Maryland
Healthy Watersheds Assessment:
Applying Health and Vulnerability Assessments to Maryland's Tier II Waters

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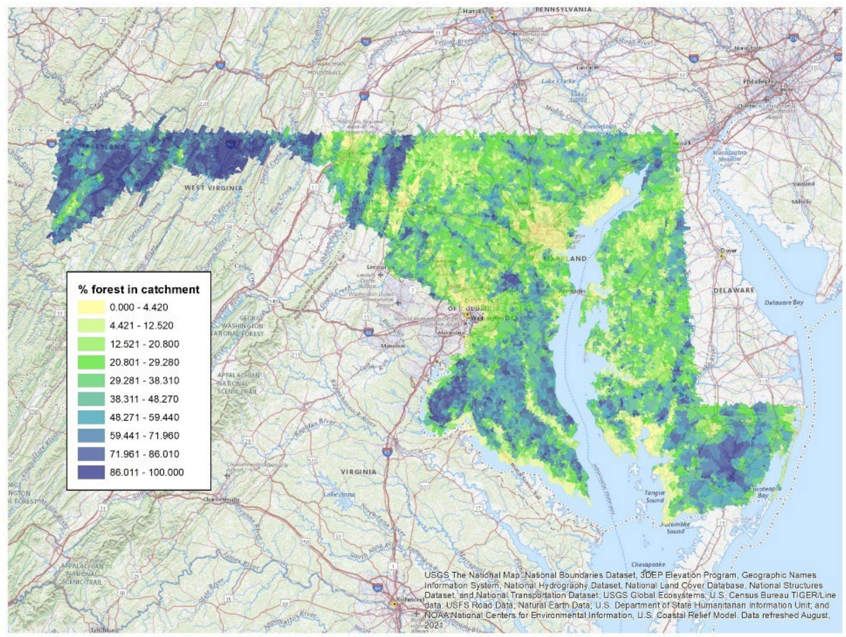

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Acronyms

- ATTAINS - Assessment and Total Maximum Daily Load Tracking and Implementation System
- BioNet – Biodiversity Conservation Network
- BIBI – Benthic Index of Biotic Integrity
- BMP – Best Management Practice
- CBP – Chesapeake Bay Program
- CBPO – Chesapeake Bay Program Office
- CDC – Center for Disease Control
- CHWA – Chesapeake Healthy Watersheds Assessment
- DEIJ – Diversity, equity, inclusion, and environmental justice
- DEM – Digital Elevation Model
- DNR – Maryland Department of National Resources
- EJ – Environmental justice
- EJSCREEN – Environmental Justice Screening and Mapping Tool
- EPA – United States Environmental Protection Agency
- FACET – Floodplain and Channel Evaluation Tool
- FIA – Forest Inventory and Assessment
- FIBI – Fish Index of Biotic Integrity
- HUC – Hydrologic unit code
- HWGIT – Maintain Healthy Watersheds Goal Implementation Team
- IBI – Index of Biotic Integrity
- MANTA – Monitoring and Non-tidal Assessment
- MBSS – Maryland Biological Stream Survey
- MD - Maryland
- MDA – Maryland Department of Agriculture
- MDE – Maryland Department of the Environment
- MDHWA – Maryland Healthy Watersheds Assessment
- NALCC – North Atlantic Landscape Conservation Cooperative
- NEAFWA – Northeast Association of Fish and Wildlife Agencies
- NFHP – National Fish Habitat Partnership
- NHDPlus V2 – National Hydrography Dataset Plus Version 2
- ORD – Office of Research and Development
- PHWA – Preliminary Healthy Watersheds Assessments
- RF – Random Forest
- SAV – submerged aquatic vegetation
- SC – Specific conductivity
- SLAMM – Sea-Level Affecting Marshes Model
- SPA – Source Water Protection Area
- SPARROW – Spatially Referenced Regression on Watershed Attributes Model
- TN – Total nitrogen
- TP – Total phosphorus
- UMD – University of Maryland
- USFS – United States Forest Service
- USGS – United States Geological Survey
- WATERS – Watershed Assessment, Tracking & Environmental Results System
- WHPA – Groundwater Wellhead Protection Area

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1. Introduction - Purpose and Objectives

The U.S. Environmental Protection Agency (EPA) defines a healthy watershed as one in which natural land cover supports (EPA 2019):

- dynamic hydrologic and geomorphic processes within their natural range of variation,
- habitat of sufficient size and connectivity to support native aquatic and riparian species, and
- physical and chemical water quality conditions able to support healthy biological communities.

Through its Healthy Watersheds Program, EPA promotes the protection of healthy watersheds using a variety of assessment and management approaches (EPA 2012). Protection of healthy watersheds is an integral component of overall strategy to meet the goal of the Clean Water Act, specifically "…to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." EPA's Healthy Watersheds efforts are intended to "protect and maintain remaining healthy watersheds having natural, intact aquatic ecosystems; prevent them from becoming impaired; and accelerate restoration successes." (EPA 2012)

The Chesapeake Bay Program (CBP) recognizes the importance of conserving healthy watersheds within the Chesapeake Bay region as part of the overall Bay restoration effort. In addition to clean water and high-quality habitat for aquatic species, healthy watersheds provide social and economic benefits such as clean drinking water, wildlife habitat, flood protection, and recreation. Conservation of healthy watersheds is a proactive approach that can reduce the need for future and costly restoration of watersheds that become degraded (CBP 2021a).

Through the Maintain Healthy Watersheds Goal Implementation Team (HWGIT), the Bay Program and its partners have established a goal of sustaining the long-term health of watersheds identified as healthy by partner jurisdictions. Quantitative information on watershed health will contribute to an understanding of the current condition of the state-identified healthy watersheds and will help to track conditions in the future. The Healthy Watersheds Outcome Management Strategy (CBP 2021a) identifies efforts underway and planned for achieving the intended outcome: that 100 percent of state-identified currently healthy waters and watersheds remain healthy.

- *Healthy Watersheds Goal: Sustain state-identified healthy waters and watersheds recognized for their high quality and/or high ecological value.*
- *Healthy Watersheds Outcome: 100 percent of state-identified currently healthy waters and watersheds remain healthy.*

- Healthy Watersheds Outcome Management Strategy (CBP 2021a)

This report documents the development of the Maryland Healthy Watersheds Assessment (MDHWA), a state-specific adaptation of the previously developed healthy watersheds assessment for the entire Chesapeake Bay watershed.

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 for all catchments across the seven Bay jurisdictions, provides a strong methodological foundation for understanding existing threats to watershed health. The CHWA was based on the foundation provided by EPA's previous compilation of watershed health data for all states nationwide through its Preliminary Healthy Watersheds Assessments (EPA 2017).

2.1 EPA's Preliminary Healthy Watersheds Assessments Framework

To support watershed management efforts across the entire country, EPA's Healthy Watersheds program developed the PHWA (EPA 2017), an initiative that complied sets of key, nationally consistent data to assess watershed health and vulnerability. The approach provided by the nationwide PHWA included an overall assessment of watershed health, incorporating six key ecological attributes inherent in the definition of healthy watersheds: landscape condition, geomorphology, habitat, water quality, hydrology, and biological condition (EPA 2017). In addition, the PHWA incorporated a limited number of potential stressors representing three categories: land use change, water use, and wildfire risk. In April 2017, EPA rolled out the PHWA, with a set of 48 statewide and 85 ecoregional-scale assessments of watershed health and vulnerability across the conterminous United States. The PHWA was intended to serve as a useful framework that could be built upon by states and regions. To support further use and refinement, EPA produced state-specific PHWA geodatabases including a suite of indicators at the 12-digit hydrologic unit code (HUC) scale.

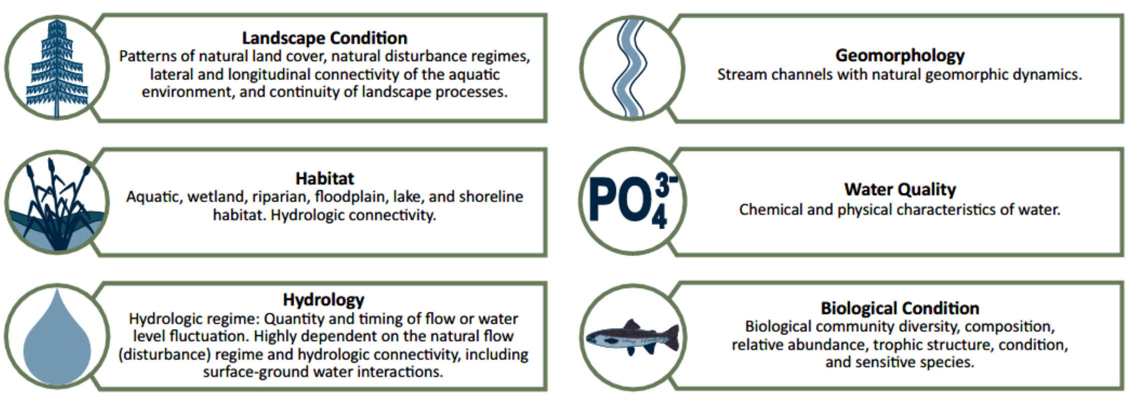


Figure 1. *Six attributes of watershed health described in EPA's Identifying and Protecting Healthy Watersheds: Concepts, Assessments, and Management Approaches (EPA 2012).*

EPA's PHWA employed a suite of metrics in each of the six overall categories for watershed health. PHWA metrics were designed to be used individually or combined into six sub-indices representing those categories and a final, overall index of watershed health. The PHWA also compiled vulnerability metrics in three categories: land use change, water use, and climate change

2.2 The Chesapeake Healthy Watersheds Assessment

The CHWA (Roth et al. 2020) 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 assessment data are important to evaluate current watershed condition, track future condition, and assess the vulnerability of these state-identified watersheds to future degradation. The healthy watersheds data and tools can also inform progress toward the Chesapeake Bay Watershed Agreement Healthy Waters and Watersheds goal to support partner jurisdictions in sustaining state-identified healthy watersheds. Building upon EPA's PHWA framework (EPA 2017), the CHWA project had three objectives:

1. To apply the PHWA framework to assess the current condition of state-identified healthy watersheds within the Chesapeake Bay Watershed.
2. To develop an approach to use the PHWA framework to track the health of state-identified healthy watersheds over time to determine if watershed health is being maintained.
3. To apply the PHWA framework to identify vulnerabilities in state-identified healthy watersheds.

Following the 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 (NFHP), the Chesapeake Bay Watershed Model for nutrient loads, and Chesapeake Bay 2013/14 high-resolution land use/land cover data. Many of the original PHWA metrics were employed, but where possible were updated with data specific to the Chesapeake Bay watershed. Several new metrics were added based on topics and data sets identified by project partners. In addition to watershed health metrics, a set of vulnerability metrics were derived representing aspects of land use change, water use, wildfire risk, and climate change.

While the PHWA had been developed at the 12-digit HUC scale, the CHWA provided watershed health and vulnerability metrics at a finer, catchment scale. CHWA metric values were compiled for the nearly 84,000 National Hydrography Dataset Plus Version 2 (NHDPlus V2, 1:100,000 map scale) catchments Bay-wide and were used to assess conditions and vulnerability within the catchments associated with the current set of state-identified healthy watersheds. The individual watershed health metrics were combined into sub-indices and an overall Watershed Health index. All of these quantitative data are available to federal, state, and local managers, providing critical information for maintaining watershed health. The CHWA provides a framework for tracking watershed condition at future intervals, with the ability to integrate new data that become available.

The assessment framework, metrics, and geodatabase created for the CHWA were intended to be useful for a variety of management applications. Primarily, the assessment supports 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. The CHWA vulnerability metrics may help to provide an "early warning" to identify factors that could cause future degradation, allowing managers to take actions to head off these potential negative effects. The CHWA is also being integrated with other Bay Program efforts in support of stream and watershed health. Although developed in support of the HWGIT, the CHWA has many cross-connections to other CBP efforts, including stream health, fish habitat assessment, water quality, climate change, and local engagement. Watershed health data are applicable in support of these interrelated programs for Bay protection and restoration. 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 created during the CHWA development (and the subsequent development of the MDHWA) to conduct future updates.

The linkages between landscape conditions and stream health have been well documented, at a range of scales from the local reach to broader watershed scale (Allan 2004). A variety of studies have investigated landscape influences on stream and riverine ecology (see review by Steel et al. 2010), particularly with the intent to inform watershed management and conservation activities. Advances in geospatial tools and data visualization bring new opportunities for applying landscape-scale data to inform the management of streams and watersheds to promote healthy conditions.

3. Purpose of the Maryland Healthy Watersheds Assessment

Development of the MDHWA establishes a framework of watershed health and vulnerability metrics for assessing Maryland (MD) waters and watersheds. Development of this statewide assessment built upon the previously completed Chesapeake Bay Healthy Watersheds Assessment (CHWA) (Roth et al. 2020), making use of more recent and refined regional data, and also integrating 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 MDHWA will increase State capacity to better understand the broad spectrum of health and vulnerability issues affecting Maryland's streams and healthy watersheds. Data are intended to be useful to the State's Tier II waters program, especially for assessing vulnerabilities of healthy watersheds to future degradation and helping to target and inform management efforts, such as conservation, restoration or inform policy decisions in these areas. MDE and others will be able to access the data and integrate the MDHWA analysis into state decision making related to the State's high-quality waters.

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 are regional or national in scope and therefore readily available for use in other jurisdictions. Some data sources used in analyses are Maryland-specific, but will serve as examples of the types of data that may be available or could be pursued in other jurisdictions. While the MDHWA is customized to Maryland's specific issues, concerns, and data sources, the approach and framework developed for Maryland is intended to be customizable for other locations.

Development of the MDWHA also afforded the opportunity to evaluate the predictive ability of watershed metrics to predict watershed health, using data from the Maryland Biological Stream Survey (MBSS) as response variables. MBSS provides quantitative ratings of stream condition based on fish and benthic macroinvertebrate data from monitored sites. MBSS uses field data to calculate Index of Biotic Integrity (IBI) scores, indicators that are constructed from multiple metrics characterizing aspects of the biological assemblages present at non-tidal stream sites. Both the fish (FIBI) and benthic (BIBI) indices provide assessments of stream health and are calibrated to reference conditions for Maryland streams (Southerland et al. 2007).

