

Physicochemical Indicators of Stream Health for the Chesapeake Bay Watershed

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Purpose



This project conducted interviews with experts, reviewed data, created a framework, provided a data inventory matrix, and made recommendations that may help develop multi-metric stream health indicators for **physicochemical** parameters. The development of these additional indicators will address the significant science and management need to better understand and communicate how streams respond to management actions.

Stream Health Work Group Chesapeake Bay Program

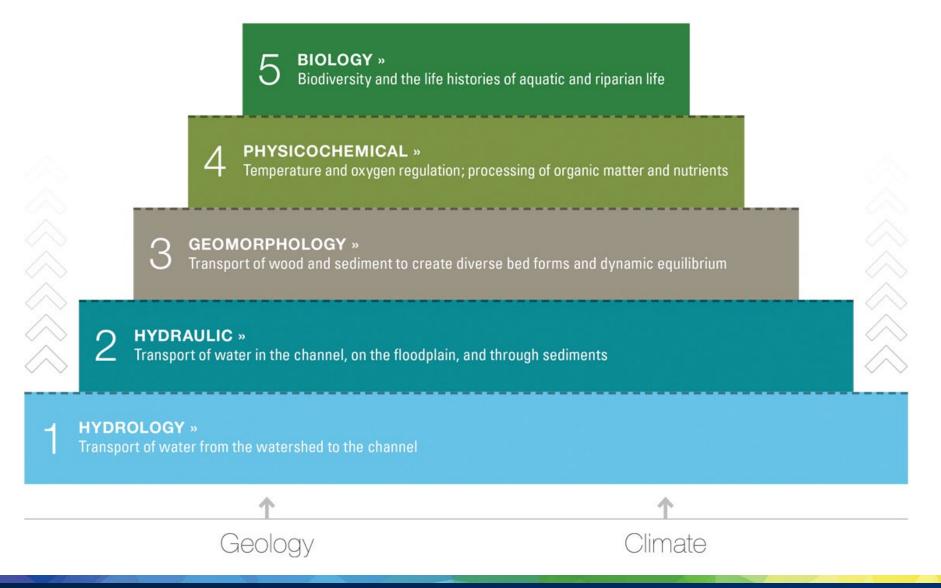
Holistic Approach



- Stream health is closely aligned with the Clean Water Act goal "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters"
- Important to recognize that physicochemical elements, and indeed all the components of stream health, interact within the watershed
- Both EPA and CBP have used a Healthy Watersheds conceptual framework that explicitly includes chemical and physical constituents of water quality as indicators of ecological health
- ➤Our approach focused on the near-term development of physicochemical indicators within **Level 4 of the Stream Functions Pyramid** in the context of supporting geomorphology, hydraulics, hydrology indicators, and landscape-scale indicators influencing the stream corridor

Stream Functions Pyramid





Interviews



- Interstate Commission on the Potomac River Basin (ICPRB)
- Maryland Department of the Environment (MDE)
- U.S. Geological Survey (USGS)
- U.S. EPA Region 3
- Fairfax County
- Virginia Department of Environmental Quality (VDEQ)
- CBP Stream Health Work Group (SHWG)

Literature Search



- General literature search to identify journal articles, reports, data, tools, and web information
- Search was conducted at a screening level (i.e., not comprehensive of all literature or resources available)
 - Targeted to capture key approaches and examples
- Information sources provided insights into the current state of the science
 - Assisted in developing the framework

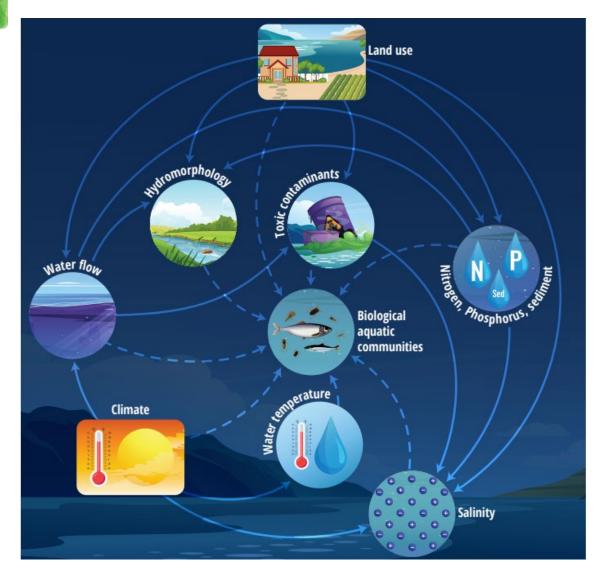
Select Physicochemical Stream Assessment Literature



- Surface water quality profiling using the water quality index, pollution index and statistical methods: A critical review
- A review of water quality index models and their use for assessing surface water quality
- Evaluation of the surface water quality using global water quality index (WQI) model perspective of river water pollution
- Water Quality Indices: Challenges and Application Limits in the Literature
- A comprehensive review of water quality indices (WQIs): history, models, attempts and perspectives

Stream Health Indicators







Landscape Condition

Patterns of natural land cover, natural disturbance regimes, lateral and longitudinal connectivity of the aquatic environment, and continuity of landscape processes.



