# Climate Change Indicators for the Chesapeake Bay Program: An Implementation Strategy

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# Introduction

## *Project Purpose and Background*

In 2016, the Chesapeake Bay Program Office (CBPO) began an effort to identify a suite of indicators that can be used to track and analyze trends, impacts, and progress towards advancing "climate resiliency." The chief aim of this initiative is to track progress toward the climate resiliency goal and outcomes in the 2014 Watershed Agreement:

- **Goal:** Increase the resiliency of the Chesapeake Bay watershed, including its living resources, habitats, public infrastructure, and communities, to withstand adverse impacts from changing environmental and climate conditions.
  - **Monitoring and Assessment outcome:** Continually monitor and assess the trends and likely impacts of changing climatic and sea level conditions on the Chesapeake Bay ecosystem, including the effectiveness of restoration and protection policies, programs and projects.
  - **Adaptation outcome:** Continually pursue, design, and construct restoration and protection projects to enhance the resiliency of Bay and aquatic ecosystems from the impacts of coastal erosion, coastal flooding, more intense and more frequent storms and sea-level rise.

To address all facets of the climate resiliency goal and outcomes, the CBPO sought a balance of indicators across three categories:

- Indicators of ***physical climate trends*** based on measurements of physical or chemical attributes of the environment.
- Indicators of ***ecological and societal impact*** that measure a) attributes of ecological systems, particularly attributes that may be influenced by physical climate trends, or b) impacts on society, such as health or economic outcomes.
- Indicators of ***programmatic progress toward resilience*** that quantify resilience or show evidence of learning or adaptation over time. Resilience is the ability to anticipate, prepare for, and adapt to changing conditions and to withstand, respond to, and recover rapidly from disruptions. Responses include management actions such as designating wetland migration corridors, as well as physical actions such as constructing living shorelines in place of hard shoreline structures (e.g., bulkheads) in coastal environments.

The CBPO contracted with Eastern Research Group, Inc. (ERG) to conduct research and lead a systematic, participatory process to identify candidate indicator topics; prioritize topics to include as part of a manageable, cohesive suite of indicators; and lay out an approach to develop each of the proposed indicators. The CBPO has expressed an interest in developing a suite of indicators that is large enough to cover a wide range of important climate-related issues, yet small enough that it will be feasible to maintain all the indicators with periodic (in many cases, annual) data updates for the foreseeable future. After careful consideration of the scope, ERG recommended a target number of approximately 20 indicators.

## *What Is an Indicator?*

Scientists and policymakers define the term "indicator" in various ways. For the sake of establishing common nomenclature, this project defines an indicator as follows:

- An indicator presents one or more numerical values derived from actual measurements of a state or ambient condition, ecological or societal response, or programmatic action, whose trends over time represent or draw attention to underlying trends in the condition of the environment or measure progress towards a desirable state or condition.

- An indicator as defined here may consist of multiple metrics. In some cases, underlying metrics may be aggregated to create a multi-metric index—for example, an index of biological integrity, which combines several distinct measurements into a single variable. However, this project will not require every indicator to be boiled down to a single variable. An indicator might present two or more variables that characterize different dimensions of a complex issue, possibly in the form of two or more distinct maps or graphs. This is especially true in cases where the variables are not easily combined, or where they provide more explanatory value on their own. For example, the proposed "precipitation" indicator could have one metric that tracks total annual precipitation and another separate metric that tracks the incidence of heavy precipitation events.

### *Indicator Criteria*

After soliciting input and compiling a list of more than 200 potential indicator topics, ERG worked with the Climate Resiliency Workgroup (CRWG) and other partners to screen and prioritize the topics according to four sets of criteria:

| Criterion | Definition |
|---|---|
| **1. Fundamental data quality standards that every proposed indicator must be able to meet, either now or in the future** | |
| Topical relevance | The indicator provides information about physical climate trends, ecological or societal response, or programmatic progress toward resilience. The connection to climate change is documented or can be explained easily. |
| Spatial coverage | The indicator provides information that is specific to the Chesapeake Bay, the Chesapeake Bay watershed, or geographic sub-units within the watershed. |
| Temporal coverage | Multiple years of data are available to describe changes or trends, and the latest available data are timely. |
| Actual observations | The indicator is based on observed data. Modeling and statistical inference (if any) is limited to spatial interpolation between data points, such as the process used to generate a gridded map. |
| Credible methods | The indicator is based on sound data collection and analytical methods that reflect the state of the science. |
| Data quality and integrity | The data provider uses quality assurance procedures to ensure data quality and management systems to protect the integrity of the data. |
| Objectivity | The indicator is developed and presented in a clear, complete, and unbiased manner that accurately represents the underlying trends in physical conditions. |
| Uncertainty | Sources of uncertainty are known and understood. |

| Criterion | Definition |
| --- | --- |
| Transparency and reproducibility | The specific data used and the specific assumptions, analytical methods, and statistical procedures employed are clearly stated. Documentation is sufficient to allow the indicator to be reproduced independently. |
| Feasibility | The indicator is feasible to construct, and a program is in place to continue to collect data, thereby allowing the indicator to be updated in the future. |
| Peer-review validation | If an indicator is based on physical measurements of environmental conditions, it must use data from a peer-reviewed publication, a program that uses peer-reviewed methods to collect and analyze data, and/or a program whose data have been used and validated in peer-reviewed publications. This criterion will likely apply to all indicators in the *physical climate trends* bin and certain indicators in the other two bins (for example, a measure of benthic community condition). For indicators that are not based on physical measurements, peer review is ideal but not required. |
| **2. "Desirable" data quality considerations to help select the best data source or metric for a given topic, if multiple sources are available** | |
| Relationship to other indicators | The ideal indicator will complement other indicators rather than duplicating them. It fills a vital role in the organizational framework. Where possible, an ideal indicator will have established causal relationships with other indicators, which can be evaluated. |
| Spatial coverage | The ideal indicator will use data collected throughout the Bay and its major tributaries or throughout the watershed, as opposed to indicators that are only measured at a few locations. |
| Spatial resolution | The ideal indicator will provide at least a total or an average for the Bay, the watershed, or the individual states that are part of the watershed. Where possible, the ideal indicator will support local-scale analysis by providing data that are downscaled further—for example, data for individual sampling sites, sub-watersheds (e.g., HUC-12), NOAA climate divisions (up to 10 per state), or a gridded map. |
| Temporal coverage | The ideal indicator will have many years of data available. The best indicators will have at least 30 years of data, which is a common threshold for climatological analysis. The ideal indicator will also have a defined baseline, particularly if it is used to assess progress toward resilience. |
| Temporal resolution | The ideal indicator will have data with at least annual frequency, with sub-annual frequency if appropriate (e.g., where seasonal variations are important to consider). |
| Consistency of methods | The ideal indicator will be based on data collection and analytical methods that are comparable across time and space. In some cases, it may be appropriate to use data that were collected or analyzed using multiple methods—for example, supplementing short-term records with longer-term |

| Criterion | Definition |
|---|---|
| | records from a different source. In such cases, the data visualization should distinguish between the different sources, such as by inserting a discontinuity in a time series or plotting multiple lines on a graph. The CBNERR indicators by UMCES and Chesapeake Data provide a good example of this approach. |
| Uncertainty | The ideal indicator will have low uncertainty—for example, small error bars or narrow confidence intervals. |
| Other limitations | The ideal indicator will have few confounding factors or other limitations that make it difficult to interpret the data or draw conclusions. |
| Understandability | The ideal indicator will provide a clear depiction of observations that can be understood by both technical and non-technical users. |
| **3. "Value-added" criteria to prioritize indicators that will provide the most relevant and useful information for the CBPO and its mission** | |
| Rate of change | To what extent is an indicator on this topic likely to show change over time? In other words, would a graph show a fairly flat line over time, or might we expect to see a more noticeable change? |
| Significance of consequences | How significant are the consequences for society or ecosystems? One could think about consequences in terms of severity, scale, probability, and/or timeframe. For physical climate stressors and societal/ecological impacts, one could consider the impact of the changes that are projected under commonly accepted climate scenarios. For suggested indicators that involve adaptation actions, one could consider the consequences if such actions are not taken. |
| Significant advancement in our understanding of climate | Would an indicator on this topic significantly advance the scientific and policy community's understanding of climate change, impacts, and resiliency in the Chesapeake watershed? In other words, would this indicator reveal something important that we don't already know or we aren't already tracking? |
| Known new need | Would an indicator on this topic address a data or tracking need that has been strongly expressed by program staff or stakeholders? |
| Relevance to CBP management actions | Does the proposed indicator track an attribute that the CRWG and the Chesapeake Bay Program could reasonably expect to be able to influence through management actions? |
| Relevance to climate resiliency goal and outcomes | This criterion focuses on the strength of each topic's connection to climate change. For physical measures and impacts, one can focus on the extent to which climate change is a key stressor that will drive any apparent trends in the indicator, as opposed to situations where climate change is just one of many factors. For resilience indicators, to what extent will each attribute or action convey resilience against climate change? |

| Criterion | Definition |
|---|---|
| **4. Considerations for assembling the overall suite** | |
| Balance across bins | Aim for at least 25% (five indicators) from each of the three bins described above (physical measures, impacts, and resilience), but recognize that some indicators straddle bins. |
| Balance of tidal and nontidal/watershed-wide | Aim for no more than 2/3 tidal or 2/3 nontidal. |
| Balance of ecological and societal/human concerns | The climate resiliency goal and outcomes refer to living resources, habitats, and ecosystems, although workgoup members suggested a focus on societal/human issues as well. |
| Balance between breadth (diversity) and depth (connections or "threads") | Cover all key climate change stressors on the Chesapeake region (temperature, precipitation, sea level, acidity); cover many types of systems and issues; avoid duplication; and include some indicators that have causal linkages and work together to tell a story, particularly across the three bins. |

These criteria were designed to focus on indicators that will be useful and relevant to technical users, such as scientists and policy analysts involved in management and oversight. Where possible, the project team considered indicators that are also relevant to a public audience.

### *About This Implementation Plan*

ERG developed this implementation plan to fulfill the following objectives:

- Lay out an initial vision for each indicator in the proposed suite.
- Describe a stepwise process that could be used to develop each indicator.
- For each step in the process, identify likely resource needs to the extent possible, in terms of tools, expertise, CBPO staff time, and funding to engage outside partners if needed.

For each indicator, this plan identifies the status of current development and describes actions and next steps for five general stages of indicator development:

1. Defining the indicator
2. Collecting data
3. Developing methods to transform the data into an indicator
4. Processing the data
5. Developing a final indicator for the Chesapeake region

Timeframes and costs have been estimated based on available information and based on experience with similar indicator development projects. However, many of these estimates are just general approximations. At best, some of the cost estimates should be taken as an indication of the order of magnitude of the effort required. In some cases, information was insufficient to allow even a ballpark estimate to be generated, due to uncertainties in precursor stages of indicator development that have yet to be completed. These instances are noted as "TBD."

This plan focuses on incremental costs—that is, costs for additional tasks that are not already covered (and funded) as part of someone's job duties. For instance, if a proposed indicator relies on data that are already being collected, and funding for continued data collection is assumed to be in place from another source, this plan identifies no additional cost. Substantial new tasks that could require support from a contractor or an academic/research partner have been estimated in dollars. For substantial new tasks that likely can be performed by CBPO personnel, this plan identifies resource needs in terms of labor hours. This plan focuses on the cost to develop technical indicator content; it does not include additional labor to develop and disseminate communication products such as web graphics, maps, or summary text.

### *Next Steps*

This plan is not set in stone. Rather, it is a "living" document, intended to provide guidance and ideas as a starting point for further discussion, development, and engagement with additional partners. As priorities evolve, new data sources emerge, and new analytical approaches are developed and published, the CBPO and its partners may find it useful to add or remove certain indicator topics or change the way the indicators are constructed.

From the outset, this project was intended to be the first step in a process to develop a suite of indicators, to be implemented over time, to measure and assess trends or "factors influencing" (i.e., physical climate drivers); ecological and societal response (i.e. impacts); and programmatic progress toward building an effective response (i.e., adaptation). Upon completion of this implementation plan, ERG will develop a small subset of indicators within the proposed suite and deliver them to the CRWG for review and approval. This subset will likely include some of the following indicators: Air Temperature, Coastal Flooding, Precipitation, Protected Lands, Restored Habitat, Sea Level Change, Stream Temperature, and Upstream Flooding. However, for those indicators that have been proposed using another agency's data or indicator products as a starting point (in particular, the U.S. EPA's national-scale indicators of climate change), no development will take place until proper arrangements have been made between the CBPO and the source agency regarding data sharing mechanisms, permission to publish, and commitments for future maintenance.

This implementation plan presents a vision of an ideal suite of indicators, but CRWG priorities and available resources will determine which indicators are actually developed, and on what timeframe.

# Summary of Indicators and Proposed Steps

## Indicator Development Status at a Glance

| Topic | Type of indicator | Stage 1: Indicator and metric(s) defined | Stage 2: Data collection program in place | Stage 3: Methods selected to transform data into an indicator | Stage 4: Data processed | Stage 5: Indicator developed for the Chesapeake |
|---|---|---|---|---|---|---|
| **Group A: Chesapeake indicator already exists** | | | | | | |
| Protected Lands | Resilience or response | ✓ | ✓ | ✓ | ✓ | ✓ |
| Restored Habitat | Resilience or response | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Group B: Existing national indicator just needs to be clipped or cropped** | | | | | | |
| Air Temperature | Physical stressors | ✓ | ✓ | ✓ | ✓ | |
| Coastal Flooding | Impacts | ✓ | ✓ | ✓ | ✓ | |
| Precipitation | Physical stressors | ✓ | ✓ | ✓ | ✓ | |
| Sea Level Change | Physical stressors | ✓ | ✓ | ✓ | ✓ | |
| Stream Water Temperature | Physical stressors | ✓ | partial | ✓ | ✓ | |
| Upstream Flooding | Impacts | ✓ | ✓ | ✓ | ✓ | |
| **Group C: Indicator defined, but need to process data and develop indicator** | | | | | | |
| Acidification | Physical stressors | ✓ | ✓ | | | |
| Bay Water Temperature | Physical stressors | ✓ | ✓ | partial | | |
| Harmful Algal Blooms | Impacts | ✓ | ✓ | ✓ | partial | partial |
| Property at Risk or Damaged | Impacts | partial | ✓ | | | |
| Urban Tree Canopy | Resilience or response | ✓ | ✓ | | | |
| Wetland Extent and Physical Buffering Capacity | Impacts | ✓ | partial | partial | | |
| **Group D: Data likely exist, but need to define and develop indicator** | | | | | | |
| Bird Species Ranges | Impacts | | ✓ | | | |
| BMPs and Green Infrastructure | Resilience or response | | | | | |
| Land Use/Land Cover | Resilience or response | | ✓ | | | |
| Shoreline Condition | Resilience or response | | ✓ | | | |
| Wetland Migration Corridors | Resilience or response | | ✓ | | | |
| **Group E: Could require a new data collection program** | | | | | | |
| Fish Population Distribution | Impacts / resilience or response | | | | | |
| Submerged Aquatic Vegetation Composition | Impacts / resilience or response | | | | | |

## Master Timeline and Summary of Costs

This implementation plan provides an itemized list of steps required to publish each of the proposed indicators, along with detailed estimates (to the extent possible) of anticipated costs and timeframes. The table below summarizes these key steps, costs, and timeframes at a glance. For ease of comparison, anticipated costs and timeframes are defined in this summary table according to the following categories:

Anticipated cost:

- **Low:** $1–$10,000 / 1–100 staff hours
- **Moderate:** $10,000–$50,000 / 100–500 hours
- **High:** $50,000+ / 500+ hours

Anticipated timeframe:

- **Short-term:** can be achieved within 1 year
- **Medium-term:** 1 to 5 years
- **Long-term:** more than 5 years

Note that the table presented here focuses only on the steps to bring an indicator online in its initial form. For several indicators, the implementation plan describes staged additions and optional enhancements that will likely require additional time and resources. These additional resource requirements are not summarized below, but can be assessed by reviewing the detailed indicator-specific sections later in this document.

The table below provides anticipated costs for *developing* each indicator. These are incremental costs beyond initiatives that are already funded. Resource planning should also consider the ongoing cost to maintain each indicator with current data. In most cases, our initial assessment is that maintenance costs will be in the "low" range once the data processing routine is operationalized. The exception would be any case where a new data collection or processing program is created for the primary purpose of informing one of these indicators. Operational costs of such a program will have to be considered case by case when more information is available.

| Indicator | Anticipated cost | Anticipated timeframe | Work needed to create initial indicator | Optional additions and enhancements |
|---|---|---|---|---|
| **Group A: Chesapeake indicator already exists** | | | | |
| **Protected Lands** | None | Short-term | None | Standardize reporting; calculate change; add conservation value and quality of protection |
| **Restored Habitat** | None | Short-term | None | N/A |
| **Group B: Existing national indicator just needs to be clipped or cropped** | | | | |
| **Air Temperature** | Low | Short-term | Crop and process EPA's datasets; acquire "Tropical Nights" data | N/A |
| **Coastal Flooding** | Low | Short-term | Crop and process EPA's dataset | N/A |
| **Precipitation** | Low | Short-term | Crop and process EPA's annual precipitation dataset | Work with NOAA's forthcoming downscaled heavy precipitation dataset |
| **Sea Level Change** | Low | Short-term | Crop and process EPA's dataset | N/A |
| **Stream Water Temperature** | Low | Medium-term | Crop and process EPA's dataset upon update from USGS | N/A |

| Indicator | Anticipated cost | Anticipated timeframe | Work needed to create initial indicator | Optional additions and enhancements |
|---|---|---|---|---|
| **Upstream Flooding** | Low | Short-term | Crop and process EPA's dataset | N/A |
| **Group C: Indicator defined, but need to process data and develop indicator** | | | | |
| **Acidification** | Low | Short-term | Determine approach for presenting pH; process data | Add enhanced metric, such as aragonite saturation |
| **Bay Water Temperature** | Moderate | Short-term | Develop methods for one dataset; process data for two datasets | Expand to entire Bay and tributaries |
| **Harmful Algal Blooms** | TBD | Short-term | Establish program to resume data processing; process data | Various methodology and data collection enhancements |
| **Property at Risk or Damaged** | High | Long-term | Select data; digitize data; develop methods; process data | Better define classifications; develop valuation methodology |
| **Urban Tree Canopy** | TBD | Short-term | Compile data; publish methods; process data for indicator | N/A |
| **Wetland Extent and Physical Buffering Capacity** | Medium | Short-term | Select and process wetland extent data | Incorporate higher-resolution data; develop and apply methods for physical buffering capacity |
| **Group D: Data likely exist, but need to define and develop indicator** | | | | |
| **Bird Species Ranges** | Medium | Medium-term | Define indicator; publish methods; process data | Incorporate additional data sources |
| **BMPs and Green Infrastructure** | High | Medium-term | Define indicator; collect data if needed; publish methods; process data | Consider expanding beyond stormwater |
| **Land Use/Land Cover** | Medium | Short-term | Select data; develop methods; process data | N/A |
| **Shoreline Condition** | High | Medium-term | Define indicator; publish methods; process data | N/A |
| **Wetland Migration Corridors** | High | Medium-term | Define indicator; select data; publish methods; process data | N/A |
| **Group E: Could require a new data collection program** | | | | |
| **Fish Population Distribution** | High | Long-term | Define indicator; establish data collection program; publish methods; process data | N/A |
| **Submerged Aquatic Vegetation Composition** | Medium | Medium-term | Define indicator; establish data collection program; publish methods; process data | N/A |

## Suggested Priorities

The proposed indicators have been divided into five groups based on the expected level of effort to develop them. Groups A and B represent the “low-hanging fruit”—eight indicators that would be easy to develop. Given that they have all been ranked as high-priority topics as a result of the scoring exercises that were part of this project, it would seem logical to go ahead and develop these eight indicators.

The CRWG may also elect to proceed with additional indicators that are already under development by other groups, where major funding is already in place and minimal additional effort will be needed to transform the resulting products into the desired indicator format. Indicators in this category include (but are not limited to) Bay Water Temperature and Urban Tree Canopy.

Otherwise, this plan defers to the CRWG for prioritization among the Group C, D, and E indicators. Decisions will undoubtedly depend on a variety of factors, including the interests of group members and stakeholders, the importance of filling particular gaps, and the availability of short- and long-term funding.

# 1. Protected Lands

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| ✓ | Stage 3: Methods developed/selected to transform data into an indicator |
| ✓ | Stage 4: Data processed |
| ✓ | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- Protecting land in an undeveloped state can help to mitigate some of the impacts of climate change. Compared with developed land, more natural landscapes can offer refugia for species, buffers against flooding and sea level rise, and other valuable ecological services.
- Given the wide scope of ecosystem services provided by protected lands, this indicator relates to many of the goals and outcomes of the Watershed Agreement, including:
    - The **Climate Resiliency** goal and outcomes, as described above.
    - The **Land Conservation** goal and outcomes, which include targets for protecting more land.
    - The **Vital Habitats** goal and outcomes, by providing a way to quantify habitat protection.
    - The **Healthy Watersheds**, **Water Quality**, and **Sustainable Fisheries** goals and outcomes, as protected lands provide ecosystem services in support of these objectives.

Relationship to other indicators in the proposed suite:

- Land protection can reduce conversion to different land use or land cover types, as measured by the proposed **land use and land cover** indicator.
- Protection of wetlands helps to maintain **wetland extent and physical buffering capacity**.
- Development restrictions can influence the extent of **living vs. hardened shorelines**.
- Protected status is an important aspect of designating effective **wetland migration corridors**.
- Protecting land in the watershed can help to manage **upstream flooding**, protecting coastal wetlands can manage the extent and severity of **coastal flooding**, and these indicators ultimately drive the amount of **property at risk or damaged**.
- Increasing the amount of protected land can help to control nutrient runoff that contributes to **harmful algal blooms**.

Notable opportunities, risks, and areas for enhancement:

- The proposed indicator is built on the existing protected lands indicator used by the Chesapeake Bay Program (CBP).
- If the CBP indicator is used, it is limited in its ability to compare data over time, due to variations in data reporting procedures. However, efforts to standardize jurisdictions' reporting format are underway.[1]
- Two optional enhancements could add more of a climate resiliency context to this indicator:
    - Consider <u>evaluating the value of protected lands</u> in terms of habitat value or conservation potential, using existing datasets like The Nature Conservancy's (TNC's) Priority Areas for Conservation dataset. Using a high-resolution land cover dataset as an overlay would allow the CBP to compare the location of protected areas against the location of priority land cover types—for example, areas of high-value intact forests. Such an enhancement would allow the

[1] See discussion on the adoption of PAD_US data standards at https://www.chesapeakebay.net/documents/22065/5_protected_lands_public_3-13-15.pdf.

protected lands indicator to inform other climate-related indicators, including **wetland migration corridors**.

- Design the indicator to differentiate between various levels of protection (e.g., state park, working forest, various types of easements), so as to characterize the quality of protection. Stronger, more permanent forms of protection (e.g., land that can never be developed in any way) or forms of protection that allow for adaptation to climate change (e.g., wetland migration) may confer higher resilience.

## Stage 1: Indicator and Metric Definition

| ✓ | **Status:** Indicator and its metric have been defined. |
|---|---|

### *Indicator Description*

This indicator will identify the total number of acres of permanently protected lands in the Chesapeake Bay watershed, at multiple jurisdictional levels, and for all land ownership types. The CBP currently defines "protected lands" as lands permanently protected from development, by either purchase or donation, through perpetual conservation or open space easements or fee ownership. Protected lands include: county, town, city, state and federal parks; designated open space and recreational land; publicly-owned forests and wetlands; privately-owned working farms or forests with conservation easements; historically-important lands; and military-owned parks and recreational areas. The current CBP indicator tracks total acres protected to evaluate progress toward the protection of an additional two million acres by 2025, compared with 2010 levels.

### *Additional Needs*

No additional work is required for the indicator as currently defined. Additional enhancements would require the following work:

| | |
|---|---|
| Additional work needed | • To evaluate the conservation value of protected lands: Identify dataset(s) that ascribe differential value to parcels of land (e.g., priority habitat areas, priority conservation lands) and outline a general approach. Consider NOAA's general principles and approach at: https://coast.noaa.gov/applyit/wetlands/prioritize.html, along with the data sources described in Stage 2 below. Build on any work that has already been done in this area—for example, conservation priority mapping done by the Cross-Goal Team and the CBPO GIS team.<br>• To evaluate the quality of protection: Review available data sources, determine the extent to which they distinguish between different types of protected land (which could require consulting with the jurisdictions that report data), develop a list of desired characteristics for protection, and outline a general approach and reporting scheme for quantifying the level of protection based on the extent to which these desired characteristics are present for a given parcel of land.<br>• For both of these optional components, consider climate resiliency—i.e., what types of protected land and what levels of protection are most important from a climate change perspective. In terms of conservation value, providing habitat for a species at risk from climate change might be a particularly compelling consideration. In terms of quality of protection, a level of protection that |

| | |
|---|---|
| | prohibits shoreline armoring or allows for wetland migration might be of particular interest. |
| Skills or resources needed, and what individuals or organizations have this capacity | Knowledge of relevant protected land datasets, statues/regulations governing different protection types, and programmatic perspective on priorities for land conservation. This capacity is likely available from existing workgroups and partner agencies. A collaborative process can be facilitated by CBPO staff or a contractor. To capitalize on existing efforts, it may be worthwhile to engage with the Chesapeake Conservation Partnership, which has worked for many years to map priority lands for conservation and identify promising topics for climate-related indicators. |
| Achievable timeframe | Within 1 year. |
| Estimated up-front cost | Up to $10,000 or 100 staff hours to facilitate the "indicator definition" process for the enhancements described here. |

## Stage 2: Data Collection

| | |
|---|---|
| ✓ | **Status:** Data collection program in place. |

### *Data Source Information*

| | |
|---|---|
| Dataset | CBP protected lands dataset. |
| Source description | Compilation of federal and state mapping layers. |
| Organization that collects the data | CPBO collects data from states and USGS Protected Areas Database of the United States (PAD-US). Data provided directly from:<br>• USGS PAD-US (includes National Conservation Easement Dataset)<br>• Delaware Department of Natural Resources and Environmental Control (Division of Fish and Wildlife)<br>• Freshwater Institute (West Virginia Protected Lands)<br>• Maryland Department of Natural Resources<br>• Maryland Department of Planning<br>• Pennsylvania Bureau of Farmland Preservation<br>• Pennsylvania Department of Conservation and Natural Resources<br>• Virginia Department of Conservation and Recreation |
| Data source contact | Renee Thompson, rthompso@chesapeakebay.net. |
| Rationale for selection | Data source for existing indicator that meets the stated need for this topic. |
| Temporal coverage | Multiple iterations of protected area datasets (2006, 2011, 2013, 2015/2016), although comparisons over time are limited by methodological variations. |
| Frequency | Updated approximately every 2 years. |
| Spatial coverage | Chesapeake watershed. |
| Spatial scale/resolution | Generally 1:24,000. |
| Access to data | Available through the CBPO. |

Protected land GIS layers are available from various sources, but the existing CBP dataset provides the most topically relevant and readily available source of data. Many of the protected land layers published by other agencies and organizations are derived from the same underlying sources as the CBP dataset. For example, the Chesapeake Conservation Partnership helps to support the LandScope Chesapeake initiative, which provides extensive information about priority lands for protection, but the data layers that LandScope provides on the protected status of lands appear to be derived from the USGS PAD-US dataset described above.

The optional enhancements proposed in this plan should be possible to implement using the existing CBP protected lands dataset or other data sources that are already available, such as:

- TNC Ecoregions Priority Areas for Conservation (http://maps.tnc.org/gis_data.html)
- Phase 6 Land Use dataset (https://chesapeake.usgs.gov/phase6/map)
- Chesapeake High-Resolution Land Cover Data Project (http://chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/land-cover-data-project/), which fed into the Phase 6 Land Use dataset
- Conservation value mapping generated under the CBP Protected Lands work plan

### *Additional Needs*

Future data collection is assumed to be funded through existing mechanisms. Also, the CBPO is planning a project to enhance the reporting process such that reporting entities (jurisdictions) will standardize datasets into PAD-US format before uploading through LandScope Chesapeake. This standardization and corresponding technical assistance to jurisdictions will help make it possible to track changes over time. This existing project is taking place separately from this climate resiliency indicator effort, so its resource needs are not considered as part of this implementation plan.

## Stage 3: Method Development/Selection

| ✓ | **Status:** Methods have been selected to transform the data into an indicator. |
|---|---|

### *Method Information*

| | |
|---|---|
| Description | • Protected lands datasets are collected from jurisdictions and PAD-US and compiled.<br>• Raw data exist in polygon format; convert to 5-meter raster grid cells.<br>• Calculate area by ownership type from 5-meter grid cells and aggregate to state level. |
| Peer-review status | Peer-review status TBD. Note that only authoritative datasets are used in the compilation for this indicator. |
| Citations | Chesapeake Bay Program. 2016. Indicator analysis and methods document. http://www.chesapeakeprogress.com/files/Analysis_and_Methods_2016_Protected_Lands_02-06-2017.pdf. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Develop an approach to quantify changes in protected acreage from one time interval to the next, which requires distinguishing between previously protected and newly protected parcels. This step has already been identified as a potential future enhancement to the existing CBP indicator.<br><br>To evaluate the conservation value of protected lands:<br>• Identify priority land cover types on which to focus (e.g., acres of protected wetland, acres of protected riparian zone).<br>• Develop and test methods for overlaying habitat or conservation priority datasets and identifying protected areas that intersect with priority areas.<br>• Consider methods to identify connections between adjacent protected areas that could serve as habitat corridors.<br><br>To evaluate the quality of protection, develop and test a method for combining multiple datasets (as needed), categorizing levels and types of protection, deriving a composite "quality" score, and mapping the results. As described above, this approach should consider what attributes of protection are most relevant from the perspective of climate resiliency. |
| Skills or resources needed, and what individuals or organizations have this capacity | Quantification of change will require familiarity with reporting formats and coordination with jurisdictional partners. The CBPO, with support from partner agencies and contractors, has this capacity.<br><br>Adding conservation value and quality of protection will require GIS software and skills, along with expertise in working with land cover/land use and ecological datasets. CBPO staff or a contractor can provide this support. |
| Achievable timeframe | Comparison over time TBD; 1 to 2 years for other enhancements. |
| Estimated up-front cost | Comparison over time is presumably already funded. Adding conservation value and quality of protection could require \$10,000–\$25,000 if contractor support is desired, or 150–300 staff hours |

## Stage 4: Data Processing

| | |
|---|---|
| ✓ | **Status:** Data have been processed to create an indicator. |

### *Data Processing Information*

| | |
|---|---|
| Summary of processing steps | Calculate percent of total protected land within each jurisdiction. |
| Processing tools and skills needed | Compilation and calculation is performed using GIS software. Final calculations and development of charts in Excel. |
| Organization that processes the data | CBPO staff. |
| Processing contact | Renee Thompson, rthompso@chesapeakebay.net. |
| Access to processed data | Compiled protected lands dataset available from the CBPO. Excel file showing calculations posted at: http://www.chesapeakeprogress.com/conserved-lands/protected-lands. |

| | |
|---|---|
| Access to processing scripts, formulae, etc. | Available through the CBPO. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Process data for future years, including change over time. Process data for optional enhancements. |
| Skills or resources needed, and what individuals or organizations have this capacity | GIS software and skills; working knowledge of Excel. CBPO staff have the capacity to perform these steps, although a contractor could assist with the optional enhancements if it makes sense with available resources. |
| Achievable timeframe | Routine processing every 2 years; adding change over time TBD; other optional enhancements likely achievable in 1 to 2 years. |
| Estimated up-front cost | Estimated $10,000–$25,000 or 100–250 staff hours for optional enhancements. |
| Estimated annual maintenance cost[2] | No additional cost to process the existing indicator, assuming the CBPO continues to maintain it. Optional enhancements will require additional maintenance; cost TBD. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| ✓ | **Status:** Indicator developed for the Chesapeake. |

### *Indicator Information*

| | |
|---|---|
| Components developed | Check all that apply:<br>☑ Graph(s)<br>☑ Map(s)<br>☑ Summary text<br>☑ Technical documentation in CBP format<br>☑ Downloadable data<br>□ Other: ________________________________ |
| Organization that publishes the indicator | CBPO. |
| Indicator contact | Renee Thompson, rthompso@chesapeakebay.net. |
| Temporal coverage | 2011–2016. |
| Frequency | Every 2 years. |
| Spatial coverage | Chesapeake watershed. |
| Spatial scale/resolution | Graph shows statewide totals; map at 1:24,000 scale. |
| Access to indicator | http://www.chesapeakeprogress.com/conserved-lands/protected-lands. |

[2] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Update existing indicator as new data become available. Add/revise graphics and revise the documentation if enhancements are added. |
| Skills or resources needed, and what individuals or organizations have this capacity | Familiarity with the data and the processing steps; CBPO staff can perform this work. |
| Achievable timeframe | Routine updates every 2 years; timeframe for adding change over time TBD; other enhancements can be added in 1 to 2 years. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[3] | TBD. |
| Final reviews or approvals needed | TBD. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[4] |
|---|---|---|---|---|---|
| **Existing CBP Protected Lands Indicator** | | | | | |
| Process data for existing indicator in future years | 4 | None[5] | Every 2 years | CBPO staff | Required |
| Update existing indicator materials in future years | 5 | None[4] | Every 2 years | CBPO staff | Required |
| **Enhancements Already Planned for Existing CBP Protected Lands Indicator** | | | | | |
| Standardize reporting | 2 | None[6] | TBD | CBPO staff and partner agencies | Optional |
| Develop an approach to quantify changes in protected acreage over time | 3 | None[5] | TBD | CBPO staff and partner agencies | Optional |
| Process change data | 4 | None[5] | TBD | CBPO staff | Optional |
| Revise indicator to incorporate new component(s) | 5 | None[5] | TBD | CBPO staff | Optional |

[3] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[4] An action is required if it is pivotal to developing or maintaining an indicator. Other actions are considered optional if they represent more of an enhancement or expansion to an indicator.

[5] Given that this indicator is already maintained by the CBPO, it likely can continue to be maintained without requiring the services of a contractor or other partners.

[6] Enhancements to jurisdictional reporting and determination of change over time have been proposed and presumably funded through other mechanisms, so this implementation plan does not add incremental costs for these steps.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[4] |
|---|---|---|---|---|---|
| **Enhancements Proposed for Climate Resiliency** | | | | | |
| Identify dataset(s) that map conservation value and/or outline an approach to quantify quality of protection, both in a climate resiliency context | 1 | Up to $10,000 or 100 staff hours | Within 1 year | CBPO staff or contractor | Optional |
| Develop methods to quantify conservation value and/or quality of protection | 3 | $10,000–$25,000 or 150–300 staff hours | 1 to 2 years | CBPO staff or contractor | Optional |
| Process data for these climate resiliency enhancements | 4 | $10,000–$25,000 or 100–250 staff hours | 1 to 2 years | CBPO staff or contractor | Optional |
| Revise indicator to incorporate climate resiliency enhancements | 5 | TBD | 1 to 2 years | CBPO staff or contractor | Optional |
| Process data in future years | 4 | TBD/yr | Every 2 years | CBPO staff | Optional |
| Update indicator materials in future years | 5 | TBD/yr | Every 2 years | CBPO staff | Optional |
| **Total one-time cost** (required components) | | **None** | | | |
| **Total one-time cost** (optional enhancements) | | **~$20,000–$60,000; 250–650 staff hours; or some combination of the two** | | | |
| **Total annual cost** (required components) | | **None** | | | |
| **Total annual cost** (optional enhancements) | | **TBD/yr** | | | |

# 2. Restored Habitat

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| ✓ | Stage 3: Methods developed/selected to transform data into an indicator |
| ✓ | Stage 4: Data processed |
| ✓ | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to address the **Climate Resiliency** goal and outcomes, as acreage of restored habitat indicates programmatic progress toward creating more refugia for species that face threats from extreme events and changing conditions.
- Oyster reefs promote **Water Quality** by filtering out pollutants, protect shorelines from erosion, and provide food and valuable habitat for other organisms. The **Sustainable Fisheries** goal and outcomes in the 2014 Watershed Agreement include a target for oyster reef restoration.
- Wetlands help to prevent pollution from running off into receiving waterbodies and, ultimately, the Bay; slow the erosion of shorelines and protect properties against floods by absorbing stormwater and dampening storm surges; provide habitat for wildlife; and support recreation. The **Vital Habitats** goal and outcomes in the Watershed Agreement include targets for creating or reestablishing wetlands and enhancing the function of degraded wetlands.

Relationship to other indicators in the proposed suite:

- Reductions in **wetland extent and/or physical buffering capacity**, **sea level rise,** and changes in **land use/land cover** are key drivers of the need for habitat restoration.
- Restored habitat shelters the shoreline of the Bay and its tributaries, thus helping to mitigate **coastal flooding** and **upstream flooding** and reducing the extent of **property at risk or damaged.**
- Restored habitat attenuates the effects of changes in **precipitation** by reducing the quantity and improving the quality of runoff to receiving water bodies.
- Habitat restoration can increase the viability of **wetland migration corridors**, increase the amount **protected land**, and increase the **extent of living (rather than hardened) shorelines**.

Notable opportunities, risks, and areas for enhancement:

- The proposed indicator is already maintained and published by the Chesapeake Bay Program (CBP). A suite of climate resiliency indicators could simply include a link to this existing indicator.
- This indicator could be enhanced in the future by adding more types of restored habitat in addition to oyster beds and wetlands on agricultural lands, or by tracking the extent to which oyster reef restoration meets certain success metrics (i.e., metrics that look at whether the restored acreage is being maintained or sustained three years and six years after restoration). Such enhancements would require further consideration before laying them out as part of an implementation plan.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| ✓ | **Status:** Indicator and its metric have been defined. |

### *Indicator Description*

This indicator identifies the acres of restored oyster reefs, along with acreage remaining to meet restoration targets, in four tributaries (Harris Creek, Maryland; Tred Avon River, Maryland; Little Choptank River, Maryland; and Lafayette River, Virginia). Tributary-specific acreage targets are based on historical oyster habitat and currently restorable area. The Lynnhaven and Piankatank rivers will be added once targets for restoration in those tributaries are established.

This indicator also identifies the acres of agricultural wetlands restored per year in the Chesapeake Bay Watershed, compared with a 2010 baseline. Specific restoration targets have been developed in conjunction with Watershed Implementation Plans to meet TMDL goals.

The oyster and wetland components are envisioned as two separate metrics, each measured on its own scale, although a combined mapping tool could be developed in the future.

### *Additional Needs*

No further work needed to define this indicator.

## Stage 2: Data Collection

| ✓ | **Status:** Data collection program in place. |
|---|---|

### *Data Source Information*

| | |
|---|---|
| Dataset | Acreage of restored habitat. |
| Source description | **Oyster reefs:** Project partners track the implementation progress of oyster restoration in selected tributaries.<br>**Wetlands:** Data are submitted by jurisdictions and incorporated in the Chesapeake Bay Program Watershed Model Scenario Input Deck. |
| Organization that collects the data | **Oyster reefs:** Organizations that coordinate restoration projects.<br>**Wetlands:** Individual jurisdictions (states). |
| Data source contact | **Oyster reefs:** Maryland and Virginia Oyster Restoration Interagency Teams (member organizations listed in the oyster restoration management strategy).<br>**Wetlands:** Jeff Sweeney, CBPO, jsweeney@chesapeakebay.net. |
| Rationale for selection | Data already approved for use by the Chesapeake Bay Program. |
| Temporal coverage | **Oyster reefs:** 2011 to present (monitoring for some locations started later).<br>**Wetlands:** 2009 to present. |
| Frequency | Data compiled annually. |
| Spatial coverage | **Oyster reefs:** Six tributaries have been selected so far and are tracked with this indicator: Harris Creek, Little Choptank River, and Tred Avon River in Maryland; Piankatank, Lafayette, and Lynnhaven rivers in Virginia. The Great Wicomico and lower York Rivers have been preliminarily selected for restoration in Virginia.<br>**Wetlands:** Throughout the Chesapeake Bay Watershed. |
| Spatial scale/resolution | **Oyster reefs:** Data are collected for individual restoration project areas.<br>**Wetlands**: Data are collected for each jurisdiction. |

| | |
|---|---|
| Access to data | **Oyster reefs:** The underlying dataset of completed acreage of oyster reefs is not compiled in one place on the web, except for the results in the final indicator (see Stage 5).<br>**Wetlands:** http://ches.communitymodeling.org/models/CBPhase5/index.php. |

A review of other possible data sources did not identify any that would provide wider geographic coverage with consistent characterization and measurement approaches. However, new developments may come to light in the future.

