Maryland Healthy Watersheds Assessment:

Strategy for Development of the Maryland Healthy Watershed Assessment

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1. Introduction

This document lays out the proposed strategy for development of the Maryland Healthy Watersheds Assessment (MDHWA), a project sponsored by the Chesapeake Bay Program (CBP) to support the Maintain Healthy Watersheds Goal Implementation Team (HWGIT). Sections of the strategy include

- an introduction providing background information,
- a description of key points gleaned from ecological literature to guide development of the assessment,
- a discussion of candidate data sources that can be used in assessing watershed health and vulnerability,
- an overview of the proposed analytical and statistical approach, and
- a discussion of data management and integration, including data deliverables.

1.1 Purpose of the Maryland Healthy Watersheds Assessment

Development of the MDHWA will establish a framework of watershed health and vulnerability indicators for Maryland waters and watersheds. Development of this state-specific assessment will build upon the recently completed Chesapeake Bay Healthy Watersheds Assessment (CHWA, Roth et al. 2020) but will also integrate state-specific data where possible. The assessment is intended to inform watershed management decision-making to sustain the health of State-identified healthy watersheds, which have been defined in Maryland as the watersheds associated with its designated high-quality, Tier II waters. The proposed MDHWA and its suite of health and vulnerability metrics will provide information related to specific threats facing Maryland, such as increased development (which can result in deleterious impacts to streams, including altered flows, higher temperatures, habitat degradation, and decreased water quality) and climate change (with resulting effects on flow, temperature, habitat, water quality, and biota). The MDHWA will increase State capacity to better understand the broad spectrum of health and vulnerability issues affecting Maryland’s streams and healthy watersheds.

1.2 Background: the Chesapeake Healthy Watersheds Assessment

The Bay watershed-wide CHWA, with its health and vulnerability assessments for state-identified healthy watersheds, as well as all catchments across the seven Bay jurisdictions, provides a strong methodological foundation for understanding existing threats to watershed health. The CHWA was developed to help the Bay Program and its partners work toward the goal of maintaining the long-term health of watersheds identified as healthy by partner jurisdictions. Quantitative indicators are important to assess current watershed condition, track future condition, and assess the vulnerability of these state-identified watersheds to future degradation. This methodology can also inform progress toward
Building upon the U.S. Environmental Protection Agency (EPA) Preliminary Healthy Watershed Assessment (PHWA) framework, the CHWA assembled a set of candidate metrics characterizing multiple aspects of landscape condition, hydrology, geomorphology, habitat, biological condition, and water quality and evaluated metrics for integration into an overall watershed health index. Geospatial analyses were structured, where possible, to leverage data from existing regional data sources such as EPA StreamCat, the National Fish Habitat Partnership, the Chesapeake Bay Watershed Model for nutrient loads, and Chesapeake Bay high-resolution land use/land cover data. In addition, a set of vulnerability metrics were derived representing aspects of land use change, water use, wildfire risk, and climate change. Metric values were compiled for the nearly 84,000 National Hydrography Dataset Plus Version 2 (NHDPlusV2) catchments Bay-wide and were used to assess conditions and vulnerability within the catchments associated with the current set of state-identified healthy watersheds. Metrics were combined into sub-indices and an overall Watershed Health index. These indicators are available to federal, state, and local managers, providing critical information for maintaining watershed health. The CHWA provides a framework for tracking condition at future intervals, with the ability to integrate new data that become available.

The assessment framework, metrics, and geodatabase created for the CHWA are intended to be useful for a variety of management applications. Primarily, the assessment will support the Chesapeake Bay Program and its jurisdiction partners in detecting signals of change in the state-identified healthy watersheds, providing information useful to support strategies to protect and maintain watershed health. Its indicators of vulnerability may help to provide an “early warning” to identify factors that could cause future degradation, allowing for steps to be taken to head off these potential negative effects. The CHWA will also be integrated with other Bay Program efforts in support of stream and watershed health. Furthermore, the CBP has developed web-based visualization tools that make CHWA data available to a broad group of data users. The CBP will be able to employ the geodatabase and code provided during the CHWA and MDHWA development to conduct future updates when new data become available.

1.3 Potential for application of approach in other jurisdictions

The MDHWA will serve as a model that can be replicated in other jurisdictions and updated in future assessments. Some of the data sets used to build the MDHWA will be regional or national in scope and therefore readily available for use in other jurisdictions. Some data sources may be Maryland-specific, such as data from the Maryland Biological Stream Survey (MBSS), but will serve as examples of the types of data that may be available in other jurisdictions. While the MDHWA will be customized to Maryland’s specific issues, concerns, and data sources, the approach and framework developed for Maryland will be customizable for other locations.

2. Review of Scientific Literature

To provide a foundation for the assessment that would be consistent with recent scientific understanding, this project began with a look to the scientific community and to the ecological literature on landscape-scale influences on stream condition, particularly in Maryland. The intent was to capture this understanding through a review of literature, as well as discussion with expert advisors, to serve as
a guide for the project’s data collection, compilation, and analysis. Here we summarize key points gleaned from the literature reviewed for this project and information available from other, concurrent literature review studies being conducted for related Bay Program efforts.

2.1 Project-Focused Literature Review

Our own review of scientific literature and discussions with the project’s Core Team and a group of Project Advisors (Appendix A) focused primarily on Maryland-specific research and on answering the following key science questions:

- Regarding stream stressors and landscape influences on stream condition, what influences are most important, particularly in Maryland and the Chesapeake Bay Watershed?
- What factors regarding vulnerability to future degradation were considered, if any?
- Was resiliency to factors that might lead to degradation addressed? What factors might make a stream or watershed more resilient, i.e., more able to sustain healthy conditions even in the face of stressors?
- What data sources are recommended?
  - Sources already incorporated in CHWA
  - Potential new data sources for similar metrics to those used in the CHWA
  - New metrics of watershed health and vulnerability specific to MD
  - Data to consider for direct stream health and relationship to CHWA landscape factors
  - For data sources, information was sought on:
    - Organization
    - Where to obtain data (URL or contact)
    - Time period
    - Type of data: Grid/raster/point/watershed or other polygon and resolution (e.g., 12-digit HUC, or 30-m grid)

- What statistical approaches have been used to relate landscape influences on stream condition?
  - What predictor variables were considered? (especially: which were significant?)
  - What response variable were considered? (and were they categorical or continuous?)
  - What statistical method was used?
  - What quantitative relationships have been established?

Key findings of our review regarding landscape relationships found in Maryland are discussed below, including several highlighted example studies. A complete summary of our literature review is provided as a spreadsheet that accompanies this document.

The deleterious effect of modified landscapes, primarily urban development, on stream condition has been known for several decades. This relationship is ubiquitous, consistently strong wherever you go in the world, and includes multiple potential causal mechanisms (e.g., flow alteration and pollutant loading). Impervious area is generally the most used and useful indicator, but there are other landscape measures that can be used (e.g., forest land cover). While the spatial arrangement of imperviousness can modulate the effect, it is usually small relative to the impact of total impervious area. It is important
to note that the effects of impervious area are influenced by ecoregional physiography. Although specific values for impervious cover may vary by data source (e.g., high-resolution data may indicate greater impervious cover), the relative amount of impervious cover remains a useful indicator for assessing overall watershed health.

- Using MBSS data, Stranko et al. (2005) found that impervious area was the best predictor of fish species presence among 25 total factors. Stranko et al. (2010) determined that the majority of streams with imperiled fish, salamander, crayfish, and mussels had <10% impervious area. More recent literature has demonstrated that much lower levels of impervious area can affect benthic macroinvertebrate communities. King et al. (2011) found that 37% of taxa responded at <2% impervious, and this was especially prominent in higher gradient, smaller catchments. Barnum et al. (2017) found that benthic macroinvertebrate composition was homogenized with increasing impervious area, across levels of <2.5%, 2.5-10%, and >10%. Hilderbrand et al. (2010) have predicted that approximately 50% of benthic macroinvertebrate taxa will be extirpated in relatively healthy watersheds (i.e., Patapsco River and Middle Patuxent River), once their projected growth in impervious area reaches 15%.