Geomorphology

Stream channels with natural geomorphic dynamics.



Habitat

Aquatic, wetland, riparian, floodplain, lake, and shoreline habitat. Hydrologic connectivity.



Water Quality

Chemical and physical characteristics of water.



HydrologyHydrologic regime: Quantity and timing of flow or water level fluctuation. Highly dependent on the natural flow (disturbance) regime and hydrologic connectivity, including surface-ground water interactions.



Biological Condition

Biological community diversity, composition, relative abundance, trophic structure, condition, and sensitive species.



Relevant Data Sources



- Chesapeake Bay Program Data Hub
- SRBC: Water Quality and Biological Indices for the Susquehanna River Basin
- USGS: Data (nutrients, suspended sediment, flow, temperature, conductance, and toxics)
- USGS: Assessments of Stream Health Condition in the Chesapeake Bay Watershed
- EPA: Ecoregion Nutrient Criteria
- EPA: Water Quality Indicator (WQI) Tool
- EPA: Integrated Assessment of Healthy Watersheds
- University of Maryland Center for Environmental Science (UMCES): Eco Health Tool

Example Physicochemical Indicator Approaches



- SRBC: Water Quality and Biological Indices for the Susquehanna River Basin
- Pennsylvania DEP Water Quality Index using Land Use
- University of Maryland Center for Environmental Science (UMCES): Eco Health Tool
- Oregon Water Quality Index: Background, Analysis and Usage
- A Water Quality Index for Washington Ecology's Stream Monitoring Program
- EPA Water Quality Assessments for Watershed Health

Key Physicochemical Parameters

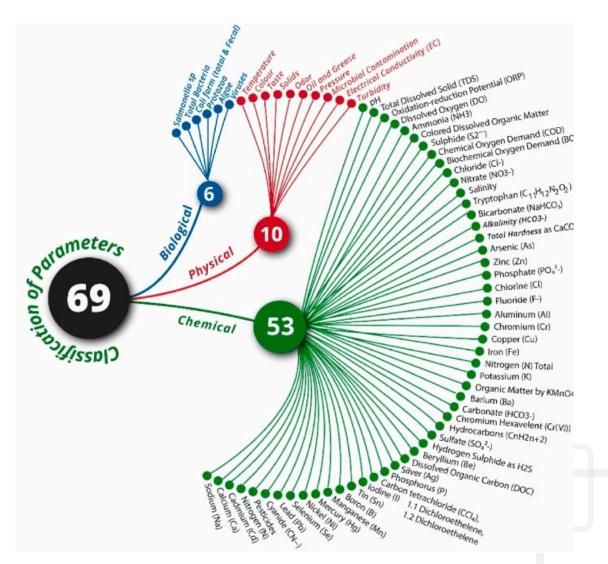


- Key physical indicators include temperature, turbidity, conductivity, and flow
 - Provide insights into the stream's habitat characteristics and water clarity
- Key **chemical** indicators include pH, dissolved oxygen, and the concentration of nutrients (like nitrogen and phosphorus)
 - Vital for assessing chemical balance of water and its potential for supporting diverse biological communities
 - Heavy metals and organic pollutants can significantly impact stream health
- Selection of parameters is the first step currently no systematic technique to formalize the parameter selection process
 - Expert opinion (Delphi method), ecological importance of the parameter, and data availability have been used

Example Physicochemical Parameters



- Scientific literature suggests about 8 to 11 parameters are typically used as indicators, but some studies have analyzed as few as 4 to determine stream health
- Metrics suggested by USGS
 - Nitrogen
 - Sediment
 - Phosphorus
 - Water Temperature
 - Salinity
 - Toxic Contaminants
 - Flow

