Development of an Integrated and Spatially Explicit Index of Chesapeake Bay Health (Bay Habitat Health Index - BHHI)

Draft

Technical Documentation (v 1.5)

April 16th, 2007

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A joint initiative of the Chesapeake Bay Program's

Tidal Monitoring and Analysis Workgroup (TMAW) &

Living Resources and Analysis Workgroup (LivRAW)

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Background

In mid 2004, a task force (Indicator Redesign Taskforce - IRT) was assembled to resolve some of the deficiencies in the Chesapeake Bay Program's (CBP) indicators and communication strategy. The taskforce proposed a new indicator structure and annual communication cycle that was adopted by the CBP at the April 2005 Implementation Committee meeting (Figure 1). Producing an annual integrated assessment of Chesapeake Bay's health was a major component of this redesign and included a number of established goals (see text box below). The annual integrated health assessment was recognized as a substantial task requiring a staggered approach in which some aspects could be achieved in a short time frame (e.g., Bay-wide assessment of some key indicators), while others would take much longer (e.g., full integration between Bay health, stressors and restoration effort).

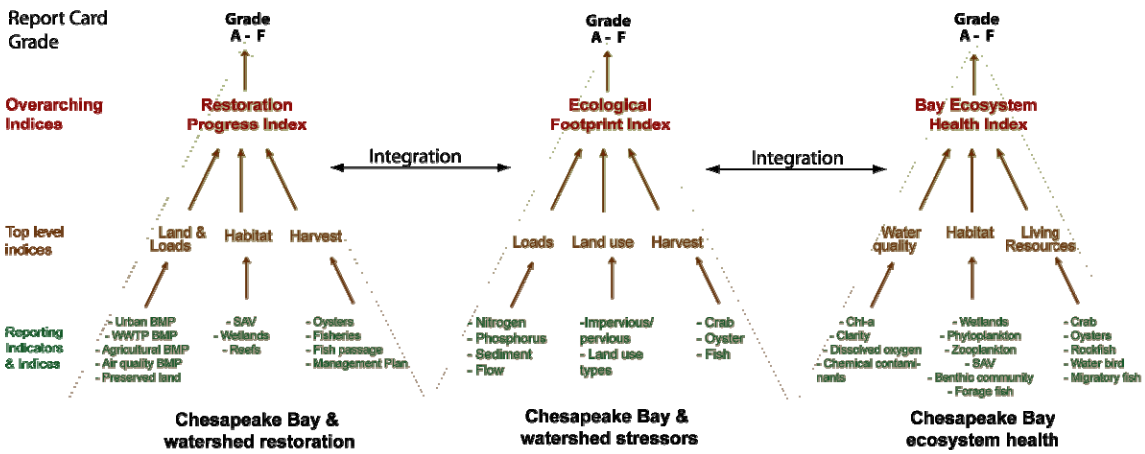


Figure 1: Conceptual relationship between indicators and overarching indices as approved by the Chesapeake Bay Program Implementation Committee.

Annual Bay Ecosystem Health Check
Goals

1. In early spring each year, conduct an annual assessment of key indicators/ reporting indicators and indices to provide an integrated assessment of the Chesapeake Bay ecosystem's conditions. This assessment includes the following:
   a. Assess key water quality conditions (e.g., dissolved oxygen, chlorophyll *a*, water clarity), living resources populations (e.g., fisheries catch, independent data on oysters, blue crabs, rockfish), and their supporting prey (e.g., plankton, benthos, forage fish) and habitats (e.g., underwater Bay grasses, tidal wetlands).
   b. Develop an integrated ecosystem health assessment for the Bay and its tidal tributaries using the identified reporting indicators and top level indices.
   c. Create a ranking valuation scheme to compare ecosystem health assessments both geographically and over time (annual assessments).
2. Develop an improved assessment capacity by a) improving the timeliness of various data processing steps and b) developing additional key indicators.
3. Effectively communicate the integrated ecosystem health assessments with spatially explicit maps and rigorous scientifically based analyses to the Chesapeake Bay community.

Goals established by the Indicator Redesign Taskforce for annual ecosystem health check

The 2005 health and restoration report published in March 2006 (EPA, 2005) achieved many of the taskforce's initial goals. For example, a set of reporting-level indicators was presented in a timely, consistent and clearly formatted manner. However, the report failed to meet one of its main goals of developing integrated and spatially-explicit indices of Chesapeake Bay health.

Over the past two years, the CBP's Tidal Monitoring and Analysis Workgroup (TMAW) and Living Resources Analysis Workgroup (LivRAW) have developed the methods for producing an integrated and spatially-explicit index of Bay health, called the Bay Habitat Heath Index (BHHI). The purpose of this document is to provide the background and methods underpinning the BHHI.

Spatially explicit index required

In addition to meeting the specific aims of the indicator redesign taskforce (IRT), development and release of an integrated and spatially explicit index of Chesapeake Bay health addresses the following needs:

- *GAO Report to Congress (October 2005):* The GAO audit recognized that improved strategies are needed to better assess, report and manage restoration progress. GAO endorsed the approach taken by the IRT and recommended the Chesapeake Bay Program "complete its efforts to develop and implement an integrated assessment approach" and "revise its reporting approach to improve the effectiveness and credibility of its reports". The BHHI is an important step in meeting the GAO recommendations.

> **What GAO Recommends**
>
> GAO recommends that the Administrator of EPA instruct the Chesapeake Bay Program Office to (1) complete its efforts to develop and implement an integrated assessment approach; (2) revise its reporting approach to improve the effectiveness and credibility of its reports; and (3) develop a comprehensive, coordinated implementation strategy that takes into account available resources. In commenting on this report, the signatories to the *Chesapeake 2000* agreement generally agreed with GAO's recommendations.

- Senate Report 109-275 – Department of the interior, environment and related agencies appropriations bill 2007. The Committee directs EPA to submit an annual performance assessment of progress made on this action plan. The Committee further directs EPA to publish and widely circulate within 6 months of the date of enactment of this act and annually thereafter a 'tributary report card' to evaluate progress…
- Tributary strategies: The Chesapeake BHHI in conjunction with the entire indicator and communication redesign processes is recognized as an important component of tracking and monitoring progress of the Maryland Tributary Strategies (see: http://www.dnr.state.md.us/bay/tribstrat/implementation _plan.html).

Goals

The following goals are a subset of those established by the Indicator Redesign Taskforce, and those approved at the April 2005 Implementation Committee meeting.

- Develop an integrated ecosystem health assessment for the Bay and its tidal tributaries using the identified reporting indicators and top-level indices.
- Create a ranking valuation scheme to compare ecosystem health assessments both geographically and over time (annual assessments).
- Effectively communicate the integrated ecosystem health assessments with spatially explicit maps and rigorous scientifically based analyses to the Chesapeake Bay community (i.e., products prepared for inclusion into the annual health and restoration report).

Comparing the BHHI to the impaired water assessment (303d listing process)

The Bay Habitat Health Index directly compliments state listings of impaired waters (303d) by providing the public with insights behind a tributary's water quality and biological impairments. Whereas the states' 303(d) lists strictly indicate whether a tidal segment is impaired, the Bay Habitat Health Index provides additional information about the relative health of these tidal habitats. Moreover, the Bay Habitat Health Index identifies the year-to-year variations in habitat quality that are not provided by the 303(d) assessment process.

Table 1: Comparison between the Bay Habitat Health Index and the impaired waters assessment.

	Bay Habitat Health Index	**Impaired water assessment (303d list)**
Rationale	Provide a simple, geographically explicit snapshot of the previous year's Bay health, with the aims of providing a timely, synthetic health assessment for each major waterway in Chesapeake Bay.	Undertaken to meet the requirements of the Clean Water Act of 1972. The CWA requires States to: 1) develop water quality standards for all surface waters; 2) monitor these waters; and 3) identify and list those waters not meeting water quality standards.
Thresholds / criteria	Thresholds based on published reference community values. Thresholds chosen are: - Indicative of good ecosystem health. - Based published reference values. - Consistent between parameters. - Set at a levels that enable a measurable response between years. - Provide a status assessment rather than the final goal of the restoration process.	- Water quality standards developed for separate designated uses within Chesapeake Bay. - Water quality criteria established to protect designated uses.
Timeframe	- Based on one year time period. - Previous year data only.	- Conducted every two years. - Based on previous 3 years of data.
Spatial unit	Only 15 reporting regions throughout the entire Bay. These regions align with the tributary strategy regions.	Conducted at CBP segment scale and, accordingly, has a large number of spatial units.

Approach

The proposed approach builds upon the methods and analysis undertaken for the annual health and restoration report (www.chesapeakebay.net/assess/index.htm), and those published by Pantus and Dennison (2003). The draft report card included the following three interrelated products and analyses aimed at meeting these goals: 1) spatially explicit interpolator maps of several water quality parameters, 2) a WQI map and 3) the BHHI. This supporting documentation will address each of these products separately.

To be consistent with the established reporting approach any index should be based on:

1) The previous year's data. The purpose of the report is to provide a timely assessment of the previous year's health. For this reason, all indices should be based on data collected in the previous year only. Most currently used indicators are based on the water year (October 1st to September 30th).

   Why this approach?

   Annual assessment and reporting has several advantages because this: (i) includes only one seasonal cycle, (ii) enables easy comparison to previous years and previous year stressors such as nutrient loads, flow or point source discharge and (iii) forces delivery and communication of data/information in a familiar timeframe that is relevant to the target audience.

2) Established reporting-level indicators. It is recognized that not all reporting-level indicators can be included since they may not be completed (i.e., wetlands), have the required spatial detail (e.g., most fisheries indicators) or have timely data availability (e.g., fish toxicant indicator).

   Why this approach?

   The indicator framework was developed specifically to provide indicator structure and hierarchy. Reporting-level indicators were chosen to provide the most pertinent information to the target audience. Including indicators other than those identified as "reporting-level indicators" would diminish the logical framework, resulting in increased complexity, misinterpretation and a confused audience.

3) Reporting progress towards established goals or thresholds.

   Why this approach?

   Reporting progress towards established goals or guidelines (i) capitalizes on the substantial effort undertaken to develop thresholds, (ii) provides direct local assessment of progress towards the thresholds and thus effectiveness of management actions, (iii) provides consistency between indicators and enables production of defendable and simple index values, and (iv) avoids subjectivity in index grades.

Indicator selection

The indicators to be included in the BHHI maps and WQI need to be consistent with those used in the Chesapeake Bay 2005 Health and Restoration Assessment (EPA 2005; http://www.chesapeakebay.net/assess/index.htm, Table 2).

Table 2: Current reporting-level indicators as they appear in the Chesapeake Bay 2005 Health report

Water quality	Habitat and lower food web	Fish and Shellfish
Dissolved oxygen	Bay grasses (SAV)	Blue crab
Clarity (Secchi depth)	Phytoplankton (Phytoplankton IBI)	Oyster
Chlorophyll *a*	Bottom habitat (Benthic IBI)	Striped Bass
Chemical contaminants	Tidal wetlands*	Shad
		Menhaden*

* Not quantified in 2005

Unfortunately, not all indicators can be included at this stage because some are still being developed (tidal wetlands and Menhaden), and others are not suitable for including in a BHHI. Indicators currently not suitable for the BHHI are:

- Chemical contaminants: Timeframe not suitable. Indicator based on data spanning from 1995 to 2003. Update frequency is every two years. Not all tributaries assessed every two years. Some major tributaries not included (e.g., Rappahannock River).
- Blue Crab: Bay-wide goals and assessment only.
- Striped Bass: Bay-wide goals and assessment only.
- Shad: Current indicator based on Susquehanna River / Conowingo dam data only. Fish passage work group working towards indicators and goal for greater number of tributaries.
- Oyster abundance: Bay-wide goals and assessment only.