### *Additional Needs*

No additional work needed to collect data, assuming the current data collection program continues.

## Stage 3: Method Development/Selection

| | |
|---|---|
| ✓ | **Status:** Methods have been selected to transform the data into an indicator. |

### *Method Information*

| | |
|---|---|
| Description | **Oyster reefs:**<br>• Acres of constructed and/or seeded oyster reefs are measured by restoration partners and reported to the Chesapeake Bay Program's Sustainable Fisheries Goal Team each year.<br>• Project-specific data are aggregated to get total acreage restored for each tributary.<br>**Wetlands:**<br>• Acres of wetlands established, rehabilitated, or reestablished on agricultural lands in the Chesapeake Bay watershed are measured.<br>• Jurisdiction-level data are aggregated to get total acreage of wetlands restored watershed-wide.<br>• Input deck data are developed using jurisdiction submissions and the Chesapeake Bay Program Scenario Builder tool. |
| Peer-review status | Calculations are administrative in nature. Peer-review validation of these methods is not required. |
| Citations | N/A |

### *Additional Needs*

No additional work needed to define methods.

## Stage 4: Data Processing

| | |
|---|---|
| ✓ | **Status:** Data have been processed to create an indicator. |

### *Data Processing Information*

| | |
|---|---|
| Summary of processing steps | **Oyster reefs:** Collect data from restoration partners. Aggregate data for each tributary of interest.<br>**Wetlands:** Collect data from jurisdictions. Aggregate to get total acreage restored watershed-wide. |
| Processing tools and skills needed | Processing tools and skills can be determined through discussion with CBPO staff. |
| Organization that processes the data | CBPO. |
| Processing contact | **Oyster reefs:** Bruce Vogt, CBPO, bruce.vogt@noaa.gov.<br>**Wetlands:** Jennifer Greiner, USFWS, jennifer_greiner@fws.gov. |
| Access to processed data | **Oyster reefs:** http://www.chesapeakeprogress.com/abundant-life/oysters.<br>**Wetlands:** http://www.chesapeakeprogress.com/abundant-life/wetlands. |
| Access to processing scripts, formulae, etc. | Via CBPO. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Process data for future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | Requires basic Excel skills and relationships with reporting partners and jurisdictions to obtain data and troubleshoot if needed. CBPO staff and partners have this capacity. |
| Achievable timeframe | This is ongoing work that is already on an annual maintenance schedule. |
| Estimated up-front cost | None. |
| Estimated annual maintenance cost[7] | No additional cost. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. If an indicator already exists at a different scale, this step requires it to be clipped or cropped to the Chesapeake watershed or similarly appropriate spatial extent, if needed. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| ✓ | **Status:** Indicator developed for the Chesapeake Bay. |

### *Indicator Information*

Two separate metrics are available: one that focuses on wetlands and one that focuses on oyster reefs.

[7] Incremental cost beyond work that is already being performed. If data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Components developed | Check all that apply:<br>☑ Graph(s)<br>☑ Map(s)<br>☑ Summary text<br>☑ Technical documentation in CBP format<br>☑ Downloadable data<br>☐ Other |
| Organization that publishes the indicator | CBPO. |
| Indicator contact | **Oyster reefs:** Bruce Vogt, Chesapeake Bay Program, bruce.vogt@noaa.gov.<br>**Wetlands:** Jennifer Greiner, USFWS, jennifer_greiner@fws.gov. |
| Temporal coverage | **Oyster reefs:** 2016.<br>**Wetlands:** 2010–2015. (Data through 2017 to be added soon.) |
| Frequency | Annual. |
| Spatial coverage | **Oyster reefs:** Harris Creek, Tred Avon River, Little Choptank River (Maryland); Lafayette River (Virginia). (More tributaries to be added as restoration projects proceed.)<br>**Wetlands:** Chesapeake watershed. |
| Spatial scale/resolution | **Oyster reefs:** Data for each project site.<br>**Wetlands:** Watershed-wide total. |
| Access to indicator | **Oyster reefs:** http://www.chesapeakeprogress.com/abundant-life/oysters.<br>**Wetlands:** http://www.chesapeakeprogress.com/abundant-life/wetlands. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | Basic skills in Excel; CBPO staff can continue to perform this step. |
| Achievable timeframe | This is ongoing work that is already on an annual maintenance schedule. |
| Estimated up-front cost | None. |
| Estimated annual maintenance cost[8] | No additional cost. |
| Final reviews or approvals needed | No additional reviews or approvals needed. |

## Summary of Actions and Anticipated Costs

No incremental costs. Just link to existing indicator.

[8] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

# 3. Air Temperature

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| ✓ | Stage 3: Methods developed/selected to transform data into an indicator |
| ✓ | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to inform the **Climate Resiliency** goal and outcomes by characterizing patterns and trends related to air temperatures, which represent the foundational impact of climate change.
- Shifts in the timing of air temperatures that represent optimal conditions for survival, growth, and reproduction of living resources can have a host of ecological implications. Phenological events throughout the year, such as blooms and migration patterns, can become offset from crucial complementary events. For example, for a given latitude and altitude in winter months, warmer temperatures influence the timing of onset, occurrence, duration, and extent of freezing temperatures, which can in turn result in numerous other effects, such as changes in pest survival over winter and longer growing seasons.
- For human populations in the Chesapeake region, increased intensity and duration of extreme heat events can threaten lives. Present studies demonstrate increasing annual temperatures and longer periods of hot temperature extremes. Economically, warmer temperatures may decrease energy costs in winter, increase energy costs in summer, and affect weather-dependent livelihoods, such as farming and fishing.

Relationship to other indicators in the proposed suite:

- Warmer air temperatures promote an increase in both the total amount and intensity of **precipitation**.
- Air temperatures are the principal factor controlling **bay water temperature** and **stream water temperature**. Water temperatures, in turn, can influence **fish population distributions** and the intensity of **harmful algal blooms**.
- Air temperatures influence **bird species ranges** and **submerged aquatic vegetation species composition**.
- In areas of human development, air temperatures can be influenced by changes to the **urban tree canopy** or **land use/land cover**.

Notable opportunities, risks, and areas for enhancement:

- The proposed indicator will have three metrics, all of which take advantage of existing data collection and compilation efforts. The Tropical Nights Index will be drawn directly from an existing hybrid analysis of Chesapeake Bay National Estuarine Research Reserve (CBNERR) and NOAA sites, based on station data that are already being collected. These data have already been aggregated to generate a composite Bay-wide trend. The other two metrics (mean air temperature and hot daily highs) will be drawn from national indicators that EPA already maintains and publishes every year, based on NOAA data.
- These arrangements that can greatly reduce the cost to develop this indicator, but they also create a risk of dependency if any of the parent parties (EPA, NOAA, and the team that developed the Tropical Nights Index) are not able to continue to maintain their respective indicators.

## Stage 1: Indicator and Metric Definition

| ✓ | **Status:** Indicator and its metrics have been defined. |
|---|---|

### *Indicator Description*

The proposed indicator will present information about hot temperature extremes and annual mean air temperatures. By including two aspects of air temperature (extremes and means), this indicator recognizes the multiple ways in which changes in frequency distributions for air temperature can affect humans and ecosystems. Three metrics are proposed:

- A “Tropical Nights Index” that combines data from long-term NOAA weather stations with recent measurements from CBNERR sites. Together, these records form the basis for a region-wide index that represents the total number of days each year when the daily low temperature does not go below 68°F.
- Station-level trends in the number of days per year with unusually warm daily high temperatures (i.e., $95^{th}$ percentile of daily high over the period of record). These trends will be presented on a map of the Chesapeake Bay region with each station’s symbol representing the change in the number of days over the entire period of record.
- A map showing the long-term rate of change in annual mean air temperatures, with individual station data rolled up by climate division. Each state has up to 10 climate divisions as defined by NOAA.

All three metrics described here could operate reasonably independently; in other words, they could all potentially trend in different directions. As the climate warms overall, though, one would expect to see all three metrics increase. The reinforcing effect of seeing similar trends across metrics provides a more compelling message about changes to the temperature regime in the Chesapeake Bay.

### *Additional Needs*

No further work is needed to define this indicator.

## Stage 2: Data Collection

| ✓ | **Status:** Data collection program in place. |
|---|---|

### *Data Source Information*

**Metric #1: Hot daily lows**

| | |
|---|---|
| Dataset | Tropical nights index. |
| Source description | Multi-year average of the total number of days each year when temperatures do not go below 68°F. |
| Organization that collects the data | NOAA and Chesapeake Bay National Estuarine Research Reserve (CBNERR). |
| Data source contact | Consult the “Changing Chesapeake” project team (http://www.chesapeakedata.com/changingchesapeake/). |

| | |
|---|---|
| Rationale for selection | Provides a long-term dataset that is blended with ongoing CBNERR scientific efforts. The emphasis on nighttime temperatures (i.e., "hot daily lows") reflects findings in the literature that from a human perspective, the most physiologically dangerous aspect of an extreme heat event is often warm nighttime temperatures that prevent the body from cooling off. |
| Temporal coverage | 1910–present. |
| Frequency | Hourly data rolled up into daily lows. |
| Spatial coverage | Chesapeake Bay region. |
| Spatial scale/resolution | Individual stations. |
| Access to data | • NOAA's USHCN data: https://www.ncdc.noaa.gov/cdo-web/.<br>• NERR data: http://cdmo.baruch.sc.edu/get/export.cfm. |

**Metric #2: Hot daily highs**

| | |
|---|---|
| Dataset | Hot daily highs. |
| Source description | Change in number of days per year hotter than the 95th percentile over the entire period of record. This means the 95th percentile is recalculated each year as additional data are added to the set. |
| Organization that collects the data | NOAA. |
| Data source contact | Deke Arndt, NOAA National Centers for Environmental Information (NCEI), derek.arndt@noaa.gov. |
| Rationale for selection | Long-term, authoritative source with a dense station network. The emphasis on the hottest temperatures of the year recognizes that extremely hot temperatures pose stresses to the human body, other species, and infrastructure (for example, the electric power grid). This map-based approach provides a spatial complement to the time-series graph that is proposed for the Tropical Nights Index. |
| Temporal coverage | 1948–present for the most complete set of stations. |
| Frequency | Hourly data rolled up into daily highs. |
| Spatial coverage | Nationwide. |
| Spatial scale/resolution | Individual stations. |
| Access to data | ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/hcn/. |

**Metric #3: Mean air temperature**

| | |
|---|---|
| Dataset | Mean air temperatures. |
| Source description | Air temperature trends from individual weather stations are spatially averaged into NOAA climate divisions. NOAA provides these climate division averages. |
| Organization that collects the data | NOAA. |
| Data source contact | Deke Arndt, NOAA NCEI, derek.arndt@noaa.gov. |
| Rationale for selection | Long-term, authoritative source with a dense station network. Changes in annual mean temperature provide a sense of the overall degree of warming in the environment and offer a basis for comparison with national and global trends. |
| Temporal coverage | 1901–present for the most complete set of stations. |
| Frequency | Hourly data rolled up into daily, monthly, and annual means. |
| Spatial coverage | Nationwide. |
| Spatial scale/resolution | Individual stations. |
| Access to data | https://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp. |

While other organizations collect air temperature data, NOAA's long-term datasets represent the authoritative source for reliable, quality-controlled climatological information from a large set of weather stations, all collecting data following consistent quality assured data collection, management, and analysis protocols. The CBNERR stations offer a useful supplement for the "tropical nights index" analysis.

### *Additional Needs*

No additional work is needed to collect data, assuming current data collection programs continue.

## Stage 3: Method Development/Selection

| ✓ | **Status:** Methods have been selected to transform the data into an indicator. |
|---|---|

### *Method Information*

**Metric #1: Hot daily lows**

| | |
|---|---|
| Description | • For each station, calculate total number of days each year when temperatures do not go below 68°F. Separate out stations geographically, if desired.<br>• Aggregate spatially. (Note: the exact method of spatial aggregation can be determined through consultation with the "Changing Chesapeake" project team.)<br>• Calculate 21-year moving average (optional). |
| Peer-review status | NOAA data have been used in many peer-reviewed publications. Status of peer review for the hybrid temperature calculations is unknown. |
| Citations | Numerous citations about the NOAA component of the dataset are available here: https://www.ncdc.noaa.gov/ushcn/references. |

**Metric#2: Hot daily highs**

| | |
|---|---|
| Description | • For every station, determine the 95$^{th}$ percentile temperature threshold of daily maximum temperature over the entire period of record. This means the 95$^{th}$ percentile is recalculated each year as additional data are added to the set.<br>• For every year at every station, calculate the number of days that exceeded the threshold.<br>• Use linear regression to calculate a trend over time for each station. |
| Peer-review status | Peer-reviewed as part of the development of EPA's indicator suite (https://www.epa.gov/climate-indicators/climate-change-indicators-high-and-low-temperatures). Peer review confirmed scientific integrity and conformance to EPA's data quality criteria. Underlying data processing methods at NOAA, including de-biasing, have also been peer-reviewed. |
| Citations | Citations for raw data: https://www.ncdc.noaa.gov/ghcn-daily-references. |

**Metric #3: Mean air temperature**

| | |
|---|---|
| Description | • Use hourly data to calculate monthly and then annual means for each station.<br>• Use NOAA's *n*ClimDiv topographically-sensitive spatial weighting approach to develop a 5-km grid, then average the results by climate division. For each division, subsequently calculate a linear trend based on the annual spatial means. |

| | |
|---|---|
| Peer-review status | Peer-reviewed as part of the development of EPA's indicator suite (https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-temperature). Peer review confirmed scientific integrity and conformance to EPA's data quality criteria. Underlying data processing methods at NOAA, including de-biasing and spatial aggregation, have also been peer-reviewed. |
| Citations | Numerous citations about this dataset are available at: https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php. |

### *Additional Needs*

No additional need to define methods.

## Stage 4: Data Processing

| | |
|---|---|
| ✓ | **Status:** Data have been processed to create an indicator. |

### *Data Processing Information*

**Metric #1: Hot daily lows**

| | |
|---|---|
| Summary of processing steps | • Download station data from the NOAA and CBNERR databases.<br>• Run a routine that calculates the total number of days per year at each station in which temperatures do not go below 68°F. Aggregate the data spatially.<br>• Calculate 21-year moving averages (optional) to smooth the line graph, if desired. |
| Processing tools and skills needed | A script or other automated calculation process is most likely used to aggregate and average temperature data. Simple Excel skills would be needed to calculate a moving average, if desired. |
| Organization that processes the data | A team consisting of the University of Maryland Center for Environmental Science, the CBNERR sites, and Chesapeake Environmental Communications (CEC) processed the data for the original indicator. |
| Processing contact | Consult the "Changing Chesapeake" project team (http://www.chesapeakedata.com/changingchesapeake/). |
| Access to processed data | Graphs of the processed data, without downloadable values available here: http://www.chesapeakedata.com/changingchesapeake/. |
| Access to processing scripts, formulae, etc. | Consult the "Changing Chesapeake" project team (http://www.chesapeakedata.com/changingchesapeake/). |

**Metric #2: Hot daily highs**

| | |
|---|---|
| Summary of processing steps | • NOAA quality-controls its weather station data.<br>• Download daily temperature data (including daily maxima) from NOAA's website.<br>• Run an R script that EPA maintains.<br>• Organize results in Excel; map using ArcGIS. |
| Processing tools and skills needed | Data are collected in Excel format and processed using R. Basic familiarity is needed in Excel, ArcGIS, and any application that can run an R script. |
| Organization that processes the data | Underlying data processing: NOAA. Processing for nationwide indicator: EPA. |

| | |
|---|---|
| Processing contact | Michael Kolian, EPA, kolian.michael@epa.gov. |
| Access to processed data | Processed data for national indicator available on EPA's website at: https://www.epa.gov/climate-indicators/climate-change-indicators-high-and-low-temperatures. |
| Access to processing scripts, formulae, etc. | Michael Kolian, EPA, kolian.michael@epa.gov. |

**Metric #3: Mean air temperature**

| | |
|---|---|
| Summary of processing steps | • NOAA performs temporal and spatial aggregation by climate division.<br>• Download division-level data from NOAA.<br>• Apply a linear regression to calculate the trend over the period of record for each climate division.<br>• Map the results. |
| Processing tools and skills needed | Processing can be performed with basic skills in Excel and ArcGIS. |
| Organization that processes the data | Underlying data processing: NOAA. Processing for nationwide indicator: EPA. |
| Processing contact | Michael Kolian, EPA, kolian.michael@epa.gov. |
| Access to processed data | Processed data displayed with all climate divisions nationwide are available on EPA's website at: https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-temperature. |
| Access to processing scripts, formulae, etc. | Excel and GIS calculations from Michael Kolian, EPA, kolian.michael@epa.gov. |

### *Additional Needs*

**Metric #1: Hot daily lows**

| | |
|---|---|
| Additional work needed | Continue to process data in future years, either through follow-on funding to the "Changing Chesapeake" project team or by adopting the team's methods in-house at the CBPO. |
| Skills or resources needed, and what individuals or organizations have this capacity | To be determined, depending on the exact methods that the "Changing Chesapeake" project team employed. |
| Achievable timeframe | Annual. |
| Estimated up-front cost | None. |
| Estimated annual maintenance cost[9] | TBD; to be discussed with the "Changing Chesapeake" project team. |

Metrics #2 and #3 also require data processing for future years, but this is ongoing work that is already on a regular maintenance schedule coordinated by NOAA and EPA. Future work could include more advanced statistical analysis—for example, determining whether the line of best fit is linear or a higher-order regression.

[9] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. If an indicator already exists at a different scale, this step requires it to be clipped or cropped to the Chesapeake watershed or similarly appropriate spatial extent, if needed. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** Regional indicator developed for hot daily lows but not documented as an official CBP indicator; national indicator developed for the other two metrics but not yet optimized for the Chesapeake. |

### *Indicator Information*

**Metric #1: Hot daily lows**

| | |
|---|---|
| Components developed | Check all that apply:<br>☑ Graph(s)<br>□ Map(s)<br>□ Summary text<br>□ Technical documentation in CBP format<br>□ Downloadable data<br>□ Other: ________________________________ |
| Organization that publishes the indicator | A team consisting of the University of Maryland Center for Environmental Science, the CBNERR sites, and Chesapeake Environmental Communications (CEC). |
| Indicator contact | Consult the "Changing Chesapeake" project team (http://www.chesapeakedata.com/changingchesapeake/). |
| Temporal coverage | 1910–2014. |
| Frequency | Annual. |
| Spatial coverage | Chesapeake region. |
| Spatial scale/resolution | Entire region, or two sub-regions ("north" and "south"). |
| Access to indicator | http://www.chesapeakedata.com/changingchesapeake/. |

**Metric #2: Hot daily highs**

| | |
|---|---|
| Components developed | Check all that apply:<br>□ Graph(s)<br>□ Map(s)<br>□ Summary text<br>□ Technical documentation in CBP format<br>□ Downloadable data<br>☑ Other: map, summary text, EPA-format technical documentation, and downloadable data available for national indicator |
| Organization that publishes the indicator | EPA. |
| Indicator contact | Michael Kolian, EPA, kolian.michael@epa.gov. |
| Temporal coverage | 1948–2015. |
| Frequency | Trend calculated for entire period, but based on annual data. |
| Spatial coverage | Nationwide. |
| Spatial scale/resolution | Individual stations. |
| Access to indicator | https://www.epa.gov/climate-indicators/climate-change-indicators-high-and-low-temperatures. |

**Metric #3: Mean air temperature**

| | |
|---|---|
| Components developed | Check all that apply:<br>□ Graph(s)<br>□ Map(s)<br>□ Summary text<br>□ Technical documentation in CBP format<br>□ Downloadable data<br>☑ Other: map, summary text, EPA-format technical documentation, and downloadable data available for national indicator |
| Organization that publishes the indicator | EPA. |
| Indicator contact | Michael Kolian, EPA, kolian.michael@epa.gov. |
| Temporal coverage | 1901–2015. |
| Frequency | Trend calculated for entire period, but based on annual data. |
| Spatial coverage | Nationwide. |
| Spatial scale/resolution | NOAA climate division (up to 10 per state). |
| Access to indicator | https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-temperature. |

### *Additional Needs*

**Metric #1: Hot daily lows**

| | |
|---|---|
| Additional work needed | Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | Knowledge of the indicator to fill out documentation. CBPO staff could complete this step in the future, but members of the team that developed the Tropical Nights Index likely have the best knowledge to populate the information in the initial year. |
| Achievable timeframe | Development within 1 year; annual updates. |
| Estimated up-front cost | ~$1,500—rough estimate of labor cost to populate technical documentation. |
| Estimated annual maintenance cost[10] | ~8 hours of staff time—cost of updating documentation and other components based on the processing in Stage 4. |
| Final reviews or approvals needed | Agreement with Chesapeake Environmental Communications (CEC) to provide processing steps, methodology, and data. |

**Metric #2: Hot daily highs**

| | |
|---|---|
| Additional work needed | Crop EPA indicator to the stations within the Chesapeake watershed. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | Knowledge of the indicator to fill out documentation. CBPO staff could complete this step, although EPA's climate indicator team might have the background to complete this step most efficiently for the initial year. |
| Achievable timeframe | Development within 1 year; annual updates. |

[10] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Estimated up-front cost | ~$1,500—labor cost for cropping EPA's indicator and populating the technical documentation. |
| Estimated annual maintenance cost[11] | ~8 hours of staff time—cost of excerpting data from EPA's indicator, assuming EPA continues to conduct annual updates. |
| Final reviews or approvals needed | Agreement with EPA to share indicator data and processing script. |

**Metric #3: Mean air temperature**

| | |
|---|---|
| Additional work needed | Crop EPA indicator to the 33 climate divisions that overlap the Chesapeake watershed. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | Knowledge of the indicator to fill out documentation. CBPO staff could complete this step, although EPA's climate indicator team might have the background to complete this step most efficiently for the initial year. |
| Achievable timeframe | Development within 1 year; annual updates. |
| Estimated up-front cost | ~$1,500—labor cost for cropping EPA's indicator and populating the technical documentation. |
| Estimated annual maintenance cost[12] | ~8 hours of staff time—cost of excerpting data from EPA's indicator, assuming EPA continues to conduct annual updates. |
| Final reviews or approvals needed | Agreement with EPA to share indicator data. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[13] |
|---|---|---|---|---|---|
| Prepare CBP indicator documentation for Tropical Nights Index: initial year | 5 | $1,500 | Within 1 year | Input from team that developed the original index | Required |
| Crop EPA maps and prepare CBP indicator documentation for the other two indicator components (hot daily highs and mean air temperature): initial year | 5 | $3,000 | Within 1 year | EPA team | Required |

11 Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

12 Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

13 An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[13] |
|---|---|---|---|---|---|
| Continue to process data for Tropical Nights Index in future years | 4 | TBD/yr | Annual | TBD | Required |
| Update all three parts of the indicator, including cropping EPA's national maps for two components, in future years | 5 | ~24 staff hours/yr | Annual | CBPO staff | Required |
| **Total one-time cost** | | **$4,500** | | | |
| **Total annual cost** | | **~24 staff hours/yr plus Tropical Nights processing cost TBD/yr** | | | |

# 4. Coastal Flooding

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| ✓ | Stage 3: Methods developed/selected to transform data into an indicator |
| ✓ | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to address the **Climate Resiliency** goal and outcomes, as sea level rise related to climate change is a key driver of the increasing frequency of coastal flooding.
- Recurrent coastal flooding can cause impacts such as frequent road closures, reduced stormwater drainage capacity, and deterioration of infrastructure not designed to withstand frequent inundation or exposure to salt water. These impacts are of particular concern because more than 8.6 million Americans live in areas susceptible to coastal flooding, and more than $1 trillion of property and structures is within a few feet of current sea level.[14] Coastal flooding can also affect human health—for example, by increasing the risk that drinking water and wastewater infrastructure will fail, putting people at risk of being exposed to pathogens and harmful chemicals.

Relationship to other indicators in the proposed suite:

- Change in **sea level** is a key driver of this indicator.
- **Wetland extent and physical buffering capacity** can help to attenuate coastal flooding.
- Trends in coastal flooding influence the extent of **property at risk or damaged**.

Notable opportunities, risks, and areas for enhancement:

- The proposed indicator will be excerpted from a nationwide indicator that EPA already maintains and publishes, based on an analysis that NOAA already compiles for EPA every year. This arrangement greatly reduces the cost to develop an indicator for the Chesapeake, but it also creates a dependency that could expose the Chesapeake Bay Program (CBP) to risk if changes in EPA or NOAA priorities preclude these agencies from maintaining the national indicator in the future.
- An opportunity is available to update this analysis to align with a 2018 NOAA publication that used flood thresholds derived from historical tide ranges, which could allow a few more locations to be added. This option should be explored in conjunction with EPA.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| ✓ | **Status:** Indicator and its metric have been defined. |

### *Indicator Description*

This indicator will identify the number of days per year in which tidal waters rose above the local threshold for minor or "nuisance" flooding at four locations (Annapolis, Baltimore, Norfolk, and Washington) where water levels have been measured by tide gauges and where locally relevant flood thresholds have been established.

[14] https://www.epa.gov/climate-indicators/climate-change-indicators-coastal-flooding

This approach captures all floods, including moderate or major events. The number of flood days per year will be averaged decadally and compared from 1950 to present.

### *Additional Needs*

No further work needed to define this indicator.

## Stage 2: Data Collection

| ✓ | **Status:** Data collection program in place. |
|---|---|

### *Data Source Information*

| | |
|---|---|
| Dataset | Real-time water levels. |
| Source description | Water levels monitored continuously by automated tide gauge stations. |
| Organization that collects the data | NOAA. |
| Data source contact | William Sweet, NOAA, william.sweet@noaa.gov. |
| Rationale for selection | Widely cited (in the assessment literature, etc.) as the authoritative source of U.S. coastal flooding data. Data collected consistently for more than a half-century. |
| Temporal coverage | At least 1950 (varies by station) to present. |
| Frequency | Data reported every six minutes. |
| Spatial coverage | 210 tide gauges nationwide; 75 in locations with corresponding flood thresholds; 27 of these stations have sufficient data from 1950 to present; four of these locations are in the Chesapeake or its tidal tributaries (Annapolis, Baltimore, Norfolk, Washington). If the analysis is updated to use derived flood thresholds (see Stage 3), at least three more long-term tide gauges in the Chesapeake region can be added. |
| Spatial scale/resolution | Data for individual stations. |
| Access to data | https://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels. |

Data may be available from other individual locations, but the source proposed here provides the most consistent long-term records. This program emphasizes the societal impact of coastal flooding by focusing on four key population centers along the Chesapeake and its tidal tributaries.

### *Additional Needs*

No additional work needed to collect data, assuming the current data collection program continues.

## Stage 3: Method Development/Selection

| ✓ | **Status:** Methods have been selected to transform the data into an indicator. |
|---|---|

### *Method Information*

| | |
|---|---|
| Description | • Calculate each day's maximum water level based on hourly water level data.<br>• Compare these daily maxima with established threshold levels for minor flooding at each tide gauge. Flood impact levels have been established locally by National Weather Service (NWS) weather forecasting offices based on many years of impact monitoring. However, NOAA (2018) released an updated version of this analysis using flood thresholds that are statistically derived from tidal ranges. This approach arguably advances the science while offering the potential to expand the analysis to additional tide gauges that did not already have NWS flood thresholds. |
| Peer-review status | Peer-reviewed as part of the development of EPA's indicator suite. Peer review confirmed scientific integrity and conformance to EPA's data quality criteria. |
| Citations | NOAA (National Oceanic and Atmospheric Administration). 2014. Sea level rise and nuisance flood frequency changes around the United States. NOAA Technical Report NOS CO-OPS 073. https://tidesandcurrents.noaa.gov/publications/NOAA_Technical_Report_NOS_COOPS_073.pdf.<br><br>Sweet, W.V., and J.J. Marra. 2015. 2014 state of nuisance tidal flooding. www.noaanews.noaa.gov/stories2015/2014%20State%20of%20Nuisance%20Tidal%20Flooding.pdf.<br><br>NOAA. 2018. Patterns and projections of high tide flooding along the U.S. coastline using a common impact threshold. NOAA Technical Report NOS CO-OPS 086, NOAA National Ocean Service Center for Operational Oceanographic Products and Services. https://tidesandcurrents.noaa.gov/publications/techrpt86_PaP_of_HTFlooding.pdf. |

### *Additional Needs*

No additional work needed to define methods. However, some reviewers of early versions of this implementation plan have suggested enhancements that would extend beyond the current methods. Enhancements could include incorporating additional locations, analyzing trends in annual data or shorter averaging periods (e.g., every 3 to 5 years) instead of decadal averages, and looking separately at trends in events that exceed higher flood thresholds (e.g., moderate or major). If EPA chooses to switch its indicator to the new NOAA (2018) approach with derived flood thresholds, the Chesapeake indicator can easily follow suit. Doing so would allow the addition of three stations with long-term tide gauge records (see the proposed Sea Level indicator): Cambridge, MD; Solomons Island, MD; and Kiptopeke, VA. If the timeframe is relaxed to allow stations that started collecting data more recently, more stations can be added.

## Stage 4: Data Processing

| | |
|---|---|
| ✓ | **Status:** Data have been processed to create an indicator. |

### *Data Processing Information*

| | |
|---|---|
| Summary of processing steps | Download data from NOAA's database. Run a script or routine to calculate daily max values, compare with local flood thresholds, and count the number of days per year with exceedances. Calculate decadal averages. |
| Processing tools and skills needed | Processing can be performed with a script (R or Python, possibly? NOAA currently performs this step) and final calculations in Excel. |

| | |
|---|---|
| Organization that processes the data | Processing script: NOAA. Excel calculations: EPA. |
| Processing contact | William Sweet, NOAA, william.sweet@noaa.gov.<br>Michael Kolian, EPA, kolian.michael@epa.gov. |
| Access to processed data | Processed data provided to EPA by William Sweet, NOAA. EPA's data posted at https://www.epa.gov/climate-indicators/climate-change-indicators-coastal-flooding. |
| Access to processing scripts, formulae, etc. | Processing script from William Sweet, NOAA. Excel calculations from Michael Kolian, EPA. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Process data for future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | • Requires ability to use a processing script (NOAA would know the format) and ability to perform basic calculations in Excel. NOAA and EPA teams can perform these steps.<br>• This long-term analysis also requires access to the back end of NOAA's database to obtain the data efficiently, as the public interface limits each query to 31 days of data at a time. NOAA has this capability. |
| Achievable timeframe | Short-term (can be achieved within 1 to 2 years). This is ongoing work that is already on an annual maintenance schedule as agreed between NOAA and EPA. |
| Estimated up-front cost | None. |
| Estimated annual maintenance cost[15] | No additional cost, assuming NOAA and EPA continue to maintain their indicator. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. If an indicator already exists at a different scale, this step requires it to be clipped or cropped to the Chesapeake watershed or similarly appropriate spatial extent, if needed. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** National indicator developed, but not yet optimized for the Chesapeake. |

### *Indicator Information*

| | |
|---|---|
| Components developed | Check all that apply:<br>☐ Graph(s)<br>☐ Map(s)<br>☐ Summary text<br>☐ Technical documentation in CBP format<br>☐ Downloadable data<br>☑ Other: graphs, maps, summary text, EPA-format technical documentation, and downloadable data available for national indicator |
| Organization that publishes the indicator | EPA |

[15] Incremental cost beyond work that is already being performed. If data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Indicator contact | Michael Kolian, EPA, kolian.michael@epa.gov. |
| Temporal coverage | 1950–2015. |
| Frequency | Decadal averages (based on annual totals). |
| Spatial coverage | 27 locations nationwide. |
| Spatial scale/resolution | Data for individual stations. |
| Access to indicator | https://www.epa.gov/climate-indicators/climate-change-indicators-coastal-flooding. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Crop EPA indicator to the four Chesapeake-region stations. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | Basic skills in Excel and ArcGIS; CBPO staff or contractors could perform this step. Knowledge of indicator to fill out documentation; CBPO staff could complete this step, although EPA's climate indicator team might have the background to complete this step most efficiently for the initial year. |
| Achievable timeframe | Short-term (can be achieved within 1 to 2 years). |
| Estimated up-front cost | ~$1,500—labor cost for contractor support to crop EPA's indicator and populate the technical documentation. |
| Estimated annual maintenance cost[16] | 10 staff hours—annualized cost of excerpting data from EPA's indicator every two years, assuming EPA continues to update its indicator. |
| Final reviews or approvals needed | Agreement with EPA and NOAA to share data. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[17] |
|---|---|---|---|---|---|
| Crop EPA's existing national indicator for the Chesapeake: initial year | 5 | ~$1,500 | Short-term | EPA team | Required |
| Crop EPA's existing national indicator for the Chesapeake: future years | 5 | 10 hours/yr | Short-term | CBPO staff | Required |
| **Total one-time cost** | | **~$1,500** | | | |
| **Total annual cost** | | **10 hours/yr** | | | |

[16] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[17] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator. In some cases, optional actions could include steps to transform a relatively weak or one-dimensional indicator that is available in the short-term into a more robust indicator in the longer term.

# 5. Precipitation

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| ✓ | Stage 3: Methods developed/selected to transform data into an indicator |
| ✓ | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator addresses the **Climate Resiliency** goal and outcomes by tracking a key aspect of the Chesapeake region's changing climate conditions. The ability to handle increasingly intense heavy precipitation events is a major aspect of resiliency.
- Through its downstream effects, changes to precipitation could also influence the **Healthy Watersheds** and **Water Quality** goals and outcomes.
- Both total annual precipitation and the incidence of extreme precipitation events have a significant influence on human and natural systems. Precipitation influences streamflow, water levels, turbidity, and other water quality parameters. Heavy precipitation events can cause erosion and flooding. Changes upstream can lead to water quality impacts in the estuary.
- Precipitation is a key factor in assessing the capacity for human systems to adapt to a changing climate. Decision-makers incorporate precipitation projections into planning and permitting for infrastructure, including stormwater management systems.

Relationship to other indicators in the proposed suite:

- Changes in global dynamics relating to **air temperature** are a key driver of precipitation patterns.
- The effects of changes in precipitation are widespread. These include **coastal flooding** (e.g., surge associated with intense storms) and **upstream flooding**—which in turn influence the amount of **property at risk or damaged**. Increased nutrient runoff associated with precipitation can also contribute to **harmful algal blooms**.
- **Land use/land cover** management (for example, permeable vs. impervious surfaces) and **BMPs/green infrastructure** are examples of actions that society can take to become more resilient in the face of increased precipitation, particularly increased heavy precipitation events.

Notable opportunities, risks, and areas for enhancement:

- **Metric #1** of this proposed indicator will be excerpted from a nationwide indicator that EPA already maintains and publishes, based on regularly updated data from NOAA. This arrangement greatly reduces the cost to develop an indicator for the Chesapeake, but it also creates a dependency that could expose the Chesapeake Bay Program (CBP) to risk if changes in EPA or NOAA priorities preclude these agencies from maintaining the national indicator in the future.
- **Metric #2** of this proposed indicator is similarly excerpted from a nationwide indicator that EPA maintains and publishes, but those data are at a spatial scale that is too broad for immediate use as a Chesapeake indicator. NOAA's National Centers for Environmental Information (NCEI) has indicated that an effort is underway to downscale this analysis to individual climate divisions, which are subdivisions of each state. This implementation plan proposes to delay development of Metric #2 until this more downscaled data product becomes available.

## Stage 1: Indicator and Metric Definition

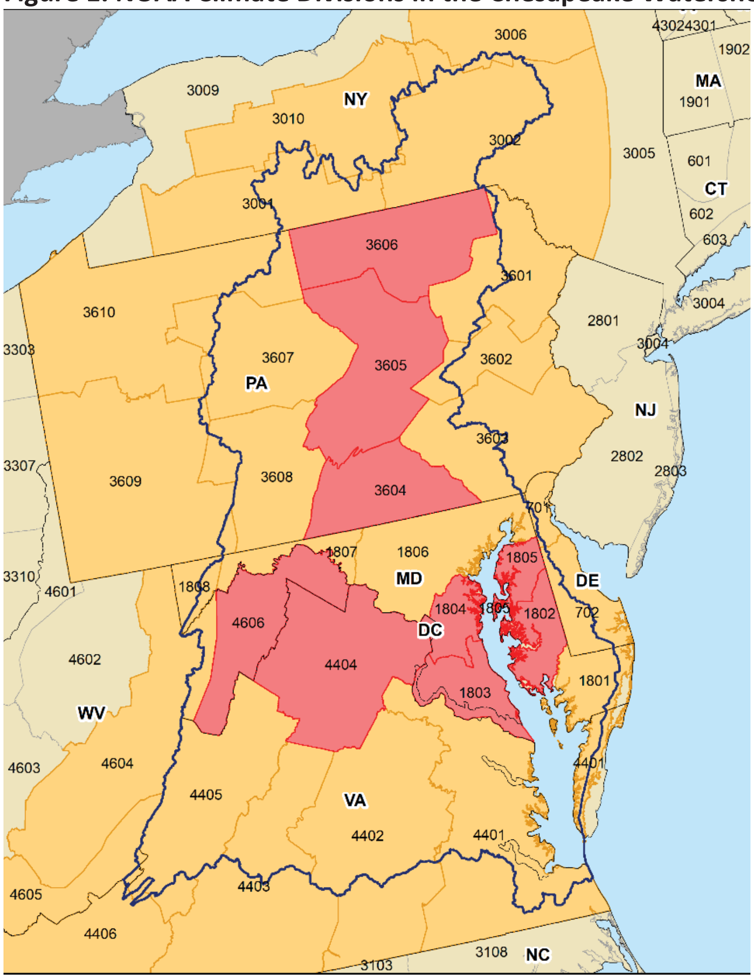
| ✓ | **Status:** Indicator and its metric have been defined. |
|---|---|

### *Indicator Description*

This indicator will consist of two metrics, which present complementary aspects to precipitation in the Chesapeake Bay region:

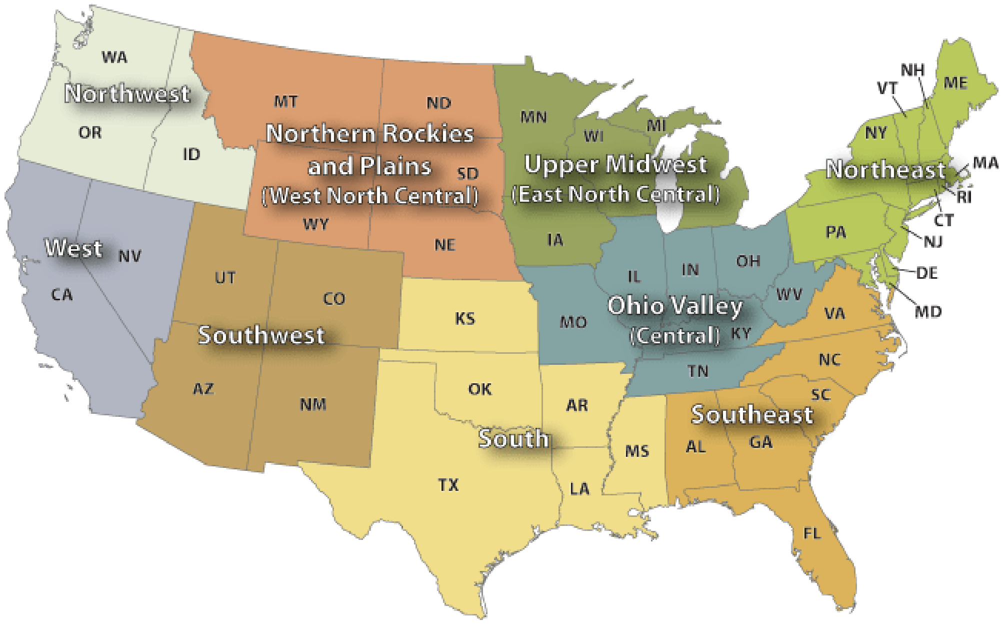
- The first metric will be displayed as a map of percent change in annual precipitation for the 33 NOAA climate divisions that intersect with the Chesapeake watershed. The period of record is from 1895 to 2015. Figure 1 below shows the climate divisions that are fully (red) or partially (orange) within the Chesapeake watershed.