The development of the MDHWA was sponsored by the CBP and involved coordination with Bay Program staff, a core group of state and federal partners, and a project advisory team. Core group and project advisory team members are listed in Appendix A. Throughout the course of the project, meetings were held to provide updates and seek input from participants.

4. State-Identified Healthy Watersheds in Maryland

Five of the seven Chesapeake Bay jurisdictions have set their own definitions of "healthy waters and watersheds" and a map of these state-identified healthy waters and watersheds is maintained by the Bay Program (CBP 2019). These waters and watersheds, as identified in 2017, will serve as the baseline from which watershed health will be assessed and progress toward the healthy watershed outcome will be measured. Individual jurisdictions have defined their local healthy waters and watersheds. In addition to region-wide efforts, individual jurisdictions have their own programs to support protection of high-quality waters and watersheds. The HWGIT encourages these efforts and also seeks to provide data and tools to assist in tracking the status of conditions in the healthy watersheds and in identifying signals of change and vulnerability (CBP 2021).

In Maryland, healthy watersheds are defined as those containing designated Tier II Waters. Streams and their catchments are designated Tier II when their biological characteristics are significantly better than minimum water quality standards. Maryland's 263 Tier II streams are designated based on biological community condition for benthic macroinvertebrates and fish (MDE 2022). The Maryland Department of the Environment (MDE) bases its decision on data collection and analysis procedures that strictly follow the MBSS protocols developed by the Maryland Department of Natural Resources (DNR). The MBSS sampling and analysis protocol generate Index of Biotic Integrity (IBI) scores for fish and benthic data (Southerland et al. 2007). MBSS IBI scores are on a scale of 1-5, where scores of 4-5 are assigned a rating of good, while lower values are rated as fair, poor, and very poor. Any streams where both independent IBI scores are 4.00 or greater are designated as Tier II waters by MDE. As new data are collected, MDE may update its list by adding new Tier II streams when these qualifications are met. As new locations are added to the Tier II list, CBP may consider revising its healthy watersheds goal to incorporate the maintenance of watershed health for these newly identified Tier II watersheds.

5. Scale of Analysis

The MDHWA makes use of the same map scale of analysis as the CHWA, which is based on catchments from the National Hydrography Dataset Plus Version 2 (NHDPlus V2, 1:100,000 map scale) geospatial dataset developed by EPA and the United States Geological Survey (USGS). These NHDPlus V2 catchments represent the direct drainage area of individual NHDPlus V2 stream reaches. Within the state of Maryland, the average area of an NHDPlus V2 catchment is 1.92 square kilometers (0.741 square miles = 474.4 acres) and the catchments range in size from less 1 square kilometer to approximately 48 square kilometers. Using the NHDPlus V2 catchments as the basic unit of analysis provides data to characterize watershed health and vulnerability within a spatial framework that supports watershed protection and planning across various spatial scales and hydrologic units. If needed, NHDPlus V2 catchment data can be aggregated up to larger landscape units. This allows for flexible reporting of results at other watershed scales appropriate for multiple management or communication objectives. However, one limitation of the 1:100,000 scale map is that some smaller streams are not included on the map. Therefore, this map scale does not support drilling down to these smaller streams, which may limit its use for some conservation or restoration actions at the local scale.

During CHWA development, a map representing the drainage areas of the healthy watersheds in Chesapeake Bay Watershed, had been created from the state-identified waters and watersheds provided by the Bay Program. A further step was to identify those NHDPlus V2 catchments associated with each of the state-identified healthy watersheds, so that catchment-specific data can be examined for these watersheds of interest, either individually or as a group. Catchments associated with Maryland's state-identified healthy watersheds are shown in Figure 2. However, MDHWA metrics were computed for all catchments across the entire state of Maryland, not only for those within healthy watersheds. This wall-to-wall coverage provides a broader context for evaluating the data associated with Maryland's healthy watersheds. In addition, as discussed in Section 10, MDHWA data may be employed for a variety of other purposes beyond the management of Tier II waters.

Other state and regional efforts to characterize and identify healthy watersheds have also selected NHDPlus catchments as the basic geographic unit for analysis. Examples include Tennessee's statewide assessment of watershed health and vulnerability (Matthews et al. 2015) and the Alabama-Mobile Bay healthy watershed assessment (Cadmus Group 2014a). As described in the Tennessee healthy watersheds assessment (Matthews et al. 2015), using the NHDPlus catchment scale provides a spatial framework for watershed protection planning at a variety of scales and offers several advantages:

> *NHDPlus is a medium-resolution dataset of all stream reaches in the nation and their corresponding catchments. Each NHDPlus catchment represents the direct, or local, drainage area…for an individual stream reach and has a common identifier (COMID) assigned to it in the dataset. A separate table identifies the "from" and "to" COMID for every catchment in the dataset, giving a complete picture of the hydrologic relationships between adjacent catchments in the stream network at the 1:100,000 scale.*

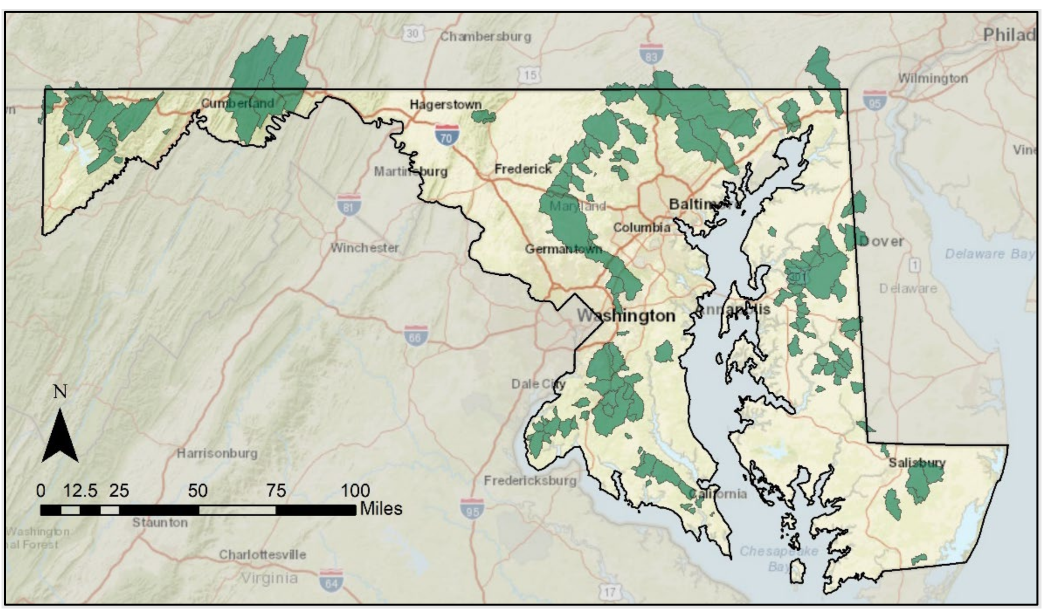


Figure 2. *Watersheds identified as Healthy by the state of Maryland.*

The hydrologic relationships in NHDPlus allow for calculations of watershed characteristics (e.g., drainage area, stream length, land use) at both the catchment (within local catchment boundaries) and accumulated scales (within all upstream catchments in watershed) for any stream reach. Accumulated values are included for some metrics (listed as “in watershed” in Table 1 and 6) in the MDHWA, because of the potential for upstream conditions to influence the health of a given stream reach. For example, high percent imperviousness in the entire accumulated upstream watershed area is expected to influence downstream biological communities, even where the impervious cover within the local catchment may be low. However, at the time of analysis, CBP land use/land cover data for 2017/18 was unavailable for calculating accumulated values for a small subset of Maryland catchments located outside of the Chesapeake Bay watershed in western Maryland. To maintain consistency across the entire study area, only the “catchment” versions of 2017/18 CBP land use/land cover metrics, and not the corresponding accumulated (“in watershed”) values, were used in statistical analyses for conducted for this report.

As in the CHWA, certain MDHWA metrics were computed for the riparian area only, defined as the area within approximately 30 meters (98.4 feet) on either side of the stream-edge. New geospatial data defining the riparian zone was developed by CBP for this project and to be used in other applications. The process to develop this new riparian “mask” made use of streams derived from the USGS Floodplain and Channel Evaluation Tool (FACET, USGS 2019) and CBP High-Resolution Land Use/Land Cover (CBPO 2022a), with a 30-m buffer applied on each side of the stream.

6. Developing an Assessment of Watershed Health for Maryland

For the MDHWA, a suite of metrics describing ecological attributes of watershed health or condition was developed. The process of metric selection and development was guided by a review of scientific information, compilation of available geospatial data, and consultation with the project’s core group and project advisory team to best incorporate management needs.

6.1 Review of Scientific Literature

To provide a foundation for the MDHWA that is consistent with recent scientific understanding, the project first interviewed the scientific community and reviewed the ecological literature on landscape-scale influences on stream condition, particularly in Maryland. This step, as well as discussion with expert advisors, served as a guide for the project’s data collection, compilation, and analysis. Documentation of the literature review (Appendix B) summarizes key points gleaned from the references reviewed for this project and information available from two other, concurrent literature review studies conducted by USGS investigators for related Bay Program efforts.

6.2 Candidate Data Sources and Metrics

To develop the MDHWA, data sources were compiled 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. To the extent possible, the assessment was constructed from existing data sources that are consistent with other CBP efforts.

Metrics were sought that provided reliable, regional or Maryland-specific information for assessing watershed health and vulnerability. In some cases, Maryland-specific data were found to provide better detail than federal or regional sources.

A list of candidate watershed health and vulnerability metrics was developed, drawn from the CHWA and other new data sources, based on factors identified in the literature review and through consultation with the project's core and project advisory teams. Criteria for selection of candidate metrics included:

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

Future availability of updated data was also considered when selecting metrics. Many of the 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.

A candidate set of metrics was developed that represent the most direct and appropriate data for characterizing five major types of watershed health factors embodied in the healthy watersheds framework: landscape condition, hydrology, geomorphology, habitat, and water quality. The PHWA and CHWA had also included biological condition as a sixth category. However, for the MDHWA, we chose to consider stream biological condition not as a parameter of watershed health, but instead as response variables to test the strength of other parameters. Biological data (FIBI and BIBI scores) from the MBSS were used to test the predictive power of other metrics, as described in Section 6.5 below.

A large number of candidate watershed health metrics were considered and narrowed to a smaller group of candidates recommended for further analysis to determine selection. These recommended candidate metrics for assessing watershed health, with a summary of data source information, are presented in Table 1. Further details can be found in Appendix C and in metadata within the accompanying geodatabase. Data were compiled and watershed health metrics were developed for each of the NHDPlus V2 catchments within Maryland and contributing drainage areas from neighboring states.

Table 1. *Recommended watershed health metrics for catchments in Maryland*

Category	Metrics	Notes: Data Source
Landscape Condition	% Natural Land Cover in Catchment	CBP high-resolution land use/land cover data, 2017/18
	% Tree Canopy in Riparian Zone in Catchment	CBP high-resolution land use/land cover data, 2017/18
	% Natural Land in Riparian Zone in Catchment	CBP high-resolution land use/land cover data, 2017/18
	Population Density	StreamCat data, based on 2010 U.S. census
	Housing Unit Density	SILVIS lab data, based on 2010 U.S. census

	Chesapeake Conservancy Active and Abandoned Mines	Chesapeake Conservancy, digitized boundaries of active and abandoned extractive areas, 2018
	% Impervious Cover in Catchment	CBP high-resolution land use/land cover data, 2017/18
	% Managed Turf Grass in Catchment	CBP high-resolution land use/land cover data, 2017/18
Hydrology	% Tree Canopy in Catchment	CBP high-resolution land use/land cover data, 2017/18
	Density Road-Stream Crossings in Watershed	StreamCat, 2010 data
	% Wetlands in Catchment	CBP high-resolution land use/land cover data, 2017/18
	Flow Alteration Intensity Score	USGS (Maloney et al. 2021 flow alteration intensity score, based on hydrologic metrics of Eng et al. 2019)
Geomorphology	Dam Density in Watershed	StreamCat (EPA 2022a), 2013 data
	Road Density in Riparian Zone, in Watershed	StreamCat (EPA 2022a), 2010 data
	Streambank Lateral Erosion	USGS (Noe et al. 2020), derived from Floodplain and Channel Evaluation Tool FACET (USGS 2019)
	Streambank Change (m2)	USGS (Noe et al. 2020) derived from FACET (USGS 2019)
	Streambank sediment flux – incorporates bank height, lateral erosion, and bulk density	USGS, Noe et al. 2020, derived from FACET (USGS 2019)
	Streambed D50	USGS, Noe et al. 2020, derived from FACET (USGS 2019)
	Streambank Fine Sediment Flux	USGS, Noe et al. 2020, derived from FACET (USGS 2019)
	Streambed Fine Sediment + Sand Cover	USGS, Noe et al. 2020, derived from FACET (USGS 2019)
	% Impervious in Riparian Zone in Catchment	CBP high-resolution land use/land cover data, 2017/18

Habitat	Nature's Network Conservation Habitats in Catchment	Nature's Network Conservation Design for the Northeast (Nature's Network 2021)
	MBSS Stronghold Watersheds	Dataset from Lynn Davidson, Maryland DNR, 2020
	Maryland Biodiversity Conservation Network (BioNet) priority areas for terrestrial and freshwater biodiversity conservation	Maryland DNR (2018)
	% Forest in Catchment	CBP high-resolution land use/land cover data, 2017/18
Water Quality	Miles of Stream Impairments in Catchment	EPA Watershed Assessment, Tracking & Environmental Results System (WATERS, EPA 2022b)
	USGS SPAtially Referenced Regression On Watershed attributes (SPARROW) sector specific loads for TN, TP, sediment (incremental loads)	USGS regional SPARROW model (Ator 2019a, 2019b)

6.3 Data Sources for Watershed Health Metrics

This section provides an overview of additional information on the data sources that contributed to construction of the watershed health metrics listed in Table 1. A variety of Federal, State, and other data sources were used to build the individual metrics. Metrics are listed here with bullets, organized under each of five categories representing different components of watershed health. Further details about the metrics and source data are found in Appendix C and in the metadata for the MDHWA geodatabase developed for this project.