Based on this assessment, the indicators proposed for inclusion in the 2006 BHHI and maps are presented in Table 3. As other indicators become available or suitable for inclusion in subsequent years they may also be included.

Table 3: Proposed indicators for inclusion in the 2006 BHHI and spatially explicit maps.

Water quality	Habitat and lower food web
Dissolved oxygen	Bay grasses (SAV)
Water Clarity (Secchi)	Phytoplankton-IBI
Chlorophyll *a*	Benthic-IBI

Reporting regions

Reporting regions are discrete regions of the Bay used for reporting and analysis. While the Bay is currently divided into 78 segments, reporting the status of each is too complicated for the purposes of providing an educational and spatially explicit communications product. Therefore, segments were grouped into larger, easily communicable reporting regions that have sufficient data to analyze spatially and incorporate into the BHHI (Table 4, Figure 2).

Table 4. Summary of data currently available for each of the proposed reporting regions

Reporting region	CBP segments included	Total surface area (km^2)	Proportion of total reporting area (%)	Number of water quality stations	Number of phytoplankton stations	Number random benthic stations
Upper Bay	CB1TF, CB2OH, CB3MH	788	6.7	8	2	25
Mid Bay	CB4MH, CB5MH	2383	20.3	17	2	13
Lower Bay	CB6PH, CB7PH,, CB8PH, MOBPH, LYNPH, PIAMH	3109	26.4	20	4	16
Patuxent River	PAXMH, PAXOH, PAXTF	126	1.1	10	3	25
Potomac River	ANATF, MATTF PISTF, POTMH POTOH, POTTF, MATTF	1275	10.8	11	3	25
Rappahannock River	CRRMH, RPPMH RPPOH, RPPTF	403	3.4	12	3	25
York River	MPNOH, MPNTF PMKOH, PMKTF YRKMH, YRKPH	211	1.8	8	3	25
James River	APPTF, CHKOH JMSMH, JMSOH JMSPH, JMSTF	640	5.4	13	3	22
Elizabeth River	EBEMH, ELIPH LAFMH, SBEMH WBEMH, ELIMH	47	0.4	12	1	28
Upper Eastern Shore	CHSMH, CHSOH CHSTF, EASMH, SASOH, BOHOH, NORTF, ELKOH, C&DOH	474	4.0	8	0	12
Choptank River	CHOMH1 & 2, CHOOH, CHOTF LCHMH	430	3.7	4	2	6
Lower Eastern Shore	TANMH, NANMH NANOH, NANTF POCTF, POCOH POCMH, HNGMH BIGMH, MANMH WICMH, FSBMH	1482	12.6	11	0	11
Patapsco River	PATMH, BACOH	110	0.9	2	1	11
Upper Western Shore	MIDOH, GUNOH BSHOH	88	0.8	3	-	-
Lower Western Shore	MAGMH, SEVMH SOUMH, RHDMH WSTMH	100	0.9	5	-	-

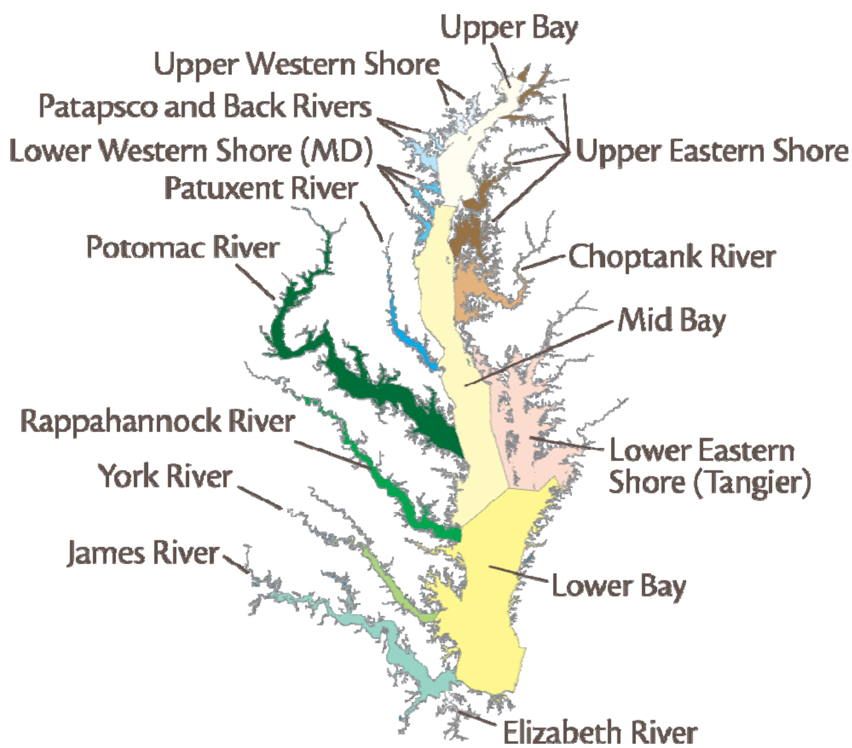


Figure 2. BHHI reporting regions.

Methods - Water Quality Index (WQI)

Data and site selection

Data for the WQI are derived from approximately 144 fixed stations that are sampled bi-monthly to monthly throughout the year (12 to 20 samples) in Chesapeake Bay (Figure 3). Data from the shallow water monitoring program data can eventually be included as the assessment methods are refined.

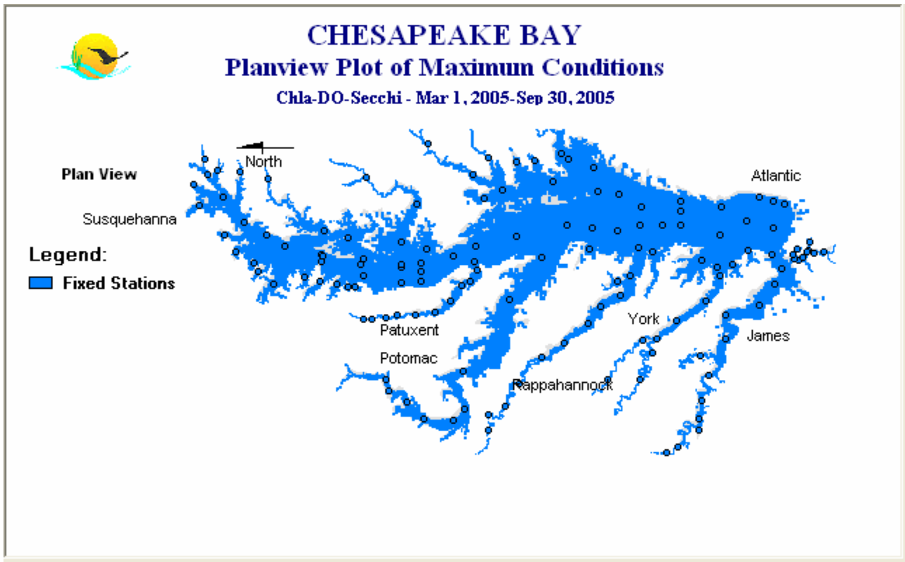


Figure 3. Locations of fixed-stations used for the collection of water quality data in Chesapeake Bay.

Water quality maps

Spatially explicit maps of water clarity, dissolved oxygen and chlorophyll-a will be based on the bi-monthly to monthly fixed-station data (mid-channel, open water). The means of each sampling station during the defined time periods (i.e., the established growing season or season of interest for that parameter) were interpolated to generate a single map for each parameter that represents typical conditions. These are: March 1 – September 30 for chlorophyll-a, June 1 - September 30 for dissolved oxygen, and April 1 – October 31 (Tidal fresh (TF), Oligohaline (OH), and Mesohaline (MH) zones) and March 1 – November 30 (Polyhaline (PH) zone) for Secchi depth. Interpolations between stations were done using spatial interpolator software developed for the Bay Program (Bahner, 2006). Chlorophyll-a was interpolated using a natural log (ln) parameter transformation and the 2-D octant search (Figure 4), dissolved oxygen (DO) with no transformation and a 3-D inverse distance-squared function (Figure 5), and Secchi depth with no transformation and a 2-D inverse distance squared function (Figure 6). Interpolation figures will be imported into ArcMap software where data ranges, scales, etc. will be added.

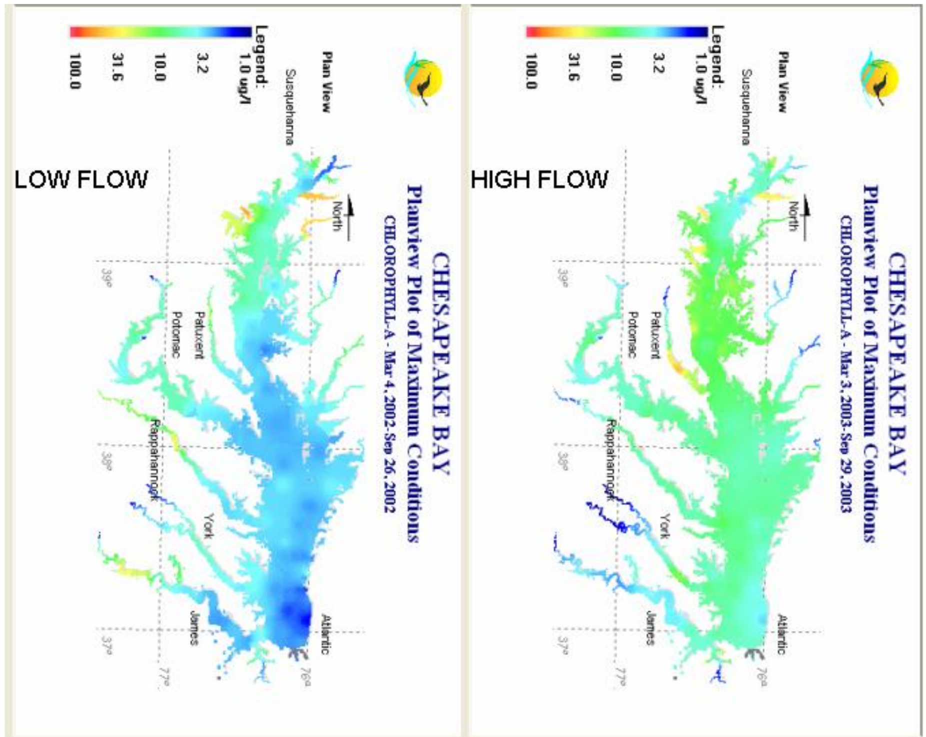


Figure 4. Spatial interpolations of mean chlorophyll-*a* concentrations for 2002 and 2003 (low and high flow years, respectively).