**Figure 1. NOAA Climate Divisions in the Chesapeake Watershed**




- The second metric will portray trends in the proportion of land receiving a much higher than normal percentage of its annual precipitation budget in the form of extreme one-day events. This analysis is part of NOAA's official Climate Extremes Index (CEI). The data are presently aggregated into large, multi-state regions that are not ideal for characterizing the Chesapeake watershed, which straddles three regions (see Figure 2 below). However, NOAA NCEI has raised the prospect of downscaling the CEI to a climate division level in the next few years. Downscaled data will allow this indicator to present either a long-term trend map or a time-series graph for the Chesapeake region.

**Figure 2. NOAA Climate Regions**




### *Additional Needs*

No further work is needed to define this indicator.

## Stage 2: Data Collection

| ✓ | **Status:** Data collection program in place. |
|---|---|

### *Data Source Information*

Both of the proposed metrics are based on the same NOAA data collection program.

| | |
|---|---|
| Dataset | Daily precipitation records. |
| Source description | Daily precipitation totals from thousands of weather stations nationwide, all following standard National Weather Service data collection protocols. |
| Organization that collects the data | NOAA. |
| Data source contact | Deke Arndt, NOAA NCEI, derek.arndt@noaa.gov. |
| Rationale for selection | Authoritative source with relatively high spatial resolution; offers the longest time series for such a large geographic area; used in numerous peer-reviewed analyses. |
| Temporal coverage | 1895–present. |
| Frequency | Daily. |
| Spatial coverage | Nationwide. |
| Spatial scale/resolution | Individual weather stations, but analyses are rolled up into larger regions. |
| Access to data | https://www.ncdc.noaa.gov/cag/ and www.ncdc.noaa.gov/extremes/cei. |

A key goal of this effort is to propose an indicator that can be constructed and kept up to date with limited resources, which means it is useful to minimize the number of discrete data sources that need to be tracked and combined. NOAA's long-term datasets represent the authoritative source for reliable, quality-controlled climatological information from a large set of weather stations, all collecting data following consistent protocols. A few other data sources have been suggested, but they have not been selected for this implementation plan for the following reasons:

- **Precipitation data from CBNERR stations.** Daily precipitation records are available from seven sites around the Bay, dating back to the 1970s (depending on the site). While these records have been used in a hybrid analysis published as part of the "Changing Chesapeake" project (http://www.chesapeakedata.com/changingchesapeake/), the bulk of the spatial and temporal coverage in that hybrid analysis comes from the NOAA long-term weather stations described above. A plan for routine future updates to the hybrid analysis is not readily available, whereas the NOAA long-term sites alone are used in an indicator that EPA maintains with annual data updates. Thus, the NOAA weather stations (as described in the table above) represent arguably the most feasible and complete data source for a "living" indicator of watershed-wide precipitation trends.

- **PRISM precipitation data.** The PRISM group at Oregon State University has spatially aggregated temperature and precipitation data for use at various scales, including watersheds. Their aggregations have proven to be useful for many studies. However, these products are fundamentally based on the same underlying data source described in the table above (NOAA's authoritative set of weather stations), and NOAA's *n*ClimDiv spatial aggregations are more readily available to support ongoing maintenance of a Chesapeake indicator—especially considering that EPA already uses these data in an indicator on which the Chesapeake indicator can be based.

- **Streamflow data.** Numerous studies have examined changes in the Chesapeake region's hydrology by focusing on streamflow, as measured by the longstanding network of stream gauges maintained by USGS and other agencies such as the U.S. Army Corps of Engineers. For example, see Rice et al. (2016).[18] EPA maintains an indicator that examines several attributes of streamflow from a climate change perspective: three-day high flows, seven-day low flows, annual average flow, and the winter-spring center of volume—a measure of the timing of snowmelt.[19] Streamflow scored highly in the screening and expert ranking process that fed into this implementation plan. In the interest of conserving future resources, though, the size of the proposed suite has been restricted to approximately 20 indicators, and a decision was made to limit the number of discrete hydrologic indicators. Precipitation was chosen as one of the core hydrologic indicators. That said, it is important to recognize that precipitation is not a perfect proxy for discharge. As Rice et al. (2016) and previous studies found, precipitation-discharge relationships vary over time and space because of lag times, travel times, land use, snowpack and timing of snowmelt, antecedent conditions, evapotranspiration, and other hydrologic factors.

### *Additional Needs*

No further work is needed to collect data, assuming the current data collection program continues.

## Stage 3: Method Development/Selection

| ✓ | **Status:** Methods have been selected to transform the data into an indicator; additional methodological development could enhance Metric #2. |
|---|---|

[18] Rice, K.C., D.L. Moyer, and A.L. Mills. 2016. Analysis of long-term hydrologic records in the Chesapeake Bay watershed: in preparation for submission to Water Resources Research.

[19] https://www.epa.gov/climate-indicators/climate-change-indicators-streamflow

## *Method Information*

**Metric #1: Total annual precipitation**

| | |
|---|---|
| Description | • Use hourly data to calculate monthly and then annual means for each station.<br>• Use NOAA's topographically-sensitive *n*ClimDiv spatial weighting approach to develop a 5-km grid, then average the results by climate division. |
| Peer-review status | Peer-reviewed as part of the development of EPA's indicator suite (https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-precipitation). Peer review confirmed scientific integrity and conformance to EPA's data quality criteria. Underlying data processing methods at NOAA, including quality control and spatial aggregation, have also been peer-reviewed. |
| Citations | Numerous citations about this dataset are available at: https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php. |

**Metric #2: Heavy precipitation**

| | |
|---|---|
| Description | • Current method involves dividing the nation into a 1-degree grid and selecting one station per grid cell. For every unit grid cell, determine each day's precipitation. Then for each year, calculate the total percentage of precipitation that came from extreme events (i.e., 10$^{th}$ percentile of all precipitation events). New analysis will require a higher resolution of analysis.<br>• For every climate region and every year, calculate the percentage of land area that received more than the normal proportion of its precipitation budget from large events, based on a percentile analysis. |
| Peer-review status | National indicator (line graph) peer-reviewed as part of the development of EPA's indicator suite (https://www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation). Peer review confirmed scientific integrity and conformance to EPA's data quality criteria. Underlying data processing methods at NOAA have also been peer-reviewed. |
| Citations | Gleason, K.L., J.H. Lawrimore, D.H. Levinson, T.R. Karl, and D.J. Karoly. 2008. A revised U.S. climate extremes index. J. Climate 21:2124–2137. |

## *Additional Needs*

**Metric #2: Heavy precipitation**

| | |
|---|---|
| Additional work needed | Add daily precipitation data to NOAA's *n*ClimDiv product; create a downscaled "extreme precipitation events" product in the future (e.g., by climate division or on a gridded 5-km scale). Determine map/graph approach. |
| Skills or resources needed, and what individuals or organizations have this capacity | This step demands complex programming skills, meteorology/climatology expertise, and expert working knowledge of (and access to) NOAA's weather and climate data archives. This work is reportedly already under development by NOAA staff. |
| Achievable timeframe | 2 to 5 years—a loose estimate based on conversations with NOAA NCEI. |
| Estimated up-front cost | No cost to CBPO; NOAA is developing this methodological improvement. |

## Stage 4: Data Processing

| ✓ | **Status:** Data have been processed to create an indicator. |
|---|---|

### *Data Processing Information*

**Metric #1: Total annual precipitation**

| | |
|---|---|
| Summary of processing steps | NOAA performs the spatial analysis. After that, download data from NOAA's website, calculate regressions for each climate division, and determine the percent change from the 1901–2000 baseline. |
| Processing tools and skills needed | Once NOAA completes its processing, the remaining processing steps can be performed with simple Excel calculations or an R script, as well as ArcGIS. |
| Organization that processes the data | EPA. |
| Processing contact | Michael Kolian, EPA, kolian.michael@epa.gov. |
| Access to processed data | Processed data for national indicator available on EPA's website at: https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-precipitation. |
| Access to processing scripts, formulae, etc. | Excel calculations from Michael Kolian, EPA, kolian.michael@epa.gov. |

**Metric #2: Heavy precipitation**

| | |
|---|---|
| Summary of processing steps | NOAA performs the percentile analysis. After that, download data from NOAA's website. If portraying a map, calculate trends in changes to extreme precipitation events for the regions of interest. |
| Processing tools and skills needed | Once NOAA completes its processing, the remaining processing steps can be performed with simple Excel calculations. |
| Organization that processes the data | EPA. |
| Processing contact | Michael Kolian, EPA, kolian.michael@epa.gov. |
| Access to processed data | Processed data for national indicator available on EPA's website at: https://www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation. |
| Access to processing scripts, formulae, etc. | Excel calculations from Michael Kolian, EPA, kolian.michael@epa.gov. |

### *Additional Needs*

Both metrics require data processing for future years, but this is ongoing work that is already on a regular maintenance schedule coordinated by NOAA and EPA.

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. If an indicator already exists at a different scale, this step requires it to be clipped or cropped to the Chesapeake watershed or similarly appropriate spatial extent, if needed. It also requires complete technical documentation in the CBP's standard format.

| | **Status:** National indicator developed, but not yet optimized for the Chesapeake. |
|---|---|

## *Indicator Information*

**Metric #1: Total annual precipitation**

| | |
|---|---|
| Components developed | Check all that apply:<br>☐ Graph(s)<br>☐ Map(s)<br>☐ Summary text<br>☐ Technical documentation in CBP format<br>☐ Downloadable data<br>☑ Other: map, summary text, EPA-format technical documentation, and downloadable data available for national indicator |
| Organization that publishes the indicator | EPA. |
| Indicator contact | Michael Kolian, EPA, kolian.michael@epa.gov. |
| Temporal coverage | 1895–2015. |
| Frequency | Annual. |
| Spatial coverage | Nationwide. |
| Spatial scale/resolution | NOAA climate division. |
| Access to indicator | https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-temperature. |

**Metric #2: Heavy precipitation**

| | |
|---|---|
| Components developed | Check all that apply:<br>☐ Graph(s)<br>☐ Map(s)<br>☐ Summary text<br>☐ Technical documentation in CBP format<br>☐ Downloadable data<br>☑ Other: graph, summary text, EPA-format technical documentation, and downloadable data available for national indicator |
| Organization that publishes the indicator | EPA. |
| Indicator contact | Michael Kolian, EPA, kolian.michael@epa.gov. |
| Temporal coverage | 1910–2015. |
| Frequency | Annual. |
| Spatial coverage | Nationwide. |
| Spatial scale/resolution | National aggregate. |
| Access to indicator | https://www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation. |

## *Additional Needs*

**Metric #1: Total annual precipitation**

| | |
|---|---|
| Additional work needed | Crop EPA's map to the Chesapeake region. Create CBP-format technical documentation. Maintain in the future. |

| | |
|---|---|
| Skills or resources needed, and what individuals or organizations have this capacity | Basic skills in ArcGIS; CBPO staff or contractors could perform this step. Knowledge of indicator to fill out documentation; CBPO staff could complete this step, although EPA's climate indicator team might have the background to complete this step most efficiently for the initial year. |
| Achievable timeframe | Initial version within 1 year; annual updates. |
| Estimated up-front cost | ~$1,500—labor cost for cropping EPA's indicator and populating the technical documentation. |
| Estimated annual maintenance cost[20] | ~8 hours of staff time—cost of updating documentation and other components based on the processing in Stage 4. |
| Final reviews or approvals needed | Agreement with EPA and NOAA to share data and documentation. |

**Metric #2: Heavy precipitation**

| | |
|---|---|
| Additional work needed | Create graph/map with new data. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | Basic skills in Excel and potentially ArcGIS; CBPO staff or contractors could perform this step. Knowledge of indicator to fill out documentation; CBPO staff could complete this step, although EPA's climate indicator team might have the background to complete this step most efficiently for the initial year. |
| Achievable timeframe | Suggest waiting 2 to 5 years for the arrival of downscaled data before compiling this part of the indicator; annual updates. |
| Estimated up-front cost | ~$2,500—labor cost for creating indicator components and populating the technical documentation. |
| Estimated annual maintenance cost[21] | ~8 hours of staff time—cost of updating documentation and other components based on the processing in Stage 4. |
| Final reviews or approvals needed | Agreement with EPA and NOAA to share data and documentation. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[22] |
|---|---|---|---|---|---|
| Crop EPA's total precipitation indicator for the Chesapeake: initial year | 5 | ~$1,500 | Within 1 year | EPA team | Required |

[20] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[21] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[22] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[22] |
|---|---|---|---|---|---|
| Crop EPA's total precipitation indicator for the Chesapeake: future years | 5 | ~8 staff hours/yr | Annual | CBPO staff | Required |
| Downscale extreme precipitation dataset by NOAA climate division | 3 | No cost to CBPO; to be done by NOAA NCEI | 2 to 5 years | NOAA | Required |
| Convert NOAA's new downscaled extreme precipitation data into part of this indicator: initial year | 5 | ~$2,500 | 2 to 5 years | EPA team | Required |
| Update extreme precipitation component in future years | 5 | ~8 staff hours/yr | Annual | CBPO staff | Required |
| **Total one-time cost** | | **~$4,000** | | | |
| **Total annual cost** | | **~16 staff hours/yr** | | | |

# 6. Sea Level Change

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| ✓ | Stage 3: Methods developed/selected to transform data into an indicator |
| ✓ | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to inform the **Climate Resiliency** goals and outcomes by characterizing the extent of sea level rise, which is one of the most significant climate-related stressors affecting the region.
- Sea level rise contributes to a multitude of problems for both human and natural systems. Rising waters increase the likelihood and severity of coastal floods and intensify the coastal impacts caused by storms. Rapidly changing sea levels can also challenge shoreline ecosystems that depend on certain conditions to thrive, thereby threatening **Vital Habitats** (especially tidal wetlands), species that depend on these habitats, and the ecological services (such as physical buffering capacity) these natural systems offer.

Relationship to other indicators in the proposed suite:

- Sea level change represents a key driver for several impact-based indicators in this proposed suite: **coastal flooding**, **property at risk or damaged**, and **wetland extent and/or physical buffering capacity**.
- Rising waters influence decision-making regarding the **extent of living vs. hardened shorelines**.

Notable opportunities, risks, and areas for enhancement:

- The proposed indicator will be excerpted from a nationwide indicator that EPA already maintains and publishes, based on an analysis that NOAA already compiles for EPA every year. This arrangement greatly reduces the cost to develop an indicator for the Chesapeake, but it also creates a dependency on EPA and NOAA priorities preclude these agencies from maintaining the national indicator in the future.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| ✓ | **Status:** Indicator and its metric have been defined. |

### *Indicator Description*

This indicator will present the relative sea level change at seven permanent tide gauge stations in the Chesapeake Bay region from 1960 to present. The metric will be displayed on a map with symbology that represents either the rate of change at each site or the total cumulative change at each site over the entire period of record.

EPA's Report on the Environment (https://cfpub.epa.gov/roe/indicator.cfm?i=87) (ROE) provides an additional gridded map that shows *absolute* (or eustatic) sea level change over the world's oceans. Absolute change is measured in relation to the center of the earth, based on satellite altimetry. Thus, it excludes the influence of vertical land motion and instead focuses purely on the increase in volume of the ocean. This option was considered for the Chesapeake but was not selected for the proposed indicator because: a) the mapping approach provides incomplete coverage of estuarine waters such as the Chesapeake Bay, b) the spatial resolution is too coarse to provide useful information at the scale needed for analysis and decision-making within the Chesapeake region, and c) sea level change relative to the shoreline elevation—the combined effect of vertical land motion and eustatic sea level change—is more relevant to the effects that communities and ecosystems along the shore will actually experience.

### *Additional Needs*

No further work needed to define this indicator.

## Stage 2: Data Collection

| ✓ | **Status:** Data collection program in place. |
|---|---|

### *Data Source Information*

| | |
|---|---|
| Dataset | Relative sea level change. |
| Source description | Relative sea level long-term annual rate of change, as calculated from monthly mean water levels. |
| Organization that collects the data | NOAA. |
| Data source contact | Chris Zervas, NOAA, Chris.Zervas@noaa.gov. |
| Rationale for selection | Offers the highest spatial and temporal resolution of the available sea level data sources. This selection of sites represents the best available source of downscaled, localized sea level results for such a long period of time. |
| Temporal coverage | At least 1950 (varies by station) to present. |
| Frequency | Water levels measured every six minutes. |
| Spatial coverage | 210 tide gauges nationwide; seven with long-term data in the Chesapeake or its tidal tributaries. |
| Spatial scale/resolution | Data for individual stations. |
| Access to data | https://tidesandcurrents.noaa.gov. |

### *Additional Needs*

No additional work needed to collect data, assuming the current data collection program continues.

## Stage 3: Method Development/Selection

| ✓ | **Status:** Methods have been selected to transform the data into an indicator. |
|---|---|

### *Method Information*

| | |
|---|---|
| Description | • For each tide gauge station presented in the indicator, use monthly mean sea level to calculate a linear regression for the long-term annual rate of change.<br>• Multiply the annual rate of change by the length of the period of record to determine total cumulative change. |

| | |
|---|---|
| Peer-review status | Peer-reviewed as part of the development of EPA's ROE and EPA's climate change indicator suite. Peer review confirmed scientific integrity and conformance to EPA's data quality criteria. Data from NOAA's tide gauges have been used in numerous peer-reviewed journal articles. |
| Citations | NOAA. 2009. Sea level variations of the United States 1854–2006. NOAA Technical Report NOS CO-OPS 053, NOAA National Ocean Service Center for Operational Oceanographic Products and Services. www.tidesandcurrents.noaa.gov/publications/Tech_rpt_53.pdf.<br><br>NOAA. 2017. Global and regional sea level rise scenarios for the United States. NOAA Technical Report NOS CO-OPS 083, NOAA National Ocean Service Center for Operational Oceanographic Products and Services. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf.<br><br>NOAA. 2018. Patterns and projections of high tide flooding along the U.S. coastline using a common impact threshold. NOAA Technical Report NOS CO-OPS 086, NOAA National Ocean Service Center for Operational Oceanographic Products and Services. https://tidesandcurrents.noaa.gov/publications/techrpt86_PaP_of_HTFlooding.pdf. |

### *Additional Needs*

No additional work needed to define methods.

## Stage 4: Data Processing

| | |
|---|---|
| ✓ | **Status:** Data have been processed to create an indicator. |

### *Data Processing Information*

| | |
|---|---|
| Summary of processing steps | Download station-specific data from NOAA's Tides and Currents website. Run a script or routine to calculate monthly means and the resulting long-term trends. Multiply by the length of record for the absolute change. Map the results. |
| Processing tools and skills needed | Processing can be performed with an automated script, which is currently performed by NOAA. Calculated values and tide gauge locations are organized in Excel and mapped using ArcGIS. |
| Organization that processes the data | Processing script: NOAA. Excel and GIS calculations: EPA. |
| Processing contact | Chris Zervas, NOAA, Chris.Zervas@noaa.gov;<br>Michael Kolian, EPA, kolian.michael@epa.gov. |
| Access to processed data | Processed data are provided to EPA by NOAA. EPA's calculated results are posted at: https://www.epa.gov/climate-indicators/climate-change-indicators-sea-level. |
| Access to processing scripts, formulae, etc. | Processing script from Chris Zervas, NOAA. Excel calculations from Michael Kolian, EPA. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Process data for future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | Requires ability to use a processing script (NOAA would know the format) and the ability to perform basic functions in Excel and ArcGIS. NOAA and EPA teams can perform these steps. |
| Achievable timeframe | Within 1 year – this is ongoing work that is already on an annual maintenance schedule, as agreed between NOAA and EPA. |
| Estimated up-front cost | None. |
| Estimated annual maintenance cost[23] | No additional cost, assuming NOAA and EPA continue to maintain their indicator. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. If an indicator already exists at a different scale, this step requires it to be clipped or cropped to the Chesapeake watershed or similarly appropriate spatial extent, if needed. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** National indicator developed, but not yet optimized for the Chesapeake. |

### *Indicator Information*

| | |
|---|---|
| Components developed | Check all that apply:<br>☐ Graph(s)<br>☐ Map(s)<br>☐ Summary text<br>☐ Technical documentation in CBP format<br>☐ Downloadable data<br>☑ Other: map, summary text, EPA-format technical documentation, and downloadable data available for the national indicator. |
| Organization that publishes the indicator | EPA. |
| Indicator contact | Michael Kolian, EPA, kolian.michael@epa.gov. |
| Temporal coverage | 1960–2015. |
| Frequency | Single trend calculation. |
| Spatial coverage | Seven tide gauge stations. |
| Spatial scale/resolution | Trends for individual stations. |
| Access to indicator | https://www.epa.gov/climate-indicators/climate-change-indicators-sea-level. |

23 Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

*Additional Needs*

| | |
|---|---|
| Additional work needed | Crop the EPA indicator to include only the seven stations in the Chesapeake Bay tidal region. Map the results from these stations. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | Basic skills in Excel and ArcGIS; CBPO staff or contractors could perform this step. Knowledge of indicator to fill out documentation; CBPO staff could provide this capacity, although EPA's climate indicator team might have the background to complete this step most efficiently for the initial year. |
| Achievable timeframe | Initial version within 1 year; future updates every year. |
| Estimated up-front cost | ~$1,500 or 20 staff hours – labor cost for cropping EPA's indicator and populating the technical documentation. |
| Estimated annual maintenance cost[24] | 10 staff hours – cost of excerpting data from EPA's indicator, assuming EPA continues to conduct annual updates, and updating technical documentation as needed. |
| Final reviews or approvals needed | Agreement with EPA and NOAA to share data. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[25] |
|---|---|---|---|---|---|
| Working from EPA's existing indicator, mask tide gauge stations outside the Chesapeake Bay region, map the resulting stations, and create documentation in CBP format: initial year | 5 | ~$1,500 or 20 staff hours | Within 1 year | CBPO staff or EPA team | Required |
| Working from EPA's existing indicator, mask tide gauge stations outside the Chesapeake Bay region, map the resulting stations, and update technical documentation as needed: future years | 5 | 10 staff hours/yr | Repeat annually | CBPO staff | Required |
| **Total one-time cost** | | **~$1,500 or 20 staff hours** | | | |
| **Total annual cost** | | **10 staff hours/yr** | | | |

[24] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[25] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator.

# 7. Stream Water Temperature

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| partial | Stage 2: Data collection program in place |
| ✓ | Stage 3: Methods developed/selected to transform data into an indicator |
| ✓ | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to address the **Climate Resiliency** goal and outcomes, as water temperatures in general are expected to rise due to climate change. In addition, stream water temperatures represent a key metric for monitoring the effectiveness of certain watershed-based resiliency efforts.
- Higher stream temperatures, and their resultant conditions, can stress aquatic ecosystems by making them less hospitable for certain species or upsetting the competitive balance between species. Such changes to ecosystem stability can result in secondary biochemical impacts, both *in situ* and downstream.
- As the chief source of water flowing into the Chesapeake Bay, the streams in the watershed directly impact Bay water temperatures. Similarly, the associated consequences of warmer water can lead to additional biochemical impacts for the Bay ecosystem, such as decreased aragonite saturation.

Relationship to other indicators in the proposed suite:

- **Air temperature** is the principal driver of stream water temperatures. Secondarily, changes in **land use** (including the prevalence of shade cover from riparian vegetation) and **green infrastructure** also factor into the evidence presented in this indicator.
- Although stream water temperatures do not represent the sole, or even main, cause of other impacts in the Bay (such as **harmful algal blooms** or **fish population distribution**), higher temperatures can be a contributing or intensifying factor.

Notable opportunities, risks, and areas for enhancement:

- The proposed indicator will be incorporated in its entirety from an indicator that EPA already maintains and publishes, based on an analysis that USGS planned to compile for EPA on a roughly biennial basis. This arrangement greatly reduces the cost to develop the indicator, as it is already appropriately scaled and applied to the region. However, it also creates a dependency that could expose the Chesapeake Bay Program to risk if changes in EPA or USGS priorities preclude these agencies from maintaining the indicator in the future.
- USGS recently alerted EPA and the CBPO to a potential challenge in maintaining this indicator. As a result of the USGS-wide implementation of a new database for time series data and associated policies, the temperature data that fed into EPA's indicator are not being retained in a readily available format. Work will be needed to overcome this challenge.

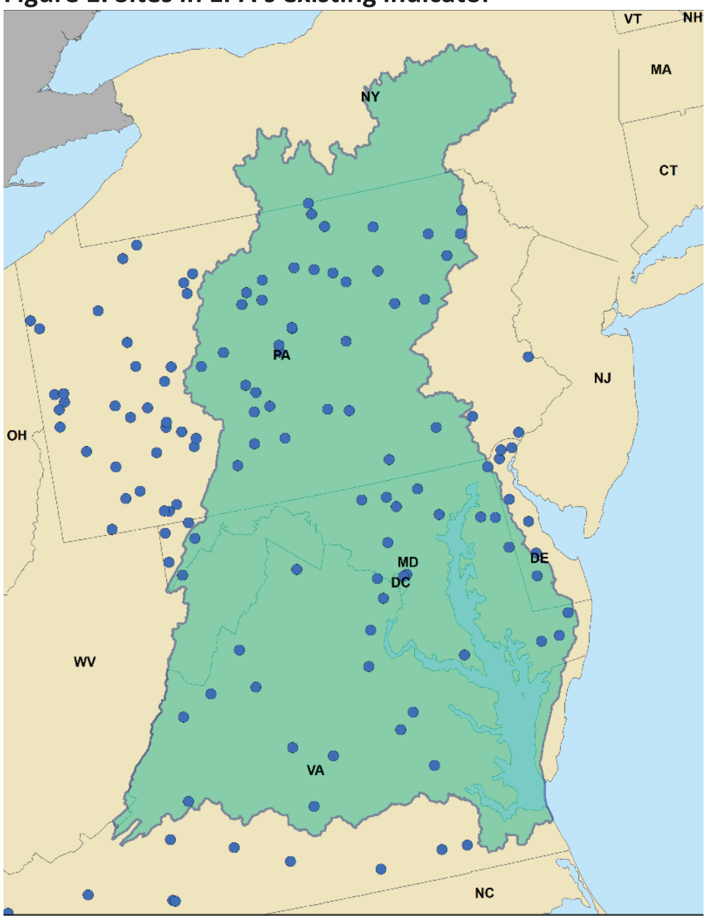
## Stage 1: Indicator and Metric Definition

| ✓ | **Status:** Indicator and its metric have been defined. |
| --- | --- |

### *Indicator Description*

This indicator presents site-specific trends (i.e., percentage increase) of the stream water temperatures at select USGS stream gauges. The trend is calculated as a linear regression over the entire period of record. Stream gauges are quality-controlled for completeness. The indicator is already limited to 129 stations in the Mid-Atlantic region, including 72 in the Chesapeake Bay watershed (see Figure 1). The EPA indicator uses shading to identify the region of the map that constitutes the watershed. CBP has the choice of whether to use the same approach, or restrict the stations presented to only those in the watershed.

**Figure 1. Sites in EPA's existing indicator**




### *Additional Needs*

No further work needed to define this indicator.

## Stage 2: Data Collection

| partial | **Status:** Data collection program in place, but work is needed to restore access to data in conjunction with a USGS database redesign. |
| --- | --- |

### *Data Source Information*

One strong data source was identified during the development of this implementation plan:

| | |
|---|---|
| Dataset | Sub-annual stream water temperatures. |
| Source description | Directly sampled stream water temperatures at designated stream gauge sites. |
| Organization that collects the data | USGS. |
| Data source contact | John Jastram, USGS, jdjastra@usgs.gov. |
| Rationale for selection | Based on the NWIS dataset of stream gauges, which is the best available collection of physical stream parameters. This quality-controlled data set further enhances the data by limiting confounding factors and sites with limited data availability. |
| Temporal coverage | 1960–present. |
| Frequency | Sub-annual, but data are presented as trend over period of record. |
| Spatial coverage | Chesapeake watershed and immediate surrounding area (129 stations total; 72 in the Chesapeake watershed). |
| Spatial scale/resolution | Data for individual stations. |
| Access to data | https://waterdata.usgs.gov/nwis. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Determine how to extract the necessary data from USGS's new database structure, which may require modifying the way data are stored and classified. |
| Skills or resources needed, and what individuals or organizations have this capacity | USGS's help will be needed to manage data and update data collection and storage protocols. |
| Achievable timeframe | TBD. |
| Estimated up-front cost | TBD whether USGS will require external funding assistance. |
| Estimated annual maintenance cost[26] | TBD. |

[26] Incremental cost beyond work that is already being performed. If data collection program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

## Stage 3: Method Development/Selection

| ✓ | **Status:** Methods have been selected to transform the data into an indicator. |
|---|---|

### *Method Information*

| | |
|---|---|
| Description | • For the area studied, exclude stream gauges with less than 90 percent data for the period 1960–2010.<br>• Calculate each site-specific monthly mean over the entire period of record and then convert temperature readings into anomalies based on the mean.<br>• Calculate an ordinary least squares regression to determine the trend of the change for each site in the study. |
| Peer-review status | Peer-reviewed as part of the development of EPA's indicator suite. Peer review confirmed scientific integrity and conformance to EPA's data quality criteria. Source study and monitoring site methods also previously peer reviewed as journal articles. |
| Citations | Jastram, J.D., and K.C. Rice. 2015. Air- and stream-water-temperature trends in the Chesapeake Bay region, 1960–2014. U.S. Geological Survey Open-File Report 2015–1207. https://dx.doi.org/10.3133/ofr20151207.<br><br>Wilde, F.D. 2006. Temperature (ver. 2). U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, Chapter A6, Section 6.1. March 2006 edition. http://water.usgs.gov/owq/FieldManual/Chapter6/Ch6_contents.html. |

### *Additional Needs*

No additional work needed to define methods.

## Stage 4: Data Processing

| ✓ | **Status:** Data have been processed to create an indicator. |
|---|---|

### *Data Processing Information*

| | |
|---|---|
| Summary of processing steps | Download data from the NWIS database. Run a script or routine to apply quality control criteria, calculate monthly means, calculate anomalies, and determine a site-specific trend. |
| Processing tools and skills needed | Processing can be performed with an automated script, which is currently performed by USGS. Calculated values and site locations are organized in Excel and mapped using ArcGIS. |
| Organization that processes the data | Processing script: USGS. Excel and GIS calculations: EPA. |
| Processing contact | John Jastram, USGS, jdjastra@usgs.gov;<br>Michael Kolian, EPA, kolian.michael@epa.gov. |
| Access to processed data | Processed data provided to EPA by John Jastram, USGS. EPA's data posted at: https://www.epa.gov/climate-indicators/climate-change-indicators-stream-temperature. |

| | |
|---|---|
| Access to processing scripts, formulae, etc. | Processing script from John Jastram, USGS. Excel calculations from Michael Kolian, EPA. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Process data for future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | Requires ability to use a processing script (USGS would know the format) and ability to perform basic functions in Excel and ArcGIS. USGS and EPA's team can perform these steps. |
| Achievable timeframe | Within 2 years. This is ongoing work that is already on a biennial maintenance schedule as agreed between USGS and EPA. |
| Estimated up-front cost | None. |
| Estimated annual maintenance cost[27] | No additional cost, assuming USGS and EPA continue to maintain their indicator. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. If an indicator already exists at a different scale, this step requires it to be clipped or cropped to the Chesapeake watershed or similarly appropriate spatial extent, if needed. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** National indicator developed, but not yet optimized for the Chesapeake. |

### *Indicator Information*

| | |
|---|---|
| Components developed | Check all that apply:<br>☐ Graph(s)<br>☐ Map(s)<br>☐ Summary text<br>☐ Technical documentation in CBP format<br>☐ Downloadable data<br>☑ Other: map, summary text, EPA-format technical documentation, and downloadable data available for non-clipped Chesapeake Bay watershed and immediate surrounding area |
| Organization that publishes the indicator | EPA. |
| Indicator contact | Michael Kolian, EPA, kolian.michael@epa.gov. |
| Temporal coverage | 1960–2014. |
| Frequency | Single trend calculation. |
| Spatial coverage | 129 stream gauges in the covered region. |
| Spatial scale/resolution | Trends for individual stations. |

[27] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Access to indicator | https://www.epa.gov/climate-indicators/climate-change-indicators-stream-temperature. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Crop the EPA indicator to exclude stations in the Mid-Atlantic that are not actually part of the Chesapeake Bay watershed (if desired). Map the remaining stations. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | Basic skills in Excel and ArcGIS; CBPO staff or contractors could perform this step. Knowledge of indicator to fill out documentation; CBPO staff could complete this step, although EPA's climate change indicator team might have the background to complete this step most efficiently for the initial year. |
| Achievable timeframe | Within 2 years. |
| Estimated up-front cost | ~$500 or 10 staff hours: labor cost to crop EPA's indicator, if desired.<br>~$1,000 or 15 staff hours: labor cost to create CBP-format technical documentation. |
| Estimated annual maintenance cost[28] | 10 staff hours every 2 years (5 hours/yr): cost of excerpting data from EPA's indicator—assuming EPA continues to conduct annual updates—and updating technical documentation. |
| Final reviews or approvals needed | Agreement with EPA and USGS to share data. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[29] |
|---|---|---|---|---|---|
| Work with USGS's new database structure to allow the data for this indicator to be compiled again | 2 | TBD | TBD | USGS | Required |
| Working from EPA's existing indicator, mask stream gauge stations outside the Chesapeake Bay watershed and map them: initial year | 5 | ~$500 or 10 staff hours | Within 2 years | CBPO staff or EPA team | Optional |
| Create CBP-format technical documentation | 5 | ~$1,000 or 15 staff hours | Within 2 years | CBPO staff or EPA team | Required |

[28] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[29] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[29] |
|---|---|---|---|---|---|
| Working from EPA's existing indicator, mask stream gauge stations outside the Chesapeake Bay watershed and map them, and maintain documentation: future years | 5 | 5 staff hours/yr | Repeat every 2 years | CBPO staff | Required |
| **Total one-time cost** | | **~$1,000–1,500 or 15–25 staff hours + USGS cost TBD** | | | |
| **Total annual cost** | | **5 staff hours/yr** | | | |

# 8. Upstream Flooding

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| ✓ | Stage 3: Methods developed/selected to transform data into an indicator |
| ✓ | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to address the **Climate Resiliency** goal and outcomes, as river/stream flooding is influenced by changing climate conditions, including the increased frequency and intensity of heavy precipitation events in some regions, as well as changes in snowpack, snowmelt timing, and streamflow patterns.
- Large flood events can damage homes, roads, bridges, and other infrastructure; wipe out farmers' crops; and harm or displace people. Although regular flooding helps to maintain the nutrient balance of soils in the flood plain, larger or more frequent floods could disrupt ecosystems by displacing aquatic life, impairing water quality, and increasing soil erosion. By inundating water treatment systems with sediment and contaminants, and promoting the growth of harmful microbes, floods can directly affect the water supplies that communities depend on.[30]

Relationship to other indicators in the proposed suite:

- Change in **precipitation** (especially heavy precipitation) is a key driver of this indicator.
- **Land cover and land use** influence river and stream flooding—particularly the extent of impervious surfaces that contribute to runoff.
- Trends in upstream flooding influence the extent of **property at risk or damaged**.

Notable opportunities, risks, and areas for enhancement:

- The proposed indicator will be excerpted from a nationwide indicator that EPA already maintains and publishes, based on an analysis that a research team at the University of Iowa has agreed to compile for EPA every two years. This arrangement greatly reduces the cost to develop an indicator for the Chesapeake, but it also creates a dependency that could expose the Chesapeake Bay Program (CBP) to risk if changes in EPA or research team priorities preclude them from maintaining the national indicator in the future.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| ✓ | **Status:** Indicator and its metric have been defined. |

### *Indicator Description*

This indicator will present two metrics:

- Trends in the magnitude of river flooding
- Trends in the frequency of river flooding

[30] https://www.epa.gov/climate-indicators/climate-change-indicators-river-flooding

It is based on an EPA indicator that presently covers the entire contiguous 48 states, based on stream gauge measurements. The indicator is restricted to a subset of USGS stream gauges that have been designated as HCDN-2009 "reference gauges." These reference gauges have been carefully selected to reflect minimal interference from human activities such as dam construction, reservoir management, wastewater treatment discharge, water withdrawal, and changes in land cover and land use that might influence runoff. The indicator provides maps that show long-term trends (1965 to present) at each site.

### *Additional Needs*

No further work needed to define this indicator.

## Stage 2: Data Collection

| ✓ | **Status:** Data collection program in place. |
|---|---|

### *Data Source Information*

| | |
|---|---|
| Dataset | Peak and daily discharge data. |
| Source description | Stream stage (water level) measured by stream gauges, then converted to discharge (streamflow). |
| Organization that collects the data | USGS. |
| Data source contact | Mark Bennett, USGS, mrbennet@usgs.gov. |
| Rationale for selection | Widely cited (in the assessment literature, etc.) as the authoritative source of U.S. streamflow and stream stage data. Data collected consistently in many places since the early 20th century. |
| Temporal coverage | Varies by station: at least 1965 (in many cases, much longer) to present. |
| Frequency | Stream stage measured every 15 minutes at most gauges. |
| Spatial coverage | More than 25,000 stations nationwide; approximately 500 stations in a subset of "reference gauges" that also meet data availability criteria for EPA's indicator; 47 sites with sufficient magnitude data and 42 with sufficient frequency data within the Chesapeake watershed. |
| Spatial scale/resolution | Data for individual stations. |
| Access to data | http://waterdata.usgs.gov/nwis/sw. |

Alternative data options are available, including (but not limited to) measures of flood stage from the same gauges and records maintained by the National Weather Service. The approach proposed here has been selected because it is used in an existing indicator that would be relatively straightforward to adapt for the Chesapeake region. Other sources might require additional method development and data processing, but should not be ruled out, as new developments may come to light in the future.

### *Additional Needs*

No additional work needed to collect data, assuming the current data collection program continues.

## Stage 3: Method Development/Selection

✓ **Status:** Methods have been selected to transform the data into an indicator.

### *Method Information*

| | |
|---|---|
| Description | • For magnitude, analyze trends in the annual maximum instantaneous peak discharge values at each site.<br>• For frequency, use a "peaks-over-threshold" approach to identify the top 100 discrete flooding events during the 50-year study period (in terms of daily discharge), then determine whether such events have become more or less common over time. |
| Peer-review status | Peer-reviewed as part of the development of EPA's indicator suite. Peer review confirmed scientific integrity and conformance to EPA's data quality criteria. |
| Citations | Mallakpour, I., and G. Villarini. 2015. The changing nature of flooding across the central United States. Nature Climate Change 5:250–254. |

### *Additional Needs*

No additional work needed to define methods.