In most Maryland landscapes, the condition of streams depends on the relative proportions of urban land, agricultural land, and forested land. The proportion of forest land cover is the second best indicator of stream condition, after impervious area. While the evidence for mitigating the effects of urban land (or imperviousness) is mixed, the presence of riparian forests has shown beneficial effects of shading and sometimes runoff attenuation. Wetlands, both natural and created, can improve stream condition through their capture of runoff, especially in low-gradient landscapes.

- Vølstad et al. (2003) did the first analysis of MBSS data with land cover and determined that degradation of streams doubled with each 10% increase in the amount of urban land. The balance of urban v. agriculture v. forested land was considered in analyses.

Another important factor in landscape effects on streams is the history of past land use and modifications, such as dams creating layers of legacy sediment in stream valleys. Therefore, it is important to consider past land cover in addition to current conditions, as effects can last decades if not longer.

- Maloney and Weller (2011) did a comparison of contemporary 2002 land use with land use change from 1952-2002 that showed adverse effects on both fish and benthic macroinvertebrate condition from historic land use. Specifically, current forests that were agricultural land 50 years ago did not achieve expected stream conditions.

Local-scale land cover and modifications (e.g., reservoirs) can also be important, but they typically mediate watershed-scale land cover, which is the primary driver of stream condition.

- Miller et al. (2019) used hierarchical models to show that development after 1980 (when stormwater management began) was 30% less deleterious than prior development and that canopy removal was 2-9 times worse than the effect of impervious area alone. They also showed that, while impervious cover was the best predictor of biological condition, other significant predictors were
  - Age of impervious area
Our review of 41 papers on the topic of factors affecting stream condition revealed the following other anthropogenic effects:

- Nitrogen
- Acidification
- Conductivity
- Phosphorus
- Chloride
- Habitat riffle quality (as assessed with local field data)
- Non-native species
- Upstream point sources
- Sediment deposits and mobility
- Flow conditions
- Dissolved organic carbon
- pH
- Chlorophyll a
- Stream incision ratio (an indicator of channel instability, calculated as bank height divided by bankfull depth)
- Riparian buffer condition

Natural conditions affecting stream condition include:

- Antecedent precipitation (precipitation falling before, but influencing the runoff yields of, a given rainfall event. Antecedent precipitation can lead to greater runoff because the ground is already partially or completely saturated.)
- Geologic soil types
- Bioregion (a region defined by characteristics of the natural environment)
- Latitude and longitude
- Stream density in watershed
- Percent sand in soil
- Topographic wetness (a physically based index of the effect of local topography on runoff flow direction and accumulation, incorporating both slope and upstream contributing area)
- Catchment physiography (physical geographic setting)

In summary, literature suggest that a combination of impervious area and forest/wetland land cover as characterized by the latest data will provide the best predictor of stream condition, especially if modified by (1) historic land cover and (2) local land cover (e.g., riparian areas). Stormwater management and other best management practices (BMPs) can mitigate land use impacts. In addition, other factors, such as those listed above, may provide additional refinement or explanatory power in predictions of stream health.

2.2 USGS Literature Review on Stream Stressors
A concurrent literature review project being led by Rosemary Fanelli of USGS for the CBP Stream Health Work Group (Fanelli et al. 2020, 2021) is focused on characterizing individual and cumulative stressors to stream ecosystems in the Chesapeake Bay region. The question guiding this review is:

- Which stressors are most affecting stream health in freshwater ecosystems in the Chesapeake Bay watershed?

Stressors include local factors that can directly affect stream health such as water quality, toxic contaminants, habitat suitability, altered flow, and temperature. Drivers are factors that influence stressor conditions or levels.

Among the 120 papers reviewed, urbanization, agriculture, and mining were the most commonly cited drivers (Fanelli et al. 2020). Other drivers included industrial point sources, wastewater, climate change, atmospheric deposition, highway construction, and hydropower. Seventy-eight studies explored multiple stressors.

A subset of 35 studies with sufficient data were included in a stressor frequency analysis, which examined the significance and importance of the following in-stream and out-of-channel stressors.

- In-stream: acidity, dissolved oxygen, flow, habitat, nutrients, salinity or major ions, sediment, temperature, toxics (mercury, metals, pesticides, other)
- Out-of-channel: three types
  - Riparian: riparian buffer width, riparian land use, etc.
  - Physical: catchment area, watershed slope, etc.
  - Landscape: land use (percent urbanization, impervious cover, agriculture, percent mining)

Among agricultural studies, nutrients, habitat, and sediment were the stressors most often measured and reported as important; pesticides were measured less frequently but were found to be important when measured. In urban studies, nutrients, habitat, and salinity were the most frequently measured; toxics, salinity and other ions, and flow were found to be the most important (Fanelli et al. 2021).

2.3 USGS Literature Review on Landscape Influence on Stream Ecosystems

Another concurrent literature review is being conducted by Billy Justus of USGS, centered on landscape influence on streams in the Chesapeake Bay watershed. This ongoing effort is in support of the HWGIT. According to USGS, preliminary findings of the literature review include:

- Sediment and nutrient inputs seem to be the most important consideration in ecosystem health.
- Management practices to reduce non-point loss of sediment and nutrients or increase retention appear to be important to the ecological recovery of streams in the watershed and to the Bay.
- In addition to sediment and nutrient data from storm runoff, hydrologic metrics describing the degree of hydrologic alteration could be important to help determine stream health and relationship to landscape factors.

2.4 Key Variables
Based on the literature review, we have identified key variables for characterizing watershed health and for examining examine relationships between landscape factors and stream response. In addition, we have identified several key factors to characterize vulnerability and resiliency. This information has guided the identification of candidate metrics to quantify these variables, which are discussed in Section 3, along with potential data sources. Where possible, this effort will seek to employ existing, known data sources.

2.5 Statistical approaches

2.5.1 Assembling and Testing Metrics

Building the MDHWA involves a number of analytical steps common to many indicator development processes. The key steps can be summarized as follows:

- Identify candidate metrics and data sources
- Assemble metrics
- Test metrics
- Select metrics
- Combine metrics for use in assessment

In this strategy document, we review data sources that can support development of candidate metrics for watershed health and vulnerability. A running list of candidate metrics has been developed and this inventory continues to be updated with information such as sources, future availability, data manipulation needed, data contacts, literature references, resolution, and geographic coverage. In some cases, if a direct metric is determined to be unavailable, surrogate metrics have been proposed to be derived from other data sets that can help to approximate the desired component. The PHWA and CHWA utilized a number of these surrogates. In the MDWHA we are seeking, where possible, to include more direct measures. For example, to characterize geomorphic condition, the CHWA included metrics for Dam Density, Vulnerable Geology, Road Density in Riparian Zone, and Percent Impervious in Riparian Zone, all factors that can influence stream geomorphology. For the MDHWA, we propose more direct metrics quantifying stream bank and bed characteristics, derived from the USGS Floodplain and Channel Evaluation Tool (FACET). Section 3 provides a discussion of data sources reviewed and that may be utilized to construct watershed health and vulnerability metrics for the MDHWA.

To assemble each metric, geospatial analyses will be performed (when needed) to assign metric values to NHDPlusV2 catchments. When source data is already available by catchment, no additional work will be needed. Comparatively, when source data is not summarized to catchments the data will likely need to be modified through projecting and/or resampling. Once the data is in the correct format, zonal statistics will be used to aggregate the source data to each NHD catchment. In some cases, this will be by determining the mean catchment value for a given dataset, and in other instances it could be the aggregate of all pixels within the individual catchment.