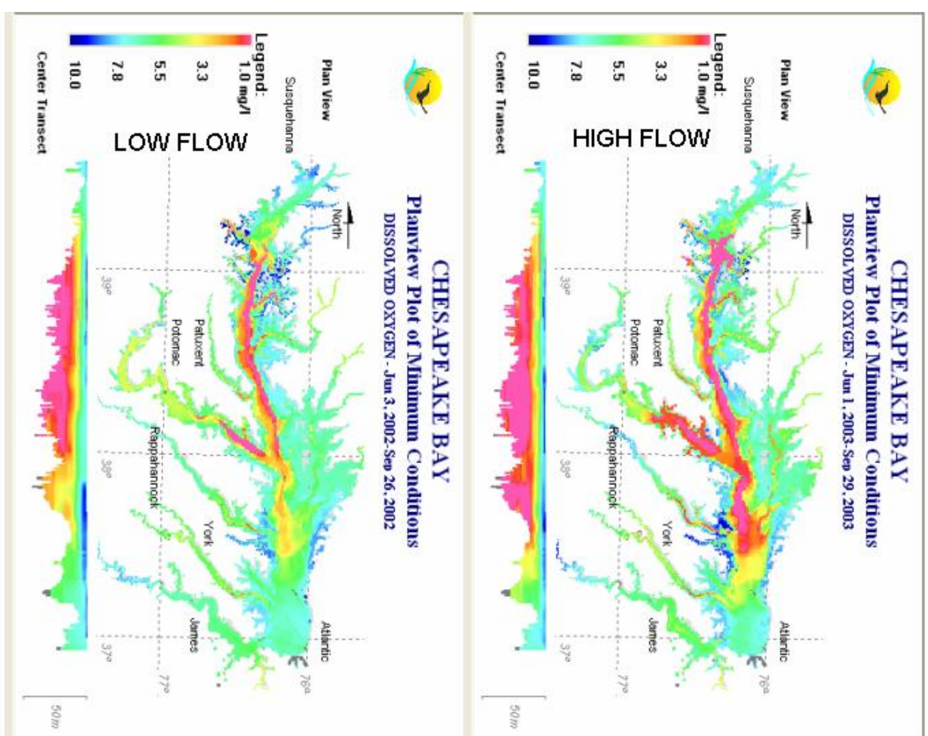


Figure 5. Spatial interpolations of mean dissolved oxygen concentrations for 2002 and 2003 (low and high flow years, respectively).

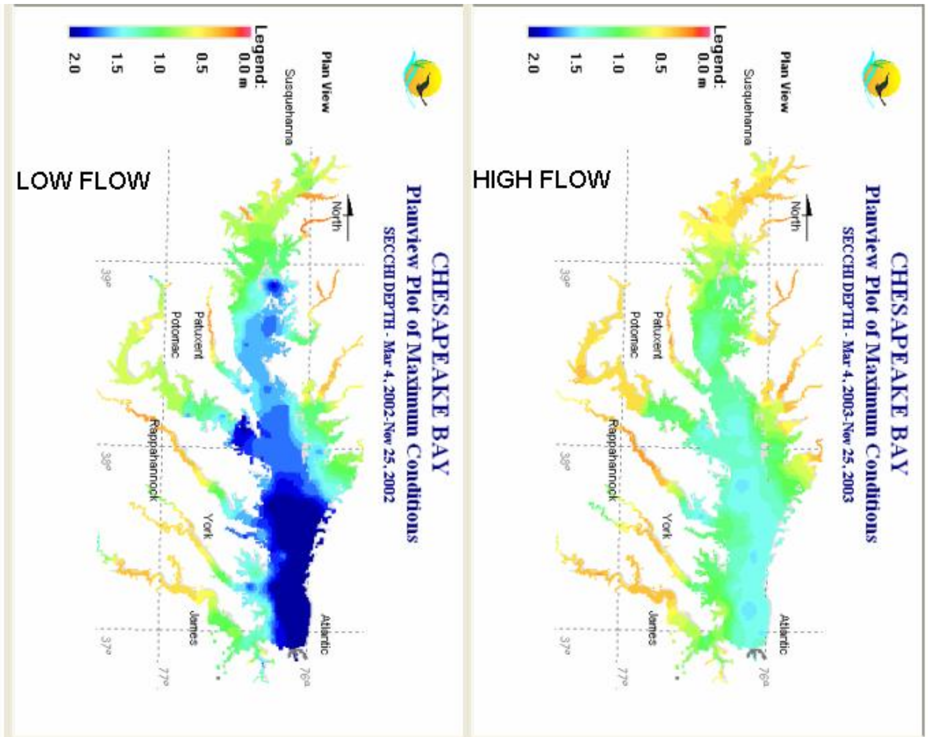


Figure 6. Spatial interpolations of mean Secchi depths for 2002 and 2003 (low and high flow years, respectively).

Sensitivity Analysis of the Water Quality Index

Water clarity (i.e., Secchi), dissolved oxygen and chlorophyll-a, and to a lesser degree SAV, are very responsive to inter-annual changes in nutrient and sediment loading. By contrast, B-IBI values are likely to require successive years of good water quality conditions to show improvement and eventually meet restoration goals. Because nutrient loads in 2002 approximated the 175 and 12.8 million pound restoration loading goals of nitrogen and phosphorus, respectively, and was consequently a year of relatively good water quality in the Bay, the parameters used in the WQI had distinct differences between 2002 and 2003 (shown above). Indeed, most of the Bay had relatively good water quality in 2002 (namely in the meso and polyhaline regions) in contrast to the wet year of 2003 that had N loads >2.5 times the nitrogen restoration loading goal and water quality conditions that were generally much worse than in 2002. Accordingly, data from the 2002-2003 water years were used in this analysis to help select the thresholds used for each parameter of the WQI and thereby improve its sensitivity to different flow and nutrient regimes.

Status thresholds

A number of different thresholds were explored to determine whether they were sensitive to variable flow and nutrient regimes (i.e., the low and high water years of 2002 and 2003), and several had good sensitivity. However, the thresholds were also chosen to have scientific rigor and an inherently clear association with the concept of ecosystem health. The final thresholds used for DO, chlorophyll-a, and Secchi depth were derived from respected scientific journals and publications (U. S. Environmental Protection

Agency, 2003; Lacouture et al., 2006; Buchanan et al., 2005), and are reproduced in Table 5.

Table 5. Thresholds used for each constituent of the Water Quality Index (WQI).

Chl-a Salinity Regime	Chl-a Season	Chl-a Reference Community Thresholds (μg L^{-1})*	Secchi Depth Salinity Regime	Secchi Depth Season	Secchi Depth Relative Status Thresholds (m)*	DO Designated Use	DO Season	DO Criteria Thresholds (mg L^{-1})‡
Tidal Fresh	**Spring**	**≤14.0**	**Tidal Fresh**	**Apr-Oct**	**≥0.85**	**Open Water**	**Jun-Sept**	**≥5.0**
Oligohaline	**Spring**	**≤20.9**	**Oligohaline**	**Apr-Oct**	**≥0.65**	**Deep Water**	**Jun-Sept**	**≥3.0**
Mesohaline	**Spring**	**≤6.2**	**Mesohaline**	**Apr-Oct**	**≥1.63**	**Deep Channel**	**Jun-Sept**	**≥1.0**
Polyhaline	**Spring**	**≤2.8**	**Polyhaline**	**Mar-Nov**	**≥2.0**			
Tidal Fresh	**Summer**	**≤12.0**						
Oligohaline	**Summer**	**≤9.5**						
Mesohaline	**Summer**	**≤7.7**						
Polyhaline	**Summer**	**≤4.5**						

* Lacouture et al., Estuaries and Coasts (2006) & Buchanan et al., Estuaries (2005);
‡U. S. Environmental Protection Agency (2003)

Frequency of passing thresholds and WQI maps

To calculate the WQI, chlorophyll-a, DO and Secchi depth data over the appropriate growing season indicated above were downloaded from the CIMS data hub. Subsequently, the frequency that each parameter at each sampling station passed the threshold values in Table 4 (i.e., the ratio of passing values to the total expressed as a percent) was calculated. The frequency of each fixed station's data that passed their respective thresholds was determined for each parameter as described below:

- Chlorophyll-a: The available surface chlorophyll-a data over the period from March - September in 2002 and 2003 at each fixed station of the Bay was compared to the concentration threshold of the applicable season and salinity zone. Those samples with chlorophyll-a concentrations lower than the threshold concentrations passed, whereas those with higher concentrations failed, and the frequency that the total number of samples over the growing season passed was applied to that station and used in the interpolation (Figure 7).

- Dissolved oxygen: Dissolved oxygen concentrations were downloaded for each month over the period from June - September in 2002 and 2003; the DO values were then compared to the criteria concentrations for each applicable designated use (i.e., thresholds of 5, 3 and 1 mg L^{-1} in open water, deep water, and deep channel designated uses, respectively; refer to EPA 2003 for more information on designated use areas). Those samples with DO concentrations higher than the criteria concentrations in all applicable designated uses that pertained to that station passed, whereas those with lower concentrations in any designated use failed. The frequency of the number of samples passing in a particular designated use was weighted by the total number of samples in each respective designated use to obtain a mean frequency value for the sampling station. Subsequently, this mean frequency was used in the interpolation (Figure 8).
- Secchi depth: Secchi depth data over the period from April – October (TF, OH and MH zones) and March – November (PH zone) at each fixed station in 2002 and 2003 was compared to the Secchi depth threshold of the applicable salinity zone. Sampling stations with Secchi depths deeper than the threshold Secchi depth for its respective salinity zone passed, whereas those with shallower Secchi depths (i.e., more turbid) than the threshold failed, and the frequency that the total number of samples over the growing season passed was applied to that station and used in the interpolation (Figure 9).

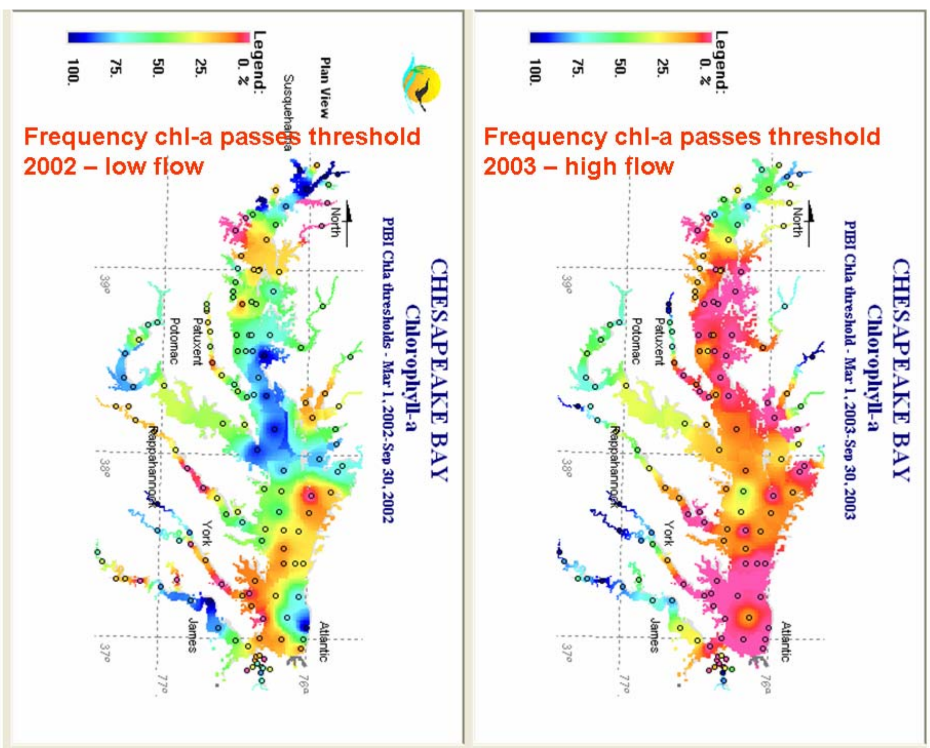


Figure 7. Spatial interpolations of the frequency of 2002 (low flow) and 2003 (high flow) chlorophyll-a concentrations passing threshold values.