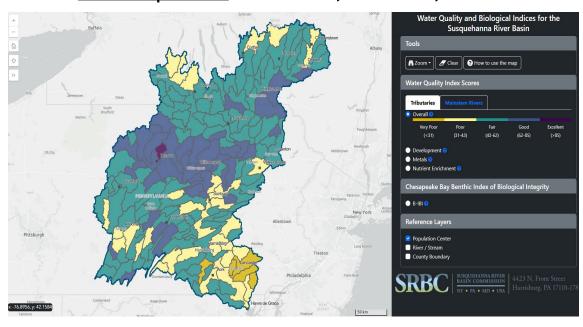


Local Examples of Physicochemical Indicators



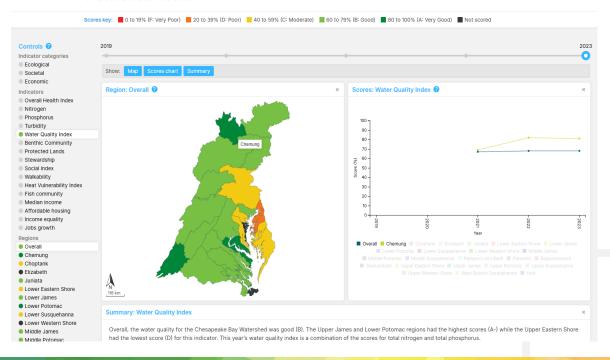
Susquehanna River Basin Commission (SRBC) and University of Maryland Center for Environmental Science (UMCES) assess metrics across jurisdictions

- SRBC Water Quality Index
 - <u>Metals</u>: Aluminum, Iron, Manganese
 - <u>Nutrients</u>: Nitrate, Phosphorus, Total Organic Carbon
 - Development: Chloride, Sodium, Sulfate



- UMCES Eco Health tool–Water Quality Index
 - Nitrogen, Phosphorus, Turbidity

Watershed Health



List of Potential Indicators



- Water Temperature
- Dissolved Oxygen
- pH
- Specific Conductance
- Nitrogen
- Phosphorus
- E. coli
- Total Suspended Solids/Suspended Sediment/Turbidity
- Flow/Water Depth/Connectivity

- Toxics, pesticides, trace metals, and microplastics are not often considered as indicators, but have been suggested in the literature
- Final recommendation of indicators that can feasibly be used will be determined after completing further assessments of ecological importance, data availability, and utility

Feasibility and Challenges of Physicochemical Indicators



- State-to-state differences in data assessment and reporting, as well as limitations in data availability
- Some indicators can be highly variable because of sensitivity to natural (e.g., seasonality) and/or human-induced factors
- Various water quality index models and approaches have been applied both nationally and internationally, but there are no accepted standard methods
- Single composite water quality index (WQI) simplifies very complex systems and can potentially lose or distort information (known as "eclipsing")
 - Sub-indexing rules, parameter weightings that do not reflect the true relative influences of parameters, or inappropriate aggregation functions

Recommendations for Indicator Development



- Define Clear Objectives and Use Cases
- 2. Prioritize Core Indicators
- 3. Address Data Gaps and Spatial Coverage
- 4. Establish Scientifically Defensible Thresholds
- 5. Build on Existing Frameworks
- **Engage Stakeholders and Provide Accessibility**
- Develop Appropriate Approach
- 8. Test the Model Case

1. Define Clear Objectives and Use Cases



- Clarify the primary purpose of the WQI or indicators
 - e.g., public communication, regulatory compliance, restoration prioritization, or trend tracking
- Tailor the design of the index or indicators to meet these objectives
 - Balancing simplicity and scientific needs
- As the Model Case—we recommend that the objective of the physicochemical indicator be Chesapeake Bay watershed-wide assessment of stream health over time





- Use the list of 9 potential physicochemical indicators (i.e., DO, temperature, TN, TP, bacteria, pH, conductivity, turbidity/TSS, flow/hydraulic regime) as a foundation
- Prioritize indicators based on:
 - High ecological relevance
 - Strong data availability
 - Clear thresholds of concern
- Consider grouping indicators into stressor-specific suites
- <u>As the Model Case</u>—we recommend grouping these indicators into Nutrient Enrichment (TN, TP), Salinization (pH, conductivity), Habitat (DO, temperature, flow, turbidity/TSS) and Human Health (bacteria)





- Consider expanding data coverage to the HUC-12 scale, where current data are sparse
 - Through water quality modeling using high-resolution input data (e.g., comparable to methods for Chessie BIBI)
- Supplement the CBP DataHub with additional datasets if feasible
 - E.g., state monitoring programs, academic studies, citizen science
- Ensure temporal sampling frequency aligns with natural variability and assessment needs
- As the Model Case—we recommend compiling indicator data on the HUC-8 scale and customizing the indicator to each of the ecoregions in Chesapeake Bay watershed





- Use Chesapeake Bay-specific guidance, and state/national standards (e.g., EPA, USGS) to define thresholds
- Validate thresholds using historical data and expert input
- Develop flexible scoring systems (binary, tiered, or continuous) to accommodate different indicator types
- <u>As the Model Case</u>—we recommend using state water quality standards and EPA guidance to establish thresholds for each of the indicators