Once candidate metrics have been constructed, they can be tested for effectiveness, in terms of the strength of the relationship between the metric and stream response. Stream response can be
quantified in terms of direct diagnostic measures of stream health, such as biological condition. MBSS data for fish and benthic Indices of Biotic Integrity (IBI) are available for a large number of sites throughout Maryland, with more than 5000 samples since the program began. Where MBSS data are available, the relationship between predictive metrics and biological condition can be assessed. For example, we expect that percent impervious cover will be negatively related to fish and/or benthic IBI, as has been shown in other bioassessment studies. Options for methods for exploring stressor-response relationships include correlation, linear regression, or categorical predictions, i.e., predicting the correct classification of IBI as Good (e.g., having good and/or fair ratings) v. Degraded (poor and/or very poor). Statistical analysis will help identify appropriate metrics for tracking watershed health in a repeatable framework that can be updated.

We propose the following approach for evaluating stressor-response relationships, using specific analyses to answer questions of interest as described below. Because MBSS data are available for both fish and benthic macroinvertebrates, we propose to run analyses separately for both the fish Index of Biotic Integrity (FIBI) and the benthic Index of Biotic Integrity (BIBI).

Categorical predictions can be tested using statistical tests including the Mann Whitney U (difference of median) and Kolmogorov-Smirnov (difference in distribution). Mann Whitney is similar to a t-test but does not require an assumption of normal distribution. Both the Mann Whitney and Kolmogorov-Smirnov tests provide p-values which can be used to evaluate statistical significance (p<0.05 is typically considered a significant difference). These statistical tests have proven effective in regional development of multimetric indicators for both freshwater and estuarine biota (Southerland et al. 2007, De-la-Ossa-Carretero et al. 2016).

The ability of a metric or index to distinguish between Good and Degraded condition will be evaluated using classification efficiency (CE), adapting a method commonly employed in multimetric indicator development (Southerland et al. 2007, De-la-Ossa-Carretero et al. 2016). CE is the percentage of Good and Degraded sites correctly classified. For positive metrics (i.e., those with values expected to be higher in healthy watersheds), CE will be calculated as the percentage of Good sites with metric values above the threshold (typically the 10th to 25th percentile of Good), plus Degraded sites below the threshold, out of the total number of sites evaluated. Metric comparisons can be conceptualized as box plots of Good and Degraded site values. For negative metrics (i.e., those with values expected to be lower in healthy watersheds), the CE calculation will be adjusted accordingly.

High classification efficiency indicates a small degree of overlap between values for Good and Degraded sites. In addition to overall CE, CE will also be reported separately for Good and Degraded sites, allowing for examination of tradeoffs in correctly classifying sites of different quality. Discrimination efficiency (DE), a similar measure used in some studies, refers to the percentage of degraded sites alone that are correctly classified (Flotemersch et al. 2006).

A second measure of metric discrimination is the Z-score, calculated as the difference between Good and Degraded site metric values divided by the standard deviation of Good values (Jessup et al. 2021). This is similar to Cohen’s d (Cohen 1988), except that the standard deviation in Z-score is only from the Good distribution, which we would prefer to be small, regardless of variability in the Degraded sites. There is no absolute Z-score value that indicates adequate metric performance, but among metrics, higher Z-scores suggest better separation of Good and Degraded values and lower variability among Good sites.
Metrics that show a clear relationship with stream condition would be the best candidates to propose combining into an overall watershed health indicator and perhaps sub-indices, by topic area. Additional metrics that provide value for certain situations (e.g., Mine Density) may also be included, as they can be important in assessing specific watersheds, although they might not be common enough to yield a strong statistical signal.

Using a stepwise Multiple Linear Regression (MLR) model, one can test the strength of prediction for metrics individually and in combination. Metrics are added to the model, with the response being Good vs Degraded (according to IBIs). The model output can be used to evaluate the relative contribution of metrics and the degree to which adding each metric improves the prediction by providing additional explanatory power. A concern with this approach is that this assumes strict linearity; one possible adaptation would be to use a mixed-effects regression model, which assigns a coefficient for the portion of variance that is not explained (often referred to as the “random” effects) by the indicators chosen.

2.5.2 Develop Overall Indicator of Watershed Health

While individual metrics are useful to understand a variety of influences on watershed health, an overall indicator that integrates those individual metrics is also a goal of the MDHWA. The approach used in the CHWA is a good example of a composite indicator (CI). CI’s are mathematical combinations (or aggregations) of a set of indicators and are used to summarize complex or multi-dimensional issues, such as the health of a watershed. In the case of the MDHWA, a CI can: 1) offer a general assessment of each catchment’s performance, 2) enable judgements to be made on catchments’ priority for improvement, and 3) facilitate communication beyond a technical/research audience.

Composite indicators are built following a common scheme:

1. Development of a theoretical framework – Ideally, a theoretical framework will allow indicators to be selected, combined, and weighted in a manner which reflects the dimensions and structure of healthy watersheds.
2. Data selection – choices are made to identify best available data sources for each identified indicator regarding validity, time series or point, availability, sensitivity, and reliability.
3. Correlation analysis – indicators are often best considered not only individually but by examining interrelationships between them. Correlation analyses helps to identify statistical dimensions within the data and to eliminate highly correlated indicators.
4. Data normalization – an important step in ensuring variables are comparable.
5. Data weighting – weighting and aggregation choices have a crucial effect of the outcome of the CI. There is not only one proper method, but various approaches can be divided into statistical and participatory approaches (see section 4.3 for our specific recommendations).
6. Data aggregation – Generally this is performed by aggregation of each indicator multiplied by the its unique weight.
7. Robustness/sensitivity analysis – Performed following selection and implementation of aggregation to better understand each sub-indicator’s relative contribution and where post-hoc corrections may be needed.
8. Visualization – Final step once all post-hoc corrections are implemented to communicate results in a simple straightforward manner.

There exists much debate regarding how to properly weight and aggregate indicator data into a single CI. While there is no single method of choice, weighting methods fall into statistical or participatory categories. For the MDHWA it is assumed a statistical approach will be utilized, however participatory methods are mentioned for covering all perspectives in constructing weighting systems.

**Statistical methods.** The three most common statistical weighting methods are (i) equal weighting, (ii) multiple linear regression, and (iii) the benefit of the doubt approach (sometimes referred to as the data envelopment analysis). This entire group is based on statistical methods that are solely data driven – there is no need for subjective value judgements. The (i) equal weighting method is straightforward, in that each indicator is given the same weight. This approach is best utilized when there is no clear reason for other approaches and for its simplicity. (ii) Multiple linear regression analysis is another approach through which weights can be elicited. This approach allows the decision maker to explore the causal link between the sub-indicators and a chosen output indicator. A concern with this approach is that this assumes strict linearity – one possible sidestep of this would be to use a mixed-effects regression model, as described above, which assigns a coefficient for the portion of variance that is not explained (often referred to as the “random” effects) by the indicators chosen. Lastly, (iii) the benefit of the doubt approach utilizes multiple weighting schemes for different boundary units. In the case of the MDHWA, each catchment (or block group, HUC12, county, ecoregion, etc.) has its own weights which are determined optimal. This is determined using linear programming to measure the relative performance of several units and to evaluate them based on a so called “efficiency” score. The score is obtained by a ratio that is computed for every unit under a minimization/maximization function. In this case, each catchment is benchmarked against known healthy watersheds where a set of weights is endogenously determined in such a way to maximize their “efficiency” under some given constraints. Proponents of this method suggest that it constitutes a more realistic application, where a particular catchment may be identified as healthy not for one specific set of high marking indicators, but based on the all of the indicators’ efficiency when compared to the benchmark catchments.