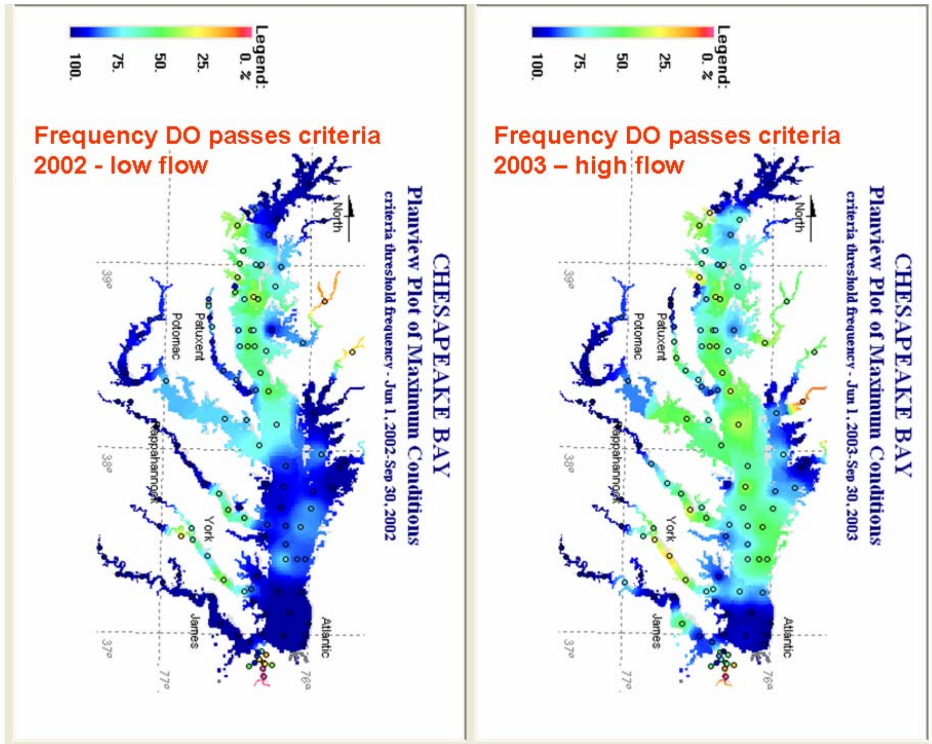


Figure 8. Spatial interpolations of the frequency of 2002 (low flow) and 2003 (high flow) dissolved oxygen concentrations passing criteria concentrations.

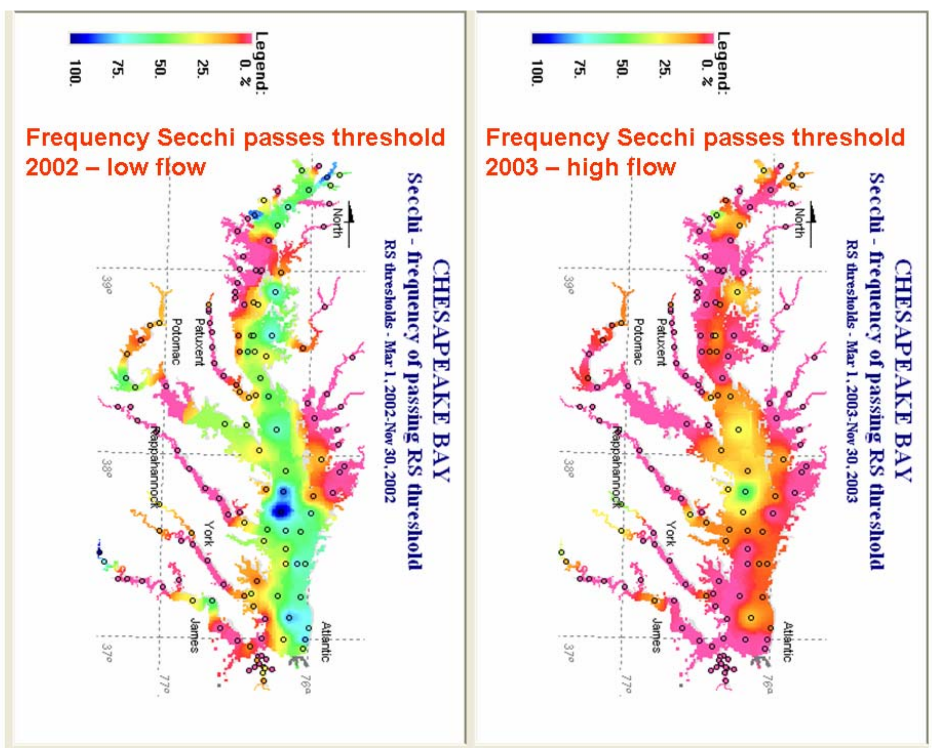


Figure 9. Spatial interpolations of the frequency of 2002 (low flow) and 2003 (high flow) Secchi depths passing threshold depths.

In this manner, the frequency of passing thresholds was attributed to each sampling station for all parameters. Subsequently, the WQI was calculated as the average of the three frequencies determined above for the water quality parameters. As for all the water quality parameters, interpolations between stations for the WQI maps were done using the spatial interpolator software developed for the Bay Program (Figure 10).

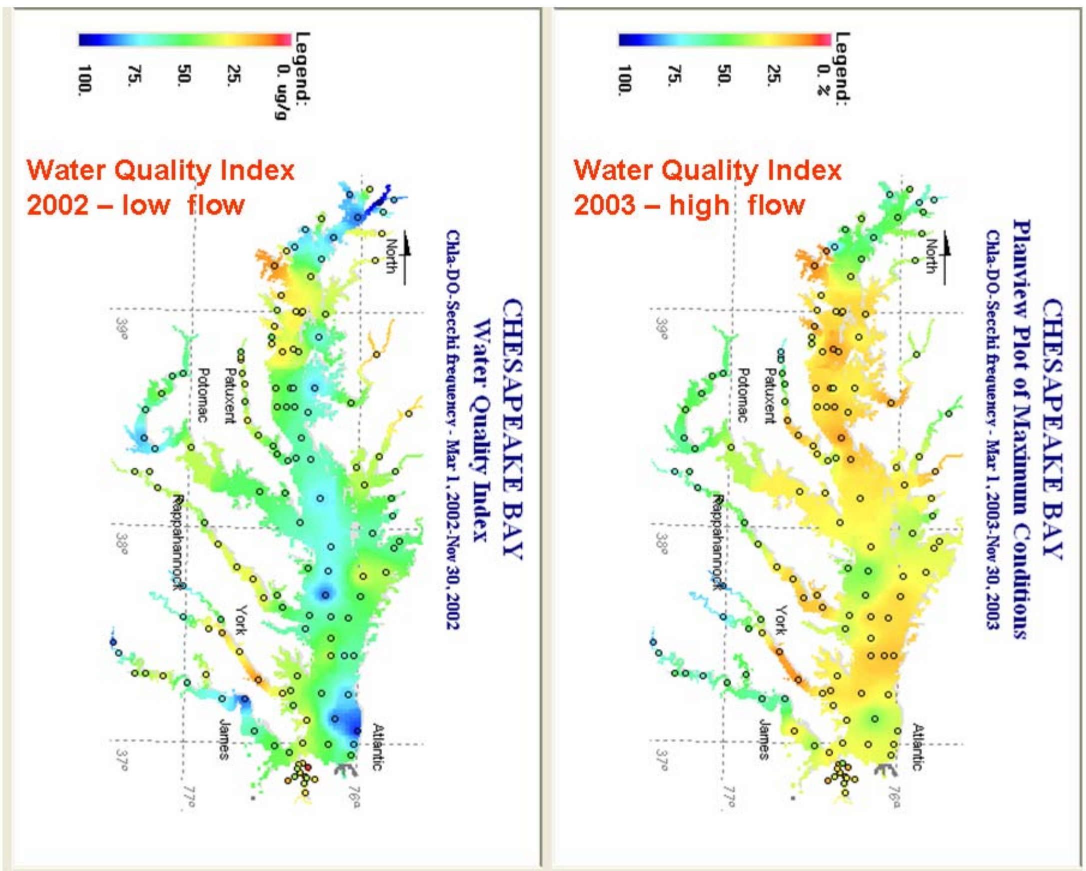


Figure 10. Spatial interpolations of the WQI values calculated for each of 144 sampling stations (% passing benchmark thresholds or criteria at each site) in Chesapeake Bay in 2002 and 2003.

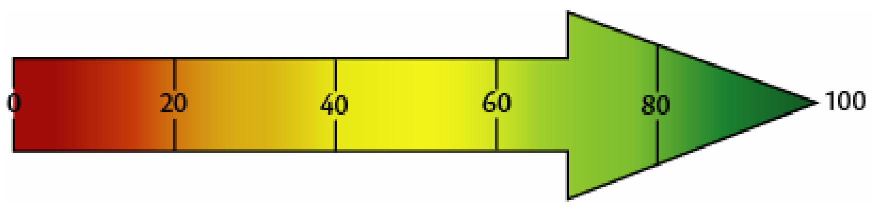
Developing WQI values for reporting regions

The WQI and associated frequency compliance (passing) values were generated for each reporting region. Compliance for each indicator was determined using the method indicated above. Once the WQI values were determined for each sampling station, all stations within a segment were averaged, and this mean was weighted by its respective segment area to determine a value for each reporting region (Table 6).

Table 6. Water Quality Index (WQI) values for Chesapeake Bay (2002 and 2003) ranked in ascending order from the worst (dark red) to the best water quality (green). The WQI was calculated as the average of chl-a, DO, and Secchi compliance in each reporting region weighted by its respective segment area.

2002 data Reporting Regions	2002 Chl-a	2002 DO	2002 Clarity	2002 WQI
Lower West Shore	2	54	0	18.4
Patapsco	0	57	0	19.1
Elizabeth	34	45	14	31.0
York	25	67	5	32.2
Patuxent	39	71	7	39.4
Rappahannock	32	84	11	42.0
Lower East (Tangier)	64	94	7	54.6
Upper Bay	52	82	30	54.8
Potomac	63	80	27	56.5
James	55	100	15	56.6
Lower Bay	29	95	47	57.0
Upper West Shore	51	92	29	57.3
Upper East Shore	50	78	49	59.0
Mid Bay	65	77	45	62.3
Choptank	70	83	49	67.2

2003 data Reporting Regions	2003 Chl-a	2003 DO	2003 Clarity	2003 WQI
Patapsco	0	48	0	16.1
Lower West Shore	0	62	0	20.7
Patuxent	13	59	4	25.2
Elizabeth	25	52	0	25.4
Choptank	4	73	0	25.8
Lower Bay	3	79	5	29.0
Mid Bay	13	61	18	30.6
Lower East (Tangier)	11	82	6	33.0
Upper East Shore	12	73	16	33.7
York	40	57	7	34.6
Rappahannock	19	80	7	35.7
Potomac	37	73	6	38.7
Upper Bay	43	80	6	42.9
James	50	85	3	45.9
Upper West Shore	44	100	7	50.4



Methods - Biotic Index

The biotic index combines the compliance measures of Submerged Aquatic Vegetation (SAV), Benthic-Index of Biotic Integrity (B-IBI) and the Phytoplankton-Index of Biotic Integrity (P-IBI). This section of the document will first describe methods used to calculate threshold compliance for each indicator and then describe how the compliance measures are combined to generate a Biotic Index (BI).

Submerged Aquatic Vegetation (SAV) compliance

Data selection and availability

Estimates of SAV cover for each the CBP segments were derived from annual aerial surveys of SAV done by the Virginia Institute of Marine Science (Orth et. al., 2005). Further information can be obtained from the VIMS website (www.vims.edu/bio/sav/).