## Stage 4: Data Processing

✓ **Status:** Data have been processed to create an indicator.

### *Data Processing Information*

| | |
|---|---|
| Summary of processing steps | Download data from USGS National Water Information System database. Run a series of scripts to select and filter stations, identify maximum annual instantaneous peak discharge, identify the top 100 daily discharge events at each site, calculate trends in magnitude using a Mann-Kendall test, and calculate trends in frequency using a Poisson regression. |
| Processing tools and skills needed | Processing can be performed with a series of scripts. Script format not known. |
| Organization that processes the data | Processing script: University of Iowa. Excel calculations: EPA. |
| Processing contact | Gabriele Villarini, University of Iowa, gabriele-villarini@uiowa.edu.<br>Michael Kolian, EPA, kolian.michael@epa.gov. |
| Access to processed data | Processed data provided to EPA by Gabriele Villarini, University of Iowa. EPA's data posted at https://www.epa.gov/climate-indicators/climate-change-indicators-river-flooding. |
| Access to processing scripts, formulae, etc. | Michael Kolian has been designated as EPA's central point of contact for this indicator. He can provide Excel calculations directly and can engage Gabriele Villarini for additional information if needed. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Process data for future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | • Requires ability to use processing scripts (University of Iowa would know the format[s]). A University of Iowa team holds access to the scripts at this time and would need to perform the work.<br>• Requires ability to perform basic calculations in Excel. EPA's team can perform these steps. |
| Achievable timeframe | Short-term (can be achieved within 1 to 2 years)—This is ongoing work that is already on a biennial maintenance schedule as agreed between the University of Iowa and EPA. |
| Estimated up-front cost | None. |
| Estimated annual maintenance cost[31] | No additional cost, assuming the University of Iowa and EPA continue to maintain their indicator. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. If an indicator already exists at a different scale, this step requires it to be clipped or cropped to the Chesapeake watershed or similarly appropriate spatial extent, if needed. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** National indicator developed, but not yet optimized for the Chesapeake. |

### *Indicator Information*

| | |
|---|---|
| Components developed | Check all that apply:<br>☐ Graph(s)<br>☐ Map(s)<br>☐ Summary text<br>☐ Technical documentation in CBP format<br>☐ Downloadable data<br>☑ Other: graphs, maps, summary text, EPA-format technical documentation, and downloadable data available for national indicator |
| Organization that publishes the indicator | EPA. |
| Indicator contact | Michael Kolian, EPA, kolian.michael@epa.gov. |
| Temporal coverage | 1965–2015. |
| Frequency | Decadal averages (based on annual totals). |
| Spatial coverage | Approximately 500 locations nationwide. |
| Spatial scale/resolution | Data for individual stations. |
| Access to indicator | https://www.epa.gov/climate-indicators/climate-change-indicators-river-flooding. |

[31] Incremental cost beyond work that is already being performed. If data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Crop EPA indicator to the Chesapeake watershed. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | Basic skills in Excel and ArcGIS; CBPO staff or contractors could perform this step. Knowledge of indicator to fill out documentation; CBPO staff could complete this step, although EPA's climate indicator team might have the background to complete this step most efficiently for the initial year. |
| Achievable timeframe | Short-term (can be achieved within 1 to 2 years). |
| Estimated up-front cost | ~$1,500—labor cost for contractor support to crop EPA's indicator and populate the technical documentation. |
| Estimated annual maintenance cost[32] | 10 staff hours—annualized cost of excerpting data from EPA's indicator every two years, assuming EPA continues to update its indicator. |
| Final reviews or approvals needed | Agreement with EPA and the University of Iowa to share data. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[33] |
|---|---|---|---|---|---|
| Crop EPA's existing national indicator for the Chesapeake: initial year | 5 | ~$1,500 | Short-term | EPA team | Required |
| Crop EPA's existing national indicator for the Chesapeake: future years | 5 | 10 hours/yr | Short-term | CBPO staff | Required |
| **Total one-time cost** | | **~$1,500** | | | |
| **Total annual cost** | | **10 hours/yr** | | | |

[32] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[33] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator. In some cases, optional actions could include steps to transform a relatively weak or one-dimensional indicator that is available in the short-term into a more robust indicator in the longer term.

# 9. Acidification

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| not completed | Stage 3: Methods developed/selected to transform data into an indicator |
| not completed | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to address the **Climate Resiliency** goal and outcomes, as acidification is a stressor associated with climate change—specifically, the increase in atmospheric carbon dioxide ($CO_2$) concentrations, which in turn leads to a higher concentration of carbonic acid in water.
- Acidification makes it more difficult for shellfish, certain plankton, and other organisms to produce calcium carbonate, which is the main ingredient in their skeletons or shells. This issue affects **Sustainable Fisheries**, both by directly impacting certain shellfish (e.g., oysters) and potentially by affecting the growth of smaller organisms that are crucial to the food chain. In addition, changes to the acidity regime of a given area may cause stress to other species, at varying life stages, in ways not yet well understood.

Relationship to other indicators in the proposed suite:

- Acidification and **Bay water temperature** can serve as concurrent stressors on populations of aquatic organisms.
- By harming certain species and disrupting the food web, acidification may ultimately influence **fish population distributions**.

Notable opportunities, risks, and areas for enhancement:

- pH data are prevalent as part of routine long-term monitoring throughout the Bay. However, some experts suggest that $pCO_2$, alkalinity, and aragonite saturation state may be more ecologically relevant variables to present. These variables are not collected as widely or frequently as pH. Thus, this implementation plan suggests a phased approach:
    - Phase 1: A near-term indicator based on pH measurements that are already being collected.
    - Phase 2: An optional longer-term enhancement based on increased monitoring of aragonite saturation state or other variables in addition to pH. This component could benefit from an expanded data collection program, given that it traditionally takes at least two of the four main acidity-related variables (pH, $pCO_2$, total alkalinity, and dissolved inorganic carbon) to resolve carbonate chemistry. However, research is also underway to investigate the use of pH as a proxy for acidification in the Chesapeake; the results of this research could help to inform the design of this indicator.

## Stage 1: Indicator and Metric Definition

| ✓ | **Status:** Indicator and its metric have been defined. |
|---|---|

### *Indicator Description*

The initial form of this indicator will track changes in the pH of the Chesapeake Bay and its tidal tributaries. Because the spatial variability of acidification is important to understand, the indicator can present a mapping tool that shows trends over time at each individual site where long-term data have been collected, or possibly averages for each Bay segment.

A future enhancement could involve replacing or supplementing pH data with measurements of aragonite saturation state ($\Omega_a$)—an acidity-related parameter that is often used for a more direct connection to biological effects—or other recommended variables. Given the limited number of sites with recurring measurement of aragonite saturation state, a presentation of site-by-site results might be necessary.

### *Additional Needs*

No further work is needed to define this indicator.

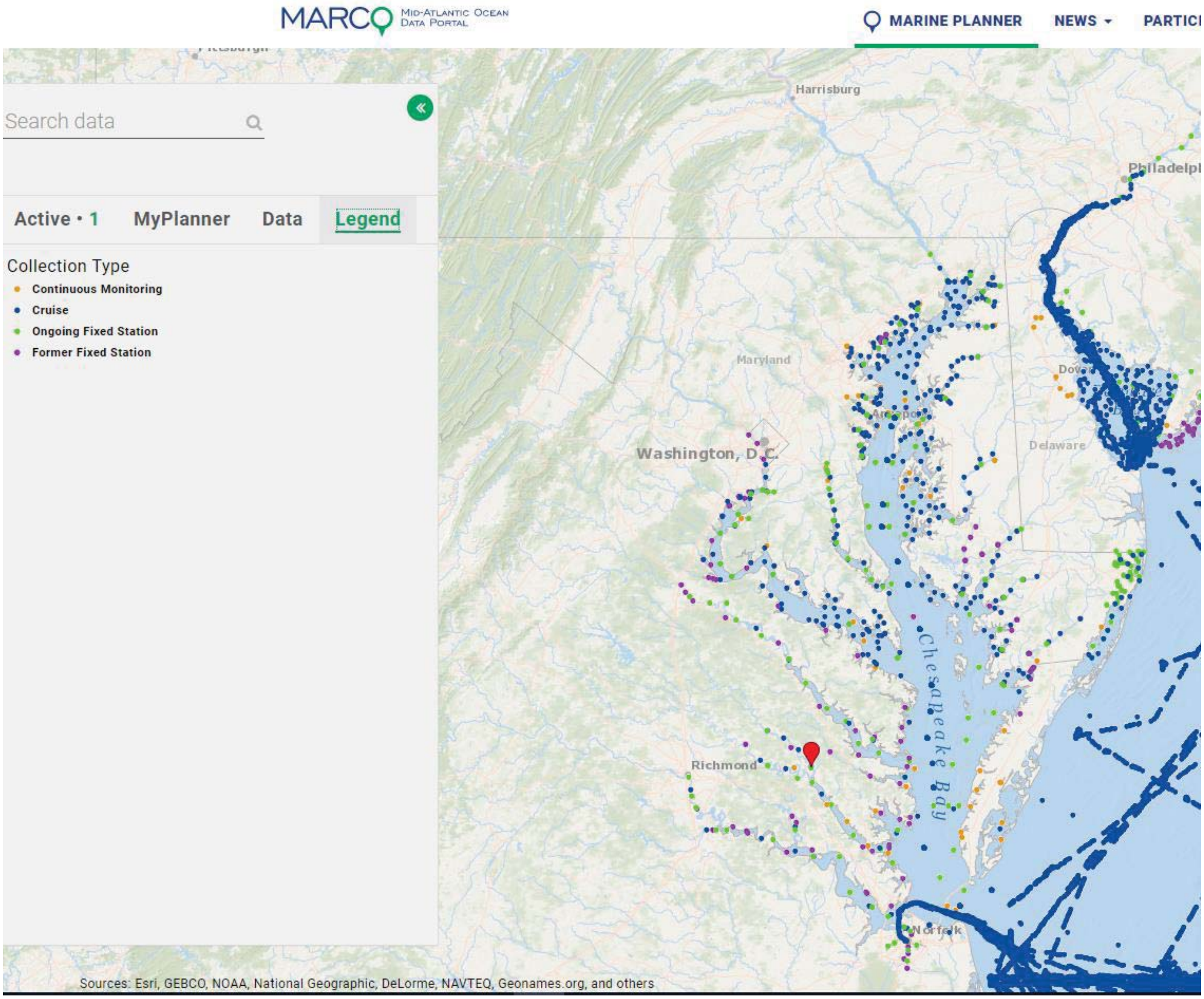
## Stage 2: Data Collection

| ✓ | **Status:** Suitable data collection program in place for pH. Aragonite saturation data not collected in widespread recurring fashion yet. |
|---|---|

### *Data Source Information*

| | |
|---|---|
| Dataset | Chesapeake Bay long-term monitoring: pH. |
| Source description | Repeated *in situ* sampling at designated long-term monitoring sites; samples collected from shore, structures (e.g., bridges), or boats. pH is part of the standard suite of water quality parameters and it is measured throughout the water column. |
| Organization that collects the data | Maryland DNR and VIMS (with some data collected by Old Dominion University, Virginia DEQ, et al.); all organizations use consistent methods. |
| Data source contact | TBD. |
| Rationale for selection | Longest record of data collected throughout the Bay using consistent methods. |
| Temporal coverage | Mid-1984 to present. |
| Frequency | Monthly; twice a month from June to August. |
| Spatial coverage | Approximately 150 sites spread throughout the mainstem Bay and tidal tributaries. |
| Spatial scale/resolution | Data for individual sites. |
| Access to data | http://datahub.chesapeakebay.net/. |

Development of this implementation plan involved consultation with the Mid-Atlantic Coastal Acidification Network (MACAN) and a review of the work they have done to assemble a map of acidity-related data collected throughout the region. MACAN does not collect data itself, but has been developing a strategy to improve coordination and prioritization of data collection in the future. MACAN has developed maps that show sample locations from a wide range of sources, including long-term monitoring programs, one-time studies, and sampling cruises, as shown in the map below.[34]




Many of the sources captured by MACAN offer high-quality data within the mid-Atlantic region, but this implementation plan focuses on one source (described in the table above) that arguably provides the strongest combination of spatial and temporal coverage, even though it may lack the ability to resolve the full carbonate chemistry at this time. A key goal of this effort is to propose an indicator that can be constructed and kept up to date with limited resources, which means it is useful to minimize the number of discrete data sources that need to be tracked and combined.

Other sources considered for this indicator include (but are not limited to):

- **The Chesapeake Bay Interpretive Buoy System (CBIBS).** CBIBS has 10 buoys located throughout the Bay and key tributaries. All 10 buoys have been in place since 2010. With continuous data collection, CBIBS provides rich temporal resolution, but it does not provide nearly as many sites or nearly as many years of data as the 1984–present long-term monitoring program that has been recommended for this

[34] For more details, see http://portal.midatlanticocean.org/news/where-acidification-being-monitored-your-area/.

indicator. Also, some stations do not collect data year-round. That said, $pCO_2$ data from CBIBS could ultimately help to inform the development of this indicator.

- **Long-term academic studies.** Results from some academic studies have been published in the literature, but they may have more localized spatial coverage than the proposed data source for this indicator, and some of the data are considered proprietary (for publishing reasons) and therefore not readily accessible to support ongoing timely updates to the proposed indicator.

- **Data from long-running individual sites such as the CBL Pier at Solomons Island and the VIMS pier at Gloucester Point.** These sites are frequently cited, and they have a notable advantage over the CBP long-term monitoring program in length of record. CBL has collected data since 1938; the VIMS pier dataset extends back to the 1950s. They do not provide the extensive spatial coverage of the long-term monitoring program or the satellite-based dataset, so they have not been suggested for this indicator. However, if a need arises for a metric based on a single site, these locations could be strong candidates.

- **The buoy at the Thomas Point lighthouse.** Thomas Point has continuous data collection back to at least 1985, and its record has been extensively studied and gap-filled. The data are readily available. While this site has the advantage of high temporal resolution, it does not offer more years of data than the long-term monitoring network, and it only covers one location. However, it could add value as a standard for calibration and assessment of variability. The team that developed the satellite-based dataset has proposed to use Thomas Point data to test the robustness of trends derived from both the satellite-based product and the CBP long-term monitoring network.

- **Sampling cruises.** As the map shows, sampling cruises help to fill many of the spatial gaps within the Bay and its tributaries. They have some limitations for use in this proposed indicator, though: many were one-time studies, most are not scheduled for repeated data collection at the exact same locations every year, and they do not collect data throughout the year, like the proposed data source does. Thus, sampling cruises are arguably not optimal sources to support an indicator that tracks trends over time and is feasible to keep updated in the future.

Some other programs have collected data from a stable set of sites on a recurring basis, but they have fewer sites than the proposed source, or they have not collected data for as many years. All of the alternative sources mentioned here could add value as supplementary data sources, or perhaps in gap-filling to help with refinement of interpolation methods. They just do not offer quite as strong a combination of temporal and spatial coverage as the CBP long-term monitoring program.

### *Additional Needs*

No additional work is required for pH data, assuming that long-term monitoring continues as expected.

A suggested optional enhancement to this indicator will require data on another dimension of acidification, such as aragonite saturation state. $\Omega_a$ is derived from parameters that are measured at a small fraction of the long-term monitoring sites described above. An enhanced indicator could examine trends in $\Omega_a$ for the small number of sites where the underlying parameters are measured routinely, or it could be developed in conjunction with an expanded monitoring program that measures these variables at more locations. The following table describes steps that could be taken to support this enhancement.

| | |
|---|---|
| Additional work needed | • Determine whether to add $\Omega_a$ or another variable other than pH to this indicator, and if so, decide whether to use existing data or attempt to expand data collection.<br>• If expanding data collection: determine funding needs, secure funding, select methods, develop protocols, and coordinate with data collection/analysis programs to integrate this new variable into their analyses. In particular, coordinate with MACAN's comprehensive monitoring plan. |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in water quality analysis—available from CBPO staff and state partners. Expansion of data collection will require coordination with the agencies and organizations that conduct long-term monitoring. Also coordinate with the NOAA Chesapeake Bay Program Office's Interpretive Buoy System Program (CBIBS), the University of Maryland Chesapeake Biological Laboratory, and MACAN, and consider recommendations outlined in the 2014 report on acidification monitoring in the Chesapeake Bay.[35] |
| Achievable timeframe | • Decision on a data source: possible within 1 year.<br>• Expanded, operationalized data collection: likely long-term (>5 years). |
| Estimated up-front cost | • No up-front cost for initial decision.<br>• Expanded data collection: incremental cost TBD. |
| Estimated annual maintenance cost[36] | Expanded, operationalized $\Omega_a$ data collection: incremental cost TBD. |

## Stage 3: Method Development/Selection

| | |
|---|---|
| | **Status:** Methods have not been developed to transform these data into an indicator. |

### *Method Information*

Methods have not been established.

[35] Science Assessment of Chesapeake Bay Acidification: Toward a Research and Monitoring Strategy. http://dnr.maryland.gov/waters/bay/Documents/MDOATF/OA_ACT-CB_AcidificationWorkshopReport_March2014.pdf.

[36] Incremental cost beyond work that is already being performed. If a data collection program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

### *Additional Needs*

**Phase 1: pH**

| | |
|---|---|
| Additional work needed | • Determine the most scientifically defensible approach to aggregate data over time. This indicator could be limited to a particular season (e.g., summer) if the intent is to represent worst-case conditions or focus on particular impacts (e.g., oyster reproduction), or it could be an annual average, recognizing that impacts on different species and systems occur throughout the year. In either case, averaging should account for variations in sampling frequency (i.e., twice as often during summer).<br>• If presenting spatial averages, determine the most scientifically defensible approach to aggregate point data spatially. The most appropriate approach depends on the sampling density and the variable in question. For some variables, aggregations have been developed and published based on interpolation tools such as the Chesapeake Bay Interpolator. For others, analyses have been published based on area-weighted averages of the Bay segments that correspond to each sampling site. pH may require special consideration because it is measured on a logarithmic scale, so it cannot simply be aggregated by arithmetic averaging techniques.<br>• Publish methods in peer-reviewed literature if they represent a novel approach. |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in acidity data and spatial aggregation methods—likely available from experts at the CBPO and partner agencies. |
| Achievable timeframe | Within 1 year. |
| Estimated up-front cost | Internal cost: 100+ staff hours. |

**Phase 2: Aragonite Saturation State (Optional Enhancement)**

| | |
|---|---|
| Additional work needed | Develop temporal aggregation approach. Develop spatial aggregation approach, if sampling density is sufficient to allow aggregation. Publish methods in peer-reviewed literature if they represent a novel approach. |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in acidity data and spatial aggregation methods—likely available from experts at the CBPO and partner agencies. |
| Achievable timeframe | • If using existing data collection program: within 1 year.<br>• If requiring more data collection: >5 years. |
| Estimated up-front cost | Internal cost: 100+ staff hours. |

## Stage 4: Data Processing

| | |
|---|---|
| | **Status:** Data have not yet been processed to create an indicator. |

### Data Processing Information

Data cannot be processed until methods are established.

### Additional Needs

| | |
|---|---|
| Additional work needed | Apply temporal and spatial aggregation methods to the entire dataset; repeat for future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | GIS skills and software; possibly familiarity with interpolation tools for the Chesapeake Bay. CBPO staff or contractors can provide this support. |
| Achievable timeframe | • pH data: within 1 year.<br>• Enhancement if using existing data collection program: within 1 year.<br>• Enhancement if requiring more data collection: >5 years.<br>• Future processing: repeated annually. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[37] | TBD. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** Indicator not developed yet. |

### Indicator Information

An indicator cannot be created until all previous stages of development are completed.

### Additional Needs

| | |
|---|---|
| Additional work needed | Create summary graphics and CBP-format technical documentation for the proposed first iteration of this indicator, based on pH. Maintain in the future. Add data and documentation for enhanced version when it is ready. |
| Skills or resources needed, and what individuals or organizations have this capacity | Familiarity with the data and methods. CBPO staff can provide this support. |

[37] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Achievable timeframe | Initial indicator likely within 1 year; enhanced component in 1 to 2 years if based on existing data collection, or >5 years if based on an expanded data collection effort . |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[38] | TBD. |
| Final reviews or approvals needed | TBD. |

## Summary of Actions and Anticipated Costs

In the table below, action items pertaining to the initial phase that has been proposed for this indicator—tracking changes of station-specific or Bay-wide pH—are noted as "required." Further steps to incorporate additional acidification metrics, such as $\Omega_a$, are noted as "optional" because they represent enhancements that would strengthen the indicator, but are not pivotal for publishing the initial version.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[39] |
|---|---|---|---|---|---|
| **Phase 1: pH** | | | | | |
| Determine appropriate aggregation approach; publish if needed | 3 | 100+ staff hours | Within 1 year | CBPO staff and partner agencies | Required |
| Apply methods to entire dataset | 4 | TBD | Within 1 year | CBPO staff or contractor with GIS capabilities | Required |
| Create initial indicator, including documentation | 5 | TBD | Within 1 year | CBPO staff | Required |
| Repeat data processing in future years | 4 | TBD/yr | Repeat annually | CBPO staff or contractor with GIS capabilities | Required |
| Update indicator in future years | 5 | TBD/yr | Repeat annually | CBPO staff | Required |
| **Phase 2: Aragonite Saturation or Other Enhanced Metric** | | | | | |
| Determine what variable to use and whether expanded data collection is needed | 2 | None | 1 to 2 years | CBPO staff and state partners | Optional |
| Expand data collection program | 2 | TBD | Likely more than 5 years | Organizations that conduct long-term monitoring | Optional |

[38] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[39] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator. In some cases, optional actions could include steps to transform a relatively weak or one-dimensional indicator that is available in the short-term into a more robust indicator in the longer term.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[39] |
|---|---|---|---|---|---|
| Determine appropriate aggregation approach; publish if needed | 3 | 100+ staff hours | 1 to 2 years for existing data; more than 5 years if depending on expanded data collection | CBPO staff and partner agencies | Optional |
| Apply methods to entire dataset | 4 | TBD | 1 to 2 years for existing data; more than 5 years if depending on expanded data collection | CBPO staff or contractor with GIS capabilities | Optional |
| Create revised indicator, including documentation | 5 | TBD | 1 to 2 years for existing data; more than 5 years if depending on expanded data collection | CBPO staff | Optional |
| Continue expanded data collection | 2 | TBD/yr | Repeat annually | Organizations that conduct long-term monitoring | Optional |
| Repeat data processing in future years | 4 | TBD/yr | Repeat annually | CBPO staff or contractor with GIS capabilities | Optional |
| Update indicator in future years | 5 | TBD/yr | Repeat annually | CBPO staff | Optional |
| **Total one-time cost** (required "Phase 1" component) | | **100+ staff hours plus additional costs TBD** | | | |
| **Total annual cost** (required "Phase 1" component) | | **TBD/yr** | | | |
| **Total one-time cost** (optional "Phase 2" component) | | **100+ staff hours plus additional costs TBD** | | | |
| **Total annual cost** (optional "Phase 2" component) | | **TBD/yr** | | | |

# 10. Bay Water Temperature

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| partial | Stage 3: Methods developed/selected to transform data into an indicator |
| not completed | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- The water temperature of the Chesapeake Bay has far-ranging impacts, which touch on four of the goals identified in the Chesapeake Bay Watershed Agreement, including **Vital Habitats**, **Sustainable Fisheries**, **Water Quality**, and **Climate Resiliency**.
- The water temperature of the Chesapeake Bay has numerous implications for marine ecosystems. Warmer temperatures lower the ability for water to carry dissolved oxygen and decrease aragonite saturation, while also contributing to conditions that support harmful algal blooms. Higher temperatures, and the conditions they promote, can stress aquatic ecosystems by making them less hospitable for certain species or by upsetting the competitive balance between species.
- The impacts on ecosystems brought about by warmer water temperatures could lead to economic impacts by influencing fishing/crabbing and recreation in the Bay.

Relationship to other indicators in the proposed suite:

- **Air temperature** is the primary driver of Bay water temperatures. **Stream temperatures** also play a role, as they relate to the temperature of water that flows into the Bay.
- The effect of Bay water temperatures can be reflected in the frequency and extent of **harmful algal blooms**, **submerged aquatic vegetation composition**, and **fish population distributions**.

Notable opportunities, risks, and areas for enhancement:

- **Metric #1** of this proposed indicator takes advantage of an ongoing NOAA project to develop a remotely sensed estuarine surface water temperature product. However, the current dataset is relatively recent, it only covers a portion of the Bay, and peer-review validation is pending. Continued development of the remote sensing product and expansion to cover the entire Bay would enhance this indicator.
- **Metric #2** of this proposed indicator provides a complementary approach to examine longer-term trends over a larger area.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| ✓ | **Status:** Indicator and its metrics have been defined. |

### *Indicator Description*

This indicator will comprise two metrics that characterize how Bay surface water temperatures have changed over the recent past:

- The first metric will use satellite data to present a static map that shows water temperature trends over the period of record, spatially averaged over 1-km grid cells. The color of each grid cell on the map correspond to either the long-term rate of change or the total change (e.g., regression slope multiplied by the number of years). Thus far, the remote sensing method correlates well with *in situ* measurements from 2007 to present for the southern portion of the Bay. Although these data are only available for about a decade, and they do not yet cover the whole Bay, the high spatial and temporal resolution and the prospect for continued data collection provide significant value in offering insight to Bay water temperatures of the recent past.

- The second metric integrates approximately 150 *in situ* sampling sites throughout the Bay and its tidal tributaries. This dataset consists of records from 1984 to the present, collected through a standardized long-term monitoring program. The indicator development team can choose whether to interpolate the stations into a single Bay-wide trend (e.g., a line graph) or calculate site-specific water temperature trends for each of the sampling locations (map).

Due to their differing data collection methods, when taken together, these two metrics will offer multiple lines of evidence regarding the changing temperature regime in the Bay.

Some end-users may find it particularly valuable to have a single number that represents the water temperature of the Bay at a glance, rather than getting bogged down in large spatial datasets. If spatial aggregation of either of the metrics described above proves to be problematic, another option would be to select one location for a long-term metric.

### *Additional Needs*

No further work needed to define this indicator.

## Stage 2: Data Collection

| | |
|---|---|
| ✓ | **Status:** Data collection program in place. |

### *Data Source Information*

**Metric #1: Remotely-sensed data**

| | |
|---|---|
| Dataset | Daily remotely-sensed Bay water temperature. |
| Source description | Daily water temperature measurements obtained by satellite and averaged by 1-km grid cells. |
| Organization that collects the data | NOAA National Environmental Satellite, Data, and Information Service (NESDIS). |
| Data source contact | Ron Vogel, NOAA, ronald.vogel@noaa.gov. |
| Rationale for selection | Despite the relatively short temporal coverage, this source possesses high spatial and temporal resolution, as well as robust scientific methods. In addition, NOAA has indicated that retroactive expansion of the dataset back to 2002 might be possible. Satellite data can be compared with *in situ* point data to confirm data quality. |
| Temporal coverage | 2007–present. |
| Frequency | Data collected several times per day and rolled up into daily means. |
| Spatial coverage | Global (but only the southern Chesapeake Bay has been validated for this project). |
| Spatial scale/resolution | 1-km grid cells. |
| Access to data | https://eastcoast.coastwatch.noaa.gov/time_series_cd.php. |

**Metric #2: *In situ* data**

| | |
|---|---|
| Dataset | Monthly *in situ* Bay water temperature. |
| Source description | Repeated *in situ* sampling at designated long-term monitoring sites; samples collected from shore, structures (e.g., bridges), or boats. Water temperature is part of the standard suite of water quality parameters. |
| Organization that collects the data | Maryland DNR and VIMS (with some data collected by Old Dominion University, Virginia DEQ, et al.); all organizations use consistent methods. |
| Data source contact | None identified. |
| Rationale for selection | Longest record of data collected throughout the Bay using consistent methods. |
| Temporal coverage | Mid-1984 to present. |
| Frequency | Monthly; twice a month from June to September. |
| Spatial coverage | Approximately 150 sites spread throughout the mainstem Bay and tidal tributaries. |
| Spatial scale/resolution | Data for individual sites. |
| Access to data | http://datahub.chesapeakebay.net/. |

Several other organizations and networks collect water temperature data in the Chesapeake Bay. Many of these other sources offer high-quality data, but this implementation plan focuses on a smaller number of sources (described above) that arguably provide the strongest combination of spatial and temporal coverage. A key goal of this effort is to propose an indicator that can be constructed and kept up to date with limited resources, which means it is useful to minimize the number of discrete data sources that need to be tracked and combined.

Other sources considered for this indicator include (but are not limited to):

- **The Chesapeake Bay Interpretive Buoy System (CBIBS).** CBIBS has 10 buoys located throughout the Bay and key tributaries. All 10 buoys have been in place since 2010. With continuous data collection, CBIBS provides rich temporal resolution, but it does not provide nearly as many sites or nearly as many years of data as the 1984–present long-term monitoring program that has been recommended for this indicator. Also, some stations do not collect data year-round. CBIBS data could add value in other ways, though—perhaps as a supplementary source for a future expansion of this indicator, or for calibration to help with further refinement of satellite data methods.

- **Data from long-running individual sites such as the CBL Pier at Solomons Island and the VIMS pier at Gloucester Point.** These sites are frequently cited, and they have a notable advantage over the CBP long-term monitoring program in length of record. CBL has collected data since 1938; the VIMS pier dataset extends back to the 1950s. They do not provide the extensive spatial coverage of the long-term monitoring program or the satellite-based dataset, so they have not been suggested for this indicator. However, if a need arises for a metric based on a single site, these locations could be strong candidates.

- **The buoy at the Thomas Point lighthouse.** Thomas Point has continuous data collection back to at least 1985, and its record has been extensively studied and gap-filled. Measured data are readily available, but the full gap-filled series is not. While this site has the advantage of high temporal resolution, it does not offer more years of data than the long-term monitoring network, and it only covers one location. However, it could add value as a standard for calibration and assessment of variability. The team that developed the satellite-based dataset has proposed to use Thomas Point data to test the robustness of trends derived from both the satellite-based product and the CBP long-term monitoring network.

Another option would be to expand this indicator to include bottom water temperature. Bottom temperature is important for many aquatic species and could provide a useful complement to the surface temperature metrics described above. *In situ* data are available, and further investigation could reveal whether the temporal and spatial coverage are sufficient to support an indicator that meets the criteria for this proposed suite.

### *Additional Needs*

No further work is needed to collect data, assuming the current data collection programs continue.

## Stage 3: Method Development/Selection

| | |
|---|---|
| partial | **Status:** Methods have been selected to transform Metric #1 for this indicator; methods to transform Metric #2 for this indicator need to be determined. |

### *Method Information*

**Metric #1: Remotely-sensed data**

| | |
|---|---|
| Description | • Calculate the annual average bay water temperature for each 1-km grid square.<br>• Spatially average all of the grid squares for a composite annual temperature for the area covered. |
| Peer-review status | Peer-review validation is pending. |
| Citations | A validation study of the remotely sensed data was performed by comparing with *in situ* measurements: Chin, T.M., J. Vazquez-Cuervo, and E.M. Armstrong. 2017. A multi-scale high-resolution analysis of global sea surface temperature. Remote Sensing of Environment 200:154–169. doi.org/10.1016/j.rse.2017.07.029 |

### *Additional Needs*

**Metric #1: Remotely-sensed data**

| | |
|---|---|
| Additional work needed | This metric could be enhanced in the future by developing and validating similar methods to cover the entire Bay and its tidal tributaries, so that Metric #1 will no longer be limited to the southern part of the Bay. |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in processing satellite data; NOAA has this capacity. |
| Achievable timeframe | TBD. |
| Estimated up-front cost | TBD. |

**Metric #2: *In situ* data**

| | |
|---|---|
| Additional work needed | • Option 1: Determine the most scientifically defensible approach to aggregate point data spatially to develop a Bay-wide indicator. The most appropriate approach depends on the sampling density and the variable in question. For some variables, aggregations have been developed and published based on interpolation tools such as the Chesapeake Bay Interpolator. For others, analyses have been published based on area-weighted averages of the Bay segments that correspond to each sampling site.<br>• Option 2: Determine protocol for calculating station-specific trends (regressions) and mapping the results for individual stations. |
| Skills or resources needed, and what individuals or organizations have this capacity | • Option 1: Expertise in water quality measurements and spatial aggregation methods—likely available from experts at the CBPO and partner agencies.<br>• Option 2: Basic Excel and script-writing skills (e.g., R, Python). This task could be performed by CBPO staff or a contractor.<br>• CBPO staff with workgroup input to select the desired option. |
| Achievable timeframe | Within 1 year. |
| Estimated up-front cost | Up to 100 hours of staff time and up to $5,000. |

## Stage 4: Data Processing

| | |
|---|---|
| | **Status:** Data have not yet been processed to create an indicator. |

### *Data Processing Information*

Neither metric has been processed into a formal indicator.

### *Additional Needs*

**Metric #1: Remotely-sensed data**

| | |
|---|---|
| Additional work needed | Calculate spatial averages. Download data and graph using Excel. Repeat in future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | NOAA uses its software tools to calculate spatial averages. CBPO staff can download data and perform remaining processing steps with basic Excel skills. |
| Achievable timeframe | Within 1 year; repeat annually. |
| Estimated up-front cost | 2 hours of staff time. |
| Estimated annual maintenance cost[40] | 2 hours of staff time per year, assuming NOAA continues to make its data available. |

[40] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

**Metric #2: *In situ* data**

| | |
|---|---|
| Additional work needed | Calculate spatial average and/or site-specific regressions. Process data for future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | Requirements depend on the method selected in Stage 3, but will likely include basic Excel and GIS skills and the ability to run an R or Python script. CBPO staff likely have the capacity to perform the necessary steps. |
| Achievable timeframe | Within 1 year; repeat annually. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[41] | TBD. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** Metric #1 has some elements of an indicator available, but not all of the required elements. Metric #2 has not been developed as an indicator. |

### *Indicator Information*

**Metric #1: Remotely-sensed data**

| | |
|---|---|
| Components developed | Check all that apply:<br>☑ Graph(s)<br>☐ Map(s)<br>☐ Summary text<br>☐ Technical documentation in CBP format<br>☑ Downloadable data<br>☐ Other: ________________________________ |
| Organization that publishes the indicator | NOAA National Environmental Satellite, Data, and Information Service (NESDIS). |
| Indicator contact | Ron Vogel, NOAA, ronald.vogel@noaa.gov. |
| Temporal coverage | 2007–2016. |
| Frequency | Annual. |
| Spatial coverage | Southern portion of the Chesapeake Bay. |
| Spatial scale/resolution | Single average annual value for the coverage area. |
| Access to indicator | https://eastcoast.coastwatch.noaa.gov/time_series_cd.php. |

Metric #2 has not been developed as an indicator yet.

[41] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Finalize indicator format; create technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | Knowledge of the indicator to fill out documentation. CBPO staff could complete this step. |
| Achievable timeframe | Within 1 year; repeat annually. |
| Estimated up-front cost | ~40 hours of staff time—labor cost for developing materials and populating the technical documentation for both metrics. |
| Estimated annual maintenance cost[42] | ~10 hours of staff time—cost of maintaining files and documentation for both metrics. |
| Final reviews or approvals needed | TBD. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[43] |
|---|---|---|---|---|---|
| Develop spatial aggregation and/or trend analysis methods for *in situ* data | 3 | Up to 100 staff hours and up to $5,000 | Within 1 year | CBPO staff, partner agencies, workgroup input, and contractor support | Required |
| Process remotely-sensed data: initial year | 4 | ~2 staff hours (not counting NOAA's processing time) | Within 1 year | CBPO staff | Required |
| Process *in situ* data: initial year | 4 | TBD | Within 1 year | CBPO staff | Required |
| Create indicator materials: initial year | 5 | ~40 staff hours | Within 1 year | CBPO staff | Required |
| Process remotely-sensed data: future years | 4 | ~2 staff hours (not counting NOAA's processing time) | Annual | CBPO staff | Required |
| Process *in situ* data: future years | 4 | TBD | Annual | CBPO staff | Required |

[42] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[43] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator. In some cases, optional actions could include steps to transform a relatively weak or one-dimensional indicator that is available in the short-term into a more robust indicator in the longer term.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[43] |
|---|---|---|---|---|---|
| Update all parts of the indicator in future years | 5 | ~10 staff hours | Annual | CBPO staff | Required |
| Expand remote sensing methods to cover entire Bay and tidal tributaries | 3 | TBD | TBD | NOAA | Optional |
| **Total one-time cost** (required elements) | | **Up to ~142 staff hours, up to $5,000, and additional processing cost TBD** | | | |
| **Total annual cost** (required elements) | | **~12 staff hours plus additional processing cost TBD** | | | |
| **Total additional cost** (optional enhancement) | | **TBD** | | | |

# 11. Harmful Algal Blooms

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| ✓ | Stage 3: Methods developed/selected to transform data into an indicator |
| partial | Stage 4: Data processed |
| partial | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to address the **Climate Resiliency** goal and outcomes, as harmful algal blooms (HABs) are influenced by changing climate conditions, including the increased frequency and intensity of heavy precipitation events and associated runoff in some regions, as well as changes in water temperature.
- HABs are influenced by nutrient levels—an important aspect of the **Water Quality** goal and outcomes in the Watershed Agreement.
- Though algae provide a food source for aquatic organisms and waterfowl, some species of algae produce toxins that can sicken or kill people and animals. Furthermore, all species of algae can affect the environment and local economies when they become overly abundant. HABs can clog the gills of aquatic organisms and smother beneficial submerged aquatic vegetation (SAV), such as native eelgrass. When algae die and begin to decay, this process depletes oxygen and can lead to "dead zones" and fish kills. HABs can affect aesthetics, tourism, and recreational enjoyment of the Bay and its tributaries by discoloring the water and producing noxious odors. In addition, HABs can raise treatment costs for drinking water.
- NOAA's definition of a HAB (http://www.noaa.gov/what-is-harmful-algal-bloom) includes excessive growth of any form of algae in the water column—not just toxin-producing species. This indicator will cover HABs as broadly as the available data will allow.

Relationship to other indicators in the proposed suite:

- **Bay water temperature** and **stream water temperature** (input temperature) can affect HABs, as warmer water tends to promote algal growth.
- Changes in **precipitation** and **upstream flooding** can affect HABs. Higher-than-usual rainfall can push nutrients, which promote HABs, into the Bay.
- Changes in **land use/land cover** can lead to more nutrients running off into the waterways, thus promoting HABs. Conversely, **protected land** and implementation of **BMPs/green infrastructure** can reduce nutrient inputs.
- HABs can affect **SAV community composition** by smothering and blocking sunlight from reaching native and ecologically beneficial species, some of which are more sensitive than their exotic competitors.

Notable opportunities, risks, and areas for enhancement:

- A phytoplankton health index has been developed with data from 1986 to 2011, and source data collection has resumed after a few years' hiatus. Overabundance of algae is one factor that can lead to a low index score. This index offers a promising data source for the initial version of this indicator.
- This indicator could be enhanced in the future by adding data on the extent of specific HABs or specific HAB-derived toxins if systematic monitoring data become available.
- Much recent work has been undertaken to improve detection of HABs via remote sensing. In particular, the Cyanobacteria Assessment Network (CyAN) oversees a program to analyze remotely sensed data to detect the extent of cyanobacteria harmful algal blooms (cyanoHABs) in lakes and estuaries throughout

the United States. There may be an opportunity to collaborate with CyAN to enhance this indicator with satellite data and to identify methods to characterize the extent of other HABs (beyond just cyanoHABs that are currently being assessed)—and in doing so, to provide coverage of the whole watershed.