**Participatory methods.** The most commonly utilized participatory method is called (i) the budget process. Based on a simple idea, it seeks to bring together a wide spectrum of experts. Each is given a certain “budget”, e.g. 100 points and should divide them among indicators according to the weights they believe should be assigned in the CI. Criticisms of this approach include the selection, number and background of experts, as well as difficulty developing weighting schemes when the number of indicators is large (e.g., 50). The (ii) “public opinion method” is similar to the budget allocation process but there is a broader pool of people contributing opinions instead of a selected group of experts, making the usage of this method even more difficult. (iii) Conjoint analysis is based on the idea of asking respondents to how much importance they would be willing to give to each individual indicator. Lastly, (iv) the analysis hierarchy process is based on using pairwise comparisons. It compares the relative importance of one criterion over another. The main advantages are that humans can easily handle the pairwise comparisons; the
disadvantages are that this process is time consuming and generally does better with fewer number of indicators.

2.6 Overlays

In addition to the suites of health and vulnerability metrics, other datasets have been identified that can provide further information useful to watershed managers. These additional data would be made available as overlays with HWA data, even if they do not lend themselves to computations at the catchment scale. These include data on watershed resilience, if available, i.e., factors associated with the ability to resist stressors, such that certain watersheds are more able to sustain a healthy condition, even when stressors are present. Examples include resiliency to changes in temperature, precipitation, or sea level associated with changing climate. Another example would be areas with high potential for restoration, such as wetland restoration on agricultural land with hydric soil. Data addressing other management considerations such as benefits to diverse communities or protection of community drinking water supplies will also be included as overlays.

3. Candidate Data Sources for Landscape and Response Variables

To develop the MDHWA, data sources will be needed to characterize landscape conditions and other influences on stream condition, along with direct measures of stream health that can serve as response variables and additional factors to examine vulnerability and resiliency. Below is a review of candidate data sources with recommendations on which sources should be pursued for further evaluation for use in the MDHWA.

To the extent possible, the MDHWA for characterizing current watershed condition is to be constructed from existing data sources that are consistent with other CBP efforts. Development of derivative data products for new metrics is beyond the scope of the current project.

Metrics are sought that provide reliable, regional or Maryland-specific information for assessing watershed health and vulnerability. In some cases, Maryland-specific data may provide better detail than a federal or regional source. Ideally, data will cover all of Maryland’s watersheds, as well as the complete upstream areas that drain into Maryland’s watersheds. For example, CBP high-resolution land use data have been developed for all of Maryland as well as the Chesapeake Bay watershed, including nearly complete areas of adjacent states that drain into Maryland. Other datasets will need to be evaluated on a case-by-case basis to ascertain whether complete statewide data are available.

Another criterion for data selection is that the scale and resolution of the data are appropriate for the MDHWA. Similar to the CHWA, the geographic units for assessment will be at the level of catchments from the National Hydrography Dataset Plus Version 2 (NHDPlusV2) geospatial dataset developed by EPA and USGS. These NHDPlus catchments represent the direct drainage area of individual NHDPlus streams, derived from 1:100K stream mapping. Within the Chesapeake Bay Watershed, the average area of an NHDPlus catchment is 2.04 square kilometers (0.79 square miles = 505.6 acres). Using the NHDPlus catchments as the basic unit of analysis provides a spatial framework that supports watershed protection and planning across various spatial scales and hydrologic units. Certain parameters, such as
broadscale climate change predictors, may be applicable at a more widespread, regional scale. The appropriateness of data sources sought for proposed metrics will be evaluated in terms of their spatial and temporal resolution. If not already at catchment scale, an evaluation will be made to decide whether data are of a scale that can be summarized at the catchment level and whether any resampling or downscaling would be required and would be considered appropriate.

Future availability of updated data will also be considered when selecting metrics. Many of the candidate data sources used in this assessment are scheduled to be updated in the coming years. By integrating future iterations of data, the HWA can be updated at intervals to track changes in condition over time. Using metrics to assess the direction and magnitude of change will provide information on the trajectory of conditions and whether management actions are warranted to sustain watershed health.

3.1 Federal Data

USGS/CBP High-Resolution Land Use / Land Cover

As in the CHWA, the CBP high-resolution land use / land cover data will serve as the foundation for a number of metrics including those characterizing forest, impervious cover, turf grass, wetlands, and natural land cover (forest + wetlands). Providing information from 1-m imagery (aggregated to 10-m data), the CBP high-resolution land use/land cover data set representing 2013 ground conditions is currently available. CBP land use/land cover data aggregated to 10-m pixels is available and appropriate for use in the MDHWA, providing more manageable file sizes but with no loss of information from the original 1-m data, because proportional values for land use/cover types are retained in the data. For future updates, a new version of the high-resolution CBP data, representing conditions in 2017, is planned for completion by December 2021.

One of the products being derived from the high-resolution data is a map of forest habitat, representing forest areas with a minimum 1-acre patch size and radius of 120 feet.

For wetlands, other wetlands data were considered, including the National Wetlands Inventory (NWI) and a Maryland-specific wetlands layer. Because the latest version of CBP high-resolution data includes updates that exceed NWI and Maryland, the CBP high-resolution data is recommended as the best available wetlands data for the MDHWA.

USGS/CBP Chesapeake Bay Land Change Model

Using the Chesapeake Bay Land Change Model (CBLCM), USGS/CBP has developed projections of anticipated future land cover change under differing scenarios. The CHWA metric for Percent Increase in Development was based on the CBP model (Phase 6), 2050 projection, a 2018 data set and was calculated as the percent of catchment land projected to undergo development by 2050. Year 2050 forecast data were provided by NHD catchment for the Current Zoning (cz2) baseline scenario.

For the MDHWA, updated projections will be available, including a range of scenarios representing current zoning, growth management, forest conservation, and agriculture conservation. A Maryland scenario, known as the Maryland Regulatory Land Policy BMP layer (approved by Maryland’s Bay
Cabinet), is a hybrid of current and conservation scenarios and likely represents the best of these options for use in the MDHWA.

USGS/CBP research on agricultural conversion, especially conversion to low-density development, may yield additional information that could be employed in examining vulnerability related to future development. In addition, USGS/CBP is investigating patterns of forest land change that account for timber harvest cycles, which may be of use in understanding patterns and degree of forest change. While some timber harvest leads to permanent forest loss, as lands are converted for other uses, other harvest represents a temporary impact as those lands remain in long-term rotational harvest. Both the agricultural conversion and forest change data are recommended as useful land management overlays.

**CBP Population and Housing Density**

USGS/CBP has developed a process for computing population and housing unit density from 2010 census block data using a dasymetric mapping approach. The term dasymetric here refers to reapportioning population and housing units to appropriate land cover classes. This approach will provide data that can be summarized at the NHDPlus catchment scale.

**CBP Vulnerable Geology**

Provided by CBP, this 2018 data layer characterizes lands that are classified as geology vulnerable to surface or groundwater degradation. Values of “carbonate” and “coarse coastal plain” are considered the vulnerable areas.

**USGS/CBP Protected Lands**

The Chesapeake Bay Program maintains a Protected Lands data layer compiled from authoritative federal and state data sources. “Protected lands” means lands permanently protected from development, whether by purchase or donation, through a perpetual conservation or open space easement or fee ownership for their cultural, historical, ecological, or agricultural value. The 2018 version of this Protected Lands data was used in the CHWA. The MDWHA should incorporate this or an updated version.

**USGS Flow Alteration**

USGS has develop a suite of flow alteration metrics for stream reaches throughout the Chesapeake Bay watershed (Maloney et al. 2021) and have demonstrated linkages between flow alteration intensity and degraded biological condition of streams. Using separate random-forest models, they developed predictions of flow status for 12 hydrologic metrics. An overall flow alteration indicator provides combined information from the individual metrics.

**USGS FACET**

Assessment of stream geomorphic condition Although data are not available at this time, the products of this effort are expected to be made available through a UGSG data release and may be useful in future healthy watershed assessment updates.