SAV restoration goals

SAV restoration goals have been developed for most of the Bay segments, and were published in the Use Attainability Analysis in 2003 (EPA, 2003). However, restoration goals adopted by both VA and MD differ from those published in this document, so the updated acreages were used in this analysis. The restoration goal for each reporting region was determined by summing the restoration goals of all segments located within each reporting region (Table 7). The total of 148,946 acres is less than the 185,000 acres total restoration goal because the reporting regions used do not include all of the Chesapeake Bay Program segments.

Table 7: SAV restoration goal for each of the reporting regions

Reporting region	CBP segments included in region	SAV restoration goal by reporting region (acres)
Upper Bay	CB1TF, CB2OH, CB3MH	14,978
Mid Bay	CB4MH, CB5MH	18,436
Lower Bay	CB6PH, CB7PH, CB8PH, MOBPH, LYNPH, PIAMH	35,872
Patuxent River	PAXMH, PAXOH, PAXTF	1,954
Potomac River	ANATF, MATTF, PISTF, POTMH, POTOH, POTTF	21,203
Rappahannock R.	CRRMH, RPPMH, RPPOH, RPPTF	2,534
York River	MPNOH, MPNTF, PMKOH, PMKTF, YRKMH & PH	3,304
James River	APPTF, CHKOH, JMSMH, JMSOH, JMSPH, JMSTF	2,629
Elizabeth River	EBEMH, ELIPH, LAFMH, SBEMH, WBEMH	No Grow Zone
Upper East Shore	CHSMH, CHSOH, CHSTF, EASMH, SASOH, BOHOH, NORTF, ELKOH, C&DOH	12,866
Choptank River	CHOMH1, CHOMH2, CHOOH, CHOTF, LCHMH	13,953
Lower East Shore	TANMH, NANMH, NANOH, NANTF, POCMH, POCOH, POCTF, BIGMH, MANMH, WICMH, FSBMH, HNGMH	57,651
Patapsco River	PATMH, BACOH	389
Upper West Shore	MIDOH, GUNOH, BSHOH	3,661
Lower West Shore	MAGMH, SEVMH, SOUMH, RHDMH, WSTMH	1,811
TOTAL		**191,241**

SAV compliance assessment

SAV attainment is normally determined as the single best year of SAV acreage of the most recent 3-yrs of data compared to the restoration acreage in each segment. However, in this analysis, only annual data were used in order to standardize the time periods used for other parameters (i.e., 2002 and 2003). A percent compliance was calculated as the ratio of the sum of the SAV acreages for each segment in a reporting region to the sum of the SAV restoration goal acreages for the same segments. In cases where an existing SAV acreage exceeded the restoration goal acreage, that segment's SAV acreage was reduced to equal the restoration goal acreage. Although this occurred in only 15% of the total number of segments used in this analysis, doing so prevented artificially inflating SAV's compliance percentages for some reporting regions. Note that the alternative method of calculating the percentage of segments that meet their SAV restoration goals for each reporting region gives values of zero for all except the Upper Bay (57% of all segments), York (40%), and Patuxent (33%).

Benthic-IBI compliance

Data selection and availability

Data from the benthic monitoring program for Chesapeake Bay were used to calculate B-IBI values. This program contains two elements: a fixed station monitoring effort designed to identify temporal trends and a probability-based sampling effort intended to assess the aerial extent of degraded benthic community conditions. Only probability-based samples are used in this assessment. Sampling is conducted annually at 48 fixed stations and 250 stratified random sampling stations (Figure 11). Summer samples are collected between July 15 to September 30 (Llansó et al., 2005). The stratified random sampling station design is based on a slightly different strata than the reporting regions used for the BHHI. As a result, the location of the random stations in any given year may not be optimal for calculating the BHHI, perhaps necessitating statistical approaches for resolving insufficient data availability (discussed in more detail below). Detailed information on the B-IBI can be obtained from the Benthic Monitoring Programs website (http://www.baybenthos.versar.com/)

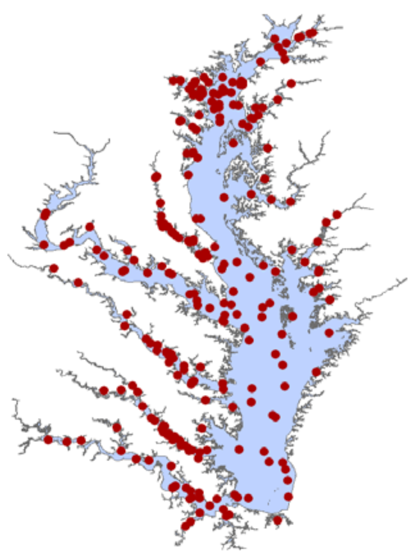


Figure 11. Location of Benthic Monitoring Program probability-based stations in 2005.

Benthic-IBI restoration goals

The Chesapeake Bay Program has adopted habitat-specific goals for the major benthic communities of the Chesapeake Bay. The benthic community restoration goals are quantitative expectations (for abundance, biomass, diversity, etc.) based on relatively unimpacted benthic communities in Chesapeake Bay. The goals are the criteria used to determine the extent of degraded habitat. The goals also provide a well-defined endpoint for restoration activities and permit intermediate determinations of progress (or lack thereof) in meeting water quality criteria. The Benthic IBI is used to measure goal attainment. The B-IBI is scaled from 1 to 5, and sites with values of 3.0 or more are considered to meet the restoration goals.

Benthic-IBI compliance assessment

The Chesapeake Bay B-IBI was developed to assess benthic community health and environmental quality. The B-IBI evaluates the ecological condition of a sample by comparing values of key benthic community attributes ("metrics") to reference values expected under non-degraded conditions in similar habitat types. It is therefore a measure of deviation from reference conditions.

The development of the Chesapeake Bay B-IBI has been described in Weisberg et al. (1997). In addition, a series of statistical and simulation studies were conducted to evaluate and optimize the B-IBI (Alden et al., 2002). The results of Alden et al. (2002) indicated that the B-IBI is sensitive, stable, robust, and statistically sound. New sets of metric and threshold combinations for the tidal freshwater and oligohaline habitats were also developed in Alden et al. (2002) with a larger dataset than was available to Weisberg et al. (1997) for these two habitats.

The Chesapeake Bay B-IBI is calculated by scoring each of several attributes of benthic community structure and function (abundance, biomass, Shannon diversity, etc.) according to thresholds established from reference data distributions. The scores (on a 1 to 5 scale) are then averaged across attributes to calculate an index value. Samples with index values of ≥ 3.0 are considered to have good benthic condition and are indicative of good habitat quality.

To estimate the amount of area in a reporting region that meets the Chesapeake Bay benthic restoration goals (p), we define for every site (i) in reporting region (h) a variable (y_{hi}) that has a value of 1 if the benthic community meets the goal, and 0 otherwise. For most reporting regions, the estimated proportion of area meeting the goals, p_h, and its variance is calculated as the mean of the y_{hi} values and their variance. For some reporting regions, estimates were calculated for subregions and these were then combined using the proportion of area as a weighting factor.

Phytoplankton IBI compliance

Data selection and availability

Development of the multi-metric Phytoplankton-Index of Biotic Integrity (P-IBI) for Chesapeake Bay is described in Lacouture et al. (2006). P-IBI scores are derived from the Virginia and Maryland Phytoplankton Monitoring Program Data (see the Data Hub on www.chesapeakebay.net/data/index.htm for more details). Data are collected 12-13 times a year at 25 fixed stations (Figure 12). Biomonitoring stations are assumed to represent the segment in which they are located because each segment has a characteristic salinity and hydrography. Not all segments are sampled, so we must also assume that the total area of segments with biomonitoring stations (8,364.18 km^2) is representative of the total area of Bay tidal waters (11,665.84 km^2). P-IBI scores are calculated for each station-date sampling event during a six-month index period: March, April, and May (spring) and July, August, and September (summer).

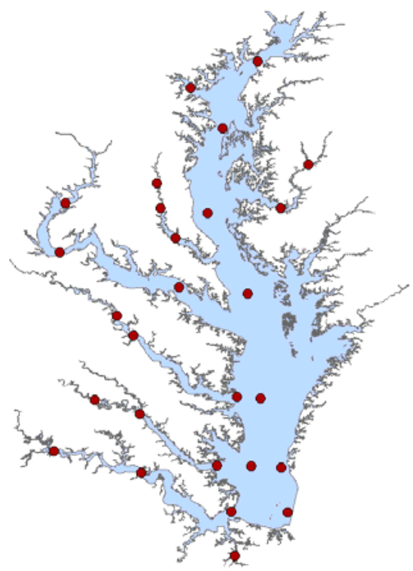


Figure 12. Location of phytoplankton monitoring survey stations in 2005.

Phytoplankton-IBI restoration goals

High P-IBI scores are associated with water quality conditions that are not impaired by excess dissolved inorganic nitrogen (DIN), excess ortho-phosphate (PO_4), or inadequate (stressful) light levels for phytoplankton photosynthesis (Figure 13). The Chesapeake Bay Program (CBP) Living Resources Subcommittee (LRSC) approved a PIBI interim goal of 4.0 on a 1.0 - 5.0 scale at its January 26, 2006 meeting. There is a large degree of certainty that phytoplankton communities with P-IBI scores between 4.0 and 5.0, or P-IBI $\geq$ 4.0, represent a high level of biological integrity. Metrics comprising the index are scored 5, 3, or 1, so at least half of the metrics score 5 (highly similar to reference community) and few or none score 1 (highly similar to degraded community) when P-IBI $\geq$ 4.0.