## Stage 1: Indicator and Metric Definition

| ✓ | **Status:** The indicator and its metric have been defined. |
|---|---|

### *Indicator Description*

The initial form of this indicator will identify phytoplankton index of biotic integrity (PIBI) scores for the Bay and its tidal tributaries and track changes in index scores over time. The PIBI incorporates both chlorophyll-*a* (an overall measure of photosynthetic activity) and the abundance of several potentially harmful species of phytoplankton.

This indicator could be enhanced with two additions in the future:

- The extent of specific HABs or HAB-derived toxins over time in the Bay and its tidal tributaries, if sufficient data are available.
- A metric based on remote sensing, which holds the potential to expand this indicator to inland water bodies throughout the watershed.

### *Additional Needs*

No additional work is needed to define the initial form of this indicator, based on the PIBI. Optional steps can be taken to investigate opportunities for future enhancement, as described below.

| | |
|---|---|
| Additional work needed | • Investigate opportunities to characterize trends in the extent of specific HABs and HAB-derived toxins. This step will involve determining HAB species and toxins of interest and reviewing data sources to learn whether any current or planned data collection programs will provide consistent observations with sufficient temporal and spatial coverage. If direct observations are not available, do any suitable proxies exist?<br>• Explore adoption of remote sensing of HABs across the entire watershed, including continued development of techniques to detect more than just cyanobacteria. |
| Skills or resources needed, and what individuals or organizations have this capacity | The suggested enhancements will require expertise in HABs and remote sensing. It will benefit from collaboration with state and federal oceanographic data collection programs, the CyAN program, and additional government and academic/research partners. |
| Achievable timeframe | Long-term development—possibly 5 years or more. |
| Estimated up-front cost | TBD. |

## Stage 2: Data Collection

| ✓ | **Status:** Suitable data collection programs are in place for the PIBI in tidal waters. |
|---|---|

### *Data Source Information*

Potential sources of algal bloom data include:

- **Bay-wide phytoplankton sampling and the PIBI.** Phytoplankton data are collected *in situ* and analyzed in a lab by state partners as part of a Bay-wide water quality monitoring program. Most data have been collected monthly starting in 1984 from approximately 35 stations throughout the Bay and its tributaries (https://www.chesapeakebay.net/what/downloads/baywide_cbp_plankton_database). There is a gap in the data from 2011 to 2016, however, due to a temporary halt in phytoplankton monitoring in Maryland. These sampling data have been used to develop the PIBI.

- **Targeted HAB sampling**. Targeted HAB sampling has been conducted by independent researchers (for example, see https://www.sciencedirect.com/science/article/pii/S0272771414004090), but systematic data collection is not ongoing.

- **Remote sensing data.** Remote sensing is used to collect data about cyanobacteria blooms throughout the United States. The data are compiled by CyAN (https://www.epa.gov/water-research/cyanobacteria-assessment-network-cyan), which is a multi-agency collaboration among NASA, NOAA, USGS, and EPA. The group is developing an early warning indicator system using historical and current satellite data to detect cyanobacteria blooms. The project began in 2015, and as of 2017, it provided coverage from 2002 to 2012. *In situ* validation data are yet to be collected and will come primarily from federal and state collaborators.

An evaluation of the data sources found that Bay-wide phytoplankton sampling offers the most promise for an indicator at this time. Many years of historical data are available, and the University of Maryland Center for Environmental Science (UMCES) has already developed a Bay health indicator from the PIBI (http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2011/indicators/phytoplankton_index/#_Trends_Graph). HAB extent data are not sufficient to meet indicator data quality requirements (i.e., widespread data collection with consistent methods over time and space), and it is unknown whether or at what frequency targeted HAB sampling may be conducted in the future. Remote sensing data continue to be collected daily, but interpretation methods are still under development and they are presently limited to cyanoHABs (and therefore exclude familiar “red tides” and some other notable species).

The table below provides basic information about the recommended data source.

| | |
|---|---|
| Dataset | Chesapeake Bay phytoplankton sampling/PIBI. |
| Source description | See narrative above. |
| Organization that collects the data | CBP partners, including Maryland DNR and VIMS. |
| Data source contact | Mike Mallonee, CBPO, mmallone@chesapeakebay.net. |
| Rationale for selection | See narrative above. |
| Temporal coverage | 1984–present, although Maryland data were not collected from 2011 to 2016. |
| Frequency | Monthly. |
| Spatial coverage | Chesapeake Bay and its tidal tributaries. |
| Spatial scale/resolution | 35 individual monitoring stations. |
| Access to data | https://www.chesapeakebay.net/what/downloads/baywide_cbp_plankton_database. |

### *Additional Needs*

No additional work is needed to collect phytoplankton sampling/PIBI data, assuming the current data collection programs continue. Additional data collection needs for the proposed enhancements are unknown at this time, given the need for further investigation and collaboration in Stage 1 concept development to determine whether the suggested enhancements are feasible.

## Stage 3: Method Development/Selection

| ✓ | **Status:** Methods are available to transform PIBI data into an indicator. |
|---|---|

### *Method Information*

The PIBI combines several pollution-sensitive, biologically important metrics of the phytoplankton community, such as chlorphyll-*a*, the abundance of several potentially harmful species, and various indicators of cell function and species composition. The index is reported on a scale of 1 to 5. When the PIBI is greater than or equal to 4, algal blooms are rare, blue-green algae biomass is low, and HABs (specifically *Microcystis aeruginosa* and *Prorocentrum minimum*) are very rare. As the PIBI index score decreases, the frequency of algal blooms and HABs increases.

UMCES has developed an indicator from the PIBI, available at http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2011/indicators/phytoplankton_index/. Indicator processing involves some form of spatial and temporal aggregation to derive an annual PIBI score for each of 15 reporting regions and for the Bay as a whole.

| | |
|---|---|
| Description | Follow the established approach to construct the PIBI and aggregate the results over time and space within each reporting region. |
| Peer-review status | The PIBI has been analyzed and validated in peer-reviewed literature. |
| Citations | Lacouture et al. (2006)[44]; Johnson and Buchanan (2014).[45] |

Johnson and Buchanan (2014) added nearly a decade of data to the PIBI. They found that the PIBI remains sensitive to changes in nutrient and light conditions, but found no discernible trends in the overall health of the Bay habitat based on phytoplankton community conditions. The authors noted that the lack of a trend is likely due to the presence of confounding factors, such as declines in water clarity and decreases in nutrient loading in the Bay.

### *Additional Needs*

Indicator methods have not been developed, peer-reviewed, or published for the proposed enhancements. Strategies and costs for method development for targeted HAB extent or watershed-wide remote sensing will be difficult to estimate until more foundational investigation and discussions take place in Stage 1.

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[44] Lacouture, R.V., J.M. Johnson, C. Buchanan, and H.G. Marshall. 2006. Phytoplankton Index of Biotic Integrity for Chesapeake Bay and its tidal tributaries. Estuaries and Coasts 29:598–616. doi:10.1007/BF02784285.

[45] Johnson, J.M., and C. Buchanan. 2014. Revisiting the Chesapeake Bay Phytoplankton Index of Biotic Integrity. Environmental Monitoring and Assessment 186:1431–1451. doi:10.1007/s10661-013-3465-z.

One possible enhancement would be to consider an approach like the Phytoplankton Taxonomic Index—a reference-based approach to score particularly discriminating taxa and then combine the scores into a multi-metric index. Such an approach was developed for an analysis project for Virginia, with a focus on high mesohaline and polyhaline waters.

One other possible methodological enhancement involves the process for spatial aggregation of the PIBI. For some other indicators in the proposed suite, this implementation plan suggests a step to determine the most scientifically defensible approach to aggregate point data spatially, noting that the most appropriate approach depends on the sampling density and the variable in question. For some variables, aggregations have been developed and published based on interpolation tools such as the Chesapeake Bay Interpolator. For others, analyses have been published based on area-weighted averages of the Bay segments that correspond to each sampling site. The existing PIBI spatial aggregation method might be completely adequate and appropriate, but it might still be worthwhile to consider alternatives if there is a possibility that they could add value to this indicator from a climate change perspective.

| | |
|---|---|
| Additional work needed | Consider the optimal spatial aggregation approach for the PIBI. |
| Skills or resources needed, and what individuals or organizations have this capacity | Requires expertise in spatial aggregation methods—likely available from experts at the CBPO and partner agencies—with input from the team that developed the original indicator. The team has been working on data improvements in addition to ongoing support for the PIBI. |
| Achievable timeframe | Within 1 year. |
| Estimated up-front cost | 50 to 100 hours of staff time. |

## Stage 4: Data Processing

| | |
|---|---|
| partial | **Status:** PIBI data were aggregated previously; need to determine whether a program is in place to aggregate new data going forward, and if not, set one up. |

### *Data Processing Information*

To be determined: Is a program in place with funding to resume processing using the approach that UMCES applied through 2011?

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Aggregate post-2011 data into the PIBI; repeat annually. |
| Skills or resources needed, and what individuals or organizations have this capacity | Requires familiarity with the original data processing methods. UMCES could perform this work, or possibly others with sufficient direction. |
| Achievable timeframe | Initial processing likely within 1 year; future processing annually. |
| Estimated up-front cost | TBD. |

| | |
|---|---|
| Estimated annual maintenance cost[46] | TBD. |

Processing needs for optional enhancements cannot be defined or estimated until earlier stages are completed.

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| partial | **Status:** An indicator was previously developed for the Chesapeake, but it has not been updated in several years, and technical documentation in the latest CBP format is not readily available. |

### *Indicator Information*

This indicator was last updated with data from 2011, which is the last year of complete data collection in Maryland. Now that Maryland has resumed data collection, it should be possible to update this indicator again going forward.

| | |
|---|---|
| Components developed | Check all that apply:<br>☑ Graph(s)<br>☑ Map(s)<br>☑ Summary text<br>□ Technical documentation in CBP format<br>☑ Downloadable data<br>□ Other: ________________________________ |
| Organization that publishes the indicator | UMCES. |
| Indicator contact | TBD. |
| Temporal coverage | 1986–2011. |
| Frequency | Annual. |
| Spatial coverage | Entire Bay and tidal tributaries. |
| Spatial scale/resolution | 15 reporting regions and Bay-wide average. |
| Access to indicator | http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2011/indicators/phytoplankton_index/. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Create CBP-format technical documentation for the proposed first iteration of this indicator, based on the PIBI. Maintain in the future. Add data and documentation for enhanced components when they are ready. |

[46] Incremental cost beyond work that is already being performed. If data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Skills or resources needed, and what individuals or organizations have this capacity | To be determined; it depends on the degree and complexity of interpretation needed, as well as the amount of documentation that can be located for the original indicator. The UMCES team that developed the original indicator could probably complete this step, or CBPO staff. |
| Achievable timeframe | Initial indicator likely within 1 year; updates annually; enhanced components TBD. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[47] | TBD. |
| Final reviews or approvals needed | TBD. |

## Summary of Actions and Anticipated Costs

In the table below, action items pertaining to the initial phase that has been proposed for this indicator—PIBI—are noted as "required." Further steps to incorporate HAB extent throughout the watershed are noted as "optional" because they represent enhancements that would strengthen the indicator, but are not pivotal for publishing the initial version.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[48] |
|---|---|---|---|---|---|
| Put a program in place to resume data processing; process data available now | 4 | TBD | Within 1 year | UMCES indicator team, or others with enough documentation | Required |
| Create CBP-format technical documentation for the proposed first iteration of this indicator | 5 | TBD | Within 1 year | UMCES indicator team, or others with enough documentation | Required |
| Process data in future years | 4 | TBD/yr | Annual | TBD | Required |
| Update the indicator in future years | 5 | TBD/yr | Annual | TBD | Required |
| Consider the optimal spatial aggregation method for the PIBI | 3 | 50–100 staff hours | Within 1 year | CBPO staff, partner agencies, and original indicator development team | Optional |
| Investigate opportunities to characterize trends in the extent of specific HABs | 1 | TBD | Likely 5 years or more | Interagency and academic/research partnerships | Optional |

[47] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[48] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator. In some cases, optional actions could include steps to transform a relatively weak or one-dimensional indicator that is available in the short-term into a more robust indicator in the longer term.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[48] |
|---|---|---|---|---|---|
| Investigate opportunities to improve and incorporate watershed-wide remote sensing of HABs | 1 | TBD | Likely 5 years or more | Interagency and academic/research partnerships | Optional |
| Data collection, method development, processing, and indicator updates to incorporate optional enhancements | 2–5 | TBD | Likely 5 years or more | Interagency and academic/research partnerships | Optional |
| **Total one-time cost** (required components) | | **TBD** | | | |
| **Total annual cost** (required components) | | **TBD/yr** | | | |
| **Total one-time cost** (optional enhancements) | | **TBD** | | | |
| **Total annual cost** (optional enhancements) | | **TBD/yr** | | | |

# 12. Property at Risk or Damaged

## Indicator at a Glance

| | |
|---|---|
| partial | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| not completed | Stage 3: Methods developed/selected to transform data into an indicator |
| not completed | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to address the **Climate Resiliency** goal and outcomes, as climate change is likely to cause an increase in the amount of property at risk or damaged, especially in coastal areas faced with rising sea level and storm surge. Implementing resiliency measures will decrease property exposure.
- Some properties contain toxic substances, especially critical facilities, industrial properties, and facilities with permits to handle hazardous materials or discharge chemicals to the environment. Storm damage may release these contaminants into the surrounding land, impairing Bay water and/or soil quality, which relates to the **Toxic Contaminants** and **Water Quality** goals and outcomes.
- **Public Access** sites such as parks, refuges, reserves, trails, and boat launches, may be located in areas at high risk of storm surge and flood damage.
- Residents in areas at high risk for climate-related damage may be good targets for outreach and education in an effort to increase watershed-wide **Stewardship.**

Relationship to other indicators in the proposed suite:

- **Sea level change** and **precipitation** (especially heavy precipitation events) measure conditions that can affect the amount of property at risk or damaged through **coastal flooding** and **upstream flooding**.
- Shoreline characteristics, including the **extent of living vs. hardened shorelines**, influence the amount of property at risk of damage and the magnitude of damage.
- **Wetland extent and physical buffering capacity** affect the magnitude of flood events and influence property risk. Wetland degradation may expose more property to flooding, compounding the impacts of climate change.
- **BMPs and green infrastructure** for stormwater management may reduce the frequency and severity of flood damage.
- Decisions related to **land use and land cover** will affect the amount of property at risk or damaged.

Notable opportunities, risks, and areas for enhancement:

- The topic of property at risk or damaged could be interpreted broadly to cover a wide range of natural hazards, several of which relate to climate change (e.g., tropical storms, wildfires). However, an "all hazard" indicator could be unwieldy and could suffer from wide variation in data availability and quality. Thus, this plan proposes an indicator that focuses on flooding, both coastal and upland, which has been identified as a high-priority threat by all Chesapeake states in their individual state hazard mitigation plans. The proposed indicator could include two complementary metrics: 1) the extent of property at risk of flooding and 2) an accounting of observed property damage.
- Several existing sources of information could be used to develop these components, but the sources vary in their coverage and consistency.
- This indicator could be developed over time in a staged fashion:

- Phase 1: Use existing data products to develop a metric that considers the amount of developed land, as a single land cover type, within zones at risk of overland or storm surge flooding. Add a separate metric to track the actual value of property damaged by storm events.
- Phase 2: Expand the first metric to estimate the *value* of property at risk—perhaps by developing proxies based on a more nuanced differentiation of various types and intensities of developed land.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| partial | **Status:** Initial metrics have been defined, but a few key questions need to be resolved before the indicator definition is complete. |

### *Indicator Description*

The initial form of this indicator could identify the areal extent (acres) of developed land within a FEMA-designated floodplain and/or within defined storm surge risk zones (Metric #1), along with historical information on estimated property damage from storm events (Metric #2). One might expect this indicator to show changes over time as the following inputs change:

- The changing extent of developed land, as captured by land cover/land use remapping (every 2 to 5 years)
- Remapping of floodplains by FEMA (infrequent)
- Remapping of storm surge risk zones, which will presumably account for concurrent relative sea level change (NOAA updates its maps after major storms)
- Additional years of observed property damage (annual updates)

Future enhancements could include differentiation of more types of developed land in the input dataset—e.g., developed open space and low-, medium-, and high-intensity development—and creation of value proxies for different development intensities, so as to more effectively estimate the value of property at risk.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | • Determine the appropriate floodplain for use in the indicator. Is it FEMA's 100-year layer or FEMA's 500-year layer?<br>• Determine the best approach to incorporate NOAA storm surge risk maps. In particular, identify the hurricane category of interest for storm surge inundation, as NOAA has distinct layers for categories 1 through 5. |
| Skills or resources needed, and what individuals or organizations have this capacity | Knowledge of flood impact analysis, emergency management best practices, and regulatory considerations, which will benefit from engagement with experts at partner agencies. CBPO staff can facilitate the discussion and help to reach final decisions. |
| Achievable timeframe | Within 1 year. |
| Estimated up-front cost | ~100 hours of staff time. |

## Stage 2: Data Collection

| | |
|---|---|
| ✓ | **Status:** Suitable data collection programs are in place. |

### *Data Source Information*

The proposed indicator will build on the best available data to provide complete, consistent coverage throughout the Chesapeake watershed to address both coastal and upstream/overland flooding.

Robust data products are already available for specific states or portions of the region; some of them might even be considered more topically ideal than the proposed indicator. Examples include assessments of property vulnerability and infrastructure exposure at the state level (through hazard mitigation planning) and for coastal portions of the watershed through NOAA's Coastal Flood Exposure Mapper (https://coast.noaa.gov/floodexposure/#/map) and other products, as well as indicators of property risk or property damage used by states and FEMA for hazard mitigation planning. For instance, the Virginia Coastal Resilience Map (http://maps.coastalresilience.org/virginia/) presents the results of economic loss analysis for the Eastern Shore of Virginia. However, many of these existing products have limited spatial coverage or methods that vary by state, thus making them less useful for a watershed-wide indicator. Hence this implementation plan proposes construction of a new indicator.

**Metric #1: Property at risk of flooding**

***Phase 1: Extent of developed land at risk***

This metric will provide a geospatial mashup of flood risk zones and developed land. The initial form of this indicator will treat developed land as a single category, without attempting to differentiate among types of development or estimate the value of the property at risk. This metric can combine flood risk data from two sources:

| | |
|---|---|
| Dataset | National Flood Hazard Layer (NFHL). |
| Source description | The FEMA flood hazard layer provides a digitized version of FEMA's floodplain maps, including both 100-year and 500-year floodplains. The NFHL was derived from flood insurance rate maps and other FEMA floodplain products. |
| Organization that collects the data | FEMA. |
| Data source contact | FEMA contact TBD. |
| Rationale for selection | Nationally standardized, high-resolution, authoritative dataset on flood risk. |
| Temporal coverage | One "current" dataset; no historical data readily available, as archived flood maps are generally paper products. |
| Frequency | Data updated periodically by FEMA on a county-by-county basis, but not on an established regular schedule. |
| Spatial coverage | Nationwide. Digitized GIS data are available for all but 12 counties in the Chesapeake Bay watershed. In counties where GIS data are not available, the underlying flood maps are still available for download as PDFs; they could be digitized. |
| Spatial scale/resolution | Exact resolution TBD, but considered very high (street/building level hazard maps). |
| Access to data | https://catalog.data.gov/dataset/national-flood-hazard-layer-nfhl/resource/89b88927-fc8e-4557-a97f-3f3729aad36d. |

| | |
|---|---|
| Dataset | Sea, Lakes, and Overland Surges from Hurricanes (SLOSH) Model. |
| Source description | NOAA produces storm surge inundation maps for each hurricane category to depict the worst-case scenario storm surge flooding vulnerability in coastal areas. Periodic updates incorporate recently observed water levels and storm surges. |
| Organization that collects the data | NOAA. |
| Data source contact | NOAA contact TBD. |
| Rationale for selection | Coverage of coastal issues that accounts for changing sea level. SLOSH inundation data can be incorporated with FEMA flood hazard zones to develop a more complete estimate of potential flood extent in coastal areas. |
| Temporal coverage | One "current" dataset; no historical data readily available. |
| Frequency | Data updated periodically by NOAA; exact interval TBD. |
| Spatial coverage | Entire Atlantic coast. |
| Spatial scale/resolution | 10-meter grid. |
| Access to data | https://www.nhc.noaa.gov/nationalsurge/#data. |

The area of developed land could come from one or more of the following geospatial datasets:

- **Chesapeake High-Resolution Land Cover Data Project.** This recent collaborative effort created a 1-meter resolution land cover map for the Chesapeake watershed to help support activities related to the Chesapeake Bay TMDL Midpoint Assessment. It differentiates among structures, impervious roads, and impervious non-roads.

- **NOAA's Coastal Change Analysis Program (C-CAP) Regional Land Cover and Change.** C-CAP data are nationally standardized, raster-based inventories of land cover for the coastal areas of the United States. C-CAP data are derived from the analysis of multiple dates of remotely sensed imagery. C-CAP includes more distinct developed land classes than some other datasets. These data are produced at a 30-meter resolution (https://coast.noaa.gov/digitalcoast/data/ccapregional.html).

- **National Land Cover Database (NLCD).** NLCD data are nationally standardized, raster-based inventories of land cover across the entire United States. NLCD data are derived from remotely sensed imagery, and were last updated with data circa 2011. These data are produced at a 30-meter resolution (https://www.mrlc.gov/nlcd11_data.php).

This implementation plan suggests using the Chesapeake high-resolution land cover dataset. Although it only has one timestamp to date, in contrast to C-CAP and the NLCD, remapping has been proposed for every 2 to 5 years.

| | |
|---|---|
| Dataset | High-resolution land cover dataset. |
| Source description | See narrative above. |
| Organization that collects the data | Chesapeake Conservancy, University of Vermont, and WorldView Solutions, based on NASA/NOAA satellite data and numerous other sources. |
| Data source contact | Contact for the high-resolution mapping initiative TBD. |
| Rationale for selection | High resolution; consistency with other CBP efforts that will be using this dataset. |
| Temporal coverage | A single snapshot with nominal year 2016; underlying data of varying vintage (~2006 to 2016). |
| Frequency | Compiled once so far; proposed frequency of 2 to 5 years, but future data collection still uncertain. |
| Spatial coverage | Entire Chesapeake watershed. |
| Spatial scale/resolution | 1-meter grid. |

| | |
|---|---|
| Access to data | https://chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/land-cover-data-project. |

***Phase 2: Value of property at risk (optional enhancement)***

The CBP may be able to incorporate a property value metric into this indicator, but several challenges exist. There is no readily available comprehensive dataset with estimates of both residential and commercial property value. All of the Chesapeake states have produced state-level hazard mitigation plans that include estimates of property at risk (in dollars), and the underlying information in these state-level plans could be used to develop a property value metric for the Chesapeake watershed, but the methods vary and timelines for data updates are inconsistent or unknown.

Another approach to incorporate a value metric would be to establish a proxy for property value. For example, different estimates of value could be applied to varying development intensities—developed open space and low-, medium-, and high-intensity development—but the methods for determining these value estimates would need to be developed. An appropriate land cover/land use dataset with differentiated land development intensities would also need to be selected. Opportunities to use the high-resolution dataset in this manner could be investigated.

**Metric #2: Property damaged by storm events**

Potential sources of property damage estimates include:

- **NOAA Storm Events Database.** NOAA releases a Storm Events Publication each month recording storm events, injuries/deaths, and property/crop damage estimates. Data are collected by the National Weather Service from a variety of sources, including county, state and federal emergency management officials; local law enforcement officials; skywarn spotters; NWS damage surveys; newspaper clipping services; the insurance industry; and the public. There are inconsistent data practices across these sources, but the data are considered acceptable for official publication by NOAA's National Centers for Environmental Information (NCEI).

- **FEMA Historical Flood Risk and Costs.** FEMA provides data by state on historical payouts for the National Flood Insurance Program (NFIP) and Individual Assistance (IA) from 1996 to 2016. These payouts could be used as an estimate of total damage by state, but they only include monies disbursed by FEMA for federally designated disasters, and only for NFIP and the IA program. These data are available at a state level (https://www.fema.gov/media-library/assets/documents/106308); a method to break the data down to the watershed boundary has not been developed.

State-level data on property damage could also be extracted from state hazard mitigation plans, but care would need to be taken to ensure the methods used by each state to calculate damage are consistent. A preliminary evaluation of these data sources suggests that the NOAA Storm Events Database will offer the most complete, consistent data source for this indicator, though further investigation will be needed to determine if the information about property damage is indeed robust enough to be useful. Another question to consider is whether NFIP data can be extrapolated to represent a broader range of insurance policies.

| | |
|---|---|
| Dataset | Storm Events Database. |
| Source description | See narrative above. |
| Organization that collects the data | NOAA. |
| Data source contact | NOAA contact TBD. |

| | |
|---|---|
| Rationale for selection | Nationwide coverage of all floods and storms, not just those with disaster designations. |
| Temporal coverage | 1950–present. |
| Frequency | Data updated monthly. |
| Spatial coverage | Nationwide. |
| Spatial scale/resolution | County level. |
| Access to data | https://www.ncdc.noaa.gov/stormevents/ftp.jsp. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | • Compile new versions of the high-resolution land cover dataset in future years.<br>• Locate digitized FEMA floodplain layers for 12 Chesapeake watershed counties where a GIS version does not seem to be readily available, or digitize them if needed.<br>• Optional enhancement: select a land cover/land use dataset that will provide optimal differentiation among developed land types and intensities. |
| Skills or resources needed, and what individuals or organizations have this capacity | • Developing future editions of the high-resolution land cover data product will require analytical skills and computing capacity to compile a large geospatial dataset, as well as access to algorithms from the original processing effort. This capacity is available from specialized organizations such as those that compiled the 2016 product.<br>• FEMA floodplain map digitization will require GIS software and skills, as well as coordination with FEMA. CBPO staff and a contractor with floodplain mapping expertise can support this step.<br>• The optional "property value at risk" enhancement will require familiarity with land cover/land use mapping and property valuation, which CBPO staff can likely cover in partnership with the Land Use Workgroup and other state and federal agencies. |
| Achievable timeframe | • Repetition of the high-resolution land cover analysis: likely 2 to 5 years.<br>• FEMA map support: 2 to 5 years.<br>• Selection of data source for optional enhancement: Possible within 1 year. |
| Estimated up-front cost | Cost for map digitization TBD, but could be large. Optional enhancement: 150+ hours of staff time. |
| Estimated annual maintenance cost[49] | Labor cost to repeat the high-resolution land cover analysis TBD, but likely high ($100,000+ every 2 to 5 years, or perhaps much more) given the level of effort described for the initial analysis, unless the developers have established a more streamlined approach to facilitate future updates or "change products." Other data collection is assumed to be ongoing. |

## Stage 3: Method Development/Selection

| | |
|---|---|
| | **Status:** A general approach has been outlined, but specific methods have not been established. |

[49] Incremental cost beyond work that is already being performed. If data collection program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

## *Method Information*

A general approach to the proposed indicator is as follows:

**Metric #1: Property at risk of flooding**

- Phase 1: Extent of developed land at risk
  - Define "developed land"
  - Intersect the NFHL and the developed land dataset
  - Calculate the area of developed land within FEMA-defined flood zones
  - Intersect the SLOSH storm surge layer with the developed land dataset
  - Calculate the area of developed land within storm surge risk zones
- Phase 2: Value of property at risk
  - Select land cover/land use dataset and choose developed land subcategories to include
  - Calculate the area of each class of developed land within NFHL and SLOSH risk zones
  - If possible, multiply areas by a proxy value (dollars per acre) to estimate value of property at risk

**Metric #2: Property damaged by storm events**

- Filter events for counties that are at least partly within the Chesapeake watershed
- Extract storm events meeting certain criteria (for example, limit the analysis to damage caused by overland flooding or the storm surge component of large storms, if possible)
- Aggregate results

## *Additional Needs*

**Required steps**

| | |
|---|---|
| Additional work needed | • Develop specific filter criteria, aggregation methods, and other parts of the analytical approach. This step will include developing an approach to merge FEMA floodplain and SLOSH storm surge layers, which may overlap in some places, to avoid double-counting. This step will also include establishing criteria for which events to include from NOAA's storm damage database.<br>• Apply and validate methods, then publish results. Publishing in the peer-reviewed literature would help to ensure a credible foundation for an indicator—particularly one that influences policy decisions. |
| Skills or resources needed, and what individuals or organizations have this capacity | Requires familiarity with underlying datasets and methods for combining multiple related geospatial datasets. Data source contacts can likely provide this expertise, with help from CBPO staff. A contracted partner can help to coordinate the analysis and publish results. |
| Achievable timeframe | 2 to 5 years. |
| Estimated up-front cost | 100+ staff hours plus $10,000–$50,000. |

**Optional enhancement**

| | |
|---|---|
| Additional work needed | Develop value proxies for the available developed land cover classes, or develop an alternative approach to estimate the value of property at risk. |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in land cover/land use mapping and valuation of property at risk of flood damage. Likely available through an academic/research partner and collaboration with state and federal agencies that engage in hazard planning. |

| | |
|---|---|
| Achievable timeframe | 2 to 5 years. |
| Estimated up-front cost | TBD. |

## Stage 4: Data Processing

| | |
|---|---|
| | **Status:** Data have not been processed to create an indicator. |

### *Data Processing Information*

Data cannot be processed until methods are established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Apply methods to entire area of interest (entire watershed). Replicate in future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | It depends on the complexity of the calculations needed, but likely requires ArcGIS spatial analysis skills and software. |
| Achievable timeframe | Initial processing in 3 to 6 years; annual updates for Metric #2 (property damaged); frequency of updates to Metric #1 (property at risk) depends on data sources TBD. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[50] | TBD. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** An indicator has not been developed for the Chesapeake. |

### *Indicator Information*

An indicator cannot be created until all previous stages of development are completed.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Create summary graphics and CBP-format technical documentation for the proposed first iteration of this indicator. Maintain in the future. Add data and documentation for the optional Phase 2 enhancement when they are ready. |

[50] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Skills or resources needed, and what individuals or organizations have this capacity | Familiarity with the indicator and its methods; Excel skills. Likely can be performed by CBPO staff or a contractor. |
| Achievable timeframe | Initial processing in 3 to 6 years; annual updates for Metric #2 (property damaged); frequency of updates to Metric #1 (property at risk) depends on data sources TBD. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[51] | TBD. |
| Final reviews or approvals needed | May need buy-in from FEMA and state hazard planning agencies to ensure consistency with their efforts. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[52] |
|---|---|---|---|---|---|
| **Required elements, including Metric #1 (Phase 1) and Metric #2** | | | | | |
| Select specific FEMA and SLOSH data layers for this indicator | 1 | ~100 hours of staff time | Within 1 year | CBPO staff with partner agency experts | Required |
| Digitize FEMA floodplain maps for up to 12 counties | 2 | TBD; likely large | 2 to 5 years | CBPO staff or contractor with mapping expertise | Required |
| Develop methods to transform data into an indicator | 3 | 100+ staff hours plus $10,000–$50,000 | 2 to 5 years | CBPO staff with contracted partner | Required |
| Apply data processing methods | 4 | TBD | 3 to 6 years | TBD, depending on complexity of methods | Required |
| Create initial indicator, including documentation | 5 | TBD | 3 to 6 years | CBPO staff or contractor | Required |

[51] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[52] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator. In some cases, optional actions could include steps to transform a relatively weak or one-dimensional indicator that is available in the short-term into a more robust indicator in the longer term.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[52] |
|---|---|---|---|---|---|
| Compile updated versions of the high-resolution land cover mapping product | 2 | Likely high (annualized cost of at least $50,000, and possibly much more)—but presumably funded through other vehicles | Possibly every 2 to 5 years | Organizations with specialized geospatial processing skills and computing capacity | Required |
| Process updated data in future years: Metric #1 | 4 | TBD/yr | Frequency TBD | TBD, depending on complexity of methods | Required |
| Process updated data in future years: Metric #2 | 4 | TBD/yr | Annual | TBD, depending on complexity of methods | Required |
| Update indicator in future years: Metric #1 | 5 | TBD/yr | Frequency TBD | CBPO staff or contractor | Required |
| Update indicator in future years: Metric #2 | 5 | TBD/yr | Annual | CBPO staff or contractor | Required |
| **Optional enhancement to Metric #1** | | | | | |
| Select source and define classifications for detailed analysis of developed land | 2 | 150+ staff hours | Within 1 year | CBPO staff with workgroup input | Optional |
| Develop estimates of value or related metric for each developed land class; apply, test, and publish methods | 3 | TBD; likely large | 2 to 5 years | Academic/research partner and collaboration with state and federal agencies | Optional |
| **Total one-time cost** (required components) | | **100+ staff hours plus $10,000–$50,000 plus extensive costs TBD** | | | |
| **Total one-time cost** (optional enhancement) | | **150+ staff hours plus extensive costs TBD** | | | |
| **Total annual cost** | | **TBD/yr** | | | |

# 13. Urban Tree Canopy

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| | Stage 3: Methods developed/selected to transform data into an indicator |
| | Stage 4: Data processed |
| | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to address the **Climate Resiliency** goal and outcomes, as trees sequester carbon dioxide, reduce runoff of sediment and contaminants into waterways, and provide shading and evapotranspiration to counteract the "urban heat island" effect, thereby reducing the risks that extreme heat events pose to human health.
- Urban trees also improve air quality and provide habitat. In recognition of air quality, water quality, and habitat benefits, the Watershed Agreement includes an urban tree cover outcome within the **Vital Habitats** goal area.

Relationship to other indicators in the proposed suite:

- Urban tree canopy is a component of **land cover**.
- Urban trees help to mitigate the human health impacts of **hot air temperatures** and the water quality impacts of **heavy precipitation** (including runoff that may ultimately contribute to **harmful algal blooms** and affect **submerged aquatic vegetation composition**).

Notable opportunities, risks, and areas for enhancement:

- The Chesapeake Bay Program (CBP) already has a project underway to develop an urban tree canopy metric based on the high-resolution land cover dataset developed for the 2017 TMDL Midpoint Assessment. The indicator that results from this effort could be shared between the Vital Habitats and Climate Resiliency teams.
- The proposed land cover/land use indicator is likely to present multiple metrics. Urban tree canopy could be incorporated as one of them, rather than treated as a completely separate indicator relying on the same data source.
- Potential enhancements could include integrating this indicator with urban heat data and/or environmental justice data (e.g., from the CBP's environmental justice screening tool, in development) as a way to drive increases in urban tree canopy in the most vulnerable areas. These enhancements involve integration with other variables, so they are not discussed further in this implementation plan, but they could be considered in the future.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| ✓ | **Status:** Indicator and its metric have been defined. |

### *Indicator Description*

This indicator will track changes over time in the acreage of tree cover within parts of the Chesapeake Bay watershed that are considered "urban."

### *Additional Needs*

Some work may be needed to define exactly how tree cover will be measured (e.g., in units of acres?) and whether it should be normalized in some way to avoid depicting an increase in urban tree canopy if it is driven solely by an increase in the acreage of developed land. This work will be performed as part of the CBP project already underway.

## Stage 2: Data Collection

| ✓ | **Status:** Data collection program in place, but needs to be repeated. |
|---|---|

### *Data Source Information*

| | |
|---|---|
| Dataset | Chesapeake Bay High-Resolution Land Cover Project. |
| Source description | Collaborative effort to develop a high-resolution land cover project to inform the Chesapeake Bay TMDL Midpoint Assessment and related planning and conservation efforts. |
| Organization that collects the data | Chesapeake Conservancy, University of Vermont, and WorldView Solutions, based on NASA/NOAA satellite data and numerous other sources. |
| Data source contact | Julie Mawhorter, USDA Forest Service, jmawhorter@fs.fed.us (contact for the indicator that is being developed from these data);<br>Peter Claggett, USGS/CBPO, pclagget@chesapeakebay.net. |
| Rationale for selection | 1-meter resolution makes it possible to detect individual trees, in contrast to previous 30-meter grids (e.g., NLCD) that were not precise enough to detect small strips or patches of urban tree canopy. |
| Temporal coverage | A single snapshot with nominal year 2016; underlying data of varying vintage (~2006 to 2016). |
| Frequency | Compiled once so far; proposed frequency of 2 to 5 years. |
| Spatial coverage | Entire Chesapeake watershed. |
| Spatial scale/resolution | 1-meter grid. |
| Access to data | https://chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/land-cover-data-project. |

While other land cover and land use data sources are available, the high-resolution product described in the table above is unique in its ability to map canopy at the scale of individual trees. Previous land cover products with 30-meter resolution were simply too coarse to capture the full extent of tree canopy in urbanized areas.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Compile new versions of the high-resolution land cover dataset in future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | Analytical skills and computing capacity to compile a large geospatial dataset; access to algorithms from the original processing effort. This capacity is available from specialized organizations such as those that compiled the 2016 product. |
| Achievable timeframe | Repetition of the analysis is likely every 2 to 5 years. |
| Estimated up-front cost | None; methods have been established and baseline data collected. |

| | |
|---|---|
| Estimated annual maintenance cost[53] | Labor cost to repeat the analysis TBD, but likely high ($100,000+ every 2 to 5 years, or perhaps much more) given the level of effort described for the initial analysis, unless the developers have established a more streamlined approach to facilitate future updates or "change products." |

## Stage 3: Method Development/Selection

| | |
|---|---|
| | **Status:** Methods need to be selected to transform the data into an indicator. |

### *Method Information*

Methods have not been established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Define scope (e.g. is "urban" based on the presence of impervious surfaces, Census definitions, or on density of development a la the NLCD?). Define what counts as "urban tree canopy," considering existing categories in the dataset: forest, tree canopy over turf, tree canopy over impervious surfaces, etc. Develop methods to quantify urban tree canopy extent, apply to a small area and validate, and publish results. Publishing in the peer-reviewed literature could help to ensure a credible foundation for an indicator—particularly one that influences policy decisions—if resources to do so are available. |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in urban tree cover and land cover mapping. The interagency team that is developing this indicator possesses this expertise. |
| Achievable timeframe | Within 1 year. |
| Estimated up-front cost | TBD, but it is assumed that the cost is already covered as part of the ongoing urban canopy indicator development effort. |

## Stage 4: Data Processing

| | |
|---|---|
| | **Status:** Data have not yet been processed to create an indicator. |

### *Data Processing Information*

Data cannot be processed until a method is established.

[53] Incremental cost beyond work that is already being performed. If data collection program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

### Additional Needs

| | |
|---|---|
| Additional work needed | Apply method to areas according to indicator needs—ranging from a subsample of sentinel sites up to the entire watershed in the case of a full census approach. Replicate in future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | It depends on the complexity of the calculations needed, but likely requires ArcGIS spatial analysis skills and software. |
| Achievable timeframe | Initial processing within 1 year. |
| Estimated up-front cost | TBD. A sampling approach rather than a census approach could help to control costs. |
| Estimated annual maintenance cost[54] | TBD. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** Indicator not yet developed. |

### Indicator Information

An indicator cannot be created until all previous stages of development are completed.