**CBP Diversity, Equity, Inclusion, and Justice (DEIJ) Data**
The CBP has committed to addressing issues of diversity, equity, inclusion, and justice throughout its restoration programs. Understanding the geographics of these issues is one important component. To support these efforts, the CBP has developed the Chesapeake Environmental Justice and Equity Dashboard (CBP 2021), a web application that integrates data from multiple sources to convey demographic, socioeconomic, environmental, and programmatic topics connected to the Chesapeake Bay Watershed Agreement and Chesapeake specific DEIJ initiatives. It includes data from USEPA’s Environmental Justice Screening and Mapping Tool (EJSCREEN), including metrics calculated from the U.S. Census Bureau’s American Community Survey 5-year summary estimates for data such as Percent People of Color, Percent Low Income, and Percent in Linguistic Isolation by census block group. The dashboard data also incorporate a Social Vulnerability Index developed by the Center for Disease Control (CDC), including 15 U.S. census variables at the census tract level, to help identify communities that may need support in preparing for hazards or recovering from disaster. These factors can be incorporated as overlays with watershed health and vulnerability data, to understand and inform management considerations.

**USFS – National Institute for Applied Climate Science (NIACS)**

Forest ecosystems will be affected directly and indirectly by a changing climate over the 21st century. The U.S. Forest Service National Institute for Applied Climate Science (NIACS) has conducted forest vulnerability assessments for regions including eastern and western Maryland (Butler-Leopold et al. 2018, Butler et al. 2015). The assessments evaluate the vulnerability of 11 forest ecosystems under a range of future climates. Climate data from NOAA and other sources include past and projected future (early, mid, and late 21st century) values for precipitation and temperature parameters. Data were used in forest impact models, which predict a range of potential tree and forest community type responses to climate. These data, while not recommended as individual metrics, may serve as useful overlays for examining watershed health and vulnerability in the context of expected changes in tree species and forest communities.

**USGS Spatially Referenced Regression on Watershed Attributes (SPARROW) Model**

Developed by USGS (Ator 2019a, Ator 2019b), the Spatially Referenced Regression on Watershed Attributes (SPARROW) Model provides estimates of nitrogen, phosphorus, and sediment loads to Chesapeake Bay. SPARROW total and source-specific incremental loads data are available for specific sectors (e.g., manure, inorganic fertilizer, atmospheric deposition, point sources, septic systems, urban) and are useful to characterize the various types of nutrient and sediment loads, in terms of kg/year. Data are available by NHDPlus V2 catchment. “Incremental” refers to values for each local catchment, rather than upstream aggregated values.

It will be useful to evaluate total and source-specific incremental loads to see how correlated they are with selected land use variables. Because the incremental loads in each catchment are a function of various land to water factors as well as source inputs, they will not necessarily be strongly correlated to land uses, but this will be a good check to see how much information SPARROW loads are able to provide, above and beyond land use data alone.

**USGS Conductivity Research**
Conductivity is a measure of the ability of water to pass an electrical current. Because dissolved salts and other inorganic chemicals conduct electrical current, conductivity increases as salinity increases. Conductivity is useful as a general measure of water quality. A water body tends to have a relatively constant range of conductivity that, once established, can be used as a baseline for comparison with regular conductivity measurements (USEPA 2021a). Significant changes in conductivity may indicate that a discharge or some other source of pollution has entered the waterbody. Generally, human disturbance tends to increase the amount of dissolved solids entering waters which results in increased conductivity. Water bodies with elevated conductivity may have other impaired or altered indicators as well.

Freshwater salinization, or the increase in ionic concentrations in freshwater ecosystems (expressed as conductivity), is an emerging global water quality issue. Increasing conductivity and associated ions may disrupt osmotic regulation in benthic organisms, thereby impacting food webs through altered community composition. Elevated ionic concentrations can increase corrosivity of water and impact drinking water supplies. Finally, elevated conductivity can also alter biogeochemical cycling.

Multiple stakeholders across the Chesapeake Bay watershed recognize conductivity as an ecological stressor. To provide information on the effects of freshwater salinization, Rosemary Fanelli of USGS is conducting work to describe spatial and temporal patterns in specific conductivity (SC) in freshwater streams in the watershed. Specifically, data products will be generated to identify areas experiencing altered levels of conductivity and identify sources of elevated conductivity. Selected trends analyses will be used to quantify changes over time and examine vulnerability in healthy watersheds.

USGS is developing datasets including predicted conductivity and departures above reference specific conductivity for most NHDPlusV2 reaches in the Chesapeake Bay watershed. For the departures dataset, USGS is using reference conductivity values that were produced by John Olson of California State University—Monterey and Susan Cormier of EPA (Olson and Cormier 2019).

A similar approach was employed by EPA in analyses of conductivity data for streams nationwide, as presented in its Freshwater Explorer data tool (USEPA 2021b). This tool for data visualization provides context for examining conductivity data with respect to expected background water quality values and departures from predicted values.

USGS Conte Lab – Brook Trout Probability of Occurrence

Brook Trout probability of occurrence data were developed by the USGS Conte Laboratory (2021) for the Northeast and Mid-Atlantic region from Virginia to Maine. The dataset provides model predictions of brook trout presence using brook trout data and landscape predictors. Predictions represent occurrence under current environmental conditions and for future increases in stream temperature. Data are available for four scenarios: current condition, plus 2 degrees C, plus 4 degrees C, and plus 6 degrees C.

EPA Drinking Water Source Protection Area Data

The U.S. Environmental Protection Agency (EPA) Office of Water has data on source water protection areas for surface water source facilities as well as wellhead protection areas for groundwater sources. These data are intended to show areas of interest for the protection of surface and ground water sources of drinking water. By identifying areas significant to drinking water source protection while obscuring the exact locations of intake facilities, this dataset gives a wide range of planners, policy
makers, and practitioners the information needed to target and prioritize areas for protection (USEPA 2020).

The two data sets are known as the Surface Water Source Facility Protection Areas (Source Water Protection Areas – SPAs) and Groundwater Wellhead Protection Areas (WHPAs). For Maryland, surface water (SPA) delineations are composed of National Hydrography Dataset Plus version 2.1 catchments located 24-hour time of travel upstream of all valid surface water source facility locations, while ground water protection areas (WHPAs) are composed of NHDPlusV 2.1 catchments that intersect wells. Because of the sensitive nature of drinking water locational data, data are not to be shared without EPA approval.

**EPA StreamCat**

Developed by EPA's Office of Research and Development (ORD), the StreamCat dataset (https://www.epa.gov/national-aquatic-resource-surveys/streamcat) is an extensive collection of landscape metrics for 2.6 million streams and associated catchments within the conterminous U.S., including both natural and human-related landscape features (Hill et al. 2016). StreamCat data are associated with the NHDPlusV2 catchments. Examples of StreamCat data that were used in the CHWA include Mine Density, Recent Forest Loss (incorporating annual Global Forest Change, Hansen et al. 2013), and Density of Road-Stream Crossings. If these or other data types are not available through state or regional sources, StreamCat may be used as the best available supplement or alternative.

**EPA EnviroAtlas**

EPA’s EnviroAtlas is a national program that provides geospatial data, easy-to-use tools, and other resources related to environmental assessment geospatial research. It is intended to provide users with data on ecosystem services, chemical and non-chemical stressors, and human health. CHWA utilized EnviroAtlas data for percent agriculture on hydric soils and agricultural, domestic, and industrial water use data (derived from USGS water data). If these or other data types are not available through state or regional sources, EnviroAtlas represents a suitable alternative. However, most data in the EnviroAtlas are provided at the HUC-12 scale and may not be spatially resolute enough to match other MDHWA data used.