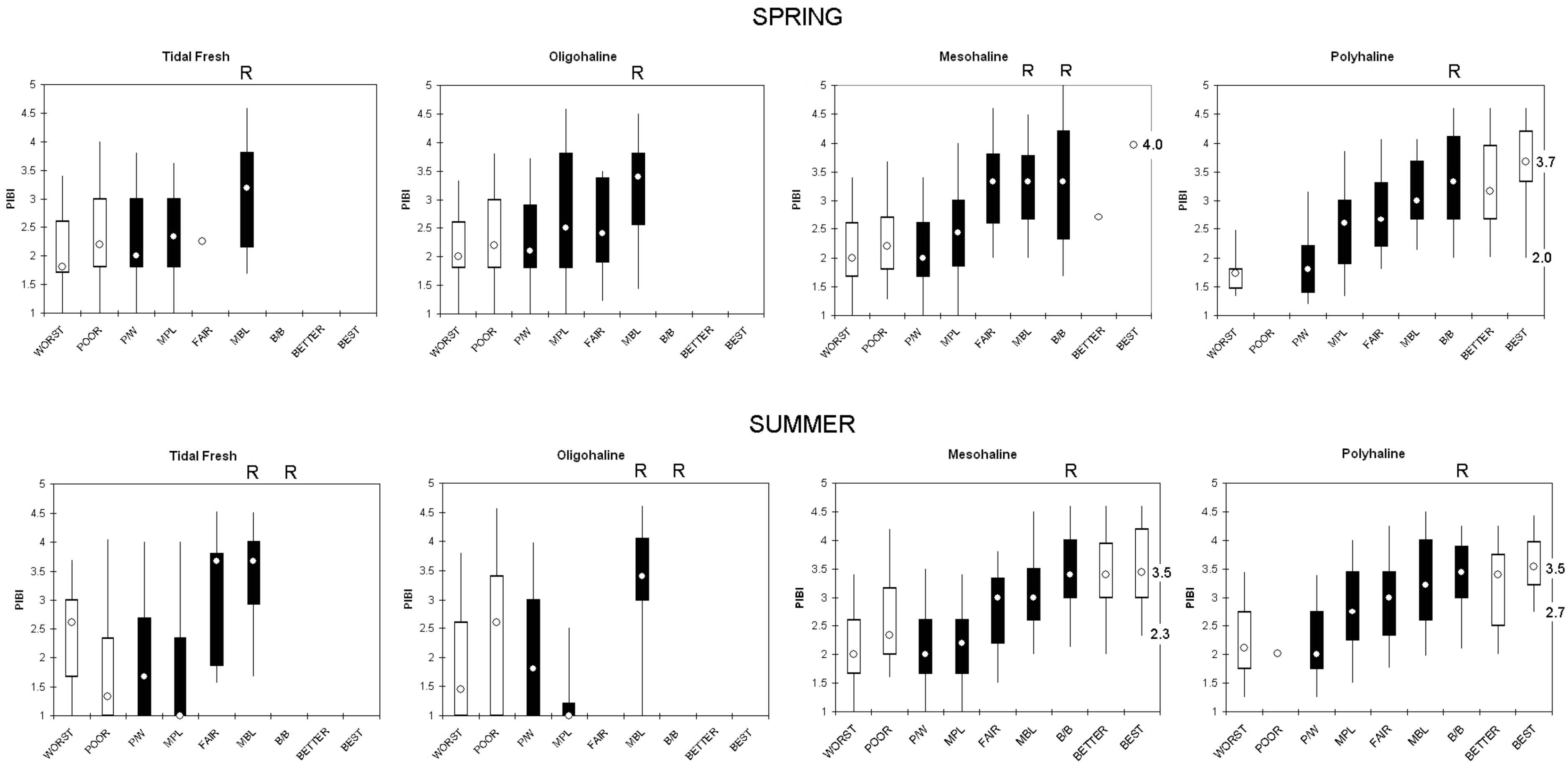


Figure 13. P-IBI distributions in water quality-based habitat categories in spring (March - May) and summer (July - September) for tidal fresh (0.0–0.5‰), oligohaline (>0.5–5.0‰), mesohaline (>5.0–18.0‰), and polyhaline (>18.0‰) salinities, 1984-2005. Water quality generally improves from left to right. The median (o), interquartile range (box), and 5^{th}% and 95^{th}% (whiskers) of the PIBI values are shown; only the median is shown if n is 5 - 9; the category is empty if n<5. Habitat categories with solid boxes: PW (Poor/Worst) = impaired conditions with excess DIN, excess PO_4 and inadequate water clarity; MPL (Mixed Poor Light) = inadequate water clarity and one or both nutrients bloom-limiting; Fair = borderline poor water clarity and near-limiting nutrients; MBL (Mixed Better Light) = adequate water clarity and one or both nutrients in excess; BB (Better/Best) = unimpaired conditions with bloom-limiting DIN and PO_4 and adequate water clarity. Open boxes: Worst and Poor are subsets of PW; Better and Best are subsets of BB. "R" indicates the habitat categories used with the 1984-2002 data to delineate reference communities (Buchanan et al., 2005).

In recommending an interim goal of 4.0, the LRSC chose a restoration goal that is commensurate with attaining Chesapeake Bay living resources habitat requirements and water quality criteria. Median concentrations of DIN, PO_4, chlorophyll *a*, and total dissolved solids (TSS) and water clarity associated with P-IBI scores $\geq$ 4.0 all meet the habitat requirements for growth and survival of SAV in nearshore areas of Chesapeake Bay and its tidal tributaries (Batiuk et al., 2000). Maximum chlorophyll *a* concentrations associated with P-IBI $\geq$ 4.0 are less than the criteria threshold of 27.5 $\mu g\ l^{-1}$ for toxic *Microcystis* algal blooms (U.S. EPA 2007). Fewer than 1% of data records with P-IBI $\geq$ 4.0 had chlorophyll *a* concentrations >15 $\mu g\ l^{-1}$ in the 1984-2005 biomonitoring station data set; the maximum concentration was 22.1 $\mu g\ l^{-1}$. Previous analysis of the 1984-2002 CBP data suggest P-IBI scores $\geq$ 4.0 will align well with attainment of the EPA recommended Chesapeake Bay water quality criteria for dissolved oxygen and water clarity (U.S. EPA 2003). Mean Secchi depths associated with P-IBI $\geq$ 4.0 are near or above the recently established water clarity criteria. Mean chlorophyll *a* concentrations associated with P-IBI $\geq$ 4.0 are near or below the model-simulated seasonal means estimated to characterize conditions supporting attainment of all dissolved oxygen criteria, except in spring oligohaline habitat.

P-IBI $\geq$ 4.0 are not uncommon despite Chesapeake Bay's overall degraded status. They occur in 435 (9.4%) of 4647 records from long-term CBP biomonitoring stations in the 1984-2005 data. Data analysis suggests the highest P-IBI values and their associated desirable water quality conditions are transient at this stage of the Bay rehabilitation. Segment monthly means can fluctuate two or more scale units in a year.

Phytoplankton-IBI compliance assessment

The LRSC did not establish how to calculate achievement of a P-IBI goal of 4.0 for the purposes of 1) ascertaining water quality criteria attainment or 2) communicating Chesapeake Bay health to the public. A method comparable to those used to report health of SAV and benthic invertebrate communities was selected by the Living Resources Analysis Workgroup (LivRAW). Individual P-IBI scores are evaluated against a threshold criterion of 3.0. Scores $\geq$ 3.0 pass; scores < 3.0 fail. More frequent sampling at some stations in some months, or at two stations in some segments, increases the accuracy of the calculated frequency. The annual frequency of passing scores in each CBP segment is area-weighted by the segment's aerial proportion of the reporting region in which it is located. Area-weighted frequencies are then summed to obtain an overall frequency of passing P-IBI scores in each reporting region.

The percentage of passing scores is placed on a 0% - 100% scale (see examples in Figure 14). Implicit in this method of presenting status is a goal of 100%, or all P-IBI scores pass the threshold criteria of 3.0. The goal of "all P-IBI passing a threshold criterion of 3.0" is very similar to the goal of a "mean P-IBI score equal or greater than to 4.0." When segment-years with 100% passing P-IBI scores are examined, the 161 scores in these segment-years have an overall mean of 3.73 (SD = .512) and a median of 3.67. The goal is also very similar the goal of "a P-IBI distribution not significantly different from that of the reference community." Reference communities in "best" habitat conditions (Figure 13) have an overall mean of 3.6 and a median of 3.67 (n = 65). The method selected to present P-IBI in the Biotic Index is therefore in general agreement with the LRSC recommended goal of P-IBI 4.0.

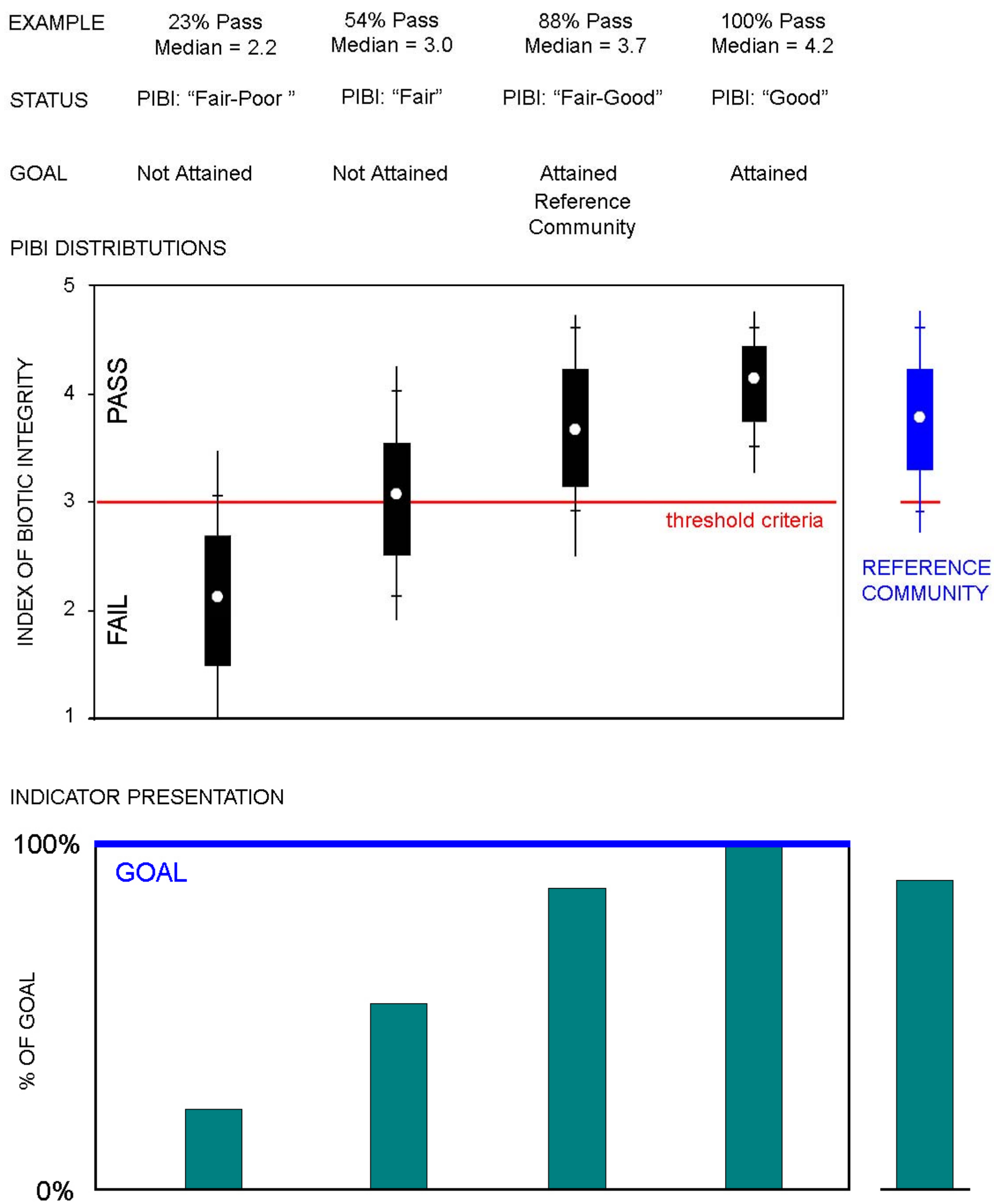


Figure 14. Four examples of different levels of achievement of the P-IBI goal: “100% P-IBI passing a threshold criterion of 3.0.” Status in the upper panel is determined by the median value of a station / segment / reporting region: 1 – 2, Poor; 2 - 2.67, Fair-Poor; 2.67 - 3.33, Fair; 3.3 – 4, Fair-Good; 4 – 5, Good (Lacouture et al., 2006).

Combining indices to generate the Biotic Index

The Biotic Index was calculated as the average of P-IBI, B-IBI and SAV compliance in each reporting region weighted by segment area (Table 8).

Table 8. Biotic Index (BI) for Chesapeake Bay in 2002 and 2003 ranked in ascending order from the least to most healthy regions. "NGZ" indicates the region is a SAV no-grow zone.