### Additional Needs

| | |
|---|---|
| Additional work needed | Create summary graphics. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | TBD; it depends on the degree and complexity of interpretation needed. |
| Achievable timeframe | TBD. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[55] | TBD. |
| Final reviews or approvals needed | Coordination with the people overseeing the indicator development project that is already underway. |

[54] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

[55] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[56] |
|---|---|---|---|---|---|
| Compile updated versions of the high-resolution land cover mapping product | 2 | Likely high (annualized cost of at least $50,000, and possibly much more) | Possibly every 2 to 5 years | Organizations with specialized geospatial processing skills and computing capacity | Required |
| Develop, test, and publish analytical methods | 3 | TBD, but presumably already funded | Within 1 year | Team that is already engaged in this effort | Required |
| Apply data processing methods to entire area of interest | 4 | TBD, but presumably already funded | Within 1 year | Team that is already engaged in this effort | Required |
| Create initial indicator, including documentation | 5 | TBD | TBD | TBD | Required |
| Replicate data processing in future years | 4 | TBD/yr | Possibly every 2 to 5 years | TBD | Required |
| Update indicator in future years | 5 | TBD/yr | Possibly every 2 to 5 years | TBD | Required |
| **Total one-time cost** | | **TBD** | | | |
| **Total annual cost** | | **TBD/yr** | | | |

[56] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator.

# 14. Wetland Extent and Physical Buffering Capacity

## Indicator at a Glance

| | |
|---|---|
| ✓ | Stage 1: Indicator defined |
| partial | Stage 2: Data collection program in place |
| partial | Stage 3: Methods developed/selected to transform data into an indicator |
| not completed | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to address the **Climate Resiliency** goal and outcomes, as acreage of wetlands can indicate programmatic progress toward creating more refugia for species that face threats from extreme events and changing conditions.
- Coastal wetlands provide a physical buffer that helps to slow the erosion of shorelines and protect properties against flooding by dampening storm surges. In its most complete form, this indicator will ideally characterize key services that wetlands provide (namely, buffering), not just areal extent.
- Upstream, wetlands protect against floods by absorbing stormwater, and they help trap nutrients, sediments, and toxins and prevent from being further mobilized and running off into receiving waterbodies and, ultimately, into the Bay.
- Wetlands also support recreation and provide valuable habitat for wildlife. Ultimately, wetlands relate to many of the goals and outcomes in the 2014 Chesapeake Watershed Agreement, including **Vital Habitats**, **Sustainable Fisheries**, **Water Quality**, and **Healthy Watersheds**. The Watershed Agreement aims to create or reestablish 85,000 acres of tidal and non-tidal wetlands and enhance the function of an additional 150,000 acres of degraded wetlands by 2025.

Relationship to other indicators in the proposed suite:

- **Sea level rise** affects wetland extent and buffering capacity.
- Wetlands shelter the shoreline of the Bay and its tributaries, thus helping to mitigate **coastal flooding** and **upstream flooding** and reducing the extent of **property at risk or damaged.**
- Wetlands attenuate the effects of changes in **precipitation** by reducing the quantity and improving the quality of runoff to receiving water bodies.
- Designated **wetland migration corridors** and the **extent of living vs. hardened shorelines** affect the ability of tidal wetlands to adapt to rising sea level.
- Wetlands are federally **protected lands** under section 404 of the Clean Water Act.
- The **restored habitat** indicator will include wetland restoration, but it will only present the net increase in wetland acreage due to restoration activities. This proposed wetland extent indicator will track the overall total extent of wetlands.
- Changes in **land use/land cover** have potential to impact wetland extent and function.

Notable opportunities, risks, and areas for enhancement:

- Two wetland extent indicators are already maintained and published by EPA. Neither has been downscaled to the Chesapeake region yet, however. The option that is arguably more precise (https://www.epa.gov/climate-indicators/atlantic-coast) only provides information about coastal wetlands, whereas the other option (https://cfpub.epa.gov/roe/indicator.cfm?i=37) covers freshwater and marine/estuarine wetlands but is based on a probabilistic survey rather than a full accounting of all wetland acreage.

- This indicator could be developed over time in a staged fashion:
  - Phase 1: Start with a robust measure of coastal/tidal wetland extent based on an established data source (NOAA's Coastal Change Analysis Program [C-CAP]).
  - Phase 2: Add upstream wetland extent, possibly in conjunction with a switch to a newer data source such as the Chesapeake High-Resolution Land Cover Data Project.
  - Phase 3: Incorporate a measure of wetland function (e.g., physical buffering capacity) by expanding and systematizing the collection of data that have thus far only been measured through localized studies.
- The proposed Phase 2 metric requires the High-Resolution Land Cover Data Project to become operationalized (i.e., re-mapped at recurring intervals). This implementation plan assumes that the cost of re-mapping (if it does occur) will be covered by other sources.
- The proposed Phase 3 metric (physical buffering capacity) will require a data collection program that presently only exists as a short-term pilot project. It will take substantial funds to set up and operate such a program, but there might be opportunities to integrate this data collection with an existing monitoring program.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| ✓ | **Status:** Indicator and its metric have been defined. |

### *Indicator Description*

The initial form of this indicator will identify the areal extent (square miles) of tidal wetlands along the Chesapeake Bay and its tributaries, by type of wetland, and track changes in extent over time. Future enhancements could include tracking the extent of non-tidal wetlands and monitoring the physical buffering capacity of tidal wetlands in response to storm surge.

### *Additional Needs*

No further work needed to define the initial form of this indicator. Further work will be required to improve the resolution and expand the spatial and topical coverage, as described in Stage 2 below.

## Stage 2: Data Collection

| | |
|---|---|
| partial | **Status:** Suitable data collection program in place for coastal wetland extent. Higher resolution data for coastal and non-tidal wetlands can be obtained from an existing program if it is continued. Physical buffering capacity data not collected in widespread recurring fashion yet. |

### *Data Source Information*

**Wetland Extent**

Potential sources of wetland extent data include:

- **NOAA's Coastal Change Analysis Program (C-CAP) Regional Land Cover and Change.** C-CAP data are nationally standardized, raster-based inventories of land cover (including wetlands) for the coastal areas of the United States. C-CAP data are derived from the analysis of multiple dates of remotely sensed imagery. Two file types are available: individual dates that supply a wall-to-wall map, and "change" files that compare one date with another. These data are produced at a 30-meter resolution (https://coast.noaa.gov/digitalcoast/data/ccapregional.html). C-CAP is the data source for EPA's "Land Loss Along the Atlantic Coast" feature (https://www.epa.gov/climate-indicators/atlantic-coast); it also provides the coastal wetland component of the National Land Cover Database.

- **U.S. Fish and Wildlife Service (USFWS).** The National Wetlands Inventory (NWI) is a publicly available resource that provides detailed information on the current abundance, characteristics, and distribution of U.S. wetlands. The NWI Wetlands Mapper (https://www.fws.gov/wetlands/data/Mapper.html) is based on a combination of high-altitude imagery and ground-truthing, and is updated on a rolling basis as new wetland mapping projects are completed. Data are submitted by a variety of organizations and individuals. The USFWS also publishes a Wetlands Status and Trends report (https://www.fws.gov/wetlands/status-and-trends/) approximately every 10 years. These reports provide nationwide estimates of wetland extent and change by wetland type, based on a probabilistic survey design that selects a set of sample plots across the nation to be analyzed via aerial imagery and field verification. EPA's "Wetland Extent, Change, and Sources of Change" indicator (https://cfpub.epa.gov/roe/indicator.cfm?i=37) is based on the Status and Trends reports.

- **Chesapeake High-Resolution Land Cover Data Project.** This recent collaborative effort (http://chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/land-cover-data-project/) created a 1-meter resolution land cover map for the Chesapeake watershed to help support activities related to the Chesapeake Bay TMDL Midpoint Assessment.

- **Other studies of wetland acreage change.** For example, Dr. Matt Kirwan at VIMS is developing a study documenting sea level rise-associated conversion of upland to wetland in the Chesapeake region since the 1850s.

An evaluation of the data sources identified the following features:

- C-CAP and USFWS Wetlands Status and Trends data have already been transformed into wetland extent indicators by EPA, and the EPA indicators have been peer-reviewed.
- Many years of historical data are available for C-CAP and for Status and Trends, whereas the Chesapeake High-Resolution Land Cover Data Project has one timestamp and Dr. Kirwan's study has not been published yet.
- C-CAP data will be updated at fairly regular 5-year intervals going forward. The Status and Trends dataset is updated at approximately 10-year intervals, and the Chesapeake High-Resolution Land Cover Data Project has the potential for 2-to-5-year recurrence, though this interval may need to be confirmed.
- The High-Resolution Land Cover Data Project does not presently classify wetlands by type.
- The method of data collection has been fairly consistent over time for C-CAP (remote sensing) and Status and Trends (aerial imagery with ground truthing), unlike for the NWI geospatial dataset, for which various data collection methods have been employed.
- Status and Trends covers coastal and freshwater wetlands, whereas C-CAP only covers coastal wetlands. However, C-CAP's methods are arguably better suited to the type of precise analysis of change over time that the proposed Chesapeake indicator would require. This is because C-CAP provides relatively high resolution based on mapping 100% of the target area, whereas Status and Trends derives estimates from a probabilistic sample that amounts to 5,000 randomly selected 4-square-mile plots nationwide.
- The NWI geospatial dataset presents the most recent inventory of wetlands, but it does not have a "change" product or archived versions from which a national change product could easily be derived.

Based on the evaluation above, C-CAP appears to be the most promising data source for near-term indicator development. As part of a staged approach, the CBP may find it useful to start with a focus on tidal wetlands using C-CAP data, and later expand the indicator to include non-tidal wetlands with a switch to the more precise, watershed-wide High-Resolution Land Cover Data Project, as long as its lack of wetland type classification does not prove to be too significant a limitation. Physical buffering capacity can also be added in the future.

**Phase 1: Wetland Extent (Tidal, Near-term)**

| | |
|---|---|
| Dataset | C-CAP. |
| Source description | See narrative above. |
| Organization that collects the data | NOAA. |
| Data source contact | Nate Herold, NOAA, nate.herold@noaa.gov. |
| Rationale for selection | See narrative above. |
| Temporal coverage | Comparable data from 1996 to 2011; 2016 data layers under development. |
| Frequency | Data collected daily; C-CAP product compiled every 5 years. |
| Spatial coverage | All U.S. coastal areas. |
| Spatial scale/resolution | 30-meter grid. |
| Access to data | https://coast.noaa.gov/digitalcoast/data/ccapwetland.html. |

**Phase 2: Wetland Extent (Tidal and Non-tidal, Longer-term)**

| | |
|---|---|
| Dataset | Chesapeake Bay High-Resolution Land Cover Project. |
| Source description | See narrative above. |
| Organization that collects the data | Chesapeake Conservancy, University of Vermont, and WorldView Solutions, based on NASA/NOAA satellite data and numerous other sources. |
| Data source contact | Contact TBD for the high-resolution mapping initiative. |
| Rationale for selection | See narrative above. |
| Temporal coverage | A single snapshot with nominal year 2016; underlying data of varying vintage (~2006 to 2016). |
| Frequency | Compiled once so far; proposed frequency of 2 to 5 years. |
| Spatial coverage | Entire Chesapeake watershed. |
| Spatial scale/resolution | 1-meter grid. |
| Access to data | https://chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/land-cover-data-project. |

**Physical Buffering Capacity**

A George Mason University research team has worked to quantify storm surge attenuation by wetlands in the Chesapeake Bay region via a concurrent hydrodynamic modeling and field data analysis approach.[57] They began field data collection in 2013 to improve knowledge of tide and storm surge hydrodynamics in wetland ecosystems. Four study sites along the Chesapeake Bay were equipped with sensors to monitor different parameters within wetland ecosystems: water levels, waves, currents, topography, and vegetation biometry. This data collection program is arguably closest to the intent of this indicator as a measure of wetlands' buffering capacity. An ideal indicator would present data from an expanded, ongoing program to measure storm surge attenuation potential at key sites throughout the mainstem Bay and tidal tributaries, based on the

[57] For a presentation of early portions of this work, see: https://www.researchgate.net/profile/Jana_Haddad/publication/287997962_Quantifying_storm_surge_attenuation_by_wetlands_Integration_of_field_monitoring_for_numerical_model_calibration/links/567c59c608ae1e63f1e33091/Quantifying-storm-surge-attenuation-by-wetlands-Integration-of-field-monitoring-for-numerical-model-calibration.pdf.

foundational research described here. Or, if such a program is not possible, the CBPO could consider other proxies, such as marsh health via remote sensing (see the recent project by The Nature Conservancy and Maryland DNR: https://earthzine.org/wp-content/uploads/2017/08/15_GSFC_ChesapeakeBayEco_Poster.pdf) or other measures of marsh resiliency suggested by Raposa et al. (2016).[58] Maryland DNR's 2016 Coastal Resiliency Assessment[59] included a Marsh Protection Potential Index that scored the state's marshes on their buffering capacity. It was based on marsh size, but the underlying literature identified other characteristics (e.g., vegetation structure) that could be combined to more thoroughly characterize buffering capacity, if sufficient observed data were available. Of all these sources, the George Mason storm surge attenuation study comes the closest to characterizing wetland protection potential based on repeatable physical measurements of the phenomenon in question, which makes it arguably the strongest candidate for the proposed indicator, given that one of this project's criteria involves seeking indicators that are based on observed measurements.

| | |
|---|---|
| Dataset | Storm surge attenuation potential monitoring study. |
| Source description | See narrative above. |
| Organization that collects the data | A George Mason University team. |
| Data source contact | Celso Ferreira, George Mason University, cferrei3@gmu.edu;<br>Nicole Carlozo, Maryland DNR, nicole.carlozo@maryland.gov. |
| Rationale for selection | See narrative above. |
| Temporal coverage | 2013–2017. |
| Frequency | A combination of continuous monitoring for some parameters, rapid deployment of additional equipment to capture more data during extreme events, and periodic vegetation and micro-topography surveys. |
| Spatial coverage | Four sites along the Chesapeake: Monie Bay, Eastern Shore National Wildlife Refuge, Dameron Marsh State Preserve, and Magothy Bay State Preserve. |
| Spatial scale/resolution | Individual sites. |
| Access to data | http://hiscentral.cuahsi.org/pub_network.aspx?n=5572. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | • If relying on C-CAP, no additional data collection is needed, assuming C-CAP continues to be updated every 5 years as planned.<br>• Compile new versions of the high-resolution land cover dataset in future years.<br>• Operationalize measurement of wetlands' storm surge attenuation potential and expand to more sites—or, alternatively, review and select the best available proxy for wetlands' physical buffering capacity. This work could include regularly reviewing and evaluating new or expanded networks of Bay-area sites that could provide direct measurements that would feed into regional or field-scale models of wetland attenuation ability. Such work could be done in conjunction with the Sentinel Site Cooperative, for example. |

[58] Raposa, K.B., K. Wasson, E. Smith, J.A. Crooks, P. Delgado, S.H. Fernald, M.C. Ferner, A. Helms, L.A. Hice, J.W. Mora, B. Puckett, D. Sanger, S. Shull, L. Spurrier, R. Stevens, and S. Lerberg. 2016. Assessing tidal marsh resilience to sea-level rise at broad geographic scales with multi-metric indices. Biological Conservation 204(B):263–275. https://www.sciencedirect.com/science/article/pii/S0006320716305742. doi:10.1016/j.biocon.2016.10.015

[59] http://dnr.maryland.gov/ccs/Documents/MARCH-2016_MDCoastalResiliencyAssessment.pdf

| | |
|---|---|
| Skills or resources needed, and what individuals or organizations have this capacity | • Developing future editions of the high-resolution land cover data product will require analytical skills and computing capacity to compile a large geospatial dataset, as well as access to algorithms from the original processing effort. This capacity is available from specialized organizations such as those that compiled the 2016 product.<br>• Continuing and expanding the storm surge attenuation data collection program will likely require dedicated funding to an organization that can deploy and maintain continuous monitoring equipment, deploy staff to install additional equipment before extreme events (if needed), conduct periodic surveys, and compile data. The CBPO might want to investigate opportunities to integrate this monitoring with other existing data collection programs (e.g., ongoing work by the National Estuarine Research Reserves) if the original methods prove to be robust and worthy of replication at additional sites. |
| Achievable timeframe | • Repetition of the high-resolution land cover analysis: likely in 2 to 5 years.<br>• Expanded, operationalized monitoring of storm surge attenuation potential: likely long-term (more than 5 years). |
| Estimated up-front cost | • No up-front cost to compile baseline C-CAP or high-resolution land cover data.<br>• Expanded, operationalized monitoring of storm surge attenuation potential: likely >$100,000 (considering the original grant to Ferreira et al. was $440,000). |
| Estimated annual maintenance cost[60] | • Assume C-CAP is already funded for continued operation.<br>• Labor cost to repeat the high-resolution land cover analysis unknown, but likely high ($100,000+ every 2 to 5 years, or perhaps much more) given the level of effort described for the initial analysis, unless the developers have established a more streamlined approach to facilitate future updates or "change products."<br>• Monitoring of storm surge attenuation potential: TBD but likely high ($50,000+ per year). |

## Stage 3: Method Development/Selection

| | |
|---|---|
| partial | **Status:** Methods are available to transform C-CAP coastal wetland data into an indicator, but methods for other metrics (those proposed as future additions to this indicator) have yet to be developed. |

### *Method Information*

**Phase 1: Wetland Extent (Tidal, Near-term)**

| | |
|---|---|
| Description | Clip C-CAP data to the Chesapeake watershed; calculate total extent of wetlands within each of the C-CAP estuarine wetland classifications for each time period of interest (1996, 2001, 2006, 2011, and beyond). This clipping might already be done; according to http://www.chesapeakeprogress.com/abundant-life/wetlands, C-CAP reported 282,291 acres of tidal wetlands in the Chesapeake watershed as of 2010. It will be useful to have acreage by wetland type in addition to the grand total. |

[60] Incremental cost beyond work that is already being performed. If data collection program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Peer-review status | A more nuanced pixel-by-pixel change analysis was peer-reviewed as part of EPA's climate change indicator suite (https://www.epa.gov/climate-indicators/atlantic-coast), but it is unclear whether a straightforward comparison as proposed here has been peer-reviewed, or if it would need to be. |
| Citations | To be discussed with NOAA C-CAP team. |

Indicator methods have not been developed, peer-reviewed, or published for the proposed Phase 2 wetland extent metric or the proposed Phase 3 physical buffering capacity metric.

### *Additional Needs*

**Phase 1: Wetland Extent (Tidal, Near-term)**

| | |
|---|---|
| Additional work needed | Address any concerns about comparability (for example, if classification schemes changed at some point during the period of interest) and identify existing compilations or time series of C-CAP wetland acreage by type for the Chesapeake. |
| Skills or resources needed, and what individuals or organizations have this capacity | Requires familiarity with C-CAP. The NOAA C-CAP team can provide this expertise, perhaps with help from members of the Wetlands Workgroup who are familiar with work that has already been done for the Chesapeake. CBPO or contractor staff can facilitate the discussion. |
| Achievable timeframe | C-CAP discussions should be possible within 1 year. |
| Estimated up-front cost | Up to $10,000 if contractor support is desired for coordination with the C-CAP team and others; otherwise it can probably be done with 100 hours of staff time. |

**Phase 2: Wetland Extent (Tidal and Non-tidal, Longer-term)**

| | |
|---|---|
| Additional work needed | Find a way to distinguish between tidal and non-tidal wetlands in the high-resolution data product, which currently has a single "Wetlands" class—perhaps by incorporating elevation data? It is possible that this type of work has already been initiated or completed—for example, in conjunction with recent lidar studies. Develop a change product to allow comparison between the baseline dataset and subsequent editions. |
| Skills or resources needed, and what individuals or organizations have this capacity | Requires familiarity with the high-resolution mapping product, as well as wetland classification expertise to advise on the potential for differentiating types of wetlands. This part of the work will benefit from engagement with the high-resolution mapping project team and with one or more wetland experts. |
| Achievable timeframe | If it is possible to distinguish by wetland type, an approach could be established within 1 year. It will take 2 to 5 years to collect another round of data, plus up to another year to develop a change product. |
| Estimated up-front cost | $10,000–$50,000 to engage outside experts to review classification issues and develop a change product. |

**Phase 3: Physical Buffering Capacity**

| | |
|---|---|
| Additional work needed | Develop an approach to aggregate site measurements over the course of a year into a meaningful indicator, possibly with a single value (either a particular variable that is most representative of buffering capacity, or a multi-metric index value) for each individual site. Consider whether it is appropriate to aggregate the indicator or index across multiple sites. |

| | |
|---|---|
| Skills or resources needed, and what individuals or organizations have this capacity | Requires expertise in wetland physical processes and the types of measurements being collected as part of the study described above. This expertise likely resides with experts at NOAA, USGS, and academic partners. |
| Achievable timeframe | 1 to 2 years to develop an indicator approach, as long as data collection protocols for the future are known (e.g., the same variables as in the original study, measured the same way). |
| Estimated up-front cost | $10,000–$50,000 to engage academic experts to develop an indicator approach. |

## Stage 4: Data Processing

| | |
|---|---|
| | **Status:** Data have not yet been processed to create an indicator. |

### *Data Processing Information*

Data cannot be processed until methods are established.

### *Additional Needs*

**Phase 1: Wetland Extent (Tidal, Near-term)**

| | |
|---|---|
| Additional work needed | Clip map to the Chesapeake and calculate total acreage by wetland type, if the C-CAP team has not already done so. Compare across years; repeat for future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | GIS skills and software; CBPO staff or contractors can provide this support. The Wetlands Workgroup and the Chesapeake Bay Sentinel Site Cooperative have members with expertise in this area and should be consulted. |
| Achievable timeframe | Initial processing within 1 year; future processing every 5 years when a new edition of C-CAP is released. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[61] | TBD. |

**Phase 2: Wetland Extent (Tidal and Non-tidal, Longer-term)**

| | |
|---|---|
| Additional work needed | Calculate total wetland acreage; distinguish by wetland type if possible; calculate change over time; repeat for future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | GIS skills and software; CBPO staff or contractors can provide this support. The Wetlands Workgroup and the Chesapeake Bay Sentinel Site Cooperative have members with expertise in this area and should be consulted. |
| Achievable timeframe | 1 to 2 years to calculate total wetland acreage and distinguish by wetland type (if possible); future processing every 2 to 5 years when a new edition of the mapping product is released. |

[61] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[62] | TBD. |

**Phase 3: Physical Buffering Capacity**

| | |
|---|---|
| Additional work needed | TBD. |
| Skills or resources needed, and what individuals or organizations have this capacity | Researchers at the Virginia Institute of Marine Science (Molly Mitchell), the Chesapeake Bay Estuarine Research Reserve System (MD and VA), The Nature Conservancy (InVest Model), the CBP Wetlands Workgroup, and the Chesapeake Bay Sentinel Site Cooperative have expertise in this area. |
| Achievable timeframe | TBD. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[63] | TBD. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. If an indicator already exists at a different scale, this step requires it to be clipped or cropped to the Chesapeake watershed or similarly appropriate spatial extent, if needed. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** Indicator not developed yet. |

### *Indicator Information*

An indicator cannot be created until all previous stages of development are completed.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Create summary graphics and CBP-format technical documentation for the proposed first iteration of this indicator, based on C-CAP. Maintain in the future. Add data and documentation for new components (high-resolution mapping of all wetlands; physical buffering capacity) when they are ready. |
| Skills or resources needed, and what individuals or organizations have this capacity | TBD; it depends on the degree and complexity of interpretation needed. |
| Achievable timeframe | Initial indicator likely within 1 year; enhanced components TBD. |
| Estimated up-front cost | TBD. |

[62] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

[63] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Estimated annual maintenance cost[64] | TBD. |
| Final reviews or approvals needed | Coordination with the Wetlands Workgroup. |

## Summary of Actions and Anticipated Costs

In the table below, action items pertaining to the initial phase that has been proposed for this indicator—coastal wetland change based on C-CAP—are noted as "required." Further steps to incorporate non-tidal wetlands throughout the watershed, higher-resolution mapping data for all wetlands, and physical buffering capacity are noted as "optional" because they represent enhancements that would strengthen the indicator, but are not pivotal for publishing the initial version.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[65] |
|---|---|---|---|---|---|
| **Phase 1: Coastal Wetland Extent from C-CAP** | | | | | |
| Determine appropriate C-CAP "change" products and comparisons, ensuring comparability over time | 3 | Likely <$10,000 or 100 staff hours | Within 1 year | C-CAP team, with Wetlands Workgroup input | Required |
| Clip C-CAP map to the Chesapeake; calculate acreage and change by wetland type | 4 | TBD | Likely within 1 year | CBPO staff or contractor with GIS capabilities | Required |
| Create initial indicator, including documentation | 5 | TBD | Likely within 1 year | CBPO staff or contractor | Required |
| Repeat C-CAP data processing in future years | 4 | TBD/yr | Repeat every 5 years | CBPO staff or contractor with GIS capabilities | Required |
| Update indicator in future years | 5 | TBD/yr | Every 5 years until superseded[66] | CBPO staff or contractor | Required |
| **Phase 2: Extent of All Wetlands from High-Resolution Mapping Product** | | | | | |
| Parse the high-resolution data product by wetland type, if possible | 3 | $5,000–$10,000 | Within 1 year, if feasible | Land cover classification experts | Optional |

[64] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[65] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator. In some cases, optional actions could include steps to transform a relatively weak or one-dimensional indicator that is available in the short-term into a more robust indicator in the longer term.

[66] The initial C-CAP-based indicator will be superseded by the high-resolution mapping product if development proceeds through Phase 2 as suggested in this implementation plan.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[65] |
|---|---|---|---|---|---|
| Compile updated versions of the high-resolution land cover mapping product | 2 | Likely high (annualized cost of at least $50,000, and possibly much more)—but presumably funded through other vehicles | Possibly every 2 to 5 years | Organizations with specialized geospatial processing skills and computing capacity | Optional |
| Develop a "change" product to allow comparison of high-resolution product over time | 3 | $5,000–$40,000 | 3 to 6 years (assume one year beyond second round of data compilation) | Land cover classification experts | Optional |
| Calculate change in wetland acreage (all types) over time | 4 | TBD | 3 to 6 years | TBD; possibly CBPO staff or contractor with GIS capabilities | Optional |
| Create revised indicator, including documentation | 5 | TBD | 3 to 6 years | CBPO staff or contractor | Optional |
| Repeat data processing in future years | 4 | TBD/yr | Repeat every 2 to 5 years | TBD | Optional |
| Update indicator in future years | 5 | TBD/yr | Every 2 to 5 years | CBPO staff or contractor | Optional |
| **Phase 3: Physical Buffering Capacity** | | | | | |
| Develop approach to turn physical buffering capacity measurements into an indicator | 3 | $10,000–$50,000 | 1 to 2 years | Experts in wetland physical processes (USGS, NOAA, academics, etc.) | Optional |
| Expand and operationalize monitoring of storm surge attenuation potential | 2 | Likely >$100,000 | More than 5 years | An organization that can deploy monitoring equipment, deploy staff for event-specific monitoring, conduct surveys, and compile data | Optional |
| Monitor storm surge attenuation potential in future years | 2 | Likely high ($50,000+/yr) | More than 5 years | An organization that can deploy monitoring equipment, deploy staff for event-specific monitoring, conduct surveys, and compile data | Optional |

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[65] |
|---|---|---|---|---|---|
| Process data from the first few years of data collection | 4 | TBD | More than 5 years[67] | TBD | Optional |
| Create revised indicator, including documentation | 5 | TBD | More than 5 years | CBPO staff or contractor | Optional |
| Repeat data processing in future years | 4 | TBD/yr | TBD; maybe annually? | TBD | Optional |
| Update indicator in future years | 5 | TBD/yr | TBD; maybe annually? | CBPO staff or contractor | Optional |
| **Total one-time cost** (required "Phase 1" components) | | **$10,000 or 100 staff hours, + other costs TBD** | | | |
| **Total annual cost** (required "Phase 1" components) | | **TBD/yr, depending on how much additional processing is needed** | | | |
| **Total one-time cost** (optional "Phase 2" components) | | **Up to $50,000** | | | |
| **Total annual cost** (optional "Phase 2" components) | | **TBD/yr; assume repeat of high-resolution mapping is funded elsewhere** | | | |
| **Total one-time cost** (optional "Phase 3" components) | | **$100,000+** | | | |
| **Total annual cost** (optional "Phase 3" components) | | **TBD/yr** | | | |

[67] Although it would be possible to develop the proposed "physical buffering capacity" metric using currently available pilot data, it may be more worthwhile to wait and conduct this step after a few years of data have been collected from a larger network of sites.

# 15. Bird Species Ranges

## Indicator at a Glance

| | |
|---|---|
| not completed | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| not completed | Stage 3: Methods developed/selected to transform data into an indicator |
| not completed | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to address the **Climate Resiliency** goal and outcomes by measuring changes in bird species ranges that may be driven by climate change—for example, the effect of changes in air temperature on the centroid of a species' population, or the effect of coastal wetland habitat loss associated with sea level rise. Actions to protect habitat can bolster resiliency in the face of these changes.

- Bird species ranges may be influenced by progress toward meeting the goals and outcomes for **Vital Habitats**, **Land Conservation**, and other areas of the Watershed Agreement.

Relationship to other indicators in the proposed suite:

- **Air temperature** determines the suitability of habitat for thermally sensitive species.
- The availability of food—including **fish population distributions** (which in turn can be influenced by **Bay water temperature** and **stream water temperature**)—also affects bird populations and their migration patterns.
- **Wetland extent** and the **extent of living shorelines** characterize the availability of habitat for certain bird species.
- Progress in preserving bird habitat can be tracked by the **protected lands**, **restored habitat**, **land use/land cover**, and **urban tree canopy** indicators.

Notable opportunities, risks, and areas for enhancement:

- EPA and the National Audubon Society have developed an indicator of bird wintering ranges that could provide a methodological basis for the proposed Chesapeake indicator.
- Standardized data collection is available from two long-running surveys—the Breeding Bird Survey and the Christmas Bird Count. These surveys have limitations that could be addressed by incorporating data from additional sources, but those additional sources are not necessarily as complete (with regard to number of species included, for example) or as consistent over time and space.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| | **Status:** Sentinel species need to be defined. |

### *Indicator Description*

This indicator will characterize selected bird species in a manner that represents the spatial extent of each population, and possibly how it is distributed throughout its range. A few key questions need to be investigated and resolved. In particular:

**1. What metrics should this indicator present?**

Survey data could be used to calculate or estimate several range-related parameters for a given species:

- The location of its center of abundance, which may or may not be located within the Chesapeake watershed. For example, the centroid for a widely distributed species such as the American Robin might be far from the Chesapeake. Center of abundance will be sensitive to temperature change.
- The total population of the species within the boundaries of the Chesapeake watershed. Total population within the watershed could change in response to temperature, particularly for species at the edge of their range. Total population will also be sensitive to habitat availability, food availability, contamination of food or water, and other factors, such as predation.
- A measure of evenness or spread, which characterizes the distribution of individual birds throughout the species' range and is analogous to the proposed fish population distributions indicator. Such a measure would be influenced by habitat, food, and temperature distributions throughout the species' range, as well as by other factors. As with the proposed fish indicator, a relatively wide and even distribution may indicate relatively high resilience to climate change and other stressors.

The indicator development team will need to consider which of these metrics will be most feasible and provide the most useful data in support of program objectives. The resulting indicator could be visualized by a graph that shows abundance or distribution over time, a graph that tracks the latitude of centroids, or a mapping tool.

**2. What seasons should this indicator cover?**

Temporal considerations are important because many bird species migrate. The two main nationwide surveys cover overwintering populations (the Christmas Bird Count) and the late spring/early summer breeding season (the Breeding Bird Survey). Neither survey alone would provide a complete accounting of all bird species that spend a significant portion of their time in the region. It may be advisable to develop an indicator that uses data from both surveys.

**3. What species should this indicator cover?**

This indicator could track a suite of climate-sensitive species representing each major guild present in the Chesapeake watershed. Depending on the specific metric selected above and the population and range characteristics of the species being considered, it may be advisable to select species for which the Chesapeake region represents the edge of their range. Candidate species could include (but are not limited to):

- American robin: This species is sensitive to the frost line due to its need for soft soil for foraging.
- American woodcock: This species is sensitive to the frost line due to its need for soft soil for foraging.
- Red-headed woodpecker: This species has experienced declines that may relate in part to temperature change (http://www.bioone.org/doi/abs/10.1650/CONDOR-16-101.1).
- Black-capped chickadee and Carolina chickadees: The contact zone between these two species has been moving northward over the past decade due to warming temperatures (http://www.cell.com/current-biology/fulltext/S0960-9822(14)00134-1).
- Sharp-tailed sparrow: The Chesapeake region is at the southern end of the range for this species.

- Brown pelican: This species is commonly associated with more southerly locales, but it is becoming more prevalent in the Chesapeake region.

- Eastern black rail: This species has highly specific habitat requirements that limit it to small sections of coastal marshes. Loss of marsh habitat and higher storm surge associated with sea level rise have led many experts to characterize the black rail as among those species in the Chesapeake region most vulnerable to climate change. This species is elusive and increasingly rare, however, so it is not well measured except by targeted surveys.

- American black duck: This species depends on wetland habitats that are vulnerable to sea level rise, and it is monitored closely in support of an outcome in the 2014 Watershed Agreement.

- Saltmarsh sparrow: As its name implies, this coastal species is dependent on the salt marshes of the eastern United States for its habitat. With males typically requiring large areas of marshland for breeding and nesting sites built typically near the high tide mark, the species is sensitive to the loss of marshes and extreme coastal weather.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | • Select the metrics of interest.<br>• Select the seasons of interest.<br>• Develop and apply objective criteria to select the "sentinel" species this indicator will track. |
| Skills or resources needed, and what individuals or organizations have this capacity | This step will benefit from coordination with any CBP teams, such as the black duck team, working on bird-related issues. An academic/research partner with expertise in ornithology is needed to help inform this step, as well as subsequent stages of indicator development. |
| Achievable timeframe | Within 1 year. |
| Estimated up-front cost | 100+ hours of staff time plus up to $10,000 to engage an academic partner and coordinate with other efforts as needed. |

## Stage 2: Data Collection

| | |
|---|---|
| ✓ | **Status:** Sufficient data are available from existing data collection programs. |

### *Data Source Information*

Two strong data sources have been identified that provide consistent long-running data for many species. Data from these two sources may be aggregated to form a complete dataset that can be used to illustrate wintering ranges as well as breeding ranges of species of interest.

- Christmas Bird Counts (http://netapp.audubon.org/CBCObservation/Historical/ResultsBySpecies.aspx?1) have been facilitated each winter since 1966 by the National Audubon Society. Volunteers traverse thousands of individual survey routes throughout the nation to collect this data. A nationwide, peer-reviewed, climate change indicator has been developed by the National Audubon Society and EPA from this source (https://www.epa.gov/climate-indicators/climate-change-indicators-bird-wintering-ranges).

- The North American Breeding Bird Survey (https://www.pwrc.usgs.gov/bbs/RawData/Choose-Method.cfm) has been facilitated each June since 1966 by the U.S. Geological Survey and Environment

Canada. Volunteers traverse thousands of individual road-based survey routes throughout the United States and Canada. Because this survey is road-based, it is not a good source for marsh bird data. EPA has used a USGS analysis to develop an indicator that provides a sense of population change over time, with species grouped by type of breeding habitat (https://cfpub.epa.gov/roe/indicator.cfm?i=83).

A few other sources of data were evaluated as part of developing this implementation plan, but were not recommended for inclusion as primary sources because of a few key limitations, compared with the two options described above. If the primary sources above do not provide sufficient data to support an indicator, though, it might be useful to supplement the primary data with data from sources such as:

- eBird Citizen Science Observations (http://ebird.org/ebird/explore). The Cornell Lab of Ornithology has been compiling citizen science data via a web-based application since 2002. Historical records dating back to the 1800s have been retroactively recorded. This source provides global coverage; it includes data from other seasonal projects, such as the Great Backyard Bird Count and May Day Bird Count, that aim to capture bird distributions at other times of the year; and it captures ad-hoc input from birders throughout the year. However, the methods for data collection are not standardized or scientifically rigorous. Nonetheless, there may be opportunities to enhance the proposed indicator in the future or collaborate with the Cornell Lab of Ornithology on other projects to track climate-sensitive bird distributions through crowd-sourced data.

- Maryland Marsh Bird Monitoring Survey (http://www.dnr.state.md.us/waters/cbnerr/Pages/monmarshbirds.aspx). The Maryland Chesapeake Bay National Estuarine Research Reserve (CBNERR-MD) monitors the status of secretive marsh birds through a volunteer-based monitoring program. The spatial coverage of this source is limited to several locations in Monie Bay, Jug Bay, and Otter Point Creek. CBNERR-MD is a participant in the National Marsh Bird Monitoring Program and follows their on-the-ground survey protocol (https://cals.arizona.edu/research/azfwru/NationalMarshBird/). Data have been collected annually for the past 10 years.

- Virginia Colonial Waterbird Survey (http://www.ccbbirds.org/maps/#waterbirds2003) (2003, 2008, 2013). The Center for Conservation Biology coordinates aerial and ground surveys to collect counts and coordinates for colonies, as well as information about habitat and other detailed conditions. Data have been collected every 5 years since 1975 in the coastal plain province of Virginia.

- The U.S. Fish and Wildlife Service's Mid-Winter Waterfowl Survey (https://migbirdapps.fws.gov/mbdc/databases/mwi/mwidb.asp). This survey has been conducted annually since 1955, with a focus on surveying waterfowl in their wintering grounds. Methods now include surveys from aircraft. This program may count some species of interest (e.g., marsh birds at risk from climate change) more effectively than road- or foot-based surveys, but it lacks a statistical sampling design, and field methods have changed over time and they vary among states.

Additional data source options may be available. If the CBPO elects to develop this indicator, it could benefit from a deeper review of possible data sources, with input from a wider array of stakeholders.

### *Data Source Information*

| | |
|---|---|
| Dataset | Christmas Bird Count. |
| Source description | See narrative above. |
| Organization that collects the data | National Audubon Society. |

| | |
|---|---|
| Data source contact | cbcadmin@audubon.org;<br>Nicole Michel, National Audubon Society, nmichel@audubon.org. |
| Rationale for selection | Standardized data collection methodology and survey routes that extend throughout the watershed; long-term historical data are available; data will likely continue to be collected for the foreseeable future. |
| Temporal coverage | 1966–present. |
| Frequency | Data compiled annually. |
| Spatial coverage | Nationwide. |
| Spatial scale/resolution | Thousands of individual survey routes. |
| Access to data | http://netapp.audubon.org/CBCObservation/Historical/ResultsBySpecies.aspx?1. |

| | |
|---|---|
| Dataset | North American Breeding Bird Survey. |
| Source description | See narrative above. |
| Organization that collects the data | U.S. Geological Survey and Environment Canada. |
| Data source contact | Keith Pardieck, USGS, kpardieck@usgs.gov;<br>Dave Ziolkowsi, USGS, dziolkowski@usgs.gov. |
| Rationale for selection | Standardized data collection methodology and survey routes that extend throughout the watershed; long-term historical data are available; data will likely continue to be collected for the foreseeable future. |
| Temporal coverage | 1966–present. |
| Frequency | Data compiled annually. |
| Spatial coverage | United States and Canada. |
| Spatial scale/resolution | Thousands of individual survey routes. |
| Access to data | https://www.pwrc.usgs.gov/bbs/RawData/Choose-Method.cfm. |

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Incorporate supplemental data sources as needed—for example, to more fully capture marsh birds that the Breeding Bird Survey undercounts. |
| Skills or resources needed, and what individuals or organizations have this capacity | An academic partner with expertise in ornithology, along with partner agencies and organizations that collect data, can inform this step. CBP workgroups can provide guidance. CBPO staff can facilitate the process. |
| Achievable timeframe | Within 1 year. |
| Estimated up-front cost | ~100 hours of staff time plus $10,000 for academic consultation. |
| Estimated annual maintenance cost[68] | None, assuming all data will come from surveys that continue to operate. |

## Stage 3: Method Development/Selection

| | |
|---|---|
| | **Status:** Methods have not yet been selected to transform the data into an indicator. |

[68] Incremental cost beyond work that is already being performed. If data collection program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

### *Method Information*

Methods have not been confirmed for this indicator, although it might be possible to adapt methods that have been used in other indicator products, such as EPA's climate change indicators or *Report on the Environment*. For example, the National Audubon Society's method for calculating species-level center of abundance from Christmas Bird Count data might be able to be applied to Breeding Bird Survey data. Other possible analytical approaches could include the Index of Community Waterbird Integrity (https://www.sciencedirect.com/science/article/pii/S0006320708002784?via%3Dihub) or the Index of Marsh Bird Community Integrity (https://link.springer.com/article/10.1672%2F0277-5212%282004%29024%5B0837%3AIOLUOT%5D2.0.CO%3B2).