6.3.1 Landscape Condition

<u>CBP High-Resolution Land Use/Land Cover</u>

As in the CHWA, the CBP high-resolution land use/land cover data (CBPO 2022a) 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, and other natural vegetation). Providing information from 1-m imagery, the CBP high-resolution land use/land cover data set representing 2017/18 ground conditions was utilized in the MDHWA. Delaware, Maryland, Virginia, and West Virginia are based on 2018 imagery; Pennsylvania, New York and DC are based on 2017. This new version of the high-resolution CBP data set, representing 2017/18 land use/land cover conditions, was completed in May 2022 and was used by CBP to calculate the series of MDHWA metrics. Note that these data provide an update to the CBP high resolution land use/land cover data used in the 2020 CHWA, which represented 2013/14 conditions. Most were used to characterize landscape condition, but three other metrics represent the categories of hydrology geomorphology and are listed within those sections below.

- % Natural Land Cover in Catchment

- % Tree Canopy in Riparian Zone in Catchment
- % Natural Land in Riparian Zone in Catchment
- % Impervious Cover in Catchment
- % Managed Turf Grass in Catchment

University of Wisconsin SILVIS Laboratory

The SILVIS lab provides block level data on population density, housing density, and change in housing density from the decennial U.S. Census Data. The most recent data available are from the 2010 census.

- Housing Unit Density

Chesapeake Conservancy

In cooperation with Washington College, Chesapeake Conservancy has developed a data set of active and abandoned mines that covers all of the state of Maryland. USGS mine location point datasets were used to locate mines, and then polygons were hand digitized around them.

- Chesapeake Conservancy Active and Abandoned Mines

EPA StreamCat

Developed by EPA's Office of Research and Development (ORD), the StreamCat dataset (EPA 2022a) 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 NHDPlus V2 catchments.

- Population Density

6.3.2 Hydrology

USGS/CBP High-Resolution Land Use/Land Cover

See overview under Landscape Condition.

- % Tree Canopy in Catchment
- % Wetlands in Catchment

EPA StreamCat

- See overview of StreamCat data under Landscape Condition. Density Road-Stream Crossings in Watershed

USGS Flow Alteration

USGS has developed a suite of flow alteration metrics for stream reaches throughout the Chesapeake Bay watershed (Maloney et al. 2021 based on Eng et al. 2019 hydrologic metrics) and has demonstrated linkages between flow alteration intensity and degraded biological condition of streams. The influence of altered flows on stream habitat and biota has been well studied (as reviewed by Poff and Zimmerman 2010). Maloney et al. (2021) used 12 hydrologic metrics developed by Eng et al. (2019) that characterize key aspects of the hydrologic regime including the duration, frequency, magnitude, and timing/seasonality of high and low flows; average annual skew of daily flows; and frequency of daily rises. Using separate random-forest models, they developed predictions of flow status for these hydrologic metrics. Predictions were in part informed by land use data. Maloney et al. (2021) also provided an overall index of flow alteration intensity by combining information from the individual metrics.

- Flow alteration intensity score

6.3.3 Geomorphology

EPA StreamCat

See overview of StreamCat data under Landscape Condition.

- Dam Density in Watershed
- Road Density in Riparian Zone, in Watershed

Sediment Models Associated with USGS Floodplain and Channel Evaluation Tool (FACET)

FACET (USGS 2019) is a Python tool developed by USGS that uses open-source modules to map the floodplain extent and derive reach-scale summaries of stream and floodplain geomorphic measurements from high-resolution digital elevation models (DEMs). Several metrics have been derived by USGS (Noe et al. 2020), building upon FACET to characterize aspects of stream geomorphic condition, as follows.

- Streambank lateral erosion
- Streambank change (m2)
- Streambank sediment flux – incorporates bank height, lateral erosion, and bulk density
- Streambed D50
- Streambank fine sediment flux
- Streambed fine sediment + sand cover

USGS/CBP High-Resolution Land Use/Land Cover

See overview under Landscape Condition.

- % Impervious in Riparian Zone in Catchment

6.3.4 Habitat

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 (NALCC) and the Northeast Association of Fish and Wildlife Agencies (NEAFWA), which coordinated a team of partners from 13 states, the U.S. Fish and Wildlife Service, nongovernmental organizations, and universities, to develop a regional conservation design for the Northeastern United States (Nature's Network 2021). The Conservation Design data were used to construct a series of metrics characterizing high quality habitat.

- Terrestrial, aquatic and imperiled species cores overlap
- Terrestrial and imperiled species cores overlap
- Terrestrial and aquatic cores overlap
- Aquatic and imperiled species cores overlap

- Terrestrial cores
- Aquatic Cores
- Core habitat and imperiled species
- Terrestrial core to core connectors

Maryland Biological Stream Survey - Stronghold Watersheds

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 from 2020 was provided by staff of DNR's Monitoring and Non-tidal Assessment (MANTA).

- MBSS Stronghold Watersheds

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 were used to construct habitat metrics for the MDHWA.

- Maryland Biodiversity Conservation Network (BioNet) by Tier

USGS/CBP High-Resolution Land Use/Land Cover

See overview under Landscape Condition.

- % Forest in Catchment

6.3.5 Water Quality

EPA WATERS

EPA has compiled summary information on the impairment status of waterbodies, i.e., waters listed as impaired through state 303(d) listings through its Assessment and Total Maximum Daily Load Tracking and Implementation System (ATTAINS) database. Data are available through the WATERS Geospatial Data Downloads site (EPA 2022b).

- Stream Impairment

USGS (SPAtially Referenced Regression On Watershed attributes) (SPARROW) Model

Developed by USGS (Ator 2019a, 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. Incremental loads in each catchment are a function of various land and water factors as well as source inputs. Despite the potential for correlation with land use/land cover, the incremental SPARROW data was retained because it could potentially provide additional information pollutant loading rates.

- USGS SPARROW sector specific loads for total nitrogen (TN), total phosphorus (TP), and sediment (incremental loads)

6.4 Correlations Among Metrics

Correlations among all proposed metrics were evaluated to identify relationships between individual candidate metrics. Correlations demonstrate how strongly (either positively or negatively) pairs of variables are related. This information was used to assess whether metrics were providing similar or redundant information. The range of Pearson correlations (r values) and a graphic depiction of correlation results are presented in Figure 3. The Pearson correlation coefficient is a test statistic that measures the relationship between two continuous variables. It is widely considered the best method for measuring the association between two variables because it provides insight into the magnitude and directionality of the correlation. Figure 3 provides a chart of correlation statistics in a visual format and is a commonly used tool for checking how closely correlated variables are. If not correlated, correlations should be near zero and if highly correlated, then one or more of the correlations will be significantly non-zero. Spatial data contains an inherent level of spatial autocorrelation, therefore we would expect some variables to show strong correlation. Correlation was found among many of the land cover metrics, especially those that had overlapping land cover classes (e.g. percent natural vs percent forest). Additionally, many of the SPARROW nitrogen, phosphorus, and suspended sediment variables were correlated among each other and with the various sediment flux and erosion variables. However, our overall findings were that the predictor variables identified for use in the predictive modeling (see Section 6.5) covered a wide range of geographic, geomorphic, aquatic, and landscape variables with acceptable and reasonable correlation.

In classical regression-based modeling approaches, correlation is used to implement feature selection. Specifically, when two or more variables are highly correlated one is removed from the list of data to be used in modeling efforts. Subsequent sections of this report detail the use of random forest (machine learning) modeling as an alternative approach to classical regression. With respect to correlation among metrics, it is worth noting that when a dataset has two (or more) correlated features, then from the viewpoint of the random forest model, any of these correlated features can be used as a predictor variable, with no concrete preference of one over the others. But once one of them is used, the importance of others is significantly reduced, since effectively the variance is already accounted for by the first feature. This is not an issue if you use feature selection; however, when interpreting the data, it can lead to the incorrect conclusion that one of the variables is a strong predictor while the others in the same correlated group are unimportant, while actually they are very close in terms of their relationship with the response variable.

While no specific variables were removed due to this correlation analysis, it provides a good indicator of whether the data being used cover a wide range of research foci. Figure 3 demonstrates that across many of the features there is relatively little to no correlation. Some features do exhibit higher levels of correlation, such as percent natural and percent forest; however this is to be expected. Understanding these relationships can be quite helpful later on when identifying variables to continually monitor or track and can be used to identify candidate replacements for those variables that may be cost or effort prohibitive to update regularly.

Figure 3. *Correlogram showing relationships between pairs of candidate watershed health metrics. The scale for Pearson correlation (r) values is from +1.0 (strong positive correlation) to -1.0 (strong negative correlation).*

6.5 Evaluating Predictive Ability of Metrics – Random Forest Model

Previous CHWA efforts for estimating watershed health relied on the use of indices. These were derived by normalizing all of the identified predictor variables and then using simple summations to derive sub-indices and an overall index of watershed health. This approach forces the assumption that all variables used in the index are equally important to watershed health, and additionally, that the sub-indices are of equal importance as well. The choice of whether to use simple sums to create sub-indices and then use those for a final index or to simply use all variables equally to design an index is not trivial. The flexibility possessed by the researcher in making this selection can lead to scores that look quite different, even if scores are normalized. Furthermore, the researcher has full discretion to include the variables that are either available to them or that they deem important, further introducing subjectivity into assessing watershed health.

For this pilot project, we demonstrate the value of using field observed data as proxy indices to indicate watershed health. Maryland provides an excellent opportunity to develop state-scale healthy watershed assessments due to the availability of statewide in-stream monitoring by the Maryland Biological Stream Survey (MBSS). The MBSS provides one-time (and sometimes repeat) sampling data collected from more than 5,000 stream segments since 1993. These data include robust IBIs for both fish and benthic macroinvertebrates (Southerland et al. 2007). Figure 4 provides the locations of each MBSS sampling event, demonstrating sampling coverage that covers the state of Maryland. Therefore, MBSS data can be used to explore the relationships of biological integrity to all the variables of interest in an objective and statistically relevant manner for the entire state.

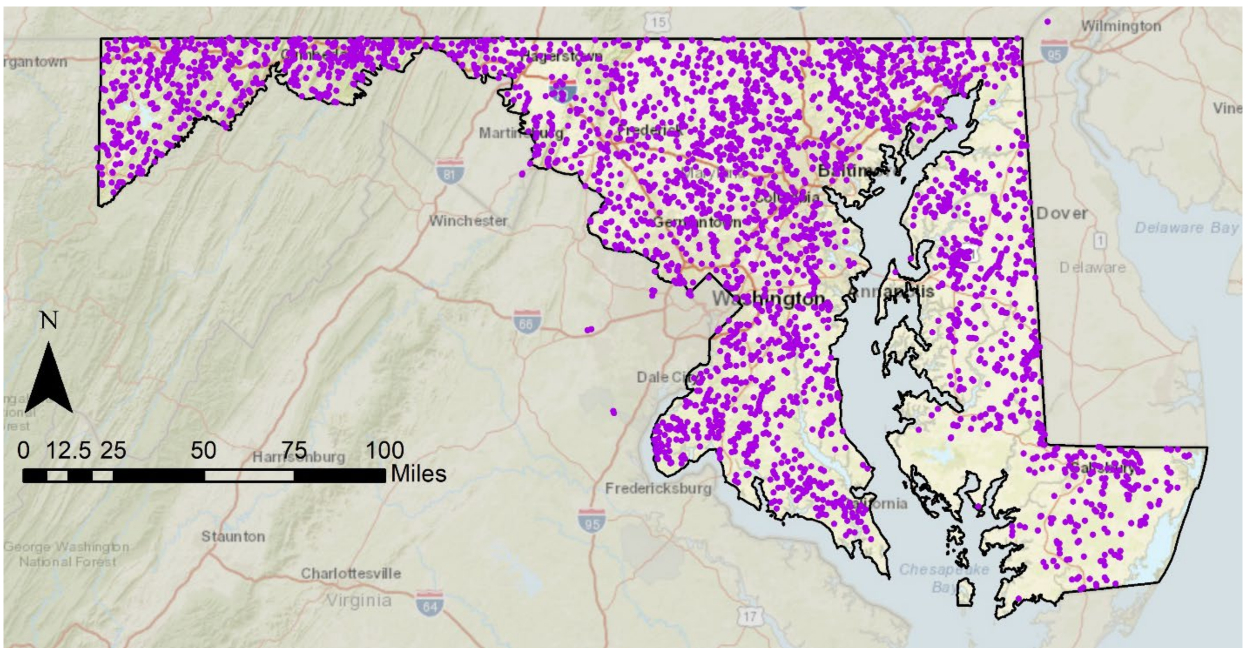


***Figure 4**. MBSS sampling locations within the state of Maryland.*

Therefore, where MBSS data were available, the MDHWA analyses used these stream data to examine relationships between landscape variables and stream response (in terms of Fish Index of Biological Integrity [FIBI] and Benthic Index of Biological Integrity [BIBI]) to assess the predictive power of proposed metrics for use in modeling stream condition. These models can subsequently be used to predict (1) current stream condition for unsampled areas and (2) future stream condition under new predicted future landscape conditions.

Similar multi-factor predictive models have been employed to predict stream quality from landscape, physical, and water chemistry data in other investigations. The healthy watersheds assessment for Wisconsin (Cadmus Group 2014b) used boosted regression tree models to predict stream nutrient and sediment concentrations, habitat ratings, and biological integrity ratings for fish and benthic macroinvertebrates, to provide values for catchments where direct data were lacking. A similar modeling approach could predict scores and compare them with known data. Hill et al. (2017) employed a random forest model with geospatial indicators of land use, land cover, climate, and other landscape features from

StreamCat to correctly predict the biological condition class of 75% of sites in national stream survey data. In the Chesapeake region, Maloney et al. (2018) developed random forest models to predict stream macroinvertebrate ratings for the Chesapeake Bay Basin-wide Index of Biotic Integrity for benthic macroinvertebrates (Chessie BIBI) from landscape, physical, and atmospheric deposition data to predict biological condition classes for unsampled watersheds. In earlier work within Maryland, Vølstad et al. (2003) integrated landscape and habitat assessments with MBSS data to predict benthic condition class under varying degrees of urbanization.