5. Build on Existing Frameworks



- Leverage existing indices as models
 - E.g., UMCES Chesapeake Bay Report Card, Susquehanna River Basin WQI, and Oregon and Washington WQIs
- Adapt successful elements to the Chesapeake Bay watershed context
 - E.g., scoring systems, parameter selection, communication tools, regionalization
- As the Model Case—we recommend following a scoring method and approach similar to WQISRB for the selected indicators

6. Engage Stakeholders and Provide Accessibility



- Document all methods, thresholds, and data sources
- Provide guidance for interpretation and use by different audiences
- Consider involving state agencies, NGOs, researchers, and community groups in:
 - Indicator selection
 - Threshold setting
 - Index design and testing
- As the Model Case—we recommend SHWG use its normal avenues to gather input at appropriate stage, which may be the overall stream health indicator suite including biological, hydromorphological, and physicochemical

7. Develop Appropriate Approach

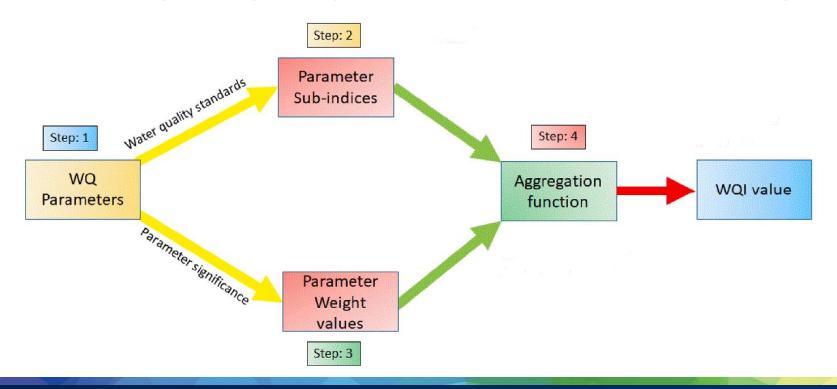


- Use a composite WQI for broad communication and trend analysis
- Maintain individual indicators for scientific assessments and targeted management
- Consider developing an interactive dashboard
 - Visualizing WQIs and individual indicator scores
 - Mapping of stream health across watersheds
 - Exporting reports for communication and decision-making
- As the Model Case—we recommend a dual approach led by a composite WQI with associated Individual Indicators





- Test the WQI and individual indicators in a subset of watersheds
- Evaluate performance using real-world data and stakeholder feedback
- Refine scoring, weighting, and communication strategies



Physicochemical Indicator Selection



Indicator	Why It Matters	Importance
Dissolved Oxygen (DO)	Supports aquatic life; low DO leads to hypoxia and fish kills.	Very High
Temperature	Influences DO, species metabolism, and habitat suitability.	Very High
Total Nitrogen (TN)	Excess TN causes eutrophication and oxygen depletion.	Very High
Total Phosphorus (TP)	Triggers algal blooms and eutrophication.	Very High
Bacteria (e.g., E. coli, fecal coliform, enterococci)	Indicates fecal contamination from human or animal waste; high levels pose health risks for recreation and drinking water.	Very High
рН	Affects chemical reactions and biological health.	High
Conductivity	Indicates dissolved salts and pollution.	High
Turbidity/TSS	Reduces light, affects habitat, and transports pollutants.	High
Flow/Hydrologic Regime	Maintains habitat, sediment transport, and pollutant dilution.	High

Note: Turbidity is not included in this table as there were less data available than TSS. Approximately 13,000 turbidity measurements were present in the dataset.

Data Matrix from Chesapeake Bay Program DataHub



- <u>Chesapeake Bay Program DataHub</u> is the primary tool for searching and downloading water quality data for the Chesapeake Bay watershed
 - Most comprehensive and practical source for data
 - Nontidal Water Quality Program and Living Resources datasets are most applicable
- Assessed spatial and temporal availability of water quality data on potential indicators for the period from 2014 to 2023 (most recent 10 years)
- Nontidal Water Quality Program includes data for all 9 of the selected parameters
- <u>Living Resources</u> only includes sufficient data for 5 parameters: water temperature, dissolved oxygen, pH, specific conductivity, and flow
- <u>Data Matrix</u> (tables and maps) accompanies recommendations report