2002 data Reporting Regions	2002 P-IBI	2002 B-IBI	2002 SAV	2002 BI
Patapsco	0	27	2	**9.8**
Patuxent	18	36	17	**23.7**
James	17	50	21	**29.5**
Elizabeth	33	29	NGZ	**31.0**
Lower West Shore	no data	27	39	**33.3**
York	11	60	34	**34.9**
Potomac	41	28	47	**38.7**
Lower East (Tangier)	no data	48	43	**45.4**
Mid Bay	86	22	28	**45.5**
Upper West Shore	no data	68	29	**48.5**
Choptank	18	60	69	**49.1**
Upper East Shore	no data	67	35	**50.7**
Upper Bay	39	68	66	**57.4**
Rappahannock	56	52	70	**59.4**
Lower Bay	94	75	60	**76.3**

2003 data Reporting Regions	2003 P-IBI	2003 B-IBI	2003 SAV	2003 BI
Patuxent	8	24	18	**16.6**
Mid Bay	30	23	9	**20.7**
Choptank	12	31	27	**23.2**
Patapsco	10	63	2	**24.7**
Potomac	25	20	39	**28.1**
Rappahannock	38	48	3	**29.4**
Elizabeth	50	22	NGZ	**36.1**
York	57	16	35	**36.1**
James	54	35	24	**37.8**
Upper West Shore	no data	56	24	**39.8**
Upper East Shore	no data	67	22	**44.2**
Lower West Shore	no data	63	34	**48.1**
Upper Bay	41	56	52	**49.7**
Lower East (Tangier)	no data	76	25	**50.5**
Lower Bay	51	56	57	**54.6**

Methods – Bay Habitat Health Index (BHHI)

The Bay Habitat Health Index (BHHI) is the mean % of the WQ and Biotic Indices (i.e., both indices weighted equally). The BHHI for each reporting region (i.e., major tributaries and northern, mid and southern sectors of the Bay) was then binned and color coded into % ranges of 0-20% (red = Very Unhealthy), 21-40% (orange = Unhealthy), 41-60% (yellow = Average Health), 61-80% (light green = Moderately Healthy), 81-100% (dark green = Very Healthy). BHHI values ranged from 14 to 67 and 20 to 46 in 2002 and 2003, respectively. All reporting regions had higher BHHI values in 2002 (dry year) than in 2003 (wet year), except for the Patapsco and Lower Western Shore (Figure 15); values for the Elizabeth, James and York were similar. All of the 15 reporting regions had BHHI values below 50 in 2003. This analysis indicates that most reporting regions had relatively severe water quality impairments in 2003 (Tables 9 and 10), likely a result of the high N and P loads to the Bay this year.

Table 9. The Bay Habitat Health Index for Chesapeake Bay in 2002 ranked in ascending order from the least to most healthy regions. The BHHI was calculated as the mean of the WQI and BI in each reporting region.

2002 data Reporting Regions	2002 Chl-a	2002 DO	2002 Clarity	2002 WQI	2002 P-IBI	2002 B-IBI	2002 SAV	2002 BI	BHHI
Patapsco	0	57	0	19.1	0	27	2	9.8	**14.4**
Lower West Shore	2	54	0	18.4	**no data**	27	39	33.3	**25.9**
Elizabeth	34	45	14	31.0	33	29	**NGZ**	31.0	**31.0**
Patuxent	39	71	7	39.4	18	36	17	23.7	**31.6**
York	25	67	5	32.2	11	60	34	34.9	**33.6**
James	55	100	15	56.6	17	50	21	29.5	**43.1**
Potomac	63	80	27	56.5	41	28	47	38.7	**47.6**
Lower East (Tangier)	64	94	7	54.6	**no data**	48	43	45.4	**50.0**
Rappahannock	32	84	11	42.0	56	52	70	59.4	**50.7**
Upper West Shore	51	92	29	57.3	**no data**	68	29	48.5	**52.9**
Mid Bay	65	77	45	62.3	86	22	28	45.5	**53.9**
Upper East Shore	50	78	49	59.0	**no data**	67	35	50.7	**54.8**
Upper Bay	52	82	30	54.8	39	68	66	57.4	**56.1**
Choptank	70	83	49	67.2	18	60	69	49.1	**58.2**
Lower Bay	29	95	47	57.0	94	75	60	76.3	**66.7**

Table 10. Bay Habitat Health Index for Chesapeake Bay in 2003 ranked in ascending order from the least to most healthy regions.

2003 data Reporting Regions	2003 Chl-a	2003 DO	2003 Clarity	2003 WQI	2003 P-IBI	2003 B-IBI	2003 SAV	2003 BI	BHHI
Patapsco	0	48	0	**16.1**	10	63	2	**24.7**	**20.4**
Patuxent	13	59	4	**25.2**	8	24	18	**16.6**	**20.9**
Choptank	4	73	0	**25.8**	12	31	27	**23.2**	**24.5**
Mid Bay	13	61	18	**30.6**	30	23	9	**20.7**	**25.6**
Elizabeth	25	52	0	**25.4**	50	22	**NGZ**	**36.1**	**30.8**
Rappahannock	19	80	7	**35.7**	38	48	3	**29.4**	**32.5**
Potomac	37	73	6	**38.7**	25	20	39	**28.1**	**33.4**
Lower West Shore	0	62	0	**20.7**	**no data**	63	34	**48.1**	**34.4**
York	40	57	7	**34.6**	57	16	35	**36.1**	**35.4**
Upper East Shore	12	73	16	**33.7**	**no data**	67	22	**44.2**	**39.0**
Lower East (Tangier)	11	82	6	**33.0**	**no data**	76	25	**50.5**	**41.8**
Lower Bay	3	79	5	**29.0**	51	56	57	**54.6**	**41.8**
James	50	85	3	**45.9**	54	35	24	**37.8**	**41.8**
Upper West Shore	44	100	7	**50.4**	**no data**	56	24	**39.8**	**45.1**
Upper Bay	43	80	6	**42.9**	41	56	52	**49.7**	**46.3**

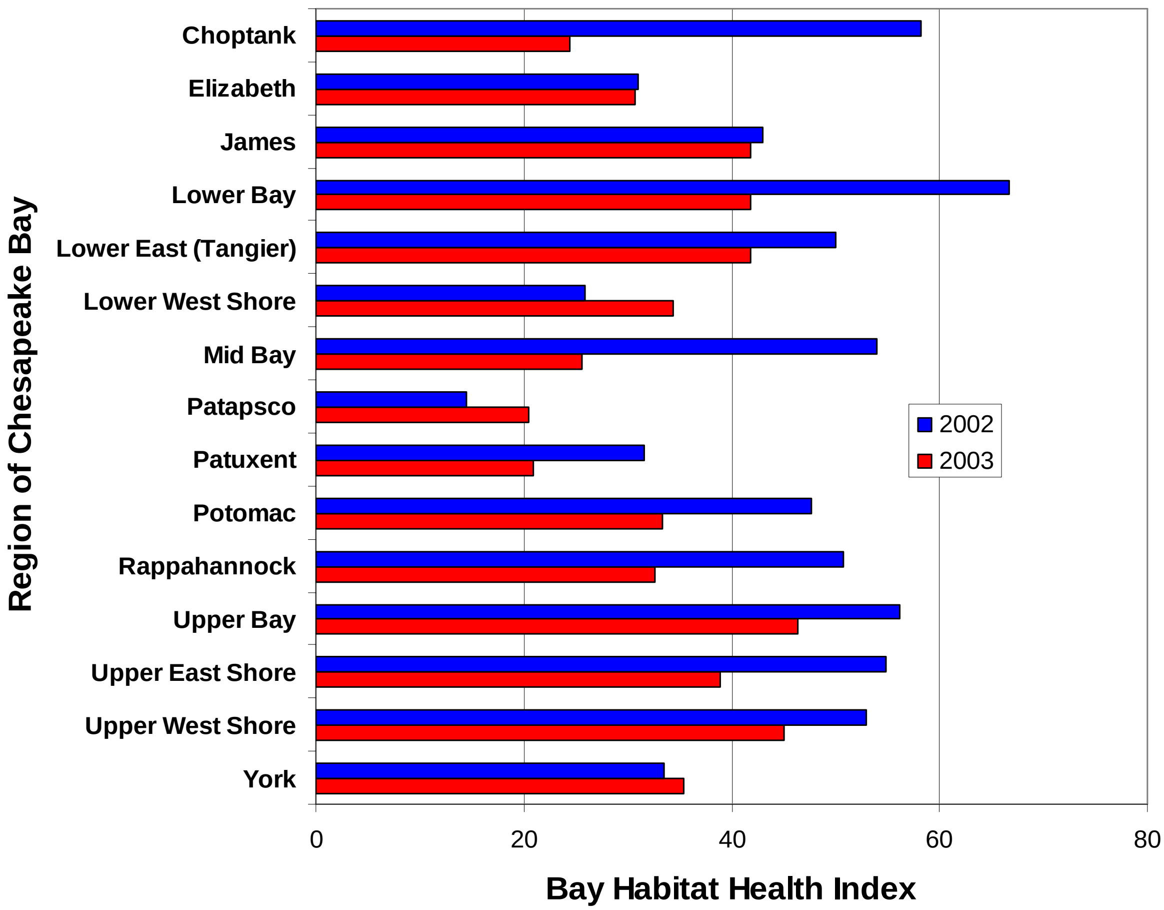


Figure 15. Comparison of the BHHI values for 2002 and 2003 in each reporting region.

Acknowledgements

The development of the BHHI has also benefited from the contributions of various TMAW and LivRAW members, particularly the chairs of both workgroups (Bill Dennison (UMCES) – TMAW and Bob Wood (NOAA) – LivRAW), and Jackie Johnson (ICPRB), Bruce Michael (MDDNR), Rick Hoffman (VADEQ), and Richard Lacouture (Morgan State Univ.).

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Document review

In addition to being reviewed by various Chesapeake Bay Program partners this document has also been reviewed by four external reviews (below). These reviews provided a solid basis from which future refinements will be based.

Reviewer: *Professor Barry Hart*
Director, Water Science Pty Ltd
63 Schoeffel Dr, Echuca
AUSTRALIA 3564

General

This is an excellent attempt to provide simple information on the 'health' of Chesapeake Bay that will be most useful for the general public.

I understand that this information will be presented in a simple report card on the Bay. I am great supporter of this form of reporting to the public, having been involved in both the Morton Bay (Queensland, Australia) and Gippsland Lakes (Victoria, Australia) report cards.

However, I have several reservations:

- As I understand it, the intention is to report annually – this is probably OK for the WQ indicators but what about some of the biological indices (e.g. seagrass)?
- There will be a huge loss of information in the attempt to provide on overall indicator (the BHHI). It might be better to produce an index such as the Index of Stream Condition (ISC) produced each 5 years in Victoria – this contains 5 combined indices – flow, riparian, channel habitat, WQ, biological. The ISC provides a score out of 50 (5x10) but retains the individual scores for the 5 components. (see http://www.vicwaterdata.net/isc/intro1.html).
- I don't follow why you wish to include the word 'habitat' in the title? Surely Bay Health Index is enough – the final index has only a small amount of information on habitat.
- I note that there is some attempt to address the question of sensitivity of each index – but after reading this I still do not have a clear impression of what the combined indices are sensitive to (from year to year), except flow (2002 vs 2003).
- There is a difference in approach in setting thresholds between biological indicators (use reference condition) vs WQ (values selected from somewhere?). Is it not possible to use the same approach for both? I really question the absolute values of some of the WQ thresholds – they seem very high (or very low).

Specific:

- Indicator selection: Surely the final indicator is reduced in effectiveness in that it does not include any fish or shellfish measures.
- Reporting regions: Not clear what criteria were used as the basis for the grouping. How were the upper, mid and lower Bay regions decided?