We used Random Forest (RF) modeling to predict FIBI and BIBI classification scores for each watershed within Maryland. RF modeling determines a set of individual decision trees that operate as an ensemble. Each individual tree in the RF predicts the class (good, fair, poor) by determining splits within each of the predictor variables. Ultimately, the class is determined by the greatest number of individual trees classifying them as such. The RF model was trained with a randomly selected subset of 80% of the FIBI (~3360 training samples) and BIBI (~3520 training samples) data, respectively. The distribution of the sample data across the three classifications was fairly consistent; therefore, we chose not to limit the sample further by using equal sample sizes. The RF algorithm uses a bootstrap sample of the training data to build the decision tree, and the remaining part of the training dataset is used for estimating out-of-bag error for each tree. Out-of-bag error is a method of measuring the prediction error of each tree within a random forest. At each node of the tree, a small sample of explanatory variables is chosen randomly to determine the best split.

This RF model was developed in Python 3.6 using the package Sklearn. Two main parameters are used to control the hypertuning of the model: n_estimators and max_features. N_estimators controls the number of decision trees to grow and max_features controls the number of predictor variables randomly sampled as candidates at each split. Using Sklearn's GridSearchCV function, all combinations of n_estimators from 100-2000 in steps of 50 were tested. For max_features, 5 to all features were considered. CVGridSearch allows for each combination of n_estimators and max_features to be tested and for the out-of-bag score to be used in determining the best set of parameters.

Overall accuracy of the FIBI and BIBI models was 0.64 and 0.61, respectively. Accuracy is determined by comparing the 20 percent withheld data for testing with the predicted classification of the model. Therefore, the RF correctly classified 64 percent and 61 percent of the FIBI and BIBI training data, respectively. These results align closely with that of Maloney et al. (2018) and other modeling efforts. Beyond overall accuracy, values for precision, recall, and F1 scores are provided for each model. Precision is the ratio of correct classifications to the total number of predicted classifications and is used to identify the correctness or classification. Recall is the ratio of correct classifications to the total number of classifications and is used to identify the sensitivity of classification. The F1 score is the harmonic mean of precision and recall and is intended as a balanced indicator of model performance. Tables 2 and 4 provide summary statistics for the random forest models for the FIBI and BIBI. Tables 3 and 5 show the confusion matrix for the FIBI and BIBI, respectively. Note that MBSS IBI ratings of "very poor" and "poor" were collapsed into a single classification of poor for these analyses. Overall, these matrices demonstrate that the RF models do a generally good job of differentiating between the poor and good classes, where much of the misclassification is found is within the fair category. This is likely due to smaller gradient changes between the fair and good categories in some cases, and/or the poor and fair categories.

Table 2. *FIBI accuracy, precision, recall and F1-score from the random forest modeling.*

FIBI Classification	Precision	Recall	F1-score
Poor	0.68	0.73	0.70
Fair	0.46	0.30	0.36
Good	0.67	0.79	0.73

Table 3. *FIBI confusion matrix.*

		Observed		
		Poor	Fair	Good
Predicted	Poor	186	32	38
	Fair	60	69	100
	Good	26	49	281

Table 4. *BIBI accuracy, precision, recall and F1-score from the random forest modeling.*

BIBI Classification	Precision	Recall	F1-score
Poor	0.71	0.75	0.73
Fair	0.41	0.29	0.34
Good	0.60	0.71	0.65

Table 5. *BIBI confusion matrix.*

		Observed		
		Poor	Fair	Good
Predicted	Poor	284	55	42
	Fair	87	70	82
	Good	29	45	185

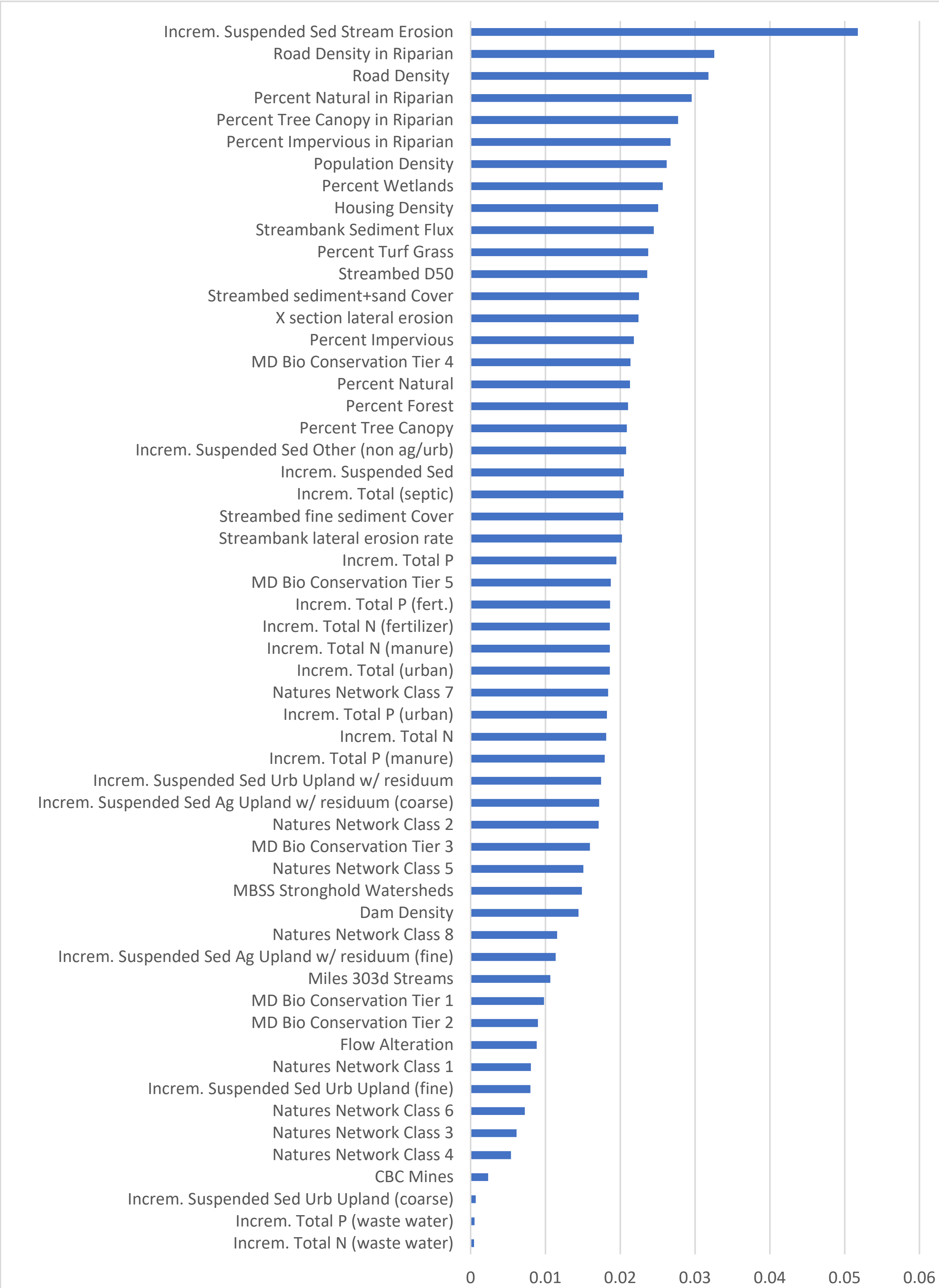


***Figure 5**. FIBI feature importance plot.*

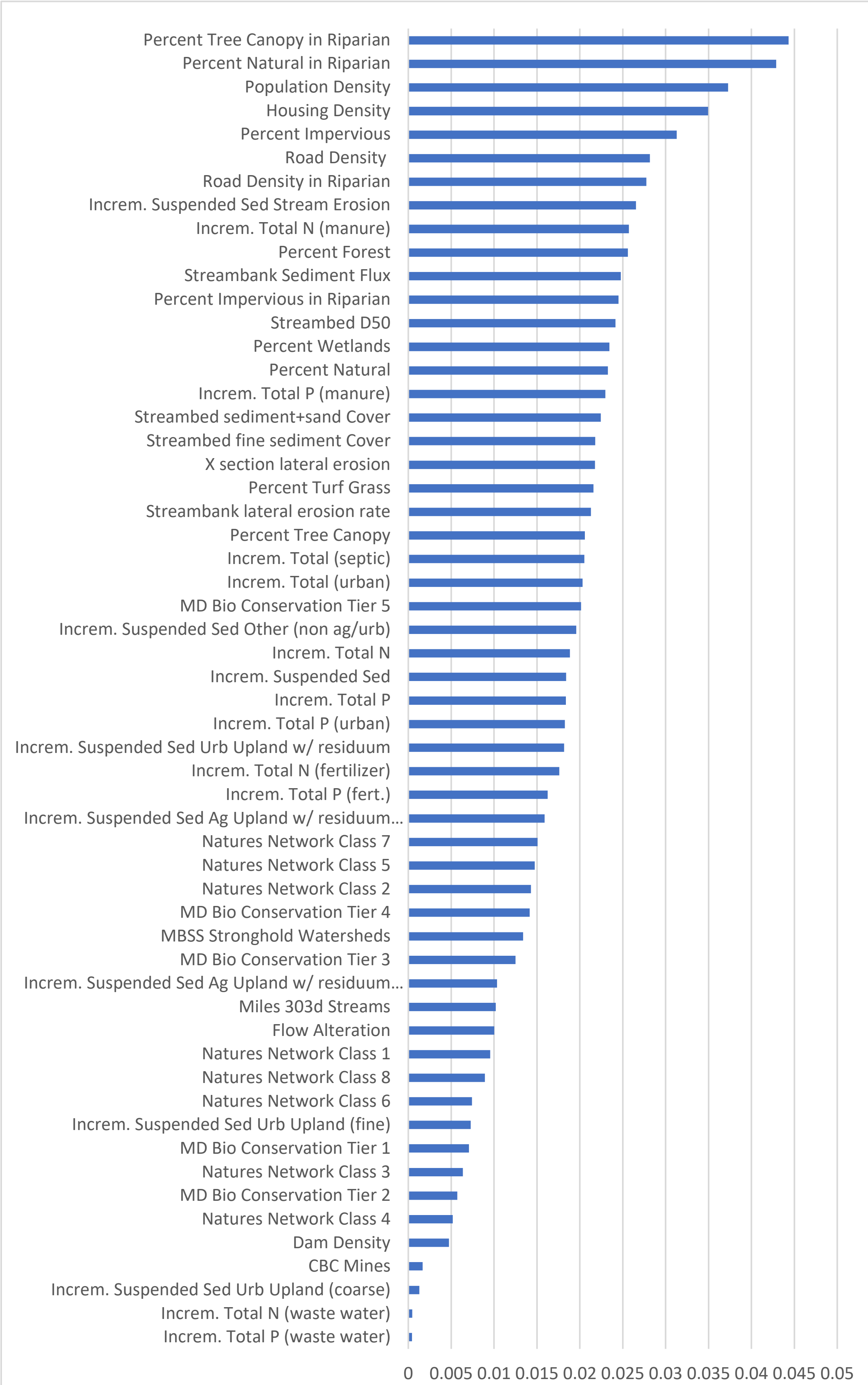


***Figure 6**. BIBI feature importance plot.*

Feature importance plots were developed to identify the relative importance of any feature within the random forest classification (Figures 5 and 6). This can also be referred to as the mean decrease in impurity and is calculated by measuring how effective the feature is at reducing uncertainty when creating decision trees within RFs. It is important to note that this is a measure of each variable's importance in determining various decision points within each of the random forest trees and does not necessarily reflect which variable is more important for determining watershed health. Nevertheless, the feature importance plots can provide a good relative indication of what metrics the model used to derive the highest accuracy. Across both the FIBI and BIBI some metrics were found to be consistently important, specifically many of the streambank and streambed erosion SPARROW sediment and nutrient, percent impervious, natural and forest cover within the riparian area and the overall catchment area as well as road density metrics These hold constant with previous research and are intuitively the types of metrics typically associated with assessing watershed health.

Following successfully tuning, running, and validating the RF models for the FIBI and BIBI classifications, the final step was to use the model to predict classifications for each catchment in Maryland. This method allows for an objective extrapolation of FIBI and BIBI classifications to each watershed, regardless of whether it was sampled in situ. Figures 7 and 8 provide the predicted FIBI and BIBI classifications based on the RF model.