Data Availability (Nontidal WQ) – Spatial Coverage



		Spatial Assessment (Number of units with sites)			
Water Quality Parameter	Number of Samples	HUC-12s (Total: 1976)	HUC-8s (Total: 53)	HUC-6s (Total: 7)	Ecoregions (Total: 12)
Water Temperature (WTEMP)	28779	146	44	7	9
Dissolved Oxygen (DO)	27930	146	44	7	9
Stream Flow (FLOW_INS)	5865	49	26	5	7
pH (PH)	27811	146	44	7	9
Specific Conductivity (SPCOND)	28788	146	44	7	9
Total Nitrogen (TN)	29291	146	44	7	9
Total Phosphorus (TP)	29671	146	44	7	9
Total Suspended Solids (TSS)	28857	144	44	7	9
Total Suspended Sediment Concentration (SCC_TOTAL)	15637	113	42	7	8
Fecal Coliform (FCOLI_C)	3104	33	16	3	5

Matrix Key	Spatial Coverage
Low	<40% coverage
Moderate	40-75% coverage
High	>75% coverage

Note: Turbidity is not included in this table as there were less data available than TSS. Approximately 13,000 turbidity measurements were present in the dataset.

Data Availability (Living Resources) – Spatial Coverage



	Number of	Spatial Assessment (number of units with sites)			
Water Quality Parameter	Samples	HUC-12s (Total: 1976)	HUC-8s (Total: 53)	HUC-6s (Total: 7)	Ecoregions (Total: 12)
Water Temperature (WTEMP)	7266	809	50	7	10
Dissolved Oxygen (DO)	7044	803	53	7	10
Stream Flow (FLOW_INS)	1617	277	35	7	9
pH (PH)	8521	816	50	7	10
Specific Conductivity (SPCOND)	8508	804	50	7	10

Matrix Key	Spatial Coverage
Low	<40% coverage
Moderate	40-75% coverage
High	>75% coverage

Note: A limited amount of turbidity data was available in this dataset (<50 measurements).



Data Availability - Temporal Coverage



Nontidal WQ

 Temporal frequency in Nontidal WQ varies by station, but typically monthly

Living Resources

 More limited temporal coverage, mostly annually or < 10 measurements per parameter

Available monitoring data does not account for short-term changes which are needed to better understand the natural variability of physicochemical parameters (e.g., temperature, dissolved oxygen)

Thresholds of Concern



Water Quality Parameter	Potential Threshold of Health	Comment
Dissolved Oxygen	>5 mg/L (7–10 mg/L preferred)	Based on minimum value for most aquatic life. Can vary depending on temperature, flow, and biological activity.
Temperature	<20°C (cold-water) <30°C (warm-water)	Based on maximum value aquatic life (cold or warm). Can vary depending designated use, region, and season.
Total Nitrogen	<1.0 mg/L	Can vary by ecoregion. Numeric criteria do not exist for states.
Total Phosphorus	<0.05 mg/L	Can vary by ecoregion. Numeric criteria do not exist for states.
Bacteria (E. coli)	<126-235 cfu/100 mL	Based on geometric mean and single sample maximum.
рН	6.5-8.5	General range considered to be suitable for aquatic life.
Conductivity	150–500 μS/cm	Can vary by ecoregion. Numeric criteria do not exist for states.
Turbidity / TSS	Turbidity: <5 NTU TSS: <25 mg/L	Can vary by ecoregion. Numeric criteria do not exist for states.
Flow / Hydrologic Regime	Assessed via deviation from natural flow	Only narrative criteria exist.

Note: Potential thresholds are based on state water quality standards (VA, WV, MD, PA, NY, DE, DC) and EPA guidance.

Threshold Scoring



- Binary scoring: Meets threshold = 1, exceeds = 0
- <u>Tiered scoring:</u> Excellent (0–25% of threshold), Good (26–50%), Fair (51–75%), Poor (>75%), e.g., Dissolved oxygen of 8 mg/L: ideal = score of 100; dissolved oxygen of 4 mg/L: threshold of concern = score of 50.
- <u>Continuous scaling</u>: Normalize values to a 0–100 scale based on proximity to the threshold.

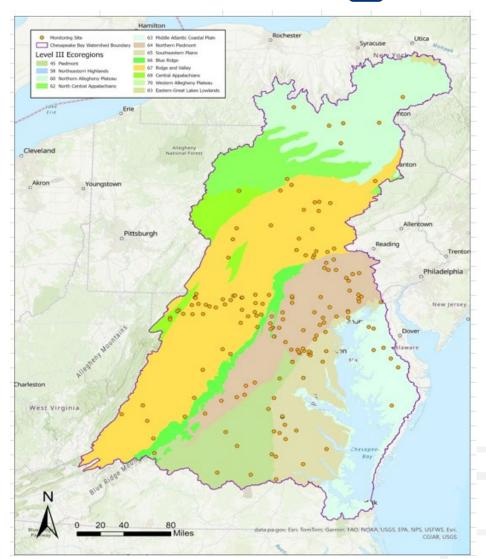
Such scoring supports integration of parameters into a WQI and comparison across sites and time