**3.2 Maryland State Data**

**Maryland Biological Stream Survey**

One of the strengths of using Maryland to develop a local-scale method through the MDHWA is the availability of statewide in-stream monitoring by Maryland Department of Natural Resources (Maryland DNR) Maryland Biological Stream Survey (MBSS), conducted by the Monitoring and Non-tidal Assessment Division (MANTA). The MBSS provides one-time (and sometimes repeat) sampling data collected from more than 5,000 stream segments since 1993. These data include robust indices of biological integrity (IBIs) for both fish and benthic macroinvertebrates. In addition, MBSS samples habitat and water quality, and associates each sample with upstream catchment land cover information. Therefore, MBSS data can be used to explore the relationships of biological integrity, habitat, and water quality to the “wall-to-wall” land cover data that is critical to HWA. Earlier land cover data products have been used by Matt Baker of UMBC, Bob Hilderbrand of UMCES-AL, and others to predict biological
condition in unsampled areas. The MDHWA could use the latest land cover data to similarly predict MBSS IBI values across the state. The accuracy of this prediction increases as the IBI-land cover relationship is modified by habitat and water quality data at each site. This is comparable to the HWA approach that includes, in its assessment, indicators for habitat and water quality separate from biology. Therefore, where MBSS data are sufficient, the MD HWA can use these stream data to (1) develop mean metric values of biological condition, habitat condition, and water quality stress (perhaps as number of threshold exceedances) for NHDPlus catchments in Maryland or (2) examine relationships between landscape variables and stream response (IBIs, habitat, and water quality) to assess the predictive power of proposed indicators for use in modeling stream condition. Once present-day relationships have been verified, these models could later be used to predict (1) current stream condition for unsampled areas and (2) future stream condition under new predicted future landscape condition.

DNR has also employed MBSS data to identify a suite of watersheds supporting freshwater stream ecosystems where conservation is needed to protect and restore areas of high aquatic biodiversity. Known as Maryland’s “Stronghold Watersheds”, these locations are the places where rare, threatened, or endangered species of fish, amphibians, reptiles, or mussels are found in greatest abundance (DNR 2021a). Data on Stronghold Watersheds is used in conjunction with other data to help DNR identify targeted areas for conservation. The Stronghold Watersheds dataset is available from MANTA.

**Maryland iMAP**

A wide variety of Maryland statewide data are available through MD iMAP, the State’s Enterprise GIS platform. This online open data portal features a robust infrastructure, access to GIS software, and delivery of authoritative data and services to support a variety of uses (imap.maryland.gov/Pages/mdimap-3.0.aspx). In many cases, iMAP data represent collaborative efforts among federal, state, and local entities for the purpose of improved data consistency, access, and robustness.

The project team conducted a thorough review of the iMAP data catalog to identify data of potential utility in the MDHWA. Findings are summarized in an Excel table that accompanies this report. Examples of specific data sets that were reviewed for their applicability to several key topics important in Maryland watersheds include the following, which may be useful as overlays with MDHWA data:

- Wastewater and other point sources
- SSURGO soils
- Coastal resilience
  - Hazard Reduction by Habitats
  - Shoreline Hazard Index
  - Priority Shoreline Areas
  - Marsh Protection Potential Index
  - Community Flood Risk Areas
  - MD Sea Level Affecting Marshes Model (SLAMM) - SLAMM uses elevation, accumulation of sediments, wetland accretion and erosion rates, and sea level rise to predicatively model long-term wetland and shoreline change.
  - MD Storm Surge - risk of storm tide flooding from hurricanes, based on potential storm tide heights calculated by the National Weather Service's SLOSH (Sea, Lake, and Overland Surge from Hurricanes) Model.
- Tier II waters – stream segments, catchments, and monitoring stations
- Ecosystem services
  - Groundwater Recharge
  - Nitrogen Removal Potential Index (based on SPARROW model)
  - Flood Prevention and Stormwater Mitigation Potential Index
  - Wildlife Habitat and Biodiversity Potential Index
  - Net Carbon Sequestration

Maryland DNR Fisheries – Fish Blockages

Maryland DNR’s Fisheries program maintains information on the locations of dams and other fish barriers. DNR’s fish barriers database is set up to prioritize blockages in the Bay watershed and is available online through the Nature Conservancy (https://maps.freshwaternetwork.org/chesapeake/). Because this dataset identifies barriers, which are a factor affecting the upstream and downstream migration of fish, it does not readily lend itself to the MDHWA’s catchment-scale data summaries, but would serve as a useful overlay of supplemental information for addressing barriers that are a stressor affecting healthy watersheds.

Maryland DNR Fisheries – Coldwater Resources

Maryland DNR’s Freshwater Fisheries Program has been updating data on the state’s coldwater stream systems (DNR 2021d, 2021e). DNR has been working to compile temperature, benthic macroinvertebrate, and trout data collected by the Department into a central database to aid in data distribution and analysis. One of the main data products is an online map showing the statewide distribution of coldwater resources. This coldwater mapping tool has been distributed to other state agencies, counties, and planning groups to support management decisions that minimize potential impacts to these resources. The mapping tool is also being used to highlight areas for conservation and stream restoration activities. These can include tree plantings, cattle exclusion fencing, agricultural buffer strips, dam and stream blockage removal, and woody debris additions.

In the same coldwater resources mapping tool, there is also a layer for locations of springs. Springs may feed freshwater systems and help maintain cooler water temperatures, even in the face of increasing temperature from urbanization and climate change.

Coldwater and springs data would both be useful as overlay information, to support management and protection of important habitat for trout and other coldwater species.

Maryland DNR – Forest Service

Maryland DNR’s forestry program maintains data on multiple issues related to forest health, including maintenance of unfragmented forest, understanding the prevalence of pest species and other threats to forests, and fire risk. CBP high-resolution data on forests (see above) are useful for characterizing unfragmented forest habitat. In addition, Maryland DNR has developed other mapping data for its 2020 Forest Action Plan (DNR 2020) that are applicable and available for use in the MDHWA.

DNR’s Forest Health Priority Map (DNR 2020) combines four data sets from the Maryland Department of Agriculture (MDA) and the U.S. Forest Service to create a weighted sum model of threats to forest health. These data inputs are:
- MDA Historic Gypsy Moth Treatment Areas depict areas in the state which are high priority forests that have been defoliated by Gypsy moths or have had suppression activities completed on them for over three years, or both.
- MDA Saltwater Intrusion areas causing tree mortality. Saltwater intrusion has begun to take a toll on forests on the Eastern Shore over the last ten years. This is due to rising sea levels and land subsidence, leading to elevated salt in the water table, causing mortality to trees, resulting in visible areas of “ghost forests”. Data represented is from 2010 to 2019.
- MDA Hemlock Treatment Stands reflect activity of the Hemlock Wooly Adelgid, a small insect that feeds on the sap of the hemlock tree and can often cause mortality.
- U.S. Forest Service, Forest Inventory and Assessment (FIA) Estimated Basal Area Loss 2013 to 2027. This dataset from the U.S. Forest Service, Forest Health Protection Program shows the projected percentage loss of total basal area from all forest pests and pathogens, assuming no remediating management, over the 2013-2027 timeframe.

The resulting Forest Health map depicts areas in the top 50% of the weighted sum of these four factors.

DNR has several options for fire risk mapping, including a composite wildfire risk layer used in its Forest Action Plan Assessment (DNR 2020), which represents the best available data for Maryland. The Wildfire Priority Map is designed to highlight areas of the state where wildfire is historically prevalent, has the potential to cause great harm to people and property, and where fuels and other conditions can increase the likelihood and intensity of wildfire. This priority area was identified by creating a weighted sum model that combines the following data:

- Maryland Forest Service Wildfire Response Locations for 2005 to 2018, which are plotted to show areas with the greatest activity.
- University of Wisconsin SILVIS Lab Wildland Urban Interface model results for "intermix" and "interface" areas of Maryland. Using US Census data for the number of households in a given area and the type of vegetation, the SILVIS Lab can locate areas where uncontrolled wildfire would be devastating to communities.
- Wildfire Hazard Potential Model (2018 version) created by the U.S. Forest Service, Rocky Mountain Research Station. This nationwide map shows areas where it would be difficult for suppression resources to contain fires. Areas are classified into low to high values of fuels; the highest values represent a higher probability of torching, crowning, and other extreme fire behavior under conducive weather conditions.