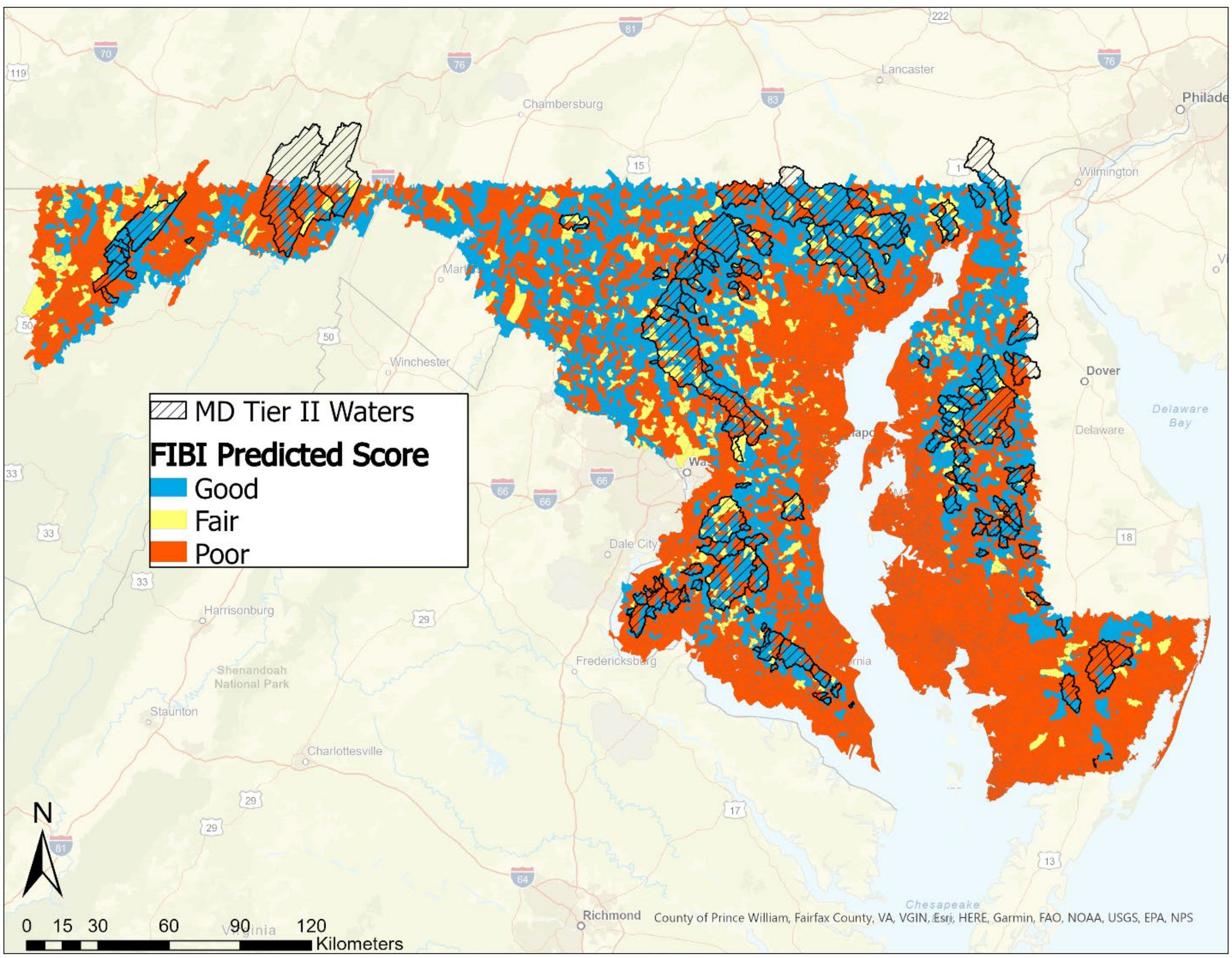


Figure 7. *Predicted FIBI score based on random forest predictive model.*

Previous efforts (e.g., PHWA and CHWA) relied on the development of sub-indices and an overall index of watershed health. While these are attractive as they provide a single value to assess health, they are highly subjective and choices by the researcher can easily influence whether a watershed is deemed “healthy” or not. For example, if ten metrics were used to develop two sub-indices, with three metrics being included in one sub-index and seven in another, and then those two indices were used together to develop an overall index, the “weight” of each metric on the overall index differs significantly. The sub-index with only three metrics means that each of those metrics has more than double the impact on the overall index compared to the metrics included in the sub-index with seven. While tempting, these methods can skew indices towards researchers own biases or simply fail to adequately capture what metrics truly are influencing watershed health.

This assessment demonstrates a fundamentally different way to approach assessing watershed health. First, the random forest removes researcher bias by allowing for all metrics determined to be potentially helpful in discerning watershed health to be included and evaluated equally. Second, using the MBSS data allows for field observations of healthy watersheds (or poor watershed health) to be used as the guide for the random forest model to select metrics of importance. This pairs real world observations with landscape data to determine what best explains these observations.

The implications of this new approach can be extended to the results as well. Figures 6 and 7 show the predicted BIBI and FIBI scores with Maryland Tier II watersheds overlayed on top. Healthy watersheds identified by Maryland are also generally identified as good or fair within the predicted catchments. At the catchment level there is now more information for identifying the heterogeneity within Tier II watersheds, and specific areas within a healthy watershed can be identified as candidate areas in need of improvement, or conversely, areas within the healthy watershed that are doing well and should be maintained. While not shown in this report, the predicted probabilities of the BIBI and FIBI scores are also included in the results and could be filtered to identify those areas where the good category was strongly predicted (e.g., predicted probabilities greater than 80%) to identify areas where the model was confident that the catchment was healthy. Alternatively, the predicted probabilities could be used to identify areas predicted to be poor with high certainty and thus represent areas in need of help. The key point to take away from this type of modeling effort is that the BIBI and FIBI scores are proxies for watershed health. Presumably, if you have benthic and fish indices of biologic integrity that are doing well, the catchment must also be quite healthy too. Previous efforts have created watershed health indices that are ambiguous, easily manipulated, and influenced by a high degree of researcher discretion. This approach provides an example of how to standardize and think about watershed health in a more objective manner.

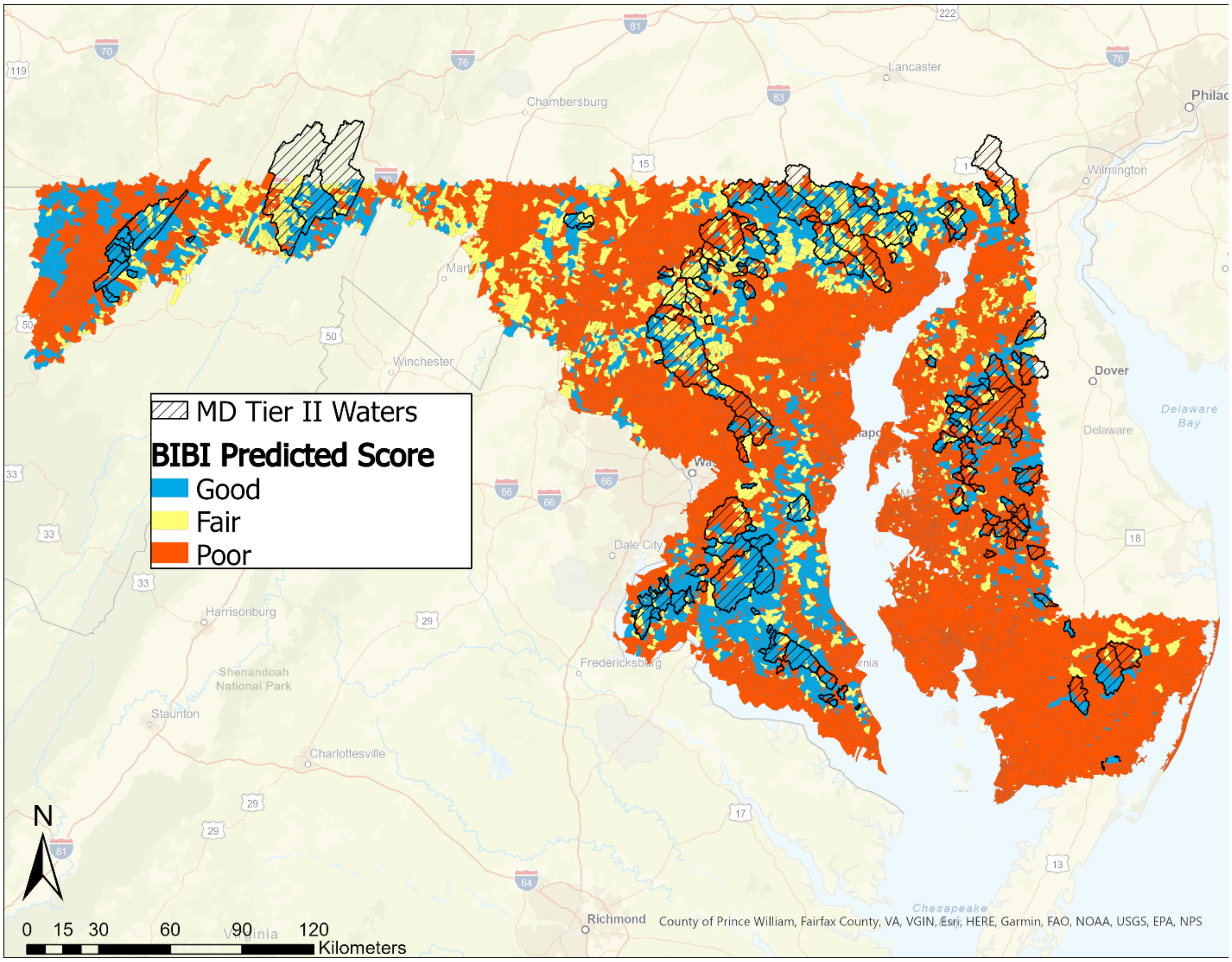


Figure 8. *Predicted BIBI score based on random forest predictive model.*

7. Developing an Assessment of Watershed Vulnerability

In addition to providing information about current conditions, one of the main objectives of the MDHWA was to provide information about the vulnerability of healthy watersheds to future degradation. Candidate vulnerability metrics, tailored to Maryland, were proposed based on literature and on recommendations from the project core team and advisors. Some of the metrics center on potential future land use change. Future land use will be important to assessing vulnerability, as land change will likely drive the trajectory of future watershed health and stream condition. Other vulnerability metrics include those characterizing water use, wildfire risk, and climate change 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 restoration or protection 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. The assessment could also be used to provide information on areas of potential improvement, for example, a large section of area under recent conservation that may improve in the coming decades.

A series of candidate metrics of watershed vulnerability was considered and evaluated as indicators of the susceptibility of watersheds to key stressors. Data were compiled and vulnerability metrics were developed for each of the NHDPlus V2 catchments within Maryland. A recommended set of metrics for assessing watershed vulnerability and data sources is provided in Table 6. Further details regarding data sources will be found in Appendix C and in metadata within the accompanying geodatabase.

Nearly all vulnerability data supported derivation of data at the catchment scale. While the three water use metrics were assigned to catchments, their values were downscaled from USGS HUC-12 data provided by EnviroAtlas, using a land-use weighted scaling, because finer-scale data were not available.

During the development of the CHWA, project partners had emphasized a strong interest in handling watershed vulnerability indicators separately to best support watershed managers in evaluating individual vulnerability factors, rather than compiling these metrics into a combined indicator. Similarly, the MDHWA vulnerability metrics are reported individually.

***Table 6**. Recommended watershed vulnerability metrics for catchments in Maryland.*

Sub-Index	Metrics	Notes: Data Source
Land Use Change	Recent Change in Forest (annual % change), 2013-2017	CBP high-resolution land use/land cover data, 2013/14 v 2017/18
	Recent Change in Impervious Cover (annual % change), 2013-2017	CBP high-resolution land use/land cover data, 2013/14 v 2017/18
	Projected Future % Natural Land Cover, 2035	CBP projections of future land use
	Projected Future % Impervious Cover, 2035	CBP projections of future land use
	% Protected Lands in Watershed	CBP Protected Lands dataset, Draft May 2022
	Change in housing unit density	SILVIS lab data, change based on difference from 1990 to 2010
Water Use	Agricultural Water Use in Catchment	Downscaled from HUC-12 data, EPA EnviroAtlas,2015
	Domestic Water Use in Catchment	Downscaled from HUC-12 data, EPA EnviroAtlas, 2015
	Industrial Water Use in Catchment	Downscaled from HUC-12 data, EPA EnviroAtlas, 2015
Wildfire Risk	Maryland Fire Priority Areas	MD DNR Forest Service, 2019
Climate Change	Change in Probability of Brook Trout Occurrence, Current Conditions v. Future Conditions	North Atlantic Landscape Conservation Cooperative (NALCC), Nature's Network Project

	(plus 2, 4, or 6 degrees C) in Catchment	
	Stream Temperature: Mean Summer Temp. (degrees C) Mean Summer Temp. (deg C) w/ Air Temp +2 deg C Mean Summer Temp. (deg C) w/ Air Temp +4 deg C Mean Summer Temp. (deg C) w/ Air Temp +6 deg C # Days/Year Temp. > 18 deg C # Days/Year Temp. > 22 degC	USGS EcoSheds (USGS no date, Walker et al. 2021)
	TNC Resilient Lands	The Nature Conservancy, 2016 data (TNC 2021b)
	Climate Stress Indicator in Catchment	North Atlantic Landscape Conservation Cooperative (NALCC), Nature's Network Project

7.1 Data Sources for Watershed Vulnerability Metrics

7.1.1 Land Use Change

USGS/CBP Chesapeake Bay Land Use/Land Cover Change

Annual rate of change in impervious and forest land use from 2013/14 to 2017/18 was provided by USGS/CBP, with the spring 2022 update to the CBP high-resolution land use/land cover that depicts 2017-2018 condition.

- Recent Change in Forest (annual % change), 2013-2018
- Recent Change in Impervious Cover (annual % change), 2013-2018

Chesapeake Bay Land Change Model

USGS has developed projections of anticipated future land cover change under differing scenarios. Projections cover a range of scenarios representing current zoning, growth management, forest conservation, and agriculture conservation. A Maryland scenario, known as the Maryland Regulatory Land Policy Best Management Practice (BMP) layer (approved by Maryland's Bay Cabinet), is a hybrid of growth management and conservation practices implemented over the time period 2017 to 2035.

- Projected Future % Natural Land Cover, 2035
- Projected Future % Impervious Cover, 2035

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. An interim update of the Protected Lands data was developed in spring 2022 by CBP for use in the MDHWA, but additional future updates are planned.

- % Protected Lands

7.1.2 Water Use

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. EnviroAtlas provided agricultural, domestic, and industrial water use data (derived from USGS water data) at the HUC-12 scale, which were downscaled to the catchment scale to match other MDHWA data.

- Agricultural Water Use in Catchment
- Domestic Water Use in Catchment
- Industrial Water Use in Catchment

7.1.3 Wildfire Risk

Maryland DNR – Forest Service

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.

- Maryland Fire Priority Area

7.1.4 Climate Change

Northeast Atlantic Landscape Conservation Cooperative, Nature Network Project – Brook Trout Probability of Occurrence

Brook trout probability of occurrence data were developed by the Northeast Atlantic Landscape Conservation Cooperative as part of the Nature Network Project 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.

- Four scenarios: Brook Trout Probability of Occurrence under current condition, plus 2 degrees C, plus 4 degrees C, and plus 6 degrees C.