Regionalization is needed to account for natural variability across the Bay watershed, for example:

- Temperature thresholds for stream health may differ between cold-water and warm-water systems (Maheu et al. 2016)
- Conductivity and nutrient concentrations may vary naturally depending on underlying geology or soil types (USEPA 2024a)



Individual Indicators OR Composite Index (WQI)

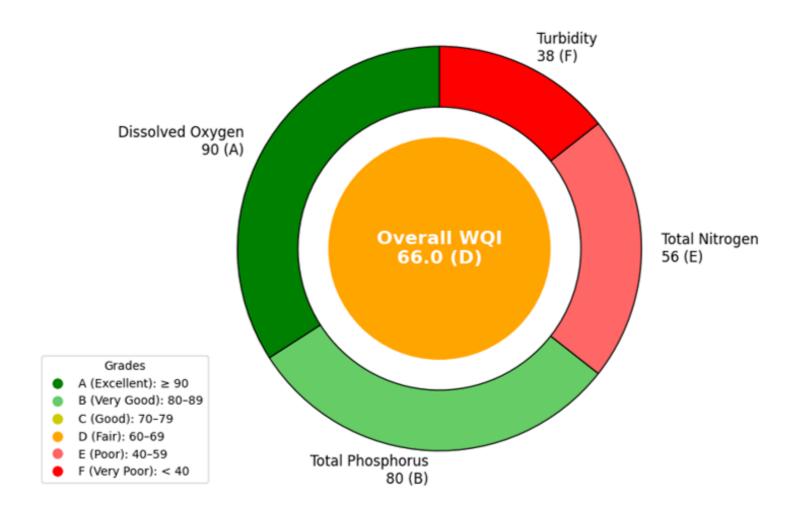


Feature	Individual Indicators	WQI	
Overview	Offers detailed insights	Provides a holistic score	
Communication	Requires technical interpretation	Easy to communicate	
Sensitivity	Highlights specific problems	May mask specific issues	
Flexibility	Parameter-specific thresholds	Customizable weighting	
Use Case	Scientific analysis and assessment	Public reporting and policy	

Individual Indicators AND Composite Index (WQI)



Water Quality Index Example

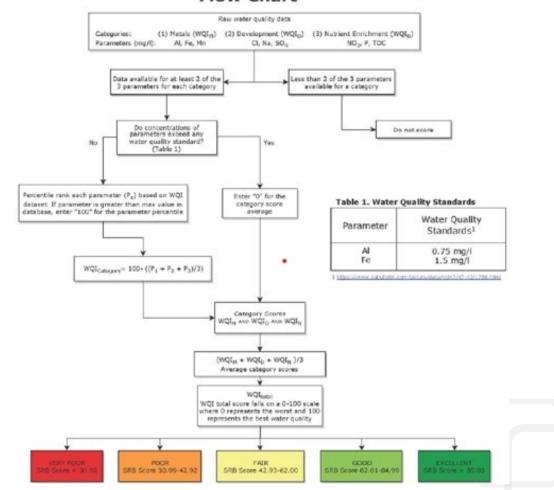


Examples of Composite WQIs in the U.S.



- WQI for Susquehanna River Basin (WQISRB)
- University of Maryland Center for Environmental Science (UMCES)—Eco Health Tool
- Oregon WQI (OWQI)
- A Water Quality Index for Washington Ecology's Stream Monitoring Program

Susquehanna River Basin Water Quality Index (WQI) Flow Chart



Test of Model Case



- Calculate metrics and WQI using thresholds
- Map site results for Northern Piedmont ecoregion and 3 HUC-8s
- Summarize results by WQI and metric groupings
- Analyze WQI and metric change over time
- Compare WQI and metrics with Chessie BIBI in watersheds with different land uses