### *Additional Needs*

| | |
|---|---|
| Additional work needed | • Develop and test a routine to aggregate source data and calculate metrics of interest for each sentinel species.<br>• Determine how to integrate data from two sources and two seasons—or whether it is more appropriate to just present separate winter and breeding-seasons metrics.<br>• Apply the routine to available data and publish results in the peer-reviewed literature. This last step will help to provide a credible foundation for an indicator—particularly one that influences policy decisions. |
| Skills or resources needed, and what individuals or organizations have this capacity | This step would benefit from continued engagement with the academic/research partner who will have advised Stages 1 and 2 and who can lead the analysis and contribute to publication of the results. USGS and the National Audubon Society can provide expertise with their respective datasets and might be able to contribute existing processing routines, such as those that fed into the two EPA indicators described above. |
| Achievable timeframe | 1 to 2 years. |
| Estimated up-front cost | $10,000–$50,000: Estimated labor costs for a modest-sized project with an academic team. |

## Stage 4: Data Processing

| | |
|---|---|
| | **Status:** Data have not been processed to create an indicator. |

### *Data Processing Information*

Data cannot be processed until methods are established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Apply methods to all species of interest. If estimating total population in the watershed, apply methods to the entire area. Replicate in future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | To be determined; it depends on the format and condition of the data and the complexity of the calculations needed. This step will likely benefit from coordination with data processing already conducted by the National Audubon Society and USGS. |
| Achievable timeframe | 1 to 2 years; updated annually. |

| | |
|---|---|
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[69] | TBD. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** This indicator has not yet been developed. |

### *Indicator Information*

An indicator cannot be created until all previous stages of development are completed.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Create summary graphics. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | TBD; it depends on the degree and complexity of interpretation needed. |
| Achievable timeframe | 1 to 2 years; updated annually. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[70] | TBD. |
| Final reviews or approvals needed | TBD. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[71] |
|---|---|---|---|---|---|
| Define how the indicator will be constructed | 1 | 100+ staff hours plus up to $10,000 | Within 1 year | Academic/research partner with input from black duck project team | Required |

[69] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

[70] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[71] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator. In some cases, optional actions could include steps to

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[71] |
|---|---|---|---|---|---|
| Incorporate supplemental data sources if needed | 2 | ~100 staff hours plus $10,000 | Within 1 year | Academic/research partner with workgroup input | Optional |
| Develop, test, and publish analytical methods | 3 | $10,000-$50,000 | 1 to 2 years | Academic/research partner working with National Audubon Society and USGS | Required |
| Apply data processing methods to all species and territory of interest | 4 | TBD | 1 to 2 years | Academic/research partner working with National Audubon Society and USGS | Required |
| Create initial indicator, including documentation | 5 | TBD | 1 to 2 years | TBD | Required |
| Replicate data processing in future years | 4 | TBD/yr | Annual | TBD | Required |
| Update indicator in future years | 5 | TBD/yr | Annual | TBD | Required |
| **Total one-time cost** (required components) | | **100+ staff hours plus $10,000–$60,000 plus further costs TBD** | | | |
| **Total one-time cost** (optional enhancement) | | **~100 staff hours plus $10,000** | | | |
| **Total annual cost** (required components) | | **TBD/yr** | | | |

transform a relatively weak or one-dimensional indicator that is available in the short-term into a more robust indicator in the longer term.

# 16. BMPs and Green Infrastructure

## Indicator at a Glance

| | |
|---|---|
| not completed | Stage 1: Indicator defined |
| not completed | Stage 2: Data collection program in place |
| not completed | Stage 3: Methods developed/selected to transform data into an indicator |
| not completed | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- Best management practices (BMPs) and green infrastructure help to mitigate the impacts of precipitation—particularly heavy precipitation events—by reducing and treating stormwater at its source. For example:
    - Rain gardens and bioswales collect and absorb runoff.
    - Permeable pavements help prevent runoff by filtrating, treating, and storing rainwater where it falls.
- This indicator helps to address the **Climate Resiliency** goal and outcomes, as heavy precipitation events are projected to increase as the climate changes. BMPs and green infrastructure can indicate programmatic progress toward increased resilience to climate change.
- By reducing polluted runoff and overflows into water bodies, BMPs and green infrastructure are also critical to meeting **Water Quality** objectives.

Relationship to other indicators in the proposed suite:

- BMPs and green infrastructure are components of **land cover and land use**.
- BMPs and green infrastructure mitigate the water quality impacts of **heavy precipitation** (including runoff that may ultimately contribute to **harmful algal blooms** and affect **submerged aquatic vegetation composition**).
- By more effectively managing heavy precipitation, green infrastructure can help to mitigate **upstream flooding** and reduce the extent of **property at risk or damaged.**

Notable opportunities, risks, and areas for enhancement:

- The proposed indicator only exists as a concept; it requires foundational efforts to define a metric and determine data needs. Because it is at such an early stage, the cost to develop and maintain this indicator is highly uncertain.
- Thus far, no comparable indicator has been identified in other regions or programs. This indicator could require novel thinking—and it could become an innovation that moves science forward.
- An optional enhancement could expand parts of this indicator to address other issues beyond stormwater. For example, the addition of other components of the built environment, such as buildings and transportation infrastructure, could reflect the extent to which resiliency is incorporated in a broader set of design decisions. Such an enhancement would require a name change that broadens the indicator scope beyond green infrastructure, which specifically reduces and treats stormwater.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| | **Status:** The indicator and its metric have not been defined. |

### *Indicator Description*

This indicator will characterize the state of green infrastructure and BMPs that are designed to reduce and treat stormwater. The proposed indicator could consist of two separate but complementary types of metrics:

- **Metric #1:** The extent to which jurisdictions have enacted policies to codify the need for climate resiliency in infrastructure planning, permitting, etc. Examples could include a jurisdiction's regulatory stormwater BMP "design-storm" standard and a jurisdiction's regulatory requirements for consideration of future climate impacts (storm surge, sea level rise, flooding) on siting and design of BMPs.

- **Metric #2:** The extent to which resilient BMPs have actually been put in place and resilient "green" infrastructure has been constructed. One approach could be to measure a given jurisdiction's reported "green" infrastructure (i.e., where regulators have concluded that BMPs comply with siting and design standards, as above). Another more difficult approach would seek to make the same determination of compliance in lieu of or in addition to a determination made by the jurisdiction's regulatory body.

These two components will work hand-in-hand to track a) the extent to which jurisdictions have put effective frameworks in place to foster the development of resilient infrastructure and b) the extent to which these frameworks have been acted upon in the design and implementation of green infrastructure. That is, the indicator will track both policy and implementation. However, more work must be done to flesh out exactly what each metric will entail.

### *Additional Needs*

Several questions need to be addressed to help define this indicator, and many individuals and organizations will have valuable input to contribute to the process. Key questions include (but are not limited to):

**Metric #1: Policies in Place**

1. What types of policies should count? Presumably this indicator could count legislation, regulations, and any other requirements that have the force of law. But it will be necessary to define what constitutes a requirement for climate resiliency. For instance, is it sufficient to require that infrastructure planning or permitting consider future climate scenarios? Do specific scenarios need to be required (for example, sea level rise corresponding to the RCP8.5 climate scenario)? What if a regulation requires consideration of future conditions but does not include the word "climate"? Should the indicator also count incentives for considering resiliency in planning? How can this metric be defined to compare "apples with apples"?

2. What jurisdictions should be considered? A default assumption would be to focus on the official jurisdictions for the Watershed Agreement (i.e., states and DC), but an indicator could also look at city or county requirements if applicable. That said, design storm standards for stormwater BMPs and siting/design standards are usually promulgated at the state level.

3. Has anyone compiled the necessary data, or would a new effort need to be conducted? An initial review did not find a clearinghouse or other source with the exact information suggested for this indicator, but other stakeholders might be aware of such a source.

4. How will jurisdictions be scored? For instance, will the indicator simply give an overall "yes" or "no" designation to each jurisdiction? "Yes"/"no" scores on several specific criteria? Grades along a spectrum? How will these scores be assigned objectively?

**Metric #2: Implementation**

1. What types of green infrastructure and BMPs should be counted? Should this indicator include every type of green infrastructure and BMP on an official list, or just those that meet certain criteria (e.g., a relatively strong connection to climate resilience)?

2. Are the necessary data compiled from all jurisdictions as inputs to the Watershed Model? What data attributes are collected? Can they be disaggregated by jurisdiction or by type of BMP for this indicator? How often are the data updated? Are the data limited to projects that used federal or state funding for implementation?

3. How will BMPs be tallied? Will this indicator simply count the number of projects? Or is there a way to count the size of projects (e.g., acreage)? To count size, it would be necessary to find a common unit that allows many different types of BMPs to be scored and aggregated together. (That is, not all practices and types of infrastructure are measured in terms of acreage, etc.)

Another option would be to measure impact or results. However, the criteria for this proposed suite of indicators emphasize the value of observed rather than modeled data. It may be difficult to characterize the effectiveness of a particular BMP based on observed data, particularly in a way that isolates any single BMP, given the interconnectedness of systems for managing stormwater.

**Optional Enhancement**

Renaming this indicator and expanding it to other issues beyond stormwater would require consideration of additional questions, such as:

1. Beyond stormwater green infrastructure, what other types of infrastructure should be included? Should the planning and design of resilient transportation infrastructure (e.g., highway and bridge design standards) be included? What about utilities (e.g., electric power grid resiliency), buildings, etc.?

2. Are the necessary data compiled from all jurisdictions? (This could pose a challenge, compared with stormwater-related data that are collected for Watershed Implementation Plans [WIPs].) What data attributes are collected? Can they be disaggregated by jurisdiction or by type of BMP for this indicator? How often are the data updated?

3. What would the new name for the expanded indicator be to reflect the broadened scope beyond green infrastructure?

**Summary of Additional Work Needed**

| | |
|---|---|
| Additional work needed | Work is needed to define how this indicator will be constructed, including:<br>• Identifying which data sources to use.<br>• Identifying which policies to include.<br>• Defining what types of BMPs and green infrastructure to include.<br>• Deciding what level of jurisdiction to consider.<br>• Determining how to score jurisdictions on their policy and implementation.<br><br>Useful starting points could include expert elicitation, a literature search, and a more in-depth review of available data sources, their characteristics, and their |

| | |
|---|---|
| | coverage. The suggested optional enhancement would require additional research and consultation. |
| Skills or resources needed, and what individuals or organizations have this capacity | Indicator definition will benefit from engagement with CBPO staff, workgroups, and state partners who are heavily involved with stormwater issues and WIPs. An academic or contracting partner can help to conduct research and facilitate the indicator design process. |
| Achievable timeframe | 1 to 2 years. |
| Estimated up-front cost | $30,000–$50,000: Estimated cost of conducting a literature search and data source review for stormwater (the proposed indicator); convening the appropriate experts (e.g., through workshops and calls) to review options and define the metric(s); and gathering input and buy-in from key stakeholders. Add $20,000 to address optional topics beyond stormwater. |

## Stage 2: Data Collection

| | |
|---|---|
| | **Status:** Sufficient data might be available from an existing data collection program, but first, the indicator must be defined. |

### *Data Source Information*

A data source has not been determined yet, pending the outcome of Stage 1 indicator development work. Thus far, no clearinghouse of policy data for the proposed Metric #1 (policies in place) has been identified. A comprehensive survey might need to be conducted. Possible data sources for Metric #2 (implementation) could include data that the CBPO already collects from jurisdictions in conjunction with WIPs and as inputs to the Watershed Model.

EPA's Multisector Evaluation Tool for identifying Resilience Opportunities (METRO) might prove useful at this stage, as it provides a framework for eliciting input from stakeholders and quantifying responses to questions such as:

- Are there incentives to reduce the amount of impervious surface, to prevent development in flood plains, to use urban forestry to reduce impacts, to use green infrastructure for stormwater management, etc.?
- To what extent was green infrastructure selected to provide the maximum ecological benefits?
- To what extent is green infrastructure implemented or planned to reduce climate change impacts on transportation systems?
- Has green infrastructure maintenance been built into the budget?

### *Additional Needs*

| | |
|---|---|
| Additional work needed | TBD. The work in Stage 1 will identify whether the indicator can be constructed from existing data collection programs or whether it requires additional data collection to provide adequate topical coverage. |
| Skills or resources needed, and what individuals or organizations have this capacity | Strong familiarity with stormwater management practices (green infrastructure and BMPs), stormwater management legislation and regulations, climate resiliency planning, and data collection in the Chesapeake watershed. This expertise is likely available from a combination of CBPO staff, workgroup members, and other state partners. |

| | |
|---|---|
| Achievable timeframe | TBD. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[72] | TBD. |

## Stage 3: Method Development/Selection

| | |
|---|---|
| | **Status:** Methods have not yet been selected to transform the data into an indicator. |

### *Method Information*

Methods have not been established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Develop methods, validate, and apply to available data for at least a portion of the Chesapeake Bay/watershed. Publishing results in the peer-reviewed literature would be nice at this point, but is not imperative, given that the proposed indicator is likely to be constructed from administrative measures rather than scientific data collection that benefits from peer-review validation. |
| Skills or resources needed, and what individuals or organizations have this capacity | Strong familiarity with stormwater management practices (green infrastructure and BMPs), stormwater management legislation and regulations, climate resiliency planning, and data collection in the Chesapeake watershed. This step can be coordinated by in-house CBPO experts with input from workgroup members and other state partners. |
| Achievable timeframe | TBD; depends on timeframe for data collection. |
| Estimated up-front cost | TBD. |

## Stage 4: Data Processing

| | |
|---|---|
| | **Status:** Data have not been processed to create an indicator. |

### *Data Processing Information*

Data cannot be processed until a method is established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Apply methods to entire area of interest (entire watershed). Replicate in future years. |
| Skills or resources needed, and what individuals or | TBD; it depends on the format and condition of the data and the complexity of the calculations needed. |

[72] Incremental cost beyond work that is already being performed. If data collection program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| organizations have this capacity | |
| Achievable timeframe | TBD; depends on timeframe for data collection. Frequency of updates also depends on the underlying data. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[73] | TBD. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** This indicator has not yet been developed. |

### *Indicator Information*

An indicator cannot be created until all previous stages of development are completed.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Create summary graphics. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | TBD; it depends on the degree and complexity of interpretation needed beyond work that is already being performed by others. |
| Achievable timeframe | TBD; depends on timeframe for data collection. Frequency of updates also depends on the underlying data. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[74] | TBD. |
| Final reviews or approvals needed | Coordination with the key people who oversee the Watershed Model and WIPs. |

[73] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

[74] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[75] |
|---|---|---|---|---|---|
| Define how the indicator will be constructed | 1 | $30,000-$50,000 | 1 to 2 years | CBPO, workgroups, state partners, and an academic or consulting partner | Required |
| Implement data collection program, if needed | 2 | TBD | TBD, depending on indicator design and data availability | CBPO, workgroups, state partners | Required |
| Develop, test, and publish analytical methods | 3 | TBD | TBD | CBPO, workgroups, state partners, and an academic or consulting partner | Required |
| Apply data processing methods to entire area of interest | 4 | TBD | TBD | TBD | Required |
| Create initial indicator, including documentation | 5 | TBD | TBD | TBD | Required |
| Replicate data processing in future years | 4 | TBD/yr | Frequency TBD, depending on data source | TBD | Required |
| Update indicator in future years | 5 | TBD/yr | Frequency TBD, depending on data source | TBD | Required |
| Investigate expansion to infrastructure issues beyond stormwater | 1 | ~$20,000 | 1 to 2 years | CBPO, workgroups, state partners, and an academic or consulting partner | Optional |
| Data collection, method development, processing, and indicator updates to incorporate additional topics beyond stormwater | 2–5 | TBD | TBD | TBD | Optional |
| **Total one-time cost** (required components) | | **$30,000–$50,000 plus several additional costs TBD** | | | |
| **Total annual cost** (required components) | | **TBD/yr** | | | |

[75] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator. In some cases, optional actions could include steps to transform a relatively weak or one-dimensional indicator that is available in the short-term into a more robust indicator in the longer term.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[75] |
|---|---|---|---|---|---|
| **Total one-time cost** (optional enhancements) | | **~$20,000 plus several additional costs TBD** | | | |
| **Total annual cost** (optional enhancements) | | **TBD/yr** | | | |

# 17. Land Use/Land Cover

## Indicator at a Glance

| | |
|---|---|
| not completed | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| not completed | Stage 3: Methods developed/selected to transform data into an indicator |
| not completed | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator relates to the **Climate Resiliency** goal and outcomes, as certain types of land cover or land use either increase or decrease resilience to climate change. For example:
  - Wetlands provide refugia for species, help to absorb floodwaters associated with heavy precipitation, and help to dampen storm surge and coastal flooding.
  - Forests and other lands in their natural state offer refugia for species.
  - Developed areas with extensive impervious surfaces contribute to the "urban heat island" effect (exacerbating human health risks from extreme heat) and may be less able to handle heavy precipitation (i.e., more runoff and flooding). Conversely, urban vegetation, light-colored surfaces, and permeable pavement offer some degree of resilience.
- This indicator also relates to several other goal areas in the Watershed Agreement, including:
  - **Vital Habitats:** Habitat can be measured in terms of the extent of various land cover types. The Watershed Agreement includes outcomes for wetlands, riparian forest buffers, and tree canopy.
  - **Water Quality** and **Healthy Watersheds:** Runoff of sediment, nutrients, and other contaminants into waterbodies is influenced by both land cover (e.g., impervious surfaces that promote runoff, riparian vegetation that stabilizes streambanks) and land use (i.e., specific types of agricultural activities).
  - **Land Conservation:** The Watershed Agreement includes "land use" outcomes that relate to measurement and management of land conversion—especially conversion to developed land with impervious surfaces.

Relationship to other indicators in the proposed suite:

- **Wetland extent** and **urban tree canopy** are specific aspects of land cover.
- Land use and land cover affect the ability of the landscape to absorb **heavy precipitation**—and thus influence the severity of **upstream flooding** and corresponding **property damage**.
- Land use and land cover influence runoff that can contribute to **harmful algal blooms**.
- The **protected land** indicator will measure the extent to which certain land can and cannot be modified or used.
- The types of land cover within developed areas will influence the severity of human health impacts associated with **extremely hot temperatures**.

Notable opportunities, risks, and areas for enhancement:

- This indicator could serve an integrative role, encompassing multiple metrics that help to track progress toward several outcomes in the Watershed Agreement.

## Stage 1: Indicator and Metric Definition

| | **Status:** Indicator and its metric(s) have not yet been defined. |
|---|---|

### *Indicator Description*

No overarching land use/land cover indicator has been defined for this effort, but examples of such indicators exist elsewhere. For example, EPA's Report on the Environment (ROE) presents national indicators that track changes over time in land cover, based on the National Land Cover Database (NLCD) (https://cfpub.epa.gov/roe/indicator.cfm?i=49), and changes over time in land use, based on USDA inventories (https://cfpub.epa.gov/roe/indicator.cfm?i=51).

To determine the best indicator(s) to use for land use and land cover in the Chesapeake watershed, it is important to first identify what the objective of such an indicator is. Key questions to consider include:

1. Should the indicator address land use, land cover, or both? While the two concepts are closely related, it is important to recognize the distinction between land use (the activities that take place on land—e.g., agricultural, residential, industrial, and recreational uses) and land cover (physical characteristics of the land surface). For instance, there may be functional differences between forested land that is available for harvesting ("timberland"), forested land used for grazing, and forested land that is not used for any economic activity—even though a land cover survey might classify them all as "forest."
2. Should the indicator attempt to track all land use/land cover types, or just certain types? The EPA land cover indicator linked above includes all land cover types, tracking total acreage and change over time by category. In contrast, the EPA land use indicator linked above focuses on selected categories that happen to be measured nationwide. If desired, an indicator for the Chesapeake could focus on certain categories that help to track progress toward climate resiliency and other outcomes in the Watershed Agreement.
3. Should the indicator cover the entire watershed, or should it focus on areas of particular concern? Areas of particular interest could include those that provide ecological services such as groundwater recharge, flood attenuation, thermal regulation (e.g., forested riparian areas adjacent to streams supporting coldwater fisheries), or vegetation migration (see the implementation plan for the **Wetland Migration Corridors** indicator).

One option for this effort would be to create an integrative indicator that helps to address several CBP priorities. It could include the following components:

- A mapping tool—or a link to an existing mapping tool.
- One or more graphs that track total extent (square miles) of each land cover/land use type throughout the watershed. The categories will reflect the classification scheme of whatever data source is being used.
- Additional graphs that focus on trends in particular categories of interest, such as urban tree canopy. In this sense, the proposed urban tree canopy indicator could be folded into a larger land use/land cover indicator instead of treated as a separate indicator. The same could also be said for the proposed wetland extent indicator.

Alternatively, if there is concern about duplicating efforts, or if other Goal Implementation Teams (GITs) prefer to pursue their own indicators related to land use and land cover, one might consider how a separate indicator could add value from a climate resiliency perspective. For example, if other classifications are being tracked elsewhere, this indicator could focus on the extent of impervious cover or certain priority habitats.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Determine priorities and approach for this indicator, addressing questions such as those outlined above. |
| Skills or resources needed, and what individuals or organizations have this capacity | Requires an understanding of programmatic priorities and what other GITs are already doing in this area. Ideal people to conduct this work are CBPO staff in coordination with the Land Use Workgroup and other key workgroups as needed. It may be helpful to connect with those who have done extensive work to hindcast and forecast land use in conjunction with the TMDL. |
| Achievable timeframe | Within 1 year. |
| Estimated up-front cost | ~100 hours of staff time. |

## Stage 2: Data Collection

| | |
|---|---|
| ✓ | **Status:** Data collection program in place. |

### *Data Source Information*

A data source cannot be selected until the indicator has been defined. There are many suitable data sources, however, and the expense of collecting and compiling a new source would likely be prohibitive (and unnecessary), so it is arguably safe to say that a program to collect data for this indicator is already in place.

Sources to consider include:

- NLCD (https://www.mrlc.gov/)
- C-CAP (coastal component of NLCD) (https://coast.noaa.gov/digitalcoast/data/ccapregional.html)
- Phase 6 Land Use dataset (https://chesapeake.usgs.gov/phase6/map)
- Chesapeake High-Resolution Land Cover Data Project (http://chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/land-cover-data-project/), which fed into the Phase 6 Land Use dataset
- USGS LCMAP (https://eros.usgs.gov/science/lcmap)—planned for release in fall 2018
- USFS FIA (https://www.fia.fs.fed.us/tools-data/)
- USDA NRI (https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/)
- LiDAR (https://nationalmap.gov/3DEP/)

All of these data sources include a commitment to future updates, provided that the high-resolution mapping layer is updated at 2-to-5-year intervals as has been suggested elsewhere. The data sources differ with respect to classifications, spatial resolution and coverage, temporal frequency, and temporal coverage. To determine the best source(s) for the proposed indicator, it will be helpful to consider questions such as:

1. Is it more important to use the highest-resolution dataset possible, or to use data with a longer historical record? For instance, the NLCD change product available now allows comparisons back to 2001, but is at a 30-meter resolution, compared with the 1-meter resolution of the new Chesapeake high-resolution product that has been compiled once so far.

2. Should the indicator rely on a single dataset, or can alternative or additional datasets be considered for different variables of interest? For example, the proposed indicator could be used to track the extent of riparian forest buffer along stream, in miles—i.e., the total extent throughout the watershed, not just

the incremental change that is presently measured—but this analysis might require incorporation of an additional streams layer.

The choice of one or several datasets requires context to understand what the data mean. For example, NLCD and C-CAP track changes in large-scale disturbances but do not detect most small changes (less than a few acres) or highly diffuse, subtle, or narrow-feature changes.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Select the most appropriate data source(s) based on the indicator goals established in Stage 1 and the considerations outlined above. Incorporate supplemental data sources as needed. |
| Skills or resources needed, and what individuals or organizations have this capacity | Data source selection will require knowledge of the various land cover and land use datasets that are available. This expertise is available through CBPO staff and the Land Use Workgroup. Future data collection will be performed by organizations that are already engaged in such efforts. |
| Achievable timeframe | Source selection within 1 year, though it may be worth waiting to incorporate the LCMAP if it meets this indicator's needs, as it will provide annual data from 1984 to 2016. Future data collection depends on the source, but likely at a frequency on the order of 5 years. |
| Estimated up-front cost | ~100 staff hours for source selection. Assume this indicator will rely on an existing data source—i.e., initial data collection will have already taken place. |
| Estimated annual maintenance cost[76] | TBD/yr. |

## Stage 3: Method Development/Selection

| | |
|---|---|
| | **Status:** Methods have not yet been selected to transform the data into an indicator. |

### *Method Information*

Methods have not been established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Develop and document methods. Unlike other indicators where the methods for transforming collected data into an indicator are complex, this indicator might not require separate peer-review validation if the methods are as simple as counting pixels with GIS software, for example. This assumes that more complex steps such as land cover classification have already been reviewed and published as part of the process of generating the underlying data product. |

[76] Incremental cost beyond work that is already being performed. If data collection program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Skills or resources needed, and what individuals or organizations have this capacity | GIS analysis skills and software—likely available from CBPO staff or partner agencies. |
| Achievable timeframe | Within 1 year. |
| Estimated up-front cost | Cost or staff hours TBD, depending on selected source and its level of complexity. |

## Stage 4: Data Processing

| | |
|---|---|
| | **Status:** Data have not been processed to create an indicator. |

### *Data Processing Information*

Data cannot be processed until a method is established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Apply methods to entire area of interest (entire watershed). Replicate in future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | GIS analysis skills and software—likely available from CBPO staff or partner agencies. |
| Achievable timeframe | Initial processing within 1 year; future updates every 2 to 5 years. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[77] | TBD/yr. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** This indicator has not yet been developed. |

### *Indicator Information*

An indicator cannot be created until all previous stages of development are completed.

[77] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Create summary graphics. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | Basic analytical skills; ability to interpret GIS data. CBPO staff could perform these steps. |
| Achievable timeframe | Initial baseline indicator within 1 year; future updates every 2 to 5 years. |
| Estimated up-front cost | ~60 staff hours to develop graphics and documentation, assuming all major data processing has taken place in Stage 4. |
| Estimated annual maintenance cost[78] | ~20 hours/yr, annualized. |
| Final reviews or approvals needed | Coordination with the Land Use Workgroup. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[79] |
|---|---|---|---|---|---|
| Determine priorities and approach for this indicator | 1 | ~100 staff hours | Within 1 year | CBPO staff, Land Use Workgroup, and others | Required |
| Select data source(s) | 2 | ~100 staff hours | Within 1 year | CBPO staff and Land Use Workgroup | Required |
| Develop methods to transform data into an indicator | 3 | TBD | Within 1 year | CBPO staff | Required |
| Apply data processing methods | 4 | TBD | Within 1 year | CBPO staff | Required |
| Create initial indicator, including documentation | 5 | ~60 staff hours | Within 1 year | CBPO staff | Required |
| Continue data collection | 2 | No incremental cost; data already being collected | Likely every 2 to 5 years | Organizations that already collect these data | Required |
| Replicate data processing in future years | 4 | TBD/yr | Likely every 2 to 5 years | CBPO staff | Required |
| Update indicator in future years | 5 | ~20 staff hours/yr | Likely every 2 to 5 years | CBPO staff | Required |

[78] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[79] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[79] |
|---|---|---|---|---|---|
| **Total one-time cost** | | **~260 staff hours + additional cost TBD** | | | |
| **Total annual cost** | | **~20 staff hours/yr + processing cost TBD** | | | |

# 18. Shoreline Condition

## Indicator at a Glance

| | |
|---|---|
| not completed | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| not completed | Stage 3: Methods developed/selected to transform data into an indicator |
| not completed | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator relates to the **Climate Resiliency** goal and outcomes in multiple ways:
  - Extensive research shows the value of *living shorelines* with features that stabilize the shoreline without severing natural connections or diminishing habitat value.[80] Shorelines in a more natural state may also be better able to adapt to changing conditions—for example, wetlands that naturally accrete and migrate—while continuing to provide valuable ecosystem services such as habitat (particularly as refugia for species threatened by climate change) and physical buffering. Promotion and implementation of living shorelines is a key action in the Chesapeake Bay Program's (CBP's) Climate Resiliency Management Strategy.
  - Some individuals and communities choose to respond to the threat of sea level rise and storm surge by armoring the shoreline. Seawalls and other structures protect property from storm damage and coastal flooding, so in that sense, they might be considered part of a resilience strategy. However, hardened structures ultimately alter and reduce habitat, and they amplify erosion of adjacent shorelines.
- Shorelines with natural features help to preserve **Vital Habitats** such as submerged aquatic vegetation (SAV), which in turn helps to support **Sustainable Fisheries** goals. Research has indicated that hardened shorelines decrease the availability of shallow shoreline areas, which provide refuge to nearshore species of fish and shellfish.[81]

Relationship to other indicators in the proposed suite:

- Unhardened shorelines offer a measure of resiliency against **sea level rise** and **coastal flooding**.
- By providing more high-quality habitat, unhardened shorelines may influence **SAV community composition** (e.g., Landry and Golden, 2017)[82] and **fish population distribution**.
- The proposed **restored habitat** indicator builds on an existing CBP indicator that tracks the extent of restored wetlands and oyster beds, which can both be part of a living shoreline.

Notable opportunities, risks, and areas for enhancement:

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[80] For example, see: Gittman, R.K., S.B. Scyphers, C.S. Smith, I.P. Neylan, and J.H. Grabowski. 2016. Ecological consequences of shoreline hardening: A meta-analysis. BioScience 66(9):763–773. doi:10.1093/biosci/biw091. See also: Bilkovic, D.M., M. Mitchell, P. Mason, and K. Duhring. 2016. The role of living shorelines as estuarine habitat conservation strategies. Coastal Management 44:3:161–174. doi:10.1080/08920753.2016.1160201.

[81] National Oceanographic and Atmospheric Administration (NOAA). 2017. Impact of hardened shorelines on aquatic resources: research summary. https://chesapeakebay.noaa.gov/images/stories/habitats/choptank%20shoreline%20synthesis.pdf.

[82] Landry, J.B., and R.R. Golden. 2017. In situ effects of shoreline type and watershed land use on submerged aquatic vegetation habitat quality in the Chesapeake and Mid-Atlantic coastal bays. Estuaries and Coasts (published online). doi:10.1007/s12237-017-0316-0.

- The proposed indicator could be tied into a forthcoming effort by the Sustainable Fisheries Goal Implementation Team (GIT) to analyze shoreline condition, review studies to date, and identify thresholds for ecological effects. A contract to support for this effort will be awarded in winter or spring 2018.
- The proposed indicator could be developed using data from shoreline inventories, but some questions will need to answered regarding the consistency and regularity of the underlying data collection efforts.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| | **Status:** Metric needs to be defined. |

### *Indicator Description*

This indicator will track the relative proportion of shoreline along the mainstem Chesapeake Bay and its tidal tributaries that is considered "hardened." It could also track the proportion of shoreline in other categories, such as shoreline in a largely natural state or engineered features that are considered to be "living shoreline." Shoreline will be measured in terms of length (miles). If/when data are available for multiple years, this indicator could take the form of a stacked bar graph that shows the proportion of shoreline miles in each category for each year of data. The indicator could also include a mapping tool.

A few fundamental questions need to be addressed in defining this indicator. Namely, what constitutes a "hardened" shoreline, and what are the minimum requirements for a shoreline to be considered "living"? Are there other categories of shoreline that should be tracked? Categorization will ideally be based on objective thresholds related to the observed physical characteristics of the shoreline. Although a property owner or a project proponent might refer to a shoreline structure as "living," that does not necessarily mean it meets the threshold for this indicator.[83] Stage 2 of this implementation plan identifies existing data sources that map the physical characteristics of the Chesapeake shoreline. Ideally, the classifications in these underlying maps will align effectively with the desired indicator classifications; for example, the indicator's "hardened" category might correspond to a specific range of shoreline structures captured in the underlying inventory.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Develop objective criteria to define "hardened," "living," and any other categories of shoreline that this indicator will track. If "living" proves to be more difficult to define, consider an initial form of the indicator that just focuses on "hardened" shoreline. Review existing literature for published thresholds to inform proven relevant, workable definitions of the terms; e.g.:<br>• DeLuca, W.V., C.E. Studds, L.L. Rockwood, and P.P. Marra. 2004. Influence of land use on the integrity of marsh bird communities of Chesapeake Bay, USA. Wetlands 24:837–847.<br>• DeLuca, W.V., C.E. Studds, R.S. King, and P.P. Marra. 2008. Coastal urbanization and the integrity of estuarine waterbird communities: Threshold responses and the importance of scale. Biological Conservation 141:2669–2678. |

[83] For example, see the argument about misclassification of "living shoreline" projects in: Pilkey, O.H., N. Longo, R. Young, and A. Coburn. 2012. Rethinking living shorelines. Program for the Study of Developed Shorelines, Western Carolina University. https://www.wcu.edu/WebFiles/PDFs/PSDS_Living_Shorelines_White_Paper.pdf.

| | |
|---|---|
| | • Patrick et al. 2016. The relationship between shoreline armoring and adjacent submerged aquatic vegetation in Chesapeake Bay and nearby Atlantic coastal bays. Estuaries and Coasts 39:158–170.<br>• Prosser, D. et al. 2017. Standardization and application of an Index of Community Integrity for waterbirds in the Chesapeake Bay, USA. Waterbirds 40(3):233–251.<br>• Kornis et al. 2017. Linking the abundance of estuarine fish and crustaceans in nearshore waters to shoreline hardening and land cover. Estuaries 40(5):1464–1486.<br><br>In seeking to define a "living" shoreline, consider what is known about the impacts of various shoreline management practices. For example, see the expert panel report, "Recommendations of the Expert Panel to Define Removal Rates for Shoreline Management Projects."[84] |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in shoreline condition and thresholds for resiliency and ecological effects. This step will benefit from coordination with the team that is developing the shoreline condition metric for the Sustainable Fisheries GIT. An additional academic partner could help to inform this step, as well as subsequent stages of indicator development.<br><br>Expertise in shore protection practices in the Chesapeake Bay, including living shoreline policy, design, and construction techniques. Several members of the Climate Resiliency Workgroup have this expertise (Bhaskar Subramanian – Maryland DNR; Molly Mitchess – VIMS). Another necessary area of expertise to bring to the project is knowledge of shoreline condition assessment methodologies and thresholds for resiliency and ecological effects. Marcia Berman (VIMS) and Catherine McCall (Maryland DNR) both could provide guidance. The second resource need will benefit from coordination with the team that is developing the shoreline condition metric for the Sustainable Fisheries GIT. An additional academic partner could help to inform this step, as well as subsequent stages of indicator development. |
| Achievable timeframe | 1 to 2 years. |
| Estimated up-front cost | Up to $10,000 to engage an academic partner and coordinate with other efforts as needed. |

## Stage 2: Data Collection

| | |
|---|---|
| ✓ | **Status:** Sufficient data are likely available from existing data collection programs. |

### *Data Source Information*

Data sources cannot be selected until the indicator has been defined. There are at least two suitable data sources, however, and the expense of collecting and compiling a new source would likely be prohibitive (and unnecessary), so it is arguably safe to say that a program to collect data for this indicator is already in place. The two suggested options are as follows:

[84] https://www.chesapeakebay.net/documents/Shoreline-Management-Protocols_Final_Approved_07132015-WQGIT-approved_Revised_06012017_formatted.pdf.

- County-level Shoreline Situation Reports (SSRs), which are based on mapping via small boat with GIS units and/or interpretation of satellite imagery. These data are available for the entire tidal shoreline of Maryland and Virginia, which is classified into numerous shoreline type categories at high (0.25-meter) resolution. Data are available at http://ccrm.vims.edu/gis_data_maps/shoreline_inventories/index.html, http://www.adaptva.org/info/maps_data.html, and http://gisapps.dnr.state.md.us/coastalatlas/WAB2/index.html. A key question to investigate is how often this mapping is repeated, which may vary by county. The indicator development team might also want to consider the availability of archived historical data to extend this indicator back in time. Historical inventories are available for 1976 and 1989 (see https://www.gpo.gov/fdsys/pkg/CZIC-gc1018-c66-1991-v-2/content-detail.html).

- NOAA's Environmental Sensitivity Index (ESI) (https://response.restoration.noaa.gov/maps-and-spatial-data/environmental-sensitivity-index-esi-maps.html)—a composite map based on a mixture of remote sensing, aerial imagery, ground truthing, and other existing maps. Shoreline types are divided into numerous classes. Gittman et al. (2015)[85] aggregated these maps and developed an analysis of shoreline hardening along U.S. coasts. More investigation is needed to learn about the underlying methods, spatial resolution, and frequency of updates.

Comparing these two sources, the SSRs and the ESI had identical scores with respect to the "desirable" data quality criteria for this preliminary investigation, but the SSR score would have been higher with evidence of peer-reviewed methods or use in a peer-reviewed publication. This source may in fact have peer review support; it just was not apparent in the initial review. Other advantages to the SSRs include a known high resolution, solid documentation, and status as official products endorsed by the State of Maryland and the Commonwealth of Virginia. Final selection of a source should consider these factors, additional information about methods and data quality, and—especially important—the certainty and frequency of future data updates.

A few other sources of data were evaluated as part of this indicator research project, but were not recommended for inclusion as primary sources because of a few key limitations, compared with the two options described above. If the primary sources above are not updated regularly enough to support an indicator, though, it might be useful to supplement the primary data with incremental changes from sources such as:

- NOAA's database of living shoreline projects (http://www.habitat.noaa.gov/restoration/techniques/livingshorelines.html and https://www.habitatblueprint.noaa.gov/storymap/ls/index.html). This source provides national coverage, but it does not characterize the condition of the entire shoreline—just incremental change. It is also limited to projects funded by NOAA, and it is possible that not every project funded through this program would meet the threshold that this indicator will establish.

- Virginia's database of permits for shoreline hardening projects (https://webapps.mrc.virginia.gov/public/habitat/ and http://ccrm.vims.edu/perms/newpermits.html). This source does not characterize the condition of the entire shoreline—just incremental change. It is limited to Virginia, although a comparable source might be available for Maryland.

Additional data source options may be available. If the CBP elects to develop this indicator, it could benefit from a deeper review of possible data sources, with input from a wider array of stakeholders.