USGS - Stream Temperature Model

USGS and its partners have developed a suite of temperature indicators for streams in the northeast. The SHEDS stream temperature model was developed to predict daily stream temperatures at both gaged and un-gaged catchments across the northeast U.S. based on geospatial characteristics and weather conditions. The model is based on a linear mixed effects framework that accounts for spatial and temporal correlations using a hierarchical Bayesian structure. Letcher et al. (2016) describe the initial development of this model framework, which was targeted to small streams. The following stream temperature metrics (Walker et al. 2021, USGS undated) were created:

- Mean Summer Temp. (degrees C)
- Mean Summer Temp. (degrees C) w/ Air Temp +2 degrees C
- Mean Summer Temp. (degrees C) w/ Air Temp +4 degrees C
- Mean Summer Temp. (degrees C) w/ Air Temp +6 degrees C
- # Days/Year Temp. > 18 degrees C
- # Days/Year Temp. > 22 degrees C

The Nature Conservancy – Resilient Lands

The Nature Conservancy (TNC) has developed extensive spatial data that provides information on climate-resilient sites to assist with conservation planning (TNC 2021a; 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 2021b).

- TNC Resilient Lands

Northeast Atlantic Landscape Conservation Cooperative, Nature Network Project– 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 as a metric representing the magnitude of stress that may be exerted on habitats in 2080.

- Climate Stress

8. Overlays

In addition to data that were used to construct the health and vulnerability metrics, other datasets were identified with potential to provide further information useful to watershed managers. Even though they do not lend themselves to computations at the catchment scale, these additional data (Table 7) can be used in conjunction with HWA data. These data address various management considerations, such as characterization of human diversity or protection of community drinking water supplies and can be included for future use as overlays.

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

An important human aspect of vulnerability is the consideration of diversity, equity, inclusion, and environmental justice (DEIJ) factors. Data on these factors, where available, can provide information to characterize community and social aspects of watershed condition. Managers can make use of DEIJ data to help address factors like demographics and community access to natural 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 (UMD) School of Public Health provide a suite of social indicators across the region and state.

Table 7. *Data sources identified at scales other than the NHDPlus catchment; data are appropriate to be provided as overlays for management use.*

Management Application	Data Source
Climate Adaptation	Maryland DNR Wetland Adaptation Areas, 2020
Source Water Protection	EPA Source Water data, 2020
Source Water Protection	MD: Community Water System's Surface Intake Watersheds, 2019
Source Water Protection	MD: Wellhead Protection Areas, 2019
Diversity, Equity, Inclusion and Justice (DEIJ)	CBP Environmental Justice and Equity Dashboard (Beta): demographic and socioeconomic data such as % persons of color, % low-income population, % linguistically isolated; social vulnerability index, 2021
Diversity, Equity, Inclusion and Justice (DEIJ)	MD Park Equity Mapping Tool: includes demographic and socioeconomic data such as proximity to public park space, concentration of low-income populations, concentration of non-white population, concentration of linguistically isolated population, and walkability, 2020
Fish Migration	Maryland DNR: Fish Barriers, 2019
Coldwater Stream Protection	Maryland DNR: Coldwater Resources
Coldwater Stream Protection	Maryland DNR: Springs
Resource Protection	Maryland DNR: Blue Infrastructure - High Priority Blue Infrastructure Shorelines and Watersheds, 2019
Resource Protection	CBP Protected Lands data 2018

Resource Protection	CBP Vulnerable Geology, 2018
Habitat Protection	Maryland DNR Forest Health, 2020
Habitat Protection	Black Duck Joint Venture, Ducks Unlimited, Atlantic Coast Joint Venture Black Duck Decision Support Tool: includes priority conservation and restoration watersheds based on availability of food energy to support Black Duck population objectives, 2022

8.1 Identified Data Sources for Overlays

<u>Maryland DNR – Wetland Adaptation Areas</u>

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.

<u>EPA Drinking Water Source Protection Area Data</u>

The U.S. Environmental Protection Agency 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 (EPA 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 NHDPlus V 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.

<u>MDE Source Water Protection</u>

Maryland Department of the Environment 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 is considered the Source Water Protection area. In this data set, wellhead protection areas are distinguished as to whether the source is in a confined or unconfined aquifer.

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 2021b), 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 EPA'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.

Maryland DNR and University of Maryland Park Equity Mapping Tool

The MDHWA 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 Maryland DNR and University of Maryland (2020) 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 environmental justice (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 MDHWA 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 in watershed health and vulnerability assessments.

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 (TNC 2022). 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 can 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 are both useful as overlay information, to support management and protection of important habitat for trout and other coldwater species.

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.

USGS/CBP Protected Lands

The CBP Protected Lands data layer is described in Section 7.1.1. In addition to creating a catchment-wide Percent Protected Lands metric, the complete coverage provided in the Protected Lands data can help local managers make decisions about where to focus conservation efforts.

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.

DNR – Maryland 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. 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 depict saltwater intrusion that 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 is a dataset from the U.S. Forest Service, Forest Health Protection Program that 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.

9. Recommendations for Tracking Watershed Health and Vulnerability

Using MDHWA metrics, the health and vulnerability of Maryland's watersheds can be tracked, offering information on the degree to which watershed health is being sustained or providing a warning sign that health may be declining or about to decline. These signals of change would be useful for management purposes, potentially helping to identify and address current or future stressors that threaten watershed health. While on-the-ground monitoring may be ideal for documenting and tracking conditions in healthy watersheds, resources for collecting field data are often limited. The MDHWA offers another way to characterize conditions, detect change, and target future monitoring if needed.

The metrics for watershed health and vulnerability compiled here represent a continuing step towards assessing and tracking conditions in the state-identified healthy watersheds, as well as other areas within the Bay watershed. As new data become available, this framework can be adapted to include new or updated data to provide a refined assessment of overall watershed condition or aspects of condition, as well as tracking changes in condition. Data will allow assessments of vulnerability using the currently available data or new data that can be incorporated at the catchment scale. The geodatabase is intended to provide a flexible framework for integrating additional data throughout Maryland, and to serve as a model for other state-specific assessments as well as the next version of the CHWA.

Some metrics lend themselves to being updated with new versions of datasets that are scheduled or likely to be updated. For example, metrics based on Chesapeake Bay high-resolution land use/land cover data can be updated at regular intervals as those data are slated to be refined frequently based on newly acquired imagery. Metrics that are derived from Maryland agencies or national sources such as EPA's StreamCat and EnviroAtlas can be updated when periodic updates of those datasets become available, although a schedule of updates has not been established. In practice, it may be useful to develop a regular schedule for updating metrics (e.g., update land use/land cover metric on four-year cycle, consistent with CBP's planned updates to its land use/land cover data). These updates can provide signals of change, while the entire MDHWA may only be updated less frequently (e.g., once per decade). Four-year updates to the random forest model that incorporate new land use (or newly projected future land use) can be employed at these interim checkpoints.

Long-term tracking of stream and watershed conditions in healthy watersheds may ideally make use of two types of data, both from actual or direct monitoring and also from indicators derived from landscape and other metrics available at a broad spatial scale. Given that monitoring data are not likely to be available at all locations or perhaps not at a frequency that would be desired, metrics such as those provided by the MDHWA can be useful predictors of condition. The relationships between metrics and diagnostic measures of stream and watershed condition can be assessed at locations where data are available and used to build models for predicting stream and watershed health applicable elsewhere.

9.1 Future Data and Topics of Interest

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 (EPA 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 NHDPlus V2 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 (EPA 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.

Additional Forest Health Data

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 United States Forest Service (USFS)-coordinated layers.

Accumulated Watershed Land Use/Land Cover

Accumulated watershed-wide values for land use/land cover can be incorporated as metrics for NHDPlus V2 catchments. Accumulated watershed values, i.e., characterizing lands not just within an individual catchment, but across its entire upstream drainage area, have been computed by USGS/CBP for the catchments in most areas of Maryland. However, at the time of analysis, CBP land use/land cover data for 2017/18 for calculating accumulated values for some of Maryland's catchments located outside of the Chesapeake Bay watershed were not available. Once data are developed for the complete upstream areas, include headwaters draining to all of Maryland's catchments, accumulated land use/land cover values calculated for these remaining areas. USGS/CBP plans to include these values in the next version of the CHWA.

Effective Impervious Cover

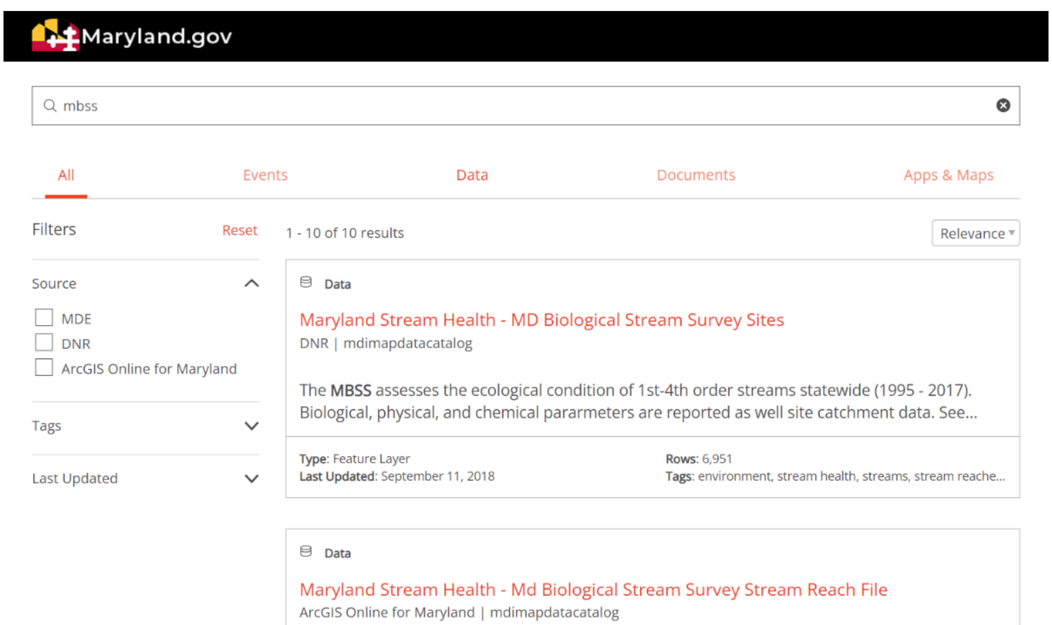
While impervious cover throughout a watershed can affect stream condition, impervious area that is most directly connected to streams hydrologically may have a relatively greater impact. The term "effective impervious cover" refers to the impervious area in catchment that is directly connected to stream channels (i.e., precipitation falling on that area is effectively transported to stream) (EPA 2022c). Methods to determine effective impervious cover include spatial analysis of impervious cover combined with stormwater infrastructure overlays, or application of published empirical relationships between total and effective impervious area. USGS/CBP is considering conducting future analyses to create a metric for effective impervious cover. Potentially, this effective impervious cover may be a useful explanatory variable, potentially with greater power in predicting watershed health than the current MDHWA metric for total impervious cover.

10. Management Applications and Availability of Maryland Healthy Watersheds Assessment Data

The assessment framework, metrics, and geodatabase created for the Maryland Healthy Watersheds Assessment are intended to be useful for a variety of management applications. Primarily, the assessment will support the Chesapeake Bay Program and its Maryland partners in detecting signals of change in Maryland Tier II waters and providing information useful to support strategies to protect and maintain watershed health. In particular, indicators of vulnerability may help to provide an "early warning" of factors that could cause future degradation, allowing for steps toward communication and management actions to head off these potential negative effects.

MDHWA data can help managers prioritize healthy watersheds in terms of risk and the need for additional protective measures, using available information on their current condition, existing protections, and relative vulnerability. The landscape metrics in the MDHWA, along with other, direct measures of stream and watershed health, can provide "signals of change" to identify locations where ecological health is threatened and where appropriate steps can be taken to help prevent further degradation.

MDHWA data will be made available through iMAP, Maryland's online mapping portal for public use (Figure 9). The MDHWA can contribute to watershed assessment and protection efforts within an overall management framework that includes interactive maps, as well as downloadable data for watershed health and vulnerability metrics. MDHWA data will also be hosted on the CBP Chesapeake Open data portal.



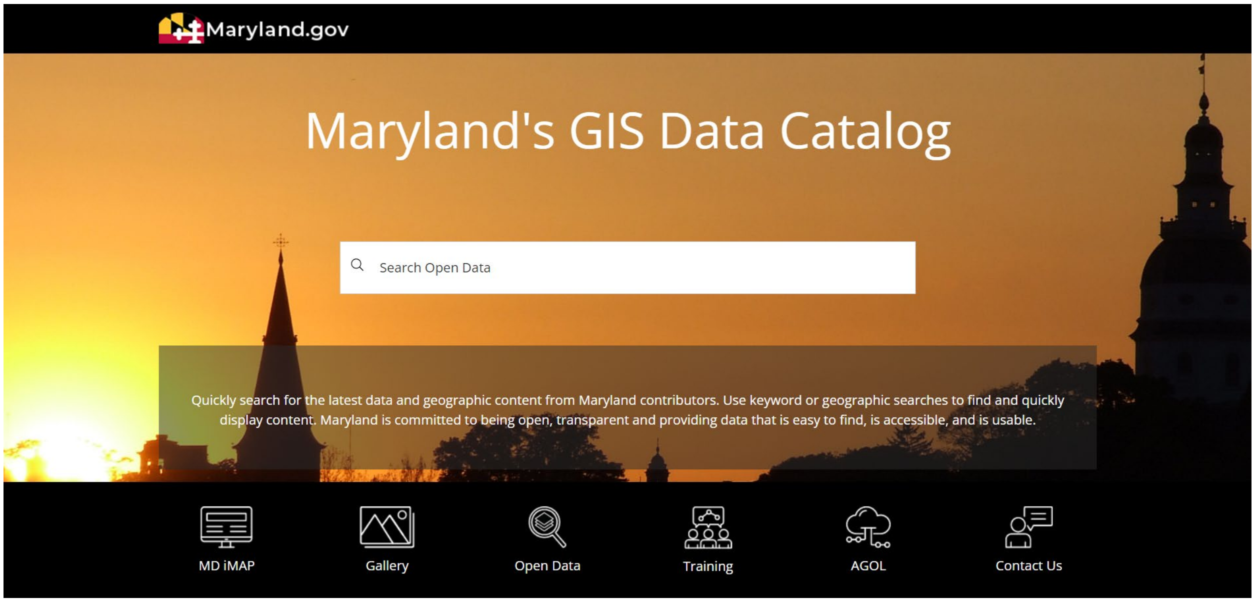


Figure 9. *Examples from Maryland iMAP Online GIS Data Catalog.*

MDE's Tier II program staff, other state agency programs, and other data users can apply the information from the MDHWA and other sources pro-actively to implement improvements to policies, incentives, plans, and tools that will reduce losses of natural lands and other stressors that threaten watershed health. For example, MDE can use MDHWA data to track conditions in its Tier II waters, identify and evaluate potential threats to watershed health, and adapt management strategies to best protect and maintain these high-quality waters. Similarly, local agencies, land trusts, and other conservation organizations can use data to guide watershed protection. The MDHWA provides a flexible framework that can be updated periodically and augmented with new or more specific local data.