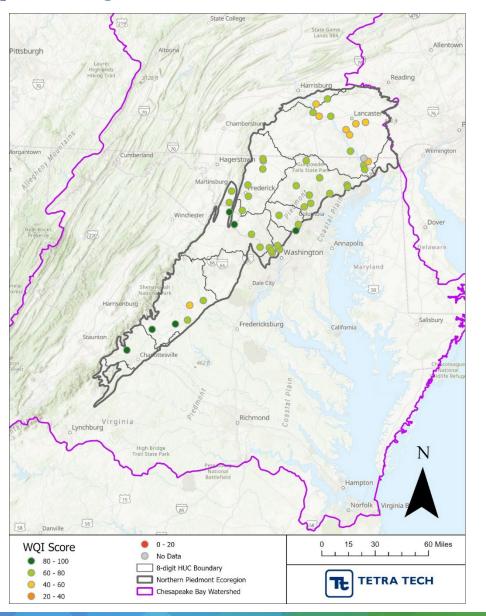


Scoring the Parameters Using Thresholds



Water Quality Parameter	Thresholds	Basis
Dissolved Oxygen	 7 to 10 mg/L: Score =100 (ideal) <7 mg/L: Score decreases linearly to 0 at 3 mg/L >10 mg/L: Score decreases linearly to 0 at 15 mg/L 	Possible thresholds based on state water quality standards
Temperature	 ≤20°C: Score = 100 (ideal) >20°C and <30°C: Score decreases linearly ≥30°C: Score = 0 (poor) 	Possible thresholds based on state water quality standards
Total Nitrogen	 ≤0.64 mg/L: Score = 100 (ideal) >0.64 and <3.66 mg/L; Score decreases linearly ≥3.66 mg/L: Score = 0 (poor) 	Possible thresholds applicable to the Northern Piedmont ecoregion from <u>UMCES (Eco Health Tool)</u>
Total Phosphorus	 ≤0.01 mg/L: Score = 100 (ideal) >0.01 and <0.09 mg/L; Score decreases linearly ≥0.09 mg/L: Score = 0 (poor) 	Possible thresholds applicable to the Northern Piedmont ecoregion from <u>UMCES (Eco Health Tool)</u>
Bacteria (fecal coliform)	 ≤200 CFU/100mL: Score = 100 (ideal) >200 CFU/100mL and <400 CFU/100mL: Score decreases linearly ≥400 CFU/100mL: Score = 0 (poor) 	Possible fecal coliform thresholds from legacy water quality standards
Conductivity	 ≤42 μS/cm: Score = 100 >42 to ≤544: Score decreases linearly ≥544 μS/cm: Score = 0 (poor 	Possible thresholds applicable to the Northern Piedmont ecoregion from <u>UMCES (Eco Health Tool)</u>
рН	 6.5 to 8.5: Score =100 (ideal) <6.5: Score decreases linearly to 0 at 5.5 >8.5: Score decreases linearly to 0 at 9.5 	Possible thresholds based on state water quality standards
Total Suspended Solids	 ≤10 mg/L: Score = 100 (ideal) >10 and <80 mg/L: Score decreases linearly ≥80 mg/L: Score = 0 (poor) 	Possible thresholds based on available guidance (e.g., EPA, 2003).

