, stations that are direct drainages to Atlantic Coastal Bays use a weight of 2 for the Mid-Atlantic B-IBI. The EMAP and M-AMBI indexes have a weight of 1 regardless of watershed. The relative weights of each index for each geographic region of Virginia’s estuarine waters are summarized in Table 4.5-24.

Table 4.5- 24 Weights employed, by geographic region and benthic index, in calculating the Integrated Benthic Score (IBS) from the index-specific degradation scores at each probabilistic estuarine site

| **Benthic Index** | **Chesapeake Bay Region** | **Coastal Delmarva Region** | **Back Bay / North Landing River** |
| --- | --- | --- | --- |
| CBP B-IBI | 2 | 0 | 0 |
| MAIA B-IBI | 1 | 2 | 2 |
| EMAP VP-IEC | 1 | 1 | 1 |
| M-AMBI | 1 | 1 | 1 |
| **Sum of Weights** | 5 | 4 | 4 |

The results of integrating the benthic community degradation scores, by calculating a single weighted mean IBS, are summarized in Table 4.5-25. Based on the criteria for regional characterization provided in Table 4.5-11, the IBS classifications are very similar to those reported for the individual benthic indices in Table 4.5-22. Statewide, the characterization of benthic communities based on their IBS scores is still “Poor”, because more than 20 percent (26.2%) of the site IBS characterizations fall into the “Poor” or “Very Poor” (degraded or severely degraded) classes, even though the percentage “Good” statewide was 47%. The Integrated Benthic Score (IBS) and threshold ranges can be found in Table 4.5-25.

Table 4.5- 25 Weighted average Integrated Benthic Score (IBS) classes and ranges of associated integrated benthic scores

|  |  |  |  |
| --- | --- | --- | --- |
| **IBS Score** | **IBS Range** | **Stations** | **Percentage** |
| Good (Meets Goals) | < 0.5 | 139 | 46.8 ± 5.7 |
| Fair (Marginal) | > 0.5 and < 1.5 | 80 | 26.94 ± 5.07 |
| Poor (Degraded) | > 1.5 and < 2.5 | 50 | 16.84 ± 4.27 |
| Very Poor (Severely Degraded) | > 2.5 | 28 | 9.43 ± 3.34 |
| **Total** |  | **297** |  |

# **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 water quality parameters however (*e.g.*, nutrients, bacteria, dissolved metals, DO, temperature, pH, *etc*.) are considered 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 2022 [Water Quality Assessment Guidance Manual](https://townhall.virginia.gov/L/ViewGDoc.cfm?gdid=6997).

It should be noted that formal aquatic life impairment designations (i.e., those placed in Category 5A) determined using the SQT and reported here, are only those with degradation of benthic communities that is attributable to toxic chemical contamination of the sediment which may be indicated through either observed sediment chemistry or sediment toxicity. Any cases of significant degradation of benthic communities that cannot be attributed directly to chemical contamination are identified as having an “Observed Effect” and are placed in Category 3B. A 3B assessment may also result from the presence of significant chemical contamination and/or observed toxicity where no significant benthic degradation was observed. Such Category 3B sites are prioritized by DEQ for follow up monitoring. When sediment screening values are exceeded or significant sediment toxicity is observed without significant *in situ* benthic degradation, the results are generally reported as Category 2 (i.e., waters are of concern to the state … [because] the water exceeds a state screening value or toxicity test). At times, ancillary information collected at probabilistic sites may be sufficient to suggest additional potential attributable causes for observed benthic degradation. For example, if sediment sand content is extremely high (≥ 95 percent) and the site is in a tidal channel or is exposed to wave action, natural degradation due to scouring may be suggested as a potential cause. Similarly, if bottom DO concentration is “Poor” or only “Fair” at the time of sampling, oxygen depletion may be suggested as a potential cause, and ancillary data on nutrient and/or chlorophyll-a concentrations may suggest eutrophication.

Table 4.5-26 summarizes the results of the toxics-related weight-of-evidence assessment of the aquatic life designated use at 297 Virginia probabilistic estuarine sites sampled from July 2015 through September 2020.

Table 4.5- 26 Assessment categories in regards to Aquatic Life Designated Use (ALU). Categories are the results of the weight-of-evidence assessment using Sediment Chemistry, Sediment Toxicity Testing, and Benthic Community inegrated scores.

|  |  |  |  |
| --- | --- | --- | --- |
| **Assessment Category** | **Category Description** | **Stations** | **Percentage** |
| 2A | Fully Supporting of ALU: benthic community meets goals, no toxic contaminants | 96 | 32.32 ± 5.34 |
| 2B | Of Concern: exceedance of screening value or toxicity test | 16 | 5.39 ± 2.58 |
| 3B | Observed Effects: prioritized for follow-up monitoring | 153 | 51.52 ± 5.71 |
| 5A | Impaired for ALU: toxic contaminants | 32 | 10.77 ± 3.54 |
| **Total** |  | **297** |  |