The resulting Fire Priority Areas map shows the top 60% of the weighted sum of the above data.

In addition to these data sets, Maryland Forest Service continues to have an interest in developing additional statewide, detailed spatial datasets for assessing forest health and quality. CBP should consider future coordination of its healthy watershed efforts with DNR and other partners. Related efforts include research by the Harry Hughes Center for AgroEcology, which has been tasked with preparing an analysis of the health and quality of forests across Maryland. A detailed spatial forest health assessment for Maryland (and relevant Bay Watershed-wide lands) may be of future interest, incorporating both state and USFS-coordinated layers.

Maryland DNR Natural Heritage Program - Biodiversity Conservation Network
Maryland DNR’s Natural Heritage Program within the Wildlife and Heritage Service maintains data on the habitats of the state’s most rare plants and animals as well as high quality and rare natural communities and other living resources of conservation concern (DNR 2016). The Biodiversity Conservation Network (BioNet) database incorporates the following types of data:

- Only known occurrences of species and habitats
- Globally rare species and habitats
- State rare species and habitats
- Animals of Greatest Conservation Need
- Watch List plants and indicators of high-quality habitats
- Animal assemblages (e.g., colonial nesting waterbirds, forest interior species)
- Hotspots for rare species and habitats
- Intact watersheds
- Wildlife corridors and concentration areas

BioNet provides a ranked prioritization of areas by their significance for biodiversity conservation. Areas are prioritized into five tiers, from Tier 1 (Critically Significant for Biodiversity Conservation) to Tier 5 (Significant for Biodiversity Conservation). BioNet data is recommended as a habitat metric for the MDHWA.

Maryland DNR – Wetland Adaptation Areas

Maryland DNR has conducted analyses to identify Wetland Adaptation Areas, places appropriate for the potential establishment of wetlands to provide resiliency against the impacts of sea level rise (DNR 2021c). In the Chesapeake Bay region, relative sea level rise is impacting coastal lands at twice the global average rate. Identifying long-term planning options to increase resiliency against coastal storm surge, flooding, and erosion is an important step in protecting Maryland’s coastal zone. Much of the watershed’s natural buffering capacity against these coastal hazards come from coastal wetlands. To better understand the impacts sea level rise may have on the State’s coastal marshes, the Sea-Level Affecting Marshes Model (SLAMM) was run for all 16 coastal counties and Baltimore City. SLAMM results were analyzed for specific conservation criteria for long-term planning that may help increase coastal resiliency in Maryland. The conservation criteria included areas that may support future wetland migration, wildlife habitat, wildlife corridors, high priority aquatic and terrestrial living resources, vulnerable wetland habitat, suitable hydric soils for wetland establishment and marsh-dependent breeding bird habitat. From these criteria a conservation model was developed to prioritize the most important areas for wetland adaptation. This data set is recommended as an overlay layer.

Maryland DNR – Blue Infrastructure Near-shore Assessment

Maryland’s Blue Infrastructure Near-shore Assessment (DNR 2021b) is a detailed spatial evaluation of coastal habitat, critical natural resources and associated human uses in the tidal waters and near-shore area of Maryland’s coastal zone. The near-shore assessment contributes to prioritization systems that help target conservation and management activities to maintain and improve coastal habitats. Blue
infrastructure ranks are assigned to segments along the shoreline, including near-shore lands and adjacent tidal waters.

Data on multiple coastal and watershed features are incorporated into the Blue Infrastructure near-shore assessment. Terrestrial near-shore data include land cover, tidal wetland cores, sensitive and shoreline-dependent species, sandy beaches, point-source discharge, and shoreline stabilization features. Associated 12-digit coastal watersheds are assessed for undeveloped, protected, and Green Infrastructure lands, as well as for amount of impervious surface. Aquatic near-shore segments (to a depth of 2 meters) are assessed for resources such as oyster bars, submerged aquatic vegetation (SAV), sandy bottom, and fish spawning and nursery areas. Total aquatic and terrestrial scores are combined into an overall rank score for each segment.

**MDE Integrated Report**

Maryland Department of the Environment (MDE) maintains data for the state’s Integrated Report on water quality, which includes reporting on 303(d) impaired waters and 305(b) monitoring and assessment efforts. The most recent 2018 report (MDE 2019) and associated data sets are available through Maryland’s Integrated Report online mapping tool (https://mdewin64.mde.state.md.us/WSA/IR-TMDL/index.html). These data can be used to flag watersheds that contain impairments, as well as to quantify the stream length associated with impairments.

**MDE Source Water Protection**

Maryland Department of the Environment (MDE) has data on source water protection areas within the state. For surface water sources, the source water protection area is effectively the entire watershed. For groundwater systems, the Wellhead Protection Area (WHPA) is considered the Source Water Protection area. Wellhead protection areas are distinguished as to whether the source is in a confined or unconfined aquifer.

**Maryland DNR and University of Maryland Park Equity Mapping Tool**

The MDWHA presents an opportunity to integrate factors important to human health and healthy communities into the environmental management of watershed health. In addition to Bay-wide DEIJ data discussed above, another promising dataset of DEIJ information is the recently updated (2020) Maryland DNR and University of Maryland School of Public Health Park Equity mapping tool. This tool adds the number of park amenities, as well as whether a park has “nature-based” or “people powered” recreation facilities to locally provided park data. It includes a scoring model with data layers such as percent of non-white population, linguistic isolation, walkability, and distance to transit. The tool provides a MD EJ Score with numerous context layers that can be used for environmental justice analysis. The MD EJ Score is comprised of data from four categories: Environmental Exposures, Environmental Effects, Socioeconomic Factors, and Sensitive Populations. A fifth category of data is currently being developed to account for climate and health stressors, such as proximity to flood zones, tree canopy, proximity to nursing locations, and location of medically underserved areas.

The MD HWA could potentially use the following factors included in the Park Equity scores to describe the relationship of healthy watersheds with underserved areas of Maryland. Each of these factors is
represented in the model as a separate data layer. The layers include Census Tract Block Groups with indicators scored for factors such as:

- Low proximity to public park space
- High concentration of low-income populations
- High population density
- High concentration of non-white population
- High concentration of linguistically isolated population
- High walkability of an area (i.e., offering the greatest potential for users to access on foot)
- Low access to transit

Data in the Park Equity tool would serve as useful overlays for understanding the human context for watershed health and vulnerability assessments.

3.3 Data from Other Organizations

**Nature’s Network – Conservation Design**

Nature’s Network Conservation Design data depict an interconnected network of lands and waters that, if protected, will support a diversity of fish, wildlife, and natural resources that the people of the Northeast and Mid-Atlantic region depend upon. Conservation Design areas include Core Habitat for Imperiled Species, Terrestrial Core-Connector Network, Grassland Core Areas, Lotic Core Areas, and Lentic Core Areas. Development of Nature’s Network was led by the North Atlantic Landscape Conservation Cooperative (LCC) and the Northeast Association of Fish and Wildlife Agencies (NEAFWA), who coordinated a team of partners from 13 states, the U.S. Fish and Wildlife Service, nongovernmental organizations, and universities, to develop a this regional conservation design for the Northeastern United States (Nature’s Network 2021). The CHWA included the Conservation Design data as a metric characterizing high quality habitat.

**Nature’s Network – Climate Stress**

This data set, developed by the Nature’s Network Project, represents the magnitude of climate stress that may be exerted on habitats in 2080. Areas where 2080 climate conditions depart substantially from conditions where underlying ecosystem type occurs are considered to be stressed. Areas with low or zero climate stress may be candidates to function as climate refugia. Climate Stress was included in the CHWA as a metric characterizing the potential for climate impacts.