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[85] Gittman, R.K., F.J. Fodrie, A.M. Popowich, D.A. Keller, J.F. Bruno, C.A. Currin, C.H. Peterson, and M.F. Piehler. 2015. Engineering away our natural defenses: An analysis of shoreline hardening in the U.S. Frontiers in Ecology and the Environment 13:301–307. doi:10.1890/150065.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Select the most appropriate data source(s) based on the indicator goals established in Stage 1. Incorporate supplemental data sources as needed. |
| Skills or resources needed, and what individuals or organizations have this capacity | Data source selection will require knowledge of shoreline inventory data collection efforts. This expertise is available through consultation with state partners, with guidance from appropriate CBP workgroups and the shoreline condition experts identified in Stage 1. CBPO staff can facilitate this process. Future data collection will be performed by organizations that are already engaged in such efforts, though future efforts might also be able to take advantage of "crowdsourcing" or citizen science observations. |
| Achievable timeframe | Source selection in 1 to 2 years; future data collection depends on the source, and the frequency of repetition is unknown. |
| Estimated up-front cost | Up to $10,000 to engage an academic/research partner for data source review. Other aspects of the work can be performed with existing staff and workgroup time. |
| Estimated annual maintenance cost[86] | TBD. |

## Stage 3: Method Development/Selection

| | |
|---|---|
| | **Status:** Methods have not yet been selected to transform the data into an indicator. |

### *Method Information*

Methods have not been established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | • Develop category definitions and thresholds.<br>• Develop a crosswalk between shoreline categories in the underlying data source and categories in the indicator (assuming a source is available that offers sufficient alignment).<br>• Develop and test a routine to aggregate source data using GIS software.<br>• Apply the routine to available data for at least a portion of the Chesapeake region and publish results in the peer-reviewed literature. This last step will help to provide a credible foundation for an indicator—particularly one that influences policy decisions. |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in shoreline condition assessment, along with GIS software and skills. This step would benefit from continued engagement with the academic/research partner who will have advised Stages 1 and 2 and who can lead the analysis and publish results. State collaborators could also assist. |
| Achievable timeframe | 1 to 2 years. |

[86] Incremental cost beyond work that is already being performed. If data collection program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Estimated up-front cost | $10,000–$50,000: Estimated labor costs for a modest-sized project with an academic team, assuming sufficient data are available and processing steps can be conducted with common GIS software. |

## Stage 4: Data Processing

| | |
|---|---|
| | **Status:** Data have not been collected or processed to create an indicator. |

### *Data Processing Information*

Data cannot be processed until a method is established and data are collected.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Apply methods to entire area of interest (all tidal portions of the Bay and its tributaries). Replicate in future years. Or consider designing a hybrid assessment with focused resampling of sentinel areas and less frequent reassessment of the entire shoreline. |
| Skills or resources needed, and what individuals or organizations have this capacity | To be determined; it depends on the format and condition of the data and the complexity of the calculations needed. |
| Achievable timeframe | TBD. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[87] | TBD. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** This indicator has not yet been developed. |

### *Indicator Information*

An indicator cannot be created until all previous stages of development are completed.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Create summary graphics. Create CBP-format technical documentation. Maintain in the future. |

[87] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Skills or resources needed, and what individuals or organizations have this capacity | To be determined; it depends on the degree and complexity of interpretation needed. |
| Achievable timeframe | Likely within 1 year of obtaining processed data. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[88] | TBD. |
| Final reviews or approvals needed | Concurrence from the Sustainable Fisheries GIT and other project partners. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[89] |
|---|---|---|---|---|---|
| Define how the indicator will be constructed | 1 | \$0–\$10,000 | 1 to 2 years | Academic/research partner with input from shoreline condition assessment project team | Required |
| Select optimal data source(s) | 2 | \$0–\$10,000 | 1 to 2 years | Academic/research partner in collaboration with state partners and workgroups | Required |
| Develop, test, and publish analytical methods | 3 | \$10,000–\$50,000 | 1 to 2 years | Academic/research partner with state assistance | Required |
| Apply data processing methods to entire area of interest | 4 | TBD | TBD | TBD | Required |
| Create initial indicator, including documentation | 5 | TBD | TBD | TBD | Required |
| Replicate data processing in future years | 4 | TBD/yr | Frequency TBD | TBD | Required |
| Update indicator in future years | 5 | TBD/yr | Frequency TBD | TBD | Required |
| **Total one-time cost** | | **\$10,000–\$70,000 + further costs TBD** | | | |

88 Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

89 An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[89] |
|---|---|---|---|---|---|
| **Total annual cost** | | **TBD/yr** | | | |

# 19. Wetland Migration Corridors

## Indicator at a Glance

| | |
|---|---|
| not completed | Stage 1: Indicator defined |
| ✓ | Stage 2: Data collection program in place |
| not completed | Stage 3: Methods developed/selected to transform data into an indicator |
| not completed | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- In support of the **Climate Resiliency** goal and outcomes, this indicator would track progress toward designating and preserving wetland migration corridors. In low-lying coastal areas, where tidal wetlands are not able to accrete at a pace to keep up with sea level rise, a resilience strategy is to preserve suitable space on the landscape for wetlands to migrate or advance inland.
- Tidal wetlands provide a physical buffer that helps to slow the erosion of shorelines and protect properties against flooding by dampening storm surges. Maintaining wetland acreage also helps to ensure the availability of habitat for species threatened by climate change.
- Ultimately, wetlands relate to many of the goals and outcomes in the 2014 Chesapeake Watershed Agreement, including **Vital Habitats**, **Sustainable Fisheries**, **Water Quality**, and **Healthy Watersheds**.

Relationship to other indicators in the proposed suite:

- **Sea level rise** drives the need for tidal wetlands to migrate upslope.
- Tidal wetlands shelter the shoreline of the Bay and its tributaries, thus helping to mitigate **coastal flooding** and reducing the extent of **property at risk or damaged.**
- The **extent of living vs. hardened shorelines** physically affects the ability of tidal wetlands to migrate in response to rising sea level.
- **Land use and land cover** affect wetland migration, as developed structures may block wetland migration.
- **Protected lands** may provide opportunities for unimpeded wetland migration.
- The **restored habitat** indicator may capture efforts to improve wetland condition and reduce barriers to migration.
- Ultimately, the degree to which wetlands are able to migrate in response to sea level rise will affect total **wetland extent and physical buffering capacity**.

Notable opportunities, risks, and areas for enhancement:

- The proposed indicator will provide an opportunity to build on work that the State of Maryland and U.S. Fish and Wildlife Service have already begun to conduct.
- The indicator as proposed here will require someone to choose among competing models and competing data sources developed by different agencies and organizations. Experts' opinions may vary. It will be important to facilitate the design and development of this indicator in a way that arrives at the best possible science-based decisions.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| | **Status:** Indicator and its metric have not been defined. |

## *Indicator Description*

This proposed indicator will focus on tidal wetlands, using land cover/land use data and spatial analysis tools to map corridors where wetlands will likely be able to migrate. The end product is envisioned as a mapping tool that shows likely migration corridors, which in turn can support jurisdiction-level projections of changes in total tidal wetland acreage under future climate and sea level scenarios. The closer a projection comes to showing no net loss in tidal wetland acreage, the more resilient the system must be.

The design of this indicator should account for numerous factors, including the physical suitability of migration corridors (e.g., elevation gradient), conservation value, and legal mechanisms that could either facilitate or impede migration (e.g., protected status of potential corridors). These considerations are described in more detail in the proposed steps below.

**Step 1: Determine where wetlands could migrate, physically**

This step requires consideration of elevation, presence or absence of structures that would block migration, and other physical factors (e.g., erosion and accretion rates, soil type).

*Step 1a: Select a model*

This step may come down to a choice between NOAA's Marsh Migration Model and the Sea Level Affecting Marshes Model (SLAMM) (https://coast.noaa.gov/digitalcoast/tools/slamm.html), which was developed with EPA funding and is maintained by Warren Pinnacle Consulting, Inc. The publication at http://dnr.maryland.gov/ccs/publication/coastalland_conserv_md.pdf offers a comparison between the two models and suggests some benefit to SLAMM because it considers more physical factors. Ideally, either model could be run with newer input data.

*Step 1b: Select input data and model parameters*

The wetland migration model needs an initial map of wetland locations (see possible sources in Stage 2 of this implementation plan), elevation data, and other physical input layers. It will also be necessary to select a range of climate scenarios to model.

*Step 1c: Run the model*

The National Wildlife Federation modeled likely wetland migration scenarios for the Chesapeake region in 2008 using SLAMM; see the project description and results at: https://www.nwf.org/GlobalWarming/EffectsonWildlifeandHabitat/EstuariesandCoastalWetlands/~/media/PDFs/Global%20Warming/Reports/FullSeaLevelRiseandCoastalHabitats_ChesapeakeRegion.ashx. Maryland conducted its own modeling in 2011; see the project description and results at: https://coast.noaa.gov/data/digitalcoast/pdf/shifting-shorelines-maryland.pdf and: https://www.epa.gov/sites/production/files/2015-10/documents/md_wetlands_slamm_final.pdf. Results are available in map form at http://gisapps.dnr.state.md.us/coastalatlas/WAB2/index.html; choose "Sea level rise wetland adaptation areas" from the layer list. The map shows potential wetland migration corridors that avoid developed areas.

The proposed indicator could build on this previous modeling, using newer inputs (for example, re-running SLAMM with higher-resolution LIDAR data) and making sure to cover the entire Chesapeake region.

*Step 1d: Address Uncertainty*

Whichever model is selected will have some inherent uncertainty, as will the range of assumptions (e.g., erosion and accretion rates) and climate scenarios used. The indicator may be able to address at least some of these uncertainties by incorporating sensitivity analyses and developing error bounds around the results. Doing so could help to identify where efforts to facilitate wetland migration are most likely to be effective for multiple future conditions.

**Step 2: Prioritize value**

This step will attempt to classify existing wetland parcels and potential migration corridors in terms of the value of the habitat or other ecological services they provide. Doing so can help those who want to use the results of Step 1 to prioritize areas for conservation. For example, Maryland's SLAMM study classified wetland migration areas into high, medium, and low categories, with the idea that these designations could help resource managers select target areas for land acquisition or other conservation strategies. For Maryland's layer descriptions, see the geospatial metadata at: https://geodata.md.gov/imap/rest/services/Weather/MD_SeaLevelRiseWetlandAdaptationAreas/MapServer/0.

NOAA provides a set of general principles to follow at: https://coast.noaa.gov/applyit/wetlands/prioritize.html. When selecting areas that are most valuable to protect because of their habitat value or other ecosystem services, attributes to consider include wetland type, size and contiguity, and connectivity to other parcels and key habitats. This step might not be obligatory, as the indicator could conceivably just look at the protected or "designated" status of all pixels with any level of wetland migration potential. But if this "value" step is performed, the indicator can be focused (if desired) on the protected status of just the highest-priority wetland migration corridors.

**Step 3: Identify "designated" status**

This step recognizes that it is not enough to just identify physically feasible wetland migration corridors. For an indicator of programmatic progress toward resilience, it is arguably more useful to track the extent to which physically feasible wetland migration corridors have actually been designated and protected as such, so that one can feel fairly confident that the modeled wetland migration would actually be allowed to take place in the future.

If any jurisdiction has a formal "designated" status that conveys legal or other protections on potential wetland migration corridors, it could be used here, and hence an indicator could be constructed that tracks the percentage or total acreage of physically feasible migration corridors (or high-priority corridors, if Step 2 takes place) that have received a formal designation. If no formal "designated" tag exists, one could overlay a map of protected land boundaries—or look at particular types of protection—to determine the percentage or total acreage of physically feasible migration corridors (or high-priority corridors) that are protected from development. If rolling easements or other legal mechanisms for ensuring successful wetland migration become more common in the future, this mapping step could include their presence. Data from the proposed **Protected Lands** indicator can be used for this step, for consistency.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Work is needed to define how this indicator will be constructed. Proposed steps are described in detail above. They include:<br>• Selecting a marsh migration model<br>• Selecting input layers and climate scenarios<br>• Running the model<br>• Accounting for uncertainties<br>• Prioritizing conservation value<br>• Incorporating "designated" or protected status of lands<br><br>Useful starting points could include consultation with Maryland DNR and a more in-depth review of available data sources, their characteristics, and their coverage. For example, it might be useful to consult the U.S. Army Corps of Engineers feasibility study described at http://www.nab.usace.army.mil/portals/63/docs/FactSheets/FY15_Factsheets/MD-ChesBayShorelineErosion-GI.pdf. |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in wetland dynamics; familiarity with legal/regulatory mechanisms for protecting lands and designating wetland migration corridors. This step would benefit from engagement with academic/research partners and coordination with Maryland DNR to learn from—and build on—their existing efforts to map wetland migration potential. CBPO staff can inform this process, facilitate collaboration, and engage the Climate Resiliency Workgroup for input and buy-in. |
| Achievable timeframe | Within 1 year. |
| Estimated up-front cost | $10,000–$20,000: Estimated cost of conducting a literature search and data source review; convening the appropriate outside experts (e.g., through workshops and calls) to review options and define the metric(s); and gathering workgroup input and buy-in. |

## Stage 2: Data Collection

| | |
|---|---|
| ✓ | **Status:** Sufficient data are likely available from existing data collection programs. |

### *Data Source Information*

Data sources cannot be selected until the indicator has been defined. There are many suitable data sources, however, and the expense of collecting and compiling a new source would likely be prohibitive (and unnecessary), so it is arguably safe to say that a program to collect data for this indicator is already in place.

Sources to consider include:

- U.S. Fish and Wildlife Service, National Wetlands Inventory (NWI) (https://www.fws.gov/wetlands/data/Mapper.html)
- C-CAP (https://coast.noaa.gov/digitalcoast/data/ccapregional.html)
- Phase 6 Land Use dataset (https://chesapeake.usgs.gov/phase6/map)
- Chesapeake High-Resolution Land Cover Data Project (http://chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/land-cover-data-project/), which fed into the Phase 6 Land Use dataset

- The Nature Conservancy, Ecoregions Priority Areas for Conservation (http://maps.tnc.org/gis_data.html)
- Conservation value mapping generated under the CBP Protected Lands work plan
- Mapping updated every two years for the CBP's Protected Lands indicator (http://www.chesapeakeprogress.com/conserved-lands/protected-lands)

Most of these data sources include a commitment to future updates. The optimal data sources for this indicator will depend on how the indicator is defined in Stage 1.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Select the most appropriate key data source(s) based on the indicator goals established in Stage 1. Incorporate supplemental data sources as needed. |
| Skills or resources needed, and what individuals or organizations have this capacity | Data source selection will require knowledge of the various land cover and land use datasets that are available. This expertise is available through CBPO staff and the Land Use Workgroup, with guidance from the wetland experts identified in Stage 1. Future data collection will be performed by organizations that are already engaged in such efforts. |
| Achievable timeframe | Source selection within 1 year; future data collection depends on the source, but likely at a frequency on the order of 2 to 5 years. |
| Estimated up-front cost | 50–100 staff hours. |
| Estimated annual maintenance cost[90] | TBD. |

## Stage 3: Method Development/Selection

| | |
|---|---|
| | **Status:** Methods have not yet been selected to transform the data into an indicator. |

### *Method Information*

Methods have not been established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Develop methods, validate, apply to available data for at least a portion of the Chesapeake Bay/watershed, and publish results in the peer-reviewed literature. This last step will help to provide a credible foundation for an indicator—particularly one that influences policy decisions. |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in wetland dynamics, along with GIS software and skills. This step would benefit from engagement with an academic/research partner that can lead the analysis and publish results. State collaborators could also assist—for example, Maryland DNR experts who have conducted a similar analysis. |
| Achievable timeframe | 1 to 2 years. |

[90] Incremental cost beyond work that is already being performed. If data collection program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Estimated up-front cost | $10,000–$50,000: Estimated labor costs for a modest-sized project with an academic team, building on existing methods and resources. |

## Stage 4: Data Processing

| | |
|---|---|
| | **Status:** Data have not been processed to create an indicator. |

### *Data Processing Information*

Data cannot be processed until a method is established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Apply methods to entire area of interest (entire Bay/watershed). Replicate in future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | To be determined; it depends on the format and condition of the data and the complexity of the calculations needed. |
| Achievable timeframe | Initial processing in 1 to 2 years; likely repeated every 2 to 5 years. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[91] | TBD. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** This indicator has not yet been developed. |

### *Indicator Information*

An indicator cannot be created until all previous stages of development are completed.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Create summary graphics. Create CBP-format technical documentation. Maintain in the future. |

[91] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Skills or resources needed, and what individuals or organizations have this capacity | TBD; it depends on the degree and complexity of interpretation needed. |
| Achievable timeframe | Initial development in 1 to 2 years; likely repeated every 2 to 5 years. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[92] | TBD. |
| Final reviews or approvals needed | Review by appropriate workgroups. |

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[93] |
|---|---|---|---|---|---|
| Define how the indicator will be constructed | 1 | \$10,000–\$20,000 | Within 1 year | Academic/research partners + Maryland DNR + CBPO and the Climate Resiliency Workgroup | Required |
| Select data source(s) | 2 | 50–100 staff hours | Within 1 year | CBPO staff + Land Use Workgroup + wetland experts | Required |
| Develop, test, and publish analytical methods | 3 | \$10,000–\$50,000 | 1 to 2 years | Academic/research partners or state collaborators | Required |
| Apply data processing methods to entire area of interest | 4 | TBD | 1 to 2 years | TBD | Required |
| Create initial indicator, including documentation | 5 | TBD | 1 to 2 years | TBD | Required |
| Continue data collection | 2 | No incremental cost; data already being collected | Likely every 2 to 5 years | Organizations that already collect these data | Required |
| Replicate data processing in future years | 4 | TBD/yr | Every 2 to 5 years | TBD | Required |
| Update indicator in future years | 5 | TBD/yr | Every 2 to 5 years | TBD | Required |

[92] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

[93] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator.

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[93] |
|---|---|---|---|---|---|
| **Total one-time cost** | | **50–100 staff hours plus $20,000–$70,000+** | | | |
| **Total annual cost** | | **TBD/yr** | | | |

# 20. Fish Population Distribution

## Indicator at a Glance

| | |
|---|---|
| not completed | Stage 1: Indicator defined |
| not completed | Stage 2: Data collection program in place |
| not completed | Stage 3: Methods developed/selected to transform data into an indicator |
| not completed | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to address the **Climate Resiliency** goal and outcomes in two distinct ways:
    - By measuring changes in fish population distributions that may result in part from climate change—for example, the effect of changes in water temperature on a thermally sensitive species.
    - By measuring the extent to which a species has dispersed itself in a broad distribution that creates resiliency through *response diversity*, including the ability to mitigate effects of spatially heterogeneous stresses and the capacity to colonize peripheral habitats under changing conditions. This rationale and other aspects of the proposed indicator are described more thoroughly by Wainger et al. (2017).[94]
- This indicator could shed light on progress toward the **Sustainable Fisheries** goal and outcomes, particularly if the indicator focuses on commercially important species or focuses on forage fish that support commercially important species.
- Fish population distributions may be influenced by progress toward meeting the goals and outcomes for **Vital Habitats**, **Water Quality**, and other areas.

Relationship to other indicators in the proposed suite:

- **Bay water temperature** and **stream water temperature** determine the suitability of habitat for thermally sensitive species.
- **Wetland extent** and **extent of living shorelines** influence the availability of habitat for many fish species.
- To maintain a widespread population, it is important to preserve habitat throughout a given species' range. Progress in doing so can be tracked by the **protected land** and **restored habitat** indicators.

Notable opportunities, risks, and areas for enhancement:

- The proposed indicator holds promise as an integrative indicator of ecological resilience.
- Development of this indicator could help to establish species-temperature relationships that then inform projections of future impacts on fish populations.
- The proposed indicator only exists as a concept; it requires foundational efforts to define a metric and determine data needs. Because it is at such an early stage, the cost to develop and maintain this indicator is highly uncertain.
- Thus far, no comparable indicator has been identified in other regions or programs. This indicator could require novel thinking—and it could become an innovation that moves science forward.

[94] Wainger, L.A., D.H. Secor, C. Gurbisz, W.M. Kemp, P.M. Glibert, E.D. Houde, J. Richkus, and M.C. Barber. 2017. Resilience indicators support valuation of estuarine ecosystem restoration under climate change. Ecosystem Health and Sustainability 3(4):e01268. http://onlinelibrary.wiley.com/doi/10.1002/ehs2.1268/full. doi:10.1002/ehs2.1268.

## Stage 1: Indicator and Metric Definition

| | **Status:** Indicator and its metric have not been defined. |
|---|---|

### *Indicator Description*

This indicator will characterize populations of selected fish species in a manner that represents the spatial extent of each population and how well it is distributed throughout its range. The exact metric has not been determined, but it could reflect a combination of abundance, density, evenness, extremes (e.g., the northernmost/southernmost or earliest/latest observations for a particular species), or other attributes. Part of the purpose of this indicator may be to identify species that have effectively colonized peripheral habitats, so it will likely be important to measure how many individuals are present in a given area—not just whether a species is present or absent. Whoever defines the metric will need to consider both spatial and temporal dimensions; for example, would it be useful to look at “evenness” over time rather than (or in addition to) over space?

To maximize utility, this indicator should not just focus on a single species, nor should it attempt to lump all measured species together into a massive index. The best approach is likely to track a suite of climate-sensitive species at multiple trophic levels (for example, a suite of predators and their diets) and with a variety of habitat requirements. Candidate species could include:

- Striped bass: a widely studied, temperature-sensitive, anadromous species that reflects the condition of both nontidal and tidal habitats.

- Forage fish such as the bay anchovy, which are abundant, widely eaten, and adaptable, yet have been shown to respond to degree-days and freshwater inputs and salinity change.

- Blue crab: widely studied, commercially and culturally important, with movement and life-cycle events tied to temperature.

- Brook trout: a native species that depends on cold, clean streams; thus, its distribution reflects water quality and temperature throughout the watershed.

- Various warm-water species that might be moving northward to become more prevalent in the Bay—for example, southern flounder, speckled trout, cobia, and red drum—or, conversely, the absence of more northerly species, such as winter flounder.

To isolate the effects of climate, it might make sense to consider fish data at various times of the year, or coinciding with extreme weather events. Work done at UMCES on forage species could help to inform this effort; for example, see the report at https://www.chesapeakebay.net/documents/Forage_Final_Report_2017_final-draft_24oct17.pdf. NOAA NMFS also has a Fish Species Climate Vulnerability Assessment Methodology that has been applied in the Northeast, and may offer some guidance (https://www.st.nmfs.noaa.gov/ecosystems/climate/northeast-fish-and-shellfish-climate-vulnerability/index). Some species such as blue crab and speckled trout are particularly sensitive to extreme winter cold events.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Work is needed to define how this indicator will be constructed, including:<br>• Which species to include.<br>• What data sources to use.<br>• What metric will best characterize population distribution.<br>• Whether it might be possible to construct a proxy measure based on habitat quality or other physical measures, which could be validated based on the presence or absence of fish species of interest.<br>• How (if at all) to isolate the effects of climate.<br><br>Useful starting points could include a literature search (with a focus on analogous ecological indices that have been developed in other contexts) and a more in-depth review of available data sources, their characteristics, and their coverage. |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in fisheries ecology. This step would benefit from engagement with NOAA and academic/research partners, as well as the additional expertise of the Fisheries Goal Implementation Team (GIT). Supporting work (literature search and data source review) could be performed by research assistants with sufficient expert guidance. Expert panel calls or meetings could benefit from a skilled facilitator or panel chair who can steer the group toward consensus. |
| Achievable timeframe | 2 to 5 years. |
| Estimated up-front cost | \$10,000–\$50,000: Estimated cost of conducting a literature search and data source review; convening the appropriate outside experts (e.g., through workshops and calls) to review options and define the metric(s); and gathering input and buy-in from the Fisheries GIT. |

## Stage 2: Data Collection

| | |
|---|---|
| | **Status:** Sufficient data might be available from an existing data collection program, but first, the indicator must be defined. |

### *Data Source Information*

A data source has not been determined yet, pending the outcome of Stage 1 indicator development work. Possible data sources could include Baywide ChesMMAP surveys, longer-running Virginia trawl surveys, Maryland’s “young-of-the-year” seine surveys for striped bass, blue crab winter dredge surveys, commercial landings data, and other options to be determined.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | To be determined. The work in Stage 1 will identify whether the indicator can be constructed from existing data collection programs or whether it requires additional data collection to provide adequate temporal and spatial coverage. |
| Skills or resources needed, and what individuals or organizations have this capacity | Strong knowledge of existing data sources, which can be achieved by collaborating with experts from Maryland DNR, VIMS, NOAA, and other agencies that collect data. |

| | |
|---|---|
| Achievable timeframe | TBD. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[95] | TBD. |

## Stage 3: Method Development/Selection

| | |
|---|---|
| | **Status:** Methods have not yet been selected to transform the data into an indicator. |

### *Method Information*

Methods have not been established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Develop methods, validate, apply to available data for at least a portion of the Chesapeake Bay/watershed, and publish results in the peer-reviewed literature. This last step is crucial to providing a credible foundation for an indicator—particularly one that influences policy decisions. Considerations could include (among others) the most scientifically defensible time step to use. Rather than track annual data points, for instance, a 10-year averaging period might be necessary to overcome the natural interannual variability inherent to fish population dynamics. |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in fisheries ecology. This step would benefit from engagement with an academic/research partner that can lead the analysis and publish results. |
| Achievable timeframe | 2 to 5 years. |
| Estimated up-front cost | $50,000+: Estimated labor costs for a multi-year project with an academic team. |

## Stage 4: Data Processing

| | |
|---|---|
| | **Status:** Data have not been processed to create an indicator. |

### *Data Processing Information*

Data cannot be processed until a method is established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Apply methods to entire area of interest (entire Bay/watershed). Replicate in future years. |

[95] Incremental cost beyond work that is already being performed. If data collection program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

| | |
|---|---|
| Skills or resources needed, and what individuals or organizations have this capacity | To be determined; it depends on the format and condition of the data and the complexity of the calculations needed. |
| Achievable timeframe | TBD. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[96] | TBD. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** This indicator has not yet been developed. |

### *Indicator Information*

An indicator cannot be created until all previous stages of development are completed.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Create summary graphics. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | TBD; it depends on the degree and complexity of interpretation needed. |
| Achievable timeframe | TBD. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[97] | TBD. |
| Final reviews or approvals needed | Agreement with data providers to share data. |

[96] Incremental cost beyond work that is already being performed. If a data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

[97] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[98] |
|---|---|---|---|---|---|
| Define how the indicator will be constructed | 1 | $10,000–$50,000 | Medium-term (2 to 5 years) | Academic/research partners + NOAA + CBPO/Fisheries GIT | Required |
| Establish enhanced data collection program if needed | 2 | TBD | TBD | TBD | TBD |
| Maintain enhanced data collection program if needed | 2 | TBD/yr | Presumably annual/ongoing | TBD | TBD |
| Develop, test, and publish analytical methods | 3 | $50,000+ | Medium-term (2 to 5 years) | Academic/research partners | Required |
| Apply data processing methods to entire area of interest | 4 | TBD | TBD | TBD | Required |
| Replicate data processing in future years | 4 | TBD/yr | Presumably annual/ongoing | TBD | Required |
| Create initial indicator, including documentation | 5 | TBD | TBD | TBD | Required |
| Update indicator in future years | 5 | TBD/yr | Presumably annual/ongoing | TBD | Required |
| **Total one-time cost** | | **$60,000–$100,000+** | | | |
| **Total annual cost** | | **TBD/yr** | | | |

[98] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator. In some cases, optional actions could include steps to transform a relatively weak or one-dimensional indicator that is available in the short-term into a more robust indicator in the longer term.

# 21. Submerged Aquatic Vegetation Composition

## Indicator at a Glance

| | |
|---|---|
| not completed | Stage 1: Indicator defined |
| not completed | Stage 2: Data collection program in place |
| not completed | Stage 3: Methods developed/selected to transform data into an indicator |
| not completed | Stage 4: Data processed |
| not completed | Stage 5: Indicator developed for the Chesapeake |

Indicator value:

- This indicator helps to address the **Climate Resiliency** goal and outcomes in a few ways:
    - Rising water temperatures, sea level rise and corresponding shoreline erosion, changes in water clarity resulting from heavy precipitation and flooding upstream, and rising carbon dioxide concentrations are all climate-related drivers that influence submerged aquatic vegetation (SAV) survival, growth, reproduction, and therefore abundance and distribution of species.
    - With regard to community composition in particular, some native species, such as eelgrass, are thermally sensitive and are already near their upper temperature limit in the Bay. Reduced water clarity exacerbates the physiological stress of increased temperatures, and has already led to declines in eelgrass in the Chesapeake Bay.[99]
    - Studies such as Gurbisz et al. (2016)[100] suggest that denser SAV beds with a more diverse range of species offer greater resilience because they are more easily able to regenerate and recover from a catastrophic event (e.g., a flood or storm), better able to adapt to changing conditions (e.g., warming; shifting in response to sea level rise), and able to harbor a more diverse array of other life forms.
- SAV is a key component of the **Vital Habitats** goal in the Watershed Agreement, and improving **Water Quality** is a key part of helping to meet SAV habitat targets. While the SAV outcome in the Watershed Agreement is measured in terms of acreage, SAV bed density and species diversity are also important attributes of the health of SAV beds.

Relationship to other indicators in the proposed suite:

- **Bay water temperature** and **stream water temperature** (input temperature) can affect SAV community composition. Some species, like native eelgrass, exhibit reduced productivity in water that is too warm. Other species, like several of the freshwater plants, exhibit increased productivity in warm water.
- Changes in **precipitation** and **upstream flooding** can affect SAV growth and community composition. Higher-than-usual rainfall can push nutrients and sediments, which cloud the water column and thus block sunlight necessary for SAV growth, into the Bay. Some non-native species of SAV, such as Hydrilla, are more tolerant to low-light conditions than their native counterparts, allowing for their competitive advantage in reduced-light environments.
- **Sea level rise**, **coastal flooding**, and **wetland acreage change**, coupled with shoreline erosion and sediment resuspension, could lead to a further decline in water clarity and SAV growth.

[99] Lefcheck, J.S., D.J. Wilcox, R.R. Murphy, S.R. Marion, and R.J. Orth. 2017. Multiple stressors threaten the imperiled coastal foundation species eelgrass (*Zostera marina*) in Chesapeake Bay, USA. Global Change Biology. doi: 10.1111/gcb.13623.

[100] Mechanisms of storm-related loss and resilience in a large submersed plant bed. Gurbisz, C., W.M. Kemp, L.P. Sanford, and R.J. Orth. 2016. Estuaries and Coasts 39:951–966. doi:10.1007/s12237-016-0074-4.

- **Shoreline condition** (hardened, natural, or "living" structures) affects the quantity and quality of SAV habitat (e.g., Landry and Golden, 2017, and Patrick et al., 2014, 2016).[101]
- Changes in **land use/land cover** can lead to more nutrients and sediment running off into the waterways, thus reducing water clarity and shading out native SAV (Patrick et al., 2017).[102] Conversely, **protected land** and implementation of **BMPs/green infrastructure** can reduce nutrient and sediment inputs, thus facilitating water clarity and native SAV survival and growth.
- The proposed **restored habitat** indicator builds on an existing CBP indicator that tracks the extent of restored wetlands and oyster beds. A future iteration could also address SAV restoration.

Notable opportunities, risks, and areas for enhancement:

- The proposed indicator has not yet been developed. Collecting species composition data tends to be relatively labor-intensive; the proposed approach requires direct *in situ* observation. New avenues for Bay-wide species data are being explored, such as crowd-sourcing data from Riverkeepers, watershed groups, and citizen scientist, but these data are still limited and a concrete bay-wide ground survey has yet to be established.

## Stage 1: Indicator and Metric Definition

| | |
|---|---|
| | **Status:** Metric needs to be defined. |

### *Indicator Description*

This indicator will characterize the community composition of SAV in the Chesapeake Bay and its tributaries. It will complement the CBP's current SAV indicator, which tracks SAV extent but does not differentiate by species.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Determine how this indicator will measure and present community composition. Options could include the Shannon diversity index, some other type of count of species richness, extent or prevalence of specific species, or other options to be determined. The optimal metric will depend in part on what parameters are actually measured as part of the data collection program that will be established in Stage 2. |
| Skills or resources needed, and what individuals or organizations have this capacity | Coordination with the team that is developing the SAV monitoring program described under "Stage 2: Data Collection" in this implementation plan. State partners (e.g., Maryland DNR and VIMS) and contractors will have the requisite subject matter expertise to inform this step. CBPO staff can contribute and facilitate the process of defining the indicator. |

[101] Landry, J.B., and R.R. Golden. 2017. In situ effects of shoreline type and watershed land use on submerged aquatic vegetation habitat quality in the Chesapeake and Mid-Atlantic coastal bays. Estuaries and Coasts (published online). doi:10.1007/s12237-017-0316-0.

Patrick, C.J., D.E. Weller, X. Li, and M. Ryder. 2014. Effects of shoreline alteration and other stressors on submerged aquatic vegetation in subestuaries of Chesapeake Bay and the Mid-Atlantic coastal bays. Estuaries and Coasts 37:1516–1531.

Patrick, C.J., D.E. Weller, and M. Ryder. 2016. The relationship between shoreline armoring and adjacent submerged aquatic vegetation in Chesapeake Bay and nearby Atlantic coastal bays. Estuaries and Coasts 39:158–170.

[102] Patrick, C., D. Weller, R. Orth, D.J. Wilcox, and M. Hannam. 2017. Land use and salinity drive changes in SAV abundance and community composition. Estuaries and Coasts. doi:10.1007/s12237-017-0250-1.

| | |
|---|---|
| Achievable timeframe | Within 1 year. |
| Estimated up-front cost | Up to 300 staff hours. |

## Stage 2: Data Collection

| | |
|---|---|
| | **Status:** Data collection program not yet in place, but under development. |

### *Data Source Information*

SAV density and spatial extent are currently measured by aerial surveys. SAV ground data collection has been a component of the annual SAV monitoring program since 1984. These data are collected by VIMS and others to characterize SAV community composition in specific reaches of the Chesapeake Bay watershed, thus yielding a fairly long-term species composition dataset. However, data collection has been sporadic, resulting in areas of the Bay with little to no data. Aside from the annual monitoring program and the new efforts towards crowd-sourcing SAV data, a long-term, Bay-wide program directed at defining the distribution of species and their densities suitable for measuring community composition and percent cover has not yet been established. It is anticipated that the efforts currently underway to coordinate Riverkeepers, watershed groups, and other citizen scientists will result in the development of an ongoing Bay-wide monitoring program that relies on volunteer citizen scientists to measure numerous attributes of SAV beds.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Develop a scientifically valid, user-friendly citizen scientist protocol/manual and training/certification program for monitoring SAV in the Bay and its tributaries. The CBPO issued a request for proposals for contractor support for development of this program, and it is evaluating proposals as of 1/31/18. The awardee will develop, test, and refine protocols and methods.<br><br>Once the program is developed, monitoring will need to be implemented and data collected and analyzed prior to development of the proposed indicator. |
| Skills or resources needed, and what individuals or organizations have this capacity | Program development will require the services of an academic, nonprofit, or commercial partner with experience developing and testing citizen science protocols. The SAV Workgroup will provide input. Organizations that participated in the 2017 pilot projects to assess *in situ* SAV distribution with species composition (Midshore Riverkeeper Conservancy, James River Association, Severn River Association, and Havre de Grace Maritime Museum Environmental Center) will also have valuable experience to add at the development stage.<br><br>Ongoing data collection will rely on citizen scientists who receive training, but will also need centralized support from a program office (CBPO or a state organization) to coordinate volunteer observers, administer the training/certification program, compile data, and ensure quality. |
| Achievable timeframe | Program development is slated for completion by the end of December 2018. The first year of Bay-wide baseline data will ideally be available in 2019 or 2020. |
| Estimated up-front cost | $25,000 budgeted for program design; funding already dedicated. |

| | |
|---|---|
| Estimated annual maintenance cost[103] | Data collection itself will be nearly free, due to reliance on volunteer observers. Program administration cost to be determined, depending on the design of the program and the extent of administrative support required. |

## Stage 3: Method Development/Selection

| | |
|---|---|
| | **Status:** Methods have not yet been selected to transform the data into an indicator. |

### *Method Information*

Methods have not been established.

### *Additional Needs*

| | |
|---|---|
| Additional work needed | Develop methods, validate, apply to available data for at least a portion of the Chesapeake Bay, and publish results in the peer-reviewed literature. This last step is crucial to providing a credible foundation for an indicator—particularly one that influences policy decisions. One possible approach could be a Measure of Species Integrity (MSI) for SAV, similar to an Index of Biological Integrity. The value would be calculated from the acreage, density, and number of species present in various areas throughout a segment, compared with the number of potential species. |
| Skills or resources needed, and what individuals or organizations have this capacity | Expertise in SAV ecology. This step would benefit from engagement with an academic, research, or government partner (such as the experts at VIMS and Maryland DNR) who can lead the analysis and publish results. |
| Achievable timeframe | 2 to 5 years. |
| Estimated up-front cost | $0–$10,000 for additional labor, assuming this work is a natural outgrowth of work that will already be done to develop metrics and reporting for the proposed data collection program. |

## Stage 4: Data Processing

| | |
|---|---|
| | **Status:** Data have not been collected or processed to create an indicator. |

### *Data Processing Information*

Data cannot be processed until a method is established and data are collected.

[103] Incremental cost beyond work that is already being performed. If a data collection program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

### Additional Needs

| | |
|---|---|
| Additional work needed | Apply methods to entire area of interest (entire Bay). Replicate in future years. |
| Skills or resources needed, and what individuals or organizations have this capacity | TBD; it depends on the format and condition of the data and the complexity of the calculations needed. |
| Achievable timeframe | TBD. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[104] | TBD. |

## Stage 5: Indicator Development

This stage involves turning the processed data into an indicator. It also requires complete technical documentation in the CBP's standard format.

| | |
|---|---|
| | **Status:** This indicator has not yet been developed. |

### Indicator Information

An indicator cannot be created until all previous stages of development are completed.

### Additional Needs

| | |
|---|---|
| Additional work needed | Create summary graphics. Create CBP-format technical documentation. Maintain in the future. |
| Skills or resources needed, and what individuals or organizations have this capacity | TBD; it depends on the degree and complexity of interpretation needed. |
| Achievable timeframe | TBD. |
| Estimated up-front cost | TBD. |
| Estimated annual maintenance cost[105] | TBD. |
| Final reviews or approvals needed | Concurrence from the SAV Workgroup and other project partners. |

[104] Incremental cost beyond work that is already being performed. If data processing program is already in place and fully funded for the foreseeable future, this field should indicate a cost of zero.

[105] Incremental cost beyond work that is already being performed. If an indicator has already been developed and a program is in place to maintain it for the foreseeable future, this field should indicate a cost of zero.

## Summary of Actions and Anticipated Costs

| Action | Stage | Cost | Timeframe | Who has capacity to do | Required or optional?[106] |
|---|---|---|---|---|---|
| Define how the indicator will be constructed | 1 | Up to 300 staff hours | Within 1 year | CBPO staff in collaboration with SAV citizen science program team | Required |
| Data collection program design | 2 | $25,000 (already funded) | To be completed in 2018 | Contractor to be announced | Required |
| Data collection | 2 | $0/yr | Presumably annual, 2019 and beyond | Volunteer citizen scientists | Required |
| Data collection program administration | 2 | TBD/yr | Presumably annual, 2019 and beyond | CBPO or designated partner (e.g., a state organization) | Required |
| Develop, test, and publish analytical methods | 3 | $0-$10,000 | 2 to 5 years | Academic, research, or government partners in conjunction with SAV citizen science reporting | Required |
| Apply data processing methods to entire area of interest | 4 | TBD | TBD | TBD | Required |
| Create initial indicator, including documentation | 5 | TBD | TBD | TBD | Required |
| Replicate data processing in future years | 4 | TBD/yr | Presumably annual/ongoing | TBD | Required |
| Update indicator in future years | 5 | TBD/yr | Presumably annual/ongoing | TBD | Required |
| **Total one-time cost** | | **$25,000–$35,000** ($25,000 already funded) **+ up to 300 staff hours + further costs TBD** | | | |
| **Total annual cost** | | **TBD/yr** | | | |

[106] An action is required if it is pivotal to developing or maintaining an indicator. Some actions may be considered optional if they represent more of an enhancement or expansion to an indicator.