# **Conclusion**

DEQ’s estuarine probabilistic monitoring program sampled 297 estuarine sites during the 2015-2020 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. (1) On the basis of the five water quality parameters sampled at each site (Table 4.5-9), 14.1 percent of the sites were rated as “good”, 75.5 percent were rated as “fair”, and 10.4 percent were rated as “poor.” (2) On the basis of sediment chemistry and acute toxicity (Table 4.5-19), 37.4 percent of sites were rated as “good”, 51.2 percent were rated as “fair”, and 11.5 percent were rated as “poor.” (3) Most of the sites had benthic communities that were classified as “good” (46.8 percent) or “fair” (26.9 percent) according to the Integrated Benthic Index (Table 4.5-24). Approximately 16.8 percent of the sites were characterized as having degraded benthic communities with 9.4 percent classified as severely degraded.

Weight-of-Evidence (WOE) assessments were carried out on each probabilistic site. WOE assessments evaluate the effects of toxic chemical contaminants on the Aquatic Life designated Use (ALU), as indicated by chemical contaminants in the sediment, acute sediment toxicity, and benthic community condition. WOE aquatic life assessments of 297 probabilistic estuarine sites (Table 4.5-25) concluded that, based on these three characterizations, 32.3 percent of probabilistic estuarine sites were fully supporting of ALU. Approximately 5.4 percent were of concern, either because of sediment toxicity without chemical and benthic community corroboration, or chemical contaminants exceeded screening values without significant toxicity or benthic degradation. About 51.5 percent of the sites had observed effects based on chemical contaminant concentrations or benthic degradation, but not both. Only 10.8 percent of the sites were assessed as impaired by toxic contaminants, corroborated by multiple lines of evidence.

**References**

Chapman, P.M., R.N. Dexter and E.R. Long. 1987. Synoptic measures of sediment contamination toxicity and infaunal community structure (the Sediment Quality Triad). Mar. Ecol. Prog. Ser. 37:75-96.

Chapman, P.M., R.N. Dexter, S.F. Cross and D.G. Mitchell. 1986. A field trial of the Sediment Quality Triad in San Francisco Bay. NOAA Technical Memorandum NOS OMA 25. National Oceanic and Atmospheric Administration, San Francisco, CA. 127 pp.

Conover, W.J. 1980. Practical Nonparametric Statistics. (2ed) John Wiley & Sons, New York. xiv + 493 pp.

Dauer, D.M., and M.F. Lane. 2005. Side-by-Side Comparison of Young Grab and Composite Petite Ponar Grab Samples for the Calculation of the Benthic Index of Biological Integrity (B-IBI). Department of Biological Sciences,

Old Dominion University, Norfolk, Virginia. Report submitted to Chesapeake Bay Program Office, Virginia Department of Environmental Quality.

Field, L.J., D.D. MacDonald, S.B. Norton, C.G. Ingersoll, C.G. Severn, D. Smorong, and R. Lindskoog. 2002. Predicting amphipod toxicity from sediment chemistry using logistic regression models. Environ. Toxicol. Chem. 21: 1993-2005.

Hyland, J., W.L. Balthis, V.D. Engle, E.R. Long, J.F. Paul, J.K. Summers, and R.F. Van Dolah. 2003. Incidence of stress in benthic communities along the U.S. Atlantic and Gulf of Mexico coasts within different ranges of sediment contamination from chemical mixtures. Environ Mon and Assess 81: 149–16.

Hyland, J, L. Balthis, I. Karakassis, P. Magni, A. Petrov, J. Shine, O. Vestergaard, R. Warwick. 2005. Organic carbon content of sediments as an indicator of stress in the marine benthos. Marine Ecology Progress Series Vol. 295: 91–103, 2005.

Hyland, J.L., R.F. Van Dolah, and T.R. Snoots. 1999. Predicting stress in benthic communities of southeastern U.S. estuaries in relation to chemical contamination of sediments. Environ Toxicol Chem 18(11): 2557-2564.

Long, E.R., D.D. MacDonald, S.L. Smith, and F.D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management 19(1):81–97.

Long, E.R., and P.M. Chapman. 1985. A sediment quality triad: Measures of sediment contamination, toxicity and infaunal community composition in Puget Sound. Mar. Pollu. Bull. 16(10): 405-415.

Llansó, R.J., L.C. Scott, D.M. Dauer, J.L. Hyland and D.E. Russell. 2002a. An Estuarine Benthic Index of Biotic Integrity for the Mid-Atlantic Region of the United States. I. Classification of Assemblages and Habitat Definition. Estuaries Vol. 25, No. 6A, p. 1219–1230.

Llansó, R.J., L.C. Scott, D.M. Dauer, J.L. Hyland, D.E. Russell and F.W. Kutz. 2002b. An Estuarine Benthic Index of Biotic Integrity for the Mid-Atlantic Region of the United States. II. Index Development. Estuaries Vol. 25, No. 6A, p. 1231–1242.