Because the MDHWA provides data on all catchments in Maryland, not just those within areas currently designated as healthy watersheds, it can also potentially be used to screen watersheds to identify high quality ecosystems that are not currently protected as healthy watersheds. MDHWA data can help to better understand watershed health, vulnerability, and resilience of catchments across the state and could potentially be used to identify watersheds that are stressed.

Other potential management applications of the MDHWA include:

- Examining/quantifying stressors affecting stream health (not just in healthy watersheds)
- Assessing landscape factors affecting fish habitat in non-tidal and tidal watersheds
- Identifying areas of brook trout populations susceptible to climate shifts
- Engagement with local governments to inform land use decisions
- Supporting land trusts and other organizations managing protected lands
- Source water protection (for drinking water)
- Examining spatial patterns of housing density and land use change associated with watershed health

The geodatabase produced for this assessment provides a framework for data management and additional analyses, with data for the various metrics organized by NHDPlus V2 Catchment (with the identifier "COMID"). The structure is simple, presenting the MDHWA watershed health metrics within the five topic areas, and vulnerability metrics within the four topic areas. In addition, the geodatabase includes other catchment attributes to assist the user in sorting data for display and analysis. The geodatabase provides a straightforward display of catchment data, readily integrated with other user data, and the ability to conduct queries by location, score, or other factors defined by the geodatabase user. Data will be made available through the CBP online platform and Maryland iMAP for a variety of users including state and local governments and watershed groups.

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Appendix A

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Appendix B

Literature Review

The follow material is excerpted from *Maryland Healthy Watersheds Assessment: Strategy for Development of the Maryland Healthy Watershed Assessment* (Tetra Tech 2021)

B.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 (weblink 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 benthic macroinvertebrate 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 <u>forest land cover</u> 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. <u>Wetlands</u>, 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 <u>past land use and modifications,</u> 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.*

<u>Local-scale land cover and modifications</u> (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*
    - *Canopy loss in stream buffers*

- *Reservoirs*
- *Wastewater treatment plants*

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 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.

B.2 USGS Literature Review on Stream Stressors

A concurrent literature review project 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, 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).

B.3 USGS Literature Review on Landscape Influence on Stream Ecosystems

Another concurrent literature review, conducted by Billy Justus of USGS, centered on landscape influence on streams in the Chesapeake Bay watershed. This effort was 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.

Appendix C

List of MDHWA Metrics and Source Data

	MDHWA Watershed Condition Metrics					
Category	**Metrics**	**Notes / Data Source**	**Notes / Future Data Availability**	**Field Name**	**Metric Description**	**Data Source Details**
Landscape Condition	% Natural Land Cover in Catchment	CBP high-resolution land use/land cover data, 2017/18	CBP high-resolution land use/land cover data - future iterations (e.g., 2021 and future updates)	PctNat17	Percent Forest + Percent Wetland Also includes Natural Succession and Harvested Forest.	Chesapeake Bay Program Office (CBPO 2022a). Metric data provided by USGS Chesapeake Bay Program. Includes the following: Forest, Other Tree Canopy, Tidal Wetlands (all LCs), Riverine Wetlands (all Land Covers [LCs]), Terrene Wetlands (all LCs), Natural Succession, Harvested Forest. 18-Class types included: FORE, TDLW, TERW, RIVW, TCOT, NATS, HARF
	% Tree Canopy in Riparian Zone in Catchment	CBP high-resolution land use/land cover data, 2017/18	CBP high-resolution land use/land cover data - future iterations (e.g., 2021 and future updates)	PctTC17	Percent Tree Canopy in the Riparian zone	CBPO (2022a). Metric data provided by USGS Chesapeake Bay Program, reflecting application of 30-m riparian buffer. Includes Forest and Tree Canopy classes, except Tree Canopy over Impervious Surfaces. 18-Class types included: FORE, TCOT, TCTG.
	% Natural Land Cover in Riparian Zone in Catchment	CBP high-resolution land use/land cover data, 2017/18	CBP high-resolution land use/land cover data - future iterations (e.g., 2021 and future updates)	PctRpNat17	Percent Forest + Percent Wetland, also includes Natural Succession and Harvested Forest.	CBPO (2022a). Metric data provided by USGS Chesapeake Bay Program, reflecting application of 30-m riparian buffer. Includes the following: Forest, Other Tree Canopy, Tidal Wetlands (all LCs), Riverine Wetlands (all Land Covers [LCs]), Terrene Wetlands (all LCs), Natural Succession, Harvested Forest. 18-Class types included: FORE, TDLW, TERW, RIVW, TCOT, NATS, HARF
	Population Density in Watershed	StreamCat, 2010 census data	StreamCat - future census data (2020 and beyond)	PopDens_ws	Mean population density (people/square km) within watershed	Population density in the watershed for each NHDPlus V2 catchment. Data was taken directly from StreamCat. Unit: people/km2
	Housing Unit Density	SILVIS lab data, based on 2010 census	2020 census data still in development by SILVIS	HUDEN_2010	Housing units/km2	The University of Wisconsin SILVIS lab provides block level data on population density, housing density, and change in housing density from the decennial U.S. Census Data. The most recent data available are from the 2010 census. Housing unit density for 2010 was calculated using zonal statistics from the SILVIS provided density raster and the NHDPlus V2 catchments.
	Chesapeake Conservancy Active and abandoned mines	Chesapeake Conservancy, digitized boundaries of active and abandoned extractive areas	Updates to Chesapeake Conservancy data	CBC_active_abandoned	Area of mines, km2	In cooperation with Washington College, Chesapeake Conservancy developed a data set of active and abandoned mines that covers all of the state of Maryland. USGS mine location point datasets were used to locate mines, and then polygons were hand digitized around them. Additional metadata within shapefile.
	% Impervious Cover in Catchment	CBP high-resolution land use/land cover data, 2017	CBP high-resolution land use/land cover data - future iterations (e.g., 2021 and future updates)	PctImp17	Percent Impervious Cover	CBPO (2022a). Metric data provided by USGS Chesapeake Bay Program. All impervious classes are included in this metric including solar panel arrays, extractive impervious surfaces, and trees over impervious surfaces. 18-Class types included: IMPS, IMPO, TCIS, ROAD
	% Managed Turf Grass in Catchment	CBP high-resolution land use/land cover data, 2017	CBP high-resolution land use/land cover data - future iterations (e.g., 2021 and future updates)	PctTurf17	Percent Managed Vegetation	CBPO (2022a). Metric data provided by USGS Chesapeake Bay Program. Includes 2 classes: Turf Grass and Tree Canopy Over Turf Grass. 18-class types included: TURF, TCTG
Hydrology	% Tree Canopy in Catchment	CBP high-resolution land use/land cover data, 2017	CBP high-resolution land use/land cover data - future iterations (e.g., 2021 and future updates)	PctTC17	Percent Tree Canopy	CBPO (2022a). Metric data provided by USGS Chesapeake Bay Program. Includes Forest and Tree Canopy classes, except Tree Canopy over Impervious Surfaces. 18-Class types included: FORE, TCOT, TCTG

	Density Road-Stream Crossings in Watershed	StreamCat, 2010 data	StreamCat - future census data (2020 and beyond)	RdCrs_ws	Density of roads-stream intersections (2010 Census Tiger Lines-NHD stream lines) within watershed (crossings/square km)	Road crossings over streams in the watershed for each NHDPlus V2 catchment. Data was taken directly from StreamCat. Unit: road crossings over streams/km2
	% Wetlands in Catchment	CBP high-resolution land use/land cover data, 2017	CBP high-resolution land use/land cover data - future iterations (e.g., 2021 and future updates)	PctWL17	Percent wetlands	CBPO (2022a). Metric data provided by USGS Chesapeake Bay Program. Includes all wetlands; includes Riverine, Tidal and Terrene wetlands (including forested and Tree Canopy over other). Refer to high-resolution 54-class descriptions.
	Flow Alteration Intensity Score	USGS flow alteration research	na	Maloney_flowAlteration	Flow alteration intensity score (range 0-12)	USGS has developed a suite of flow alteration metrics for stream reaches throughout the Chesapeake Bay watershed (Maloney et al. 2021, based on hydrologic metrics of Eng et al. 2019) and has demonstrated linkages between flow alteration intensity and degraded biological condition of streams. Using separate random-forest models, USGS developed predictions of flow status for 12 hydrologic metrics. Their overall flow alteration intensity indicator provides combined information from the individual metrics.
Geomorphology	Dam Density in Watershed	StreamCat, 2013 data	StreamCat updates	DamDensity_ws	Density of georeferenced dams within watershed (dams/ square km)	Density of georeferenced dams within the upstream watershed (Ws). Shapefile of georeferenced dam locations (points) and associated dam and reservoir characteristics (where available), such as dam height, reservoir volume, and year constructed from the National Inventory of Dams.
	Road Density in Riparian Zone, in Watershed	StreamCat	StreamCat updates	RdDensRp100_ws	Density of roads (2010 Census Tiger Lines) within watershed and within a 100-m buffer of NHD stream lines (km/square km)	Mean of all rddens values within the upstream watershed (Ws). Raster of road density calculated using 2010 Census Tiger Line files and the ArcGIS Line Density tool.
	Streambank lateral erosion	USGS (Noe et al. 2020) derived from FACET (USGS 2019)	na	sb_lat_erosion	Streambank lateral erosion rate, cm yr-1	Data represents the predicted streambank lateral erosion rate. USGS (Noe et al. 2020) derived streambank and sediment variables from FACET. FACET (USGS 2019) is a Python tool developed by USGS that uses open source modules to map the floodplain extent and derive reach-scale summaries of stream and floodplain geomorphic measurements from high-resolution digital elevation models (DEMs). Data are summarized to the NHDPlus V2 catchment scale.
	Streambank erosional change	USGS (Noe et al. 2020) derived from FACET (USGS 2019)	na	sb_x_erosion_change	Streambank cross-sectional lateral erosion area change, m2 yr-1	Data represents the predicted streambank cross-sectional lateral erosion area change. USGS (Noe et al. 2020) derived streambank and sediment variables from FACET. FACET (USGS 2019) is a Python tool developed by USGS that uses open source modules to map the floodplain extent and derive reach-scale summaries of stream and floodplain geomorphic measurements from high-resolution digital elevation models (DEMs). Data are summarized to the NHDPlus V2 catchment scale.
	Streambank sediment flux – incorporates bank height, lateral erosion, and bulk density	USGS (Noe et al. 2020) derived from FACET (USGS 2019)	na	sb_sediment_flux	Streambank sediment flux, kg-sed m-1 yr-1	Data represents the predicted streambank sediment flux. USGS (Noe et al. 2020) derived streambank and sediment variables from FACET. FACET (USGS 2019) is a Python tool developed by USGS that uses open source modules to map the floodplain extent and derive reach-scale summaries of stream and floodplain geomorphic measurements from high-resolution digital elevation models (DEMs). Data are summarized to the NHDPlus V2 catchment scale.

	Streamed D50	USGS (Noe et al. 2020) derived from FACET (USGS 2019)	na	sb_D50	Streambank D50 particle size, mm	Data represents the predicted streambank D50 particle size (mm). USGS (Noe et al. 2020) derived streambank and sediment variables from FACET. FACET (USGS 2019) is a Python tool developed by USGS that uses open source modules to map the floodplain extent and derive reach-scale summaries of stream and floodplain geomorphic measurements from high-resolution digital elevation models (DEMs). Data are summarized to the NHDPlus V2 catchment scale.
	Streambank fine sediment flux	USGS (Noe et al. 2020) derived from FACET (USGS 2019)	na	sb_fine_sed_flux	Streambank fine sediment flux, kg-finesed m-1 yr-1	Data represents the predicted streambank fine sediment flux. USGS (Noe et al. 2020) derived streambank and sediment variables from FACET. FACET (USGS 2019) is a Python tool developed by USGS that uses open source modules to map the floodplain extent and derive reach-scale summaries of stream and floodplain geomorphic measurements from high-resolution digital elevation models (DEMs). Data are summarized to the NHDPlus V2 catchment scale.
	Streambed fine sediment + sand cover	USGS (Noe et al. 2020) derived from FACET (USGS 2019)	na	sb_fine_sed_sand	Streambed fine sediment + sand cover, percent	Data represents the predicted fine sediment and sand cover. USGS (Noe et al. 2020) derived streambank and sediment variables from FACET. FACET (USGS 2019) is a Python tool developed by USGS that uses open source modules to map the floodplain extent and derive reach-scale summaries of stream and floodplain geomorphic measurements from high-resolution digital elevation models (DEMs). Data are summarized to the NHDPlus V2 catchment scale.
	% Impervious in Riparian Zone in Catchment	CBP high-resolution land use/land cover data, 2017	CBP high-resolution land use/land cover data - future iterations (e.g., 2021 and future updates)	PctRpImp	Percent impervious in riparian zone	CBPO (2022a). Metric data provided by USGS Chesapeake Bay Program, reflecting application of 30-m riparian buffer. All impervious classes are included in this metric including solar panel arrays, extractive impervious surfaces, and trees over impervious surfaces. 18-Class types included: IMPS, IMPO, TCIS, ROAD
Habitat	Nature's Network Conservation Habitats in Catchment	Landscope / Nature's Network Conservation Design for the Northeast	Updates to Landscope / Nature's Network Conservation Design for the Northeast	NatNetwork(01-08)	Nature's Network Conservation Design depicts 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. Includes Core Habitat for Imperiled Species, Terrestrial Core-Connector Network, Grassland Bird Core Areas, Lotic Core Areas, and Lentic Core Areas.	From Nature's Network Conservation Design for the Northeast, available at http://naturesnetwork.org/data-tools/download-tables/. Conservation Design data are a simplified composite layer, available along with its components including Core Habitat for Imperiled Species, Terrestrial Core-Connector Network, Grassland Bird Core Areas, Lotic Core Areas, and Lentic Core Areas. Further information is available at https://www.naturesnetwork.org/
	MBSS Stronghold Watersheds	Maryland DNR MANTA. 2020 data	na	MBSS_stronghold_watershed_sqkm	2020 version - Stronghold Watersheds were developed to provide information for the conservation of freshwater fauna.	DNR has 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 was provided by DNR's Monitoring and Non-Tidal Assessment (MANTA) staff. Target areas were summarized for the total km2 in each NHDPlus V2 catchment.