**The Nature Conservancy – Resilient Lands**

The Nature Conservancy (TNC) has developed extensive spatial data that provide information on climate-resilient sites to assist with conservation planning (https://maps.tnc.org/resilientland/ Anderson et al. 2016). In the face of changing climate, conservation strategies are needed that anticipate changes in conditions and identify areas that will continue to provide valuable habitat. Resilient sites are defined as areas of “land where high microclimatic diversity and low levels of human modification provide species with connected, diverse climatic conditions they will need to persist and adapt to changing regional climates.” Resilience Scores were determined by evaluating and quantifying physical characteristics that foster resilience, particularly the site’s landscape diversity and local connectedness (TNC 2021).
3.4 Data Gaps

Comprehensive, Maryland-wide data sources of catchment data have not been identified for some topics identified as important to stream health. These include invasive pest species (both aquatic and terrestrial), pesticides, and other toxic pollutants. If new data on these topics become available, they would be candidates for incorporation into future versions of the MDHWA.

4. Proposed Approach

4.1 Developing metrics

Metrics for the MDHWA are proposed that will enable characterization of the factors most important to sustaining watershed health based on the literature. A list of candidate watershed health and vulnerability metrics, drawn from the CHWA and from data sources reviewed above, has been prepared. To date, criteria for selection of metrics for this candidate list included:

- relevance to characterizing aspects of watershed health
- availability of data
- consistency with other Bay Program efforts
- appropriate spatial scale to support developing catchment-scale metrics
- spatial coverage
- appropriate temporal scale

A list of candidate metrics has been prepared as an Excel spreadsheet documenting data sources, contacts, and other information. This metric inventory list will continue to be refined as data are gathered and evaluated for their utility in the MDHWA.

From a review of all data considered, we have recommended a candidate set of metrics that represent the most direct and appropriate data for characterizing the five major types of watershed health factors embodied in the healthy watersheds framework: landscape condition, hydrology, geomorphology, habitat, and water quality. We have chosen to consider stream biological condition not as a parameter of watershed health, but instead as a response variable to test the strength of other parameters. Biological data from the MBSS will be used to test the predictive power of other metrics and to validate the performance of watershed health subindices or the watershed health index.

Candidate vulnerability metrics, tailored to Maryland, have been proposed based on literature and on recommendations from the project core team and advisors. Building upon the vulnerability metrics used in the CHWA, additional metrics were proposed, and a set of vulnerability metrics are recommended as the focus of this effort, also documented in the metric inventory spreadsheet. Future land use, derived from the CBLCM, will be important to assessing vulnerability, as land change will likely drive the trajectory of future watershed health and stream condition. Vulnerability metrics include those characterizing climate threats to non-tidal, freshwater aquatic and terrestrial ecosystems.

Understanding the influence of future development and climate change will help identify areas in need of protection or restoration to forestall degradation. In addition, it may be possible to identify factors that lend resiliency to systems, allowing streams to persist in healthy condition even when exposed to...
added stressors. However, these factors may be difficult to discern in a statewide assessment and a more complete picture may require future, site-specific data exploration.

Although CBP’s set of state-identified healthy watersheds (including Maryland’s current Tier II watersheds) are all located in non-tidal systems, tidal datasets have also been identified as relevant for other management purposes. For example, Maryland’s mapping of Wetland Adaptation Areas providing data relevant to tidal wetland migration in the face of sea level rise and coastal vulnerability, has been identified as an overlay data set.

Another aspect of vulnerability is a consideration of DEIJ data, where available, to incorporate information that will help characterize community and social aspects of watershed condition. Managers can then consider factors like demographics and community access to natural and recreational areas when making decisions on environmental concerns. The Bay Program’s DEIJ data and Maryland’s Park Equity mapping tool developed by Maryland DNR and University of Maryland School of Public Health provide indicators across the region and state.

4.2 Evaluating statistical relationships among landscape factors and stream response variables

The MBSS data provides a rich source for evaluating the statistical relationships among various factors. While there is not a sole method for evaluating these relationships, several steps are required to prepare the metric data, regardless. After landscape factors are identified, a correlation analysis should be completed to ensure all factors used within the statistical analyses are not highly correlated. In instances where two data sources are highly correlated, one may be dropped from the analysis, unless there is a strong reason for retaining the information it provides. Following the calculation of individual metrics, the data will be normalized for comparability, including ensuring that the highest values of a dataset correspond to the highest score. In some instances, the inverse of the data will need to be taken. An approach similar to that used in the CHWA would likely be followed. Positive CHWA metrics (i.e., those such as Percent Forest, with values expected to be higher in healthy watersheds) were not further transformed, but negative metrics (i.e., those such as Percent Impervious Cover, with values expected to be lower in healthy watersheds) were transformed as one minus the metric, to yield an adjusted score that would be positively associated with watershed health.

Following normalization of the data, several parallel but divergent analysis could occur. Given the wide range of end users, it is recommended that composite sub-indices be created first using a simple sum approach. These sub-indices would be simple to understand and calculate, as well as would facilitate a clear extension of the previous healthy watershed assessments.

In addition to a set of equally weighted composite indices, we would propose to test watershed health metrics against the MBSS benthic and fish biotic integrity metrics and the instream habitat quality index. This categorical data would allow for multiple linear regression models to be explored, as well as possible use of multi-level mixed effects models.

While there exist more sophisticated weighting techniques, further complicating the analysis may result in greater difficulty in understanding and interpreting results for likely little improvement in the final results. Additionally, validation of the equal weighting scheme should be compared to the regression models to determine how well each correctly predicts the IBI and habitat quality indices. An equal
weighting system offers advantages in terms of simplicity and ease of explanation; equal weighting would therefore be a good choice if other weighting systems do not offer substantial added benefit.

5. Data Management and Integration

Tetra Tech will apply the newly developed MDHWA strategy to all watersheds in Maryland (at the NHDPlusV2 catchment scale) to establish relative Tier II watershed health baseline condition and future vulnerabilities. Elements of our data deliverables include: Development of R-scripts and Python code for management of geospatial data to develop the MDHWA (metric transformations, index calculations, and graphical analyses). Code will include any necessary comments to ensure transferability and easy understanding by CBP and other users.

- A final project geodatabase including a complete set of metrics employed in the MDHWA.
- A manual on how to navigate and visualize the map layers and a video recording (e.g., webinar format) providing a tutorial detailing step-by-step procedures for using the map layers.

Following the validation of indicators, results statewide and specifically including Maryland’s Tier II waters, will be prepared in final geodatabase format. The MDHWA will be developed into data suitable to be integrated into MD iMAP. The database will follow the EPA’s data standards and policies, and those required for data integration into MD iMAP.

5.1 Geodatabase

In order to maintain and contain a consistent data environment Tetra Tech will utilize an ESRI file geodatabase. This will offer a centralized environment to maintain all spatial and tabular data developed for the MDHWA. The geodatabase format will also allow any data developed to conform to Maryland’s recommended spatial data requirements.

5.2 Integration with Maryland iMAP

The final MDHWA indices and metric scores will be compiled into a geodatabase containing shapefiles and related data tables that conform to MD iMAP data submission policy guidelines. All spatial data will be projected in WGS 1984 Web Mercator (auxiliary sphere) and contain attribute fields that are compliant and consistent with ESRI operational field names. All extraneous data will be removed from the final datasets sent to the MD iMAP team. All submitted datasets/geodatabases will have associated metadata that conforms to ESRI’s “Item Description” metadata style. Metadata attribute descriptions will identify fields full name and alias and describe the nature of the metric value being presented as well as a summary of how it was developed. The iMAP version of the MDHWA may differ in composition to the final geodatabase makeup provided to the HWGIT as end users and display methods may differ.

6. References


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Appendix A

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