MacDonald, D.D., C.G. Ingersoll, T.A. Berger. 2000. Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems. Arch. Environ. Contam. Toxicol. 39:20-31.

Paul, J.F., K.J. Scott, D.E. Campbell, J.H. Gentile, C.S. Strobel, R.M. Valente, S.B. Weisberg, A.F. Holland, J.A. Ranasinghe. 2001. Developing and applying a benthic index of estuarine condition for the Virginian Biogeographic Province. Ecological Indicators 1 (2001) 83–99.

Pelletier, M.C., D.J. Gillett, A. Hamilton, T. Grayson, V. Hansene, E.W. Leppo, S.B. Weisberg, and A. Borja. 2018. Adaptation and application of multivariate AMBI (M-AMBI) in US coastal waters. Ecological Indicators, Volume 89, June 2018, Pages 818-827.

U.S. EPA (United States Environmental Protection Agency). 1996. Ecological Effects Test Guidelines: OPPTS 850:1740: Whole Sediment Acute Toxicity Invertebrates, Marine. Technical Report EPA 712 C-96-355. U.S. Environmental Protection Agency, Washington, DC.

U.S. EPA (United States Environmental Protection Agency). 2001. National Coastal Condition Report. EPA-620/R-01/005. Office of Research and Development and Office of Water, Washington, DC.

<http://water.epa.gov/type/oceb/assessmonitor/nccr/downloads.cfm>

U.S. EPA. 2003. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. EPA-600-R-02-013. Office of Research and Development. Washington, DC 20460

U.S. EPA. (United States Environmental Protection Agency). 2004. National Coastal Condition Report II. EPA-620/R-03/002. Office of Research and Development and Office of Water, Washington, DC.

<http://water.epa.gov/type/oceb/assessmonitor/nccr/downloads.cfm>

U.S. EPA. (United States Environmental Protection Agency). 2008. National Coastal Condition Report III. EPA/842-R-08-002. Office of Research and Development and Office of Water, Washington, DC.

<http://water.epa.gov/type/oceb/assessmonitor/downloads.cfm>

U.S. EPA (United States Environmental Protection Agency). 2012. National Coastal Condition Report IV. EPA-842-R-10-003. Office of Research and Development and Office of Water, Washington, DC.

<http://water.epa.gov/type/oceb/assessmonitor/nccr/downloads.cfm>

U.S. EPA. (United States Environmental Protection Agency). 2014a. National Coastal Condition Assessment Quality Assurance Project Plan. United States Environmental Protection Agency, Office of Water, Office of Wetlands, Oceans and Watersheds. Washington, D.C. EPA 841-R-14-005. 2014.

<https://www.epa.gov/sites/production/files/2016-05/documents/ncca_2015_qapp_version_2.1.pdf>

U.S. EPA. 2014b National Coastal Condition Assessment: Field Operations Manual. EPA-841-R-14-007. U.S. Environmental Protection Agency, Washington, DC.

<https://www.epa.gov/sites/production/files/2016-03/documents/national_coastal_condition_assessment_2015_field_operation_manual_version_1.0_1.pdf>

U.S. EPA (U.S. Environmental Protection Agency) 2015. National Coastal Condition Report V. Office of Water and Office of Research and Development. National Coastal Condition Assessment 2010 (EPA 841-R-15-006). Washington, DC. December 2015.

<https://www.epa.gov/national-aquatic-resource-surveys/national-coastal-condition-assessment-2010-report>

U.S. EPA (U.S. Environmental Protection Agency) 2016. NCCA 2010 Technical Report. National Coastal Condition Assessment 2010. <https://www.epa.gov/sites/production/files/2016-01/documents/ncca_2010_technical_report_20160127.pdf>.

This document provides supplemental technical information on the background and development of the Benthic Index, Water Quality Index, Sediment Quality Index, and Ecological Fish Tissue Contaminants Index used in the National Coastal Condition (NCCA) 2010 Report. It was developed by EPA to provide technical information to readers of the NCCA 2010 Report.

Van Sickle, J., J.L. Stoddard, S.G. Paulsen, and A.R. Olsen. 2006. Using Relative Risk to Compare the Effects of Aquatic Stressors at a Regional Level. Environ. Manage. 38:1020-1030.

Venice System. 1958. Symposium for the Classification of Brackish Waters. Venice, April 8 – 14, 1958. Arch. Oceanogr. Limnol. 11 (Suppl), 1-248, and subsequently published in:

(2003) The Venice System for the Classification of Marine Waters According to Salinity. Limnology and Oceanography, 3, doi: 10.4319/lo.1958.3.3.0346.

Virginia DEQ.2019. [WATER QUALITY ASSESSMENT GUIDANCE MANUAL for 2020 305(b)/303(d) Integrated Water Quality Report](https://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityAssessments/2020WQAGuidanceManual.aspx). July 2019.

Weisberg, S.B., J.A. Ranasinghe, D.M. Dauer, L.C. Schaffner, R.J. Diaz, and J.B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. Estuaries 20:149-158.