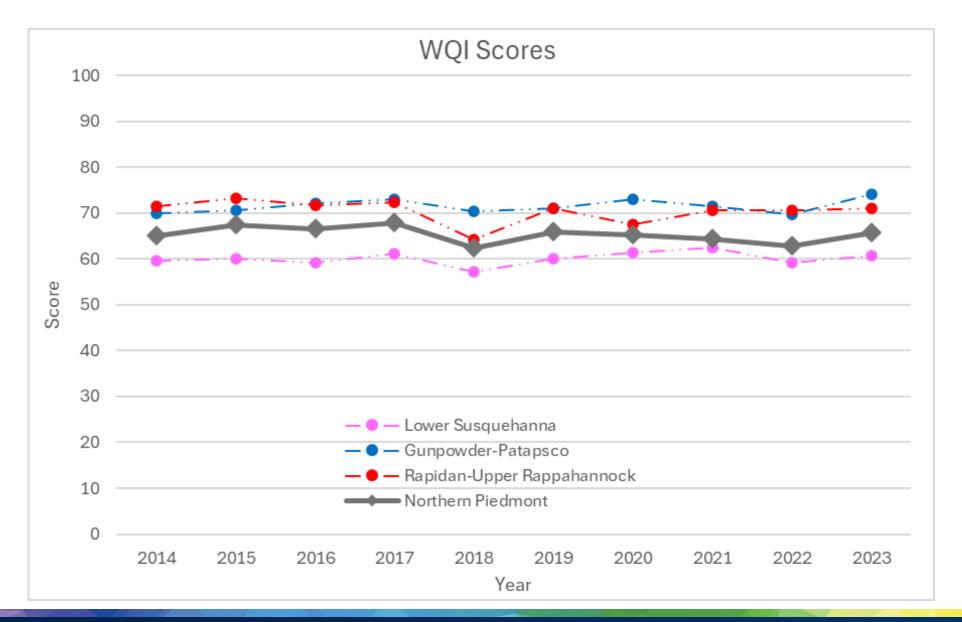
Example WQI Scores in Northern Piedmont



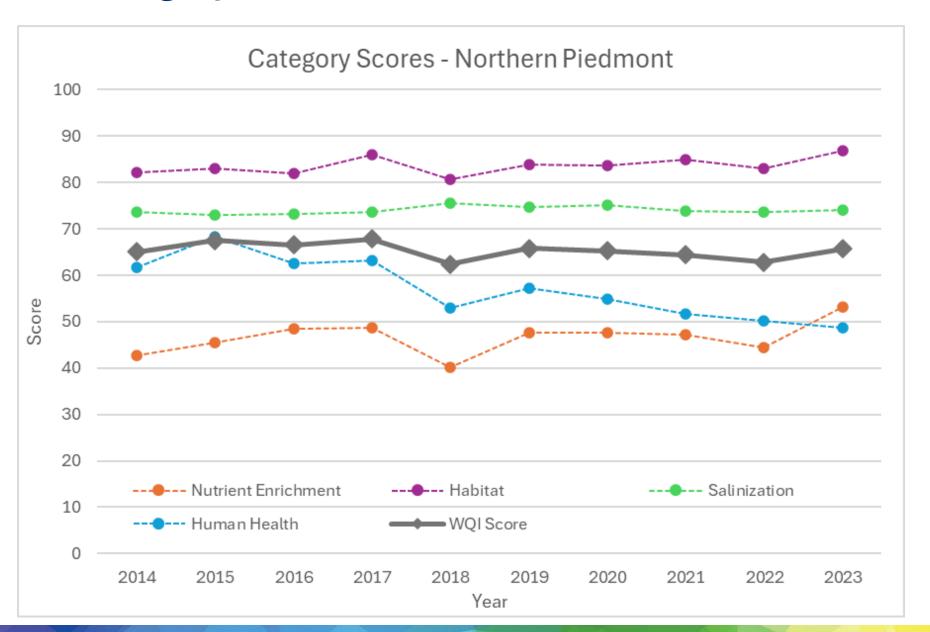


WQI Scores in 3 Northern Piedmont HUC-8 Watersheds





Category WQI Scores in the Northern Piedmont





Comparison of WQI and Chessie BIBI in Northern Piedmont





WQI and Chessie BIBI in Forested Watershed



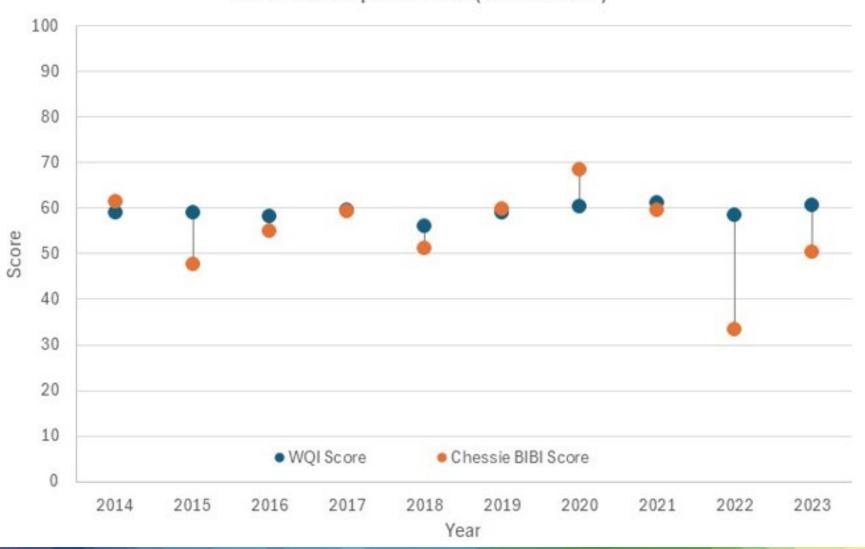
Rapidan-Upper Rappahannock (02080103)



WQI and Chessie BIBI in Agricultural Watershed



Lower Susquehanna (02050306)



WQI and Chessie BIBI in Urban Watershed



Gunpowder-Patapsco (02060003)





Physicochemical and Biological Scores



- WQI and component category scores were generally consistent over 10 years from 2014-2023
- Nutrient and Human Health scores were lower than Habitat and Salinization scores
- Chessie BIBI scores were consistently lower than WQI, indicating the effects of other stressors
- WQI and BIBI scores were highest in forested watershed
- WQI and BIBI scores were similar in agricultural and forested watersheds, but much different in urban watershed, where unaccounted-for flow and habitats stressors may occur

Conclusions



- No standard approach to physicochemical indicators, but many useful examples exist
- Of 69 possible parameters, literature suggests 8 to 11 parameters
- Chesapeake Bay Program DataHub has two useful datasets:
 - Water Quality
 - Living Resources
- Selected parameters should be ecologically important, have agreed upon thresholds of concern, and be spatially and temporally robust
- Composite WQI with transparent individual parameters is recommended

Discussion and Timeline



- Presentation to SHWG on December 19
- Draft Report available
- Comments by December 26

• Final Report and Factsheet to SHWG and CBT on January 31, 2026