	Maryland Biodiversity Conservation Network (BioNet)	Priority areas for terrestrial and freshwater biodiversity conservation	DNR updates	MD_BioNet_Tier[1-5]	Maryland's Biodiversity Conservation Network (BioNet) is a digital map that prioritizes areas for terrestrial and freshwater biodiversity conservation.	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: 1) Only known occurrences of species and habitats, 2) Globally rare species and habitats, 3) State rare species and habitats, 4) Animals of Greatest Conservation Need, 5) Watch List plants and indicators of high-quality habitats, 6) Animal assemblages (e.g., colonial nesting waterbirds, forest interior species), 7) Hotspots for rare species and habitats, 8) Intact watersheds, 9) Wildlife corridors and concentration areas. BioNet provides a ranked prioritization of areas by their significance for biodiversity conservation. BioNet was developed as a tool for the Natural Heritage Program and its conservation partners to use for proactive land conservation activities, such as targeting for acquisitions and easements, locating appropriate areas for project mitigation or habitat restoration, and planning for areas that require management to sustain dwindling species and habitats. The criteria used within BioNet primarily have a dual focus on both the most irreplaceable species and habitats, as well as on the habitats that concentrate larger numbers of rare species.
	% Forest in Catchment	CBP high-resolution land use/land cover data, 2017	CBP high-resolution land use/land cover data - future iterations (e.g., 2021 and future updates)	PctFor17	Percent Forest	CBPO (2022a). Metric data provided by USGS Chesapeake Bay Program. This metric characterizes larger forest habitats (>= 1 acre, 240-ft width) required by forest-interior dwelling birds and other forest-dependent species. 18-Class included: FORE.
Water Quality	% of Stream Length Impaired in Catchment	EPA ATTAINS / WATERS	Future versions of EPA ATTAINS and State data	stream_imp_miles	Percent Impaired Streams in Local Catchment	Under Section 303(d) of the CWA, states, territories, and authorized tribes (referred to here as states) are required to develop lists of impaired waters. These are waters that are too polluted or otherwise degraded to meet the state water quality standards. The law requires that these jurisdictions establish priority rankings for waters on the lists and develop TMDLs for these waters. Note: the CWA Section 303(d) list of impaired waters does not contain impaired waters with an established TMDL, impaired waters for which other pollution control mechanisms are in place and expected to attain water quality standards, or waters impaired as a result of pollution. For more information, please see EPA's Integrated Reporting Guidance at: http://www.epa.gov/tmdl/integrated-reporting-guidance. 2015. Data are summarized by EPA ATTAINS and are available through EPA WATERS (EPA 2022b).

	USGS SPARROW sector specific loads (manure, fertilizer, urban nonpoint, urban wastewater, septic, streambank and uplands) for TN, TP, and sediment (incremental loads)	USGS regional model	Future iterations of SPARROW	tp_ip, tp_ip_poin, tp_ip_fert, tp_ip_manu, tp_ip_urb, tn_in, tn_in_poin, tn_in_fert, tn_in_sept, tn_in_manu, tn_in_urb, ss_is, ss_is_strm, ss_is_othr, ss_is_ufin, ss_is_umed, ss_is_ures, ss_is_afin, ss_is_ares	Sector specific incremental loads Incremental total phosphorus load (kg/yr) and individual sectors (each in kg/yr): Incremental total phosphorus load from the following sectors (each in kg/yr): point-source wastewater treatment facilities, fertilizer applications, manure applications, and urban non-point sources Incremental total nitrogen load (kg/yr) and individual sectors (each in kg/yr): Incremental total nitrogen load from wastewater treatment facility point sources, fertilizer applications, septic system effluent, manure applications, and other urban non-point sources Incremental suspended-sediment load (megagrams/yr) and Incremental suspended-sediment load from individual sectors (each in megagrams/yr): streambank erosion, non-agricultural and non-urban uplands, urban uplands with fine sediment, urban uplands with medium or coarse sediment, urban uplands with residuum, agricultural uplands with fine sediment, and agricultural uplands with medium or coarse sediment or residuum	SPAtially Referenced Regression On Watershed attributes (SPARROW) models were developed to quantify and improve the understanding of the sources, fate, and transport of nitrogen, phosphorus, and suspended sediment in the northeastern United States (Ator 2019 a, 2019b). Excessive nutrients and suspended sediment from upland watersheds and tributary streams have contributed to ecological and economic degradation of northeastern surface waters. Recent efforts to reduce the flux of nutrients and suspended sediment in northeastern streams and to downstream estuaries have met with mixed results, and expected ecological improvements have been observed in some areas but not in others. Effective watershed management and restoration to improve surface-water quality are complicated by the multitude of nutrient sources in the Northeast and the multitude of natural and human landscape processes affecting the delivery of nutrients and suspended sediment from upland areas to and within surface waters. Individual models were constructed representing streamflow and the loads of total nitrogen, total phosphorus, and suspended sediment from watersheds draining to the Atlantic Ocean from southern Virginia through Maine.
	MDHWA Watershed Vulnerability Metrics					
Category	**Metrics**	**Notes / Data Source**	**Notes / Future Data Availability**	**Field Name**	**Metric Description**	**Data Source Details**
Land Use Change	Recent Change in Forest (annual % change), 2013-2017	CBP high-resolution land use/land cover data, 2013/14 v 2017/18	CBP high-resolution land use/land cover data - future iterations (e.g., 2021 and future updates)	PctForChg (catchment), PctForChgWs (accumulated)	Annual percent change in forest for time period 2013/14 to 2017/18	Chesapeake Bay Program Office (CBPO 2022b). Change in FORE class.

	Recent Change in Impervious Cover (annual % change), 2013-2017	CBP high-resolution land use/land cover data, 2013/14 v 2017/18	CBP high-resolution land use/land cover data - future iterations (e.g., 2021 and future updates)	PctImpCHG (catchment), PctImpCHGWs (accumulated)	Annual percent change in impervious cover for time period 2013/14 to 2017/18	CBPO (2022b). Change in impervious cover. Impervious includes classes IMPS, IMPO, TCIS, ROAD
	Projected Future % Natural Land Cover, 2035	CBP land change projections	CBP future updates of land use projections	PctNAT35 (catchment), PctWsNAT35 (accumulated)	Projected future percent natural land cover in year 2035	USGS/CBP. The data include percentages for impervious, natural, and agricultural land uses projected out to 2035. The 2035 values were calculated using forecasted land use acres from 2017 using the Chesapeake Bay Land Change Model. The state of MD used its 2021 custom scenario, while the remaining states used the current zoning 2021 scenario. The 2017 starting point for the model was derived using version 1 high-resolution data.
	Projected Future % Impervious Cover, 2035	CBP land change projections	CBP future updates of land use projections	PctIMP35 (catchment), PctWsIMP35 (accumulated)	Projected future percent impervious cover in year 2035	USGS/CBP. Impervious includes 3 classes: Impervious Roads, Impervious Non Road, and Tree Canopy Over Impervious. The data include percentages for impervious, natural, and agricultural land uses projected out to 2035. The 2035 values were calculated using forecasted land use acres from 2017 using the Chesapeake Bay Land Change Model. The state of MD used its 2021 custom scenario, while the remaining states used the current zoning 2021 scenario. The 2017 starting point for the model was derived using version 1 high-resolution data.
	% Protected Lands in Watershed	CBP Protected Lands data	Future iterations of CBP Protected Lands data		Percent of land protected	USGS/CBP. 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. An interim update (June 2022) was used in the MDWHA.
	Change in housing unit density	SILVIS lab data, change in housing unit density 1990-2010	SILVIS lab 2020 census and future data		Change in housing unit density	SILVIS lab data, change in housing unit density 1990 to 2010, based on 2010 census
Water Use	Agricultural Water Use in Catchment	EPA EnviroAtlas, 2015	Updates to USGS water use data	AgWaterUse	Daily agricultural water use in the HUC12 (million gallons per day).	Agricultural water use includes surface and groundwater that is self-supplied by agricultural producers or supplied by water providers (governments, private companies, or other organizations). Data summaries by HUC12 had been completed in previous CHWA. However, new zonal summary was run based on updated catchment boundary and land use land cover analysis to inform downscaling to catchment scale.

	Domestic Water Use in Catchment	EPA EnviroAtlas, 2015	Updates to USGS water use data	DomesticWaterUse	Daily domestic water use in the HUC12 (million gallons per day).	Domestic water use includes indoor and outdoor household uses, such as drinking, bathing, cleaning, landscaping, and pools. Domestic water can include surface or groundwater that is self-supplied by households or publicly-supplied. Data summaries by HUC12 had been completed in previous CHWA. However, new zonal summary was run based on updated catchment boundary and land use land cover analysis to inform downscaling to catchment scale.
	Industrial Water Use in Catchment	EPA EnviroAtlas, 2015	Updates to USGS water use data	IndustrialWaterUse	Daily industrial water use in the HUC12 (million gallons per day).	Industrial water use includes water used for chemical, food, paper, wood, and metal production. Only includes self-supplied surface water or groundwater by private wells or reservoirs. Industrial water supplied by public water utilities is not counted. Data summaries by HUC12 had been completed in previous CHWA. However, new zonal summary was run based on updated catchment boundary and land use land cover analysis to inform downscaling to catchment scale.
Wildfire Risk	Maryland Fire Priority Areas	MD DNR Forest Service	Updates to MD Forest Service data	MD_priority_fire_sqkm	Weighted sum of fire risk components	The Protect Forest From Harm (PFFH) 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 data sources: ○ Maryland Forest Service Wildfire Response Locations for 2005 to 2018. ○ University of Wisconsin SILVIS Lab Wildland Urban Interface model results for "intermix" and "interface" areas of Maryland. ○ Wildfire Hazard Potential Model (2018 version) created by the U.S. Forest Service, Rocky Mountain Research Station.
Climate Change	Brook Trout Probability of Occurrence	North Atlantic Landscape Conservation Cooperative (NALCC), Nature's Network Project, USGS Conte Lab, 2017	na	Brook_Trout_Occur_Current Brook_Trout_Occur_2CTempChange Brook_Trout_Occur_4CTempChange Brook_Trout_Occur_6CTempChange	Brook Trout probability of occurrence is intended to provide predictions of occupancy (probability of presence) under current environmental conditions and for future increases in stream temperature. Probability of Brook Trout Occurrence, Current Conditions and Future Conditions (plus 2, 4, or 6 degrees C) in Catchment	Brook Trout probability of occurrence was developed by the Conte Lab for the Northeast and Mid-Atlantic region from Virginia to Maine (USGS no date). The dataset provides predictions 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.
	Stream temperature - Several metrics	USGS EcoSheds (USGS no date, Walker et al. 2021)	na	mean_summer_temp mean_summer_temp_air2 mean_summer_temp_air4 mean_summer_temp_air6 n_day_temp_gt_18 n_day_temp_gt_22	Current and future temperature summary statistics: Mean Summer Temp. (degrees C) for Current Conditions and Future Conditions (with Air Temp plus 2, 4, or 6 degrees C); # Days/Year Temp. > 18 degrees C # Days/Year Temp. > 22 degrees C	Data modeled by USGS (Walker et al. 2021) for EcoShed catchments. Available for catchments throughout region; see Regions 02 (includes most of MD) and 05 (includes western MD). The SHEDS stream temperature model was developed to predict daily stream temperatures at both gaged and un-gaged catchments across the northeast U.S. based on geospatial characteristics and weather conditions. The model is based on a linear mixed effects framework that accounts for spatial and temporal correlations using a hierachical Bayesian structure. Letcher et al. (2016) describe the initial development of this model framework. Crosswalked from EcoSheds catchments to NHDPlus v2 catchments.

	Resilient Lands	TNC Resilient Lands data	na	Resilience scores		The Nature Conservancy, 2016 data (TNC 2021b, Anderson et al. 2016)
	Climate Stress Indicator in Catchment	North Atlantic Landscape Conservation Cooperative (NALCC), Nature's Network Project	na	climate_stress	Climate Stress represents the magnitude of stress that may be exerted on habitats in 2080	The Climate Stress Metric is one of a suite of products from the Nature's Network project (naturesnetwork.org). Nature's Network is a collaborative effort to identify shared priorities for conservation in the Northeast, considering the value of fish and wildlife species and the natural areas they inhabit. This dataset represents a measure of the estimated magnitude of climate stress that may be exerted on habitats (ecosystem types) in 2080, on a scale of 30 m2 cells. Cells where 2080 climate conditions depart substantially from conditions where the underlying ecosystem type currently occurs (the ecosystem's "climate niche") are considered to be stressed. Cells where the projected 2080 climate conditions are not substantially different from the current climate niche in the Northeast region are considered to be under low climate stress. Areas with low or zero climate stress may be candidates to function as climate refugia; these are places where ecosystems and associated species can persist relatively longer, compared to typical locations where the ecosystems currently occur.