- Water quality maps: As a general observation I would question the use of mean values – is this the best measure to use? In assessing risk I would prefer to use 90%ile (or10%ile) values – although some of the values in Chesapeake (e.g. DO) can become extremely low. I would like to see a justification for adopting mean values and not some extreme measure as suggested above.
- Status thresholds:
    - I support the adoption of different thresholds for different salinity regimes.
    - I have not been able to check the references given, but find many of the thresholds are surprisingly high (Chl a) or low (DO) – e.g. a DO threshold of 1.0 mg/L for deep channels seems very low – I doubt any animals could live in this environment for long. Adoption of a low (or high) threshold will of course mean that there will be a greater compliance given the way your index is proposed. These thresholds need to be well chosen and on the basis of good ecological information. How do they relate to the EPA WQ criteria for ecosystem health?
    - I question the implied accuracy of some of these thresholds, e.g. a secchi of 0.85m implies an accuracy of 1/85 or around 1% (1 cm). Can this be justified?
- Frequency of passing thresholds and WQI maps
    - I am not comfortable with the use of pass/fail compliance – this hides much of the detail and assumes the threshold has no uncertainty.
    - It would be useful if you could find a way to also show the number of samples and perhaps some statistic that gives a measure of how far from the thresholds the yearly values were. E.g. assuming a threshold of <21 with the pass/fail being 80%, it is a much different result if the 20% that failed were in the range 22-25 compared with another situation where the range was 25-60.
    - I don't see that the combining of these three WQ indices helps, apart from giving one number rather than three.
    - Is there any scientific justification for assuming a linear combination of these 3 indicators?
    - Surely secchi and Chlorophylla are correlated so why combine.
    - The story needs some more comment on why other indices are not being used (e.g. nutrients).
- Developing WQI values for reporting regions
    - There seems something suspect about this linear combination of the averages of these three WQ indices – surely this will tend to smooth out variations. Is this what you want – a pass/fail of <u>average</u> conditions.
    - In the Australian WQ guidelines we adopted a more stringent comparison of mean of the indicator with the 80%ile of the reference condition situation – see Australian document.
    - Also I would recommend only quoting 2 significant figures for the WQI – a figure of 67.2 implies an accuracy of 1/672 or around 0.1% - can you justify?
- SAV indicator: I would like to see some comment (and evidence) on the sensitivity of this measure on an annual basis.
- Benthic-IBI restoration goals: I like the fact that the IBI approach is based on reference communities - why can't this reference site approach be used for other

indicators? Or are there no relevant reference sites for these? What is the rationale for the 3.0 threshold?

- Phytoplankton IBI (and other sections) Don't like the term pass/fail – since this assumes undue accuracy in the threshold – is there another term that could be used?
- Combining indices to generate the Biotic Index: Need some justification for the use of averages and the linear combination.

Combining indices to generate the Biotic Index: Need some justification for the use of averages and the linear combination. Unreasonable accuracy quoted for Biotic index. I doubt that readers will be able to interpret the tables – needs more explanation in the caption or as a footnote. Is it possible to show on this graph where the management agency wants to get to by certain dates – at present there is no long term goal. How should I interpret a BHHI of 40 compared with one of 60? How do I interpret 2002 vs 2003 – wet year is bad?

Reviewer: *Suzanne Bricker (PhD)*
NOAA, National Ocean Service,
National Centers for Coastal Ocean Science,
Silver Springs, MD

- In general I think this is a good idea, to use all the data that exists, or as much of it as possible, to provide the most comprehensive and complete assessment of Chesapeake Bay health that is possible. I like the idea also of combining the biotic and chemical indices for the same reason. And, comparison to the restoration criteria/goals is good so that we can see where we measure up and where we don't thus pointing us in the direction of where management efforts should be targeted.
- Conceptually I really like this, however, this document leave some explaining to be done. In particular, the idea should be introduced early that the BHHI is the average of the WQI and the BI and that the BI is made up of 3 components. The explanation of the WQI is fair enough but I got bogged down in the explanation of the three components of the BI and kind of lost the plot a little. It's pretty thick and some additional explanations should be made to help the reader along. This can be set up early and then followed through in the text later on. Also, there are some additional tables that might be useful for comparing the year to year changes. When this is done, it should be made clear that some changes are the result of weather patterns rather than "real" increases in loading…though the weather patterns do result in greater delivery of nutrients to the bay. Finally, I think a summing up at the end which talks a little about targeting management by using these tools would be really useful….would justify too the continuation of these assessments.
- Does it also indicate causes of changes/differences from year to year? If not, this should be added i.e. whether differences are a result of actual changes in load or whether they are a result of different weather/climate patterns i.e. wet vs dry years.
- The approach section should also tell (more clearly than it is) what the final outcome is : that you use an average of two indicators 1) the Water Quality Index and 2) the Biotic Index (which is a combination of SAV, Phytoplankton and Benthic Indices) to determine the overall integrated health of the Bay. Although most of the pieces are here, I got to the methods sections and was wondering about how it all hangs together. Introduce that in the beginning so the reader can go through knowing that

the pieces come together in the end. The other thing that is missing is where the restoration goals come from and that they are used as criteria….all of a sudden in the text they show up without much explanation…that should be introduced here too.

- One of the reasons for conducting annual assessment is stated as " enables easy comparison to previous years and previous year stressors such as nutrient loads". Total nutrient loads are notoriously difficult to estimate, how will this be accomplished on an accurate basis from year to year timeframes?, flow or point source discharge point sources are easier to estimate on small time scales.
- Data used to generate the water quality maps and the associated indices relates to very specific periods and not the whole year: How were the index periods determined? Are these from the EPA National Coastal Assessment? But there is annual data? Except only these time periods are used? Doesn't this narrow the amount of data for each station to something that isn't really that robust (ie if you have monthly sampling you'd have 12 samples which still isn't a lot but then to narrow it to these 7 months? You may want to say something about why you do this and how you keep enough to have a robust determination.
- The document often uses the terminology "Frequency of passing"` you may want to use a different word than pass since it's ambiguous…does it mean that the concentrations passed through the thresholds and are higher (Chl) or lower (secchi, DO) or that they passed in the sense that you pass/fail a class?? How about exceed? Or compliant? thresholds and WQI maps.
- Method used to area weight the index scores need to be more clearly explained; Based on the interpolated and sampled results? This really needs to be explained a bit more clearly.
- Suggest providing summary tables for each index (water quality, Biotic and bay habitat health index) that shows the area of the Bay that falls into each category for each year. E.g.

BHHI	2002 total area (percent area)	2003 total area (percent area)
Red		
Red/yellow Yellow		
green		
TOTAL AREA	11,666 sq km (100%)	11,666 sq km (100%)

Reviewers: *Mark Tedesco*
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General Comments

This is an important and worthwhile effort. The BHHI produced is easily understood and can be presented to the public in a variety of formats. One challenge is to truly integrate multiple indicators of ecosystem status. The inability to integrate fish and shellfish measures is one example and the consequences on the sensitivity and power could be further discussed in future drafts. Another is the lack of pathogen indicators (beach closing, shellfish harvesting, etc.). My view is that we (Long Island Sound included) tend to underemphasize these ecosystem measures that are directly important for human use. But these measures are certainly an integral aspect of ecosystem-based management using most commonly accepted definitions. There may be very good reasons for not including them and I sure those reasons have been discussed at length elsewhere. I mention it because I've had a nagging and guilty feeling that even since the EMAP work of the early 1990s and the recent NCA, even EPA has not done a very good job trying to integrate these important water quality measures.

Specific comments

- *"Indicator selection: Blue Crab not included due to lack of regionally specific goals and reporting:"* Reason why bay-wide goal is not adequate should be explained in the previous Approach section. Can these bay-wide fish and shellfish goals be combined with the other water and habitat and lower food web categories in a Bay-wide BHHI? This will not be spatially explicit but will produce a more integrated Bay-wide snapshot.
- *"Indicator selection: Oyster not included due to lack of regionally specific goals and reporting:"* Are there any plans for regional goals? If not, some discussion of the implications of not incorporating fish and shellfish indicators would be helpful.
- *"Sensitivity Analysis of the Water Quality Index: …the parameters used in the WQI had distinct differences between 2002 and 2003."* How does the flow and nutrient loading from 2002 and 2003 compare to longer term averages? Just how low and high a water year were they?
- *"SAV restoration goals have been developed for most of the Bay segments, and were published in the Use Attainability Analysis in 2003 (EPA, 2003). However, restoration goals adopted by both VA and MD differ from those published in this document, so the updated acreages were used in this analysis:"* These restoration goals are different from water quality criteria or benthic reference conditions in that they are not, necessarily, established to attain a designated use or represent a reference condition. I'm not familiar with the details of the UAA or the VA/MD SAV restoration target development, so the targets may have been established with consideration of ecosystem needs or reference conditions. The Long Island Sound restoration targets reflect the practicalities of achieving restoration than a specific analysis of ecosystem functions or needs.
- *"Phytoplankton-IBI restoration goals: High P-IBI scores are associated with water quality conditions that are not impaired by excess dissolved inorganic nitrogen (DIN), excess ortho-phosphate (PO_4), or inadequate (stressful) light levels for phytoplankton photosynthesis".* Some information on the metrics in the P-IBI would be helpful, similar to the level of detail provided in the B-IBI introduction.

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- *"Methods - Water Quality Index (WQI) Data and site selection. Data for the WQI are derived from approximately 144 fixed stations that are sampled bi-monthly to monthly throughout the year (12 to 20 samples):"* Is the initial choice of stations random?

- *"Water quality maps: Spatially explicit maps of water clarity, dissolved oxygen and chlorophyll-a will be based on the bi-monthly to monthly fixed-station data (mid-channel, open water)."* I'm a bit unclear here. The sampling design properly addresses what is occurring across the regions. However, you can't assess condition at local scales since the variation is associated with the regional design. Was there any consideration of conducting some hierarchical subsampling?
- *"Water quality maps: Spatially explicit maps of water clarity ….and Secchi depth with no transformation and a 2-D inverse distance squared function (Figure 6)."* Another issue to consider with this approach is that in reality these measurement have a high amount of spatial co-variation. In other words their impact is strongly correlated with the sampling scale that you choose. If you use one scale you over or underestimate the impact of any of these variables.
- *"Developing WQI values for reporting regions: Once the WQI values were determined for each sampling station, all stations within a segment were averaged, and this mean was weighted by its respective segment area to determine a value for each reporting region (Table 6)."* The scale issue has been dealt with here but how do you deal with sample size imbalance? This seems a bit unclear. Even though you have sub-sampled the variation in the measurements is still associated with a regional scale design.
- *"SAV restoration goals have been developed … The total of 148,946 acres is less than the 185,000 acres total restoration goal because the reporting regions used do not include all of the Chesapeake Bay Program segments."* Why this number? Is this the minimum threshold for meeting some basic ecosystem service requirement?
- *"Benthic-IBI compliance, Data selection and availability: …Summer samples are collected between July 15 to September 30 (Llansó et al., 2005):"* This seems to be a slightly different sampling approach from measurements of water quality sampling. Will this affect how you interpret the two when making an overall assessment of environmental quality?
- *"Benthic-IBI compliance, Data selection and availability: The Chesapeake Bay B-IBI is calculated by scoring each of several attributes of benthic community structure and function (abundance, biomass, Shannon diversity, etc.)"* Shannon Index does a good job for single species across a large (global) region. Did you also look at the Simpson Index? It tends to do a better job for multiple species in a specific habitat type. Also, why so many measurements? For example, biomass may just indicate you have a lot of one large species.