Revisiting the Chesapeake Healthy Watersheds Assessment

Updated Health and Vulnerability Assessments for Catchments within the Chesapeake Bay Watershed

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Executive Summary

The Chesapeake Bay Program, through its Maintain Healthy Watersheds Goal Implementation Team, has a goal of maintaining the long-term health of watersheds identified as healthy by its partner jurisdictions. Quantitative indicators are important to assess current watershed conditions, track future conditions, and assess the vulnerability of these state-identified watersheds to future degradation. Building upon the U.S. Environmental Protection Agency (EPA) Preliminary Healthy Watershed Assessment (PHWA), Chesapeake Bay Healthy Watersheds Assessment 1.0, and the Maryland Healthy Watersheds Assessment frameworks, a set of candidate metrics characterizing multiple aspects of landscape condition, hydrology, geomorphology, habitat, biological condition, and water quality were assembled and evaluated for integration into an overall watershed health index. Geospatial analyses were structured, where possible, to leverage data from EPA StreamCat, the National Fish Habitat Partnership, the Chesapeake Bay Watershed Model for nutrient loads, Chesapeake Bay high-resolution land use / land cover data, and other regional data sources. In addition, a set of vulnerability metrics were derived representing aspects of land use change, water use, wildfire risk, and climate change. Metric values were compiled for the nearly 84,000 NHDPlus (v.2) catchments Bay-wide and were used to assess conditions and vulnerability within the catchments associated with the current set of state-identified healthy watersheds. In this update, metrics were analyzed using Maryland Healthy Watershed Assessment's as a blueprint, which includes utilizing a Random Forest model rather than using sub-indices and an overall Watershed Health index. These indicators will be available to federal, state, and local managers as a geospatial tool, providing critical information for maintaining watershed health.

The Chesapeake Healthy Watersheds Assessment (CHWA) provides a framework for tracking condition at future intervals, with the ability to integrate new data that becomes available. The assessment framework, metrics, and geodatabase created for the CHWA are intended to be useful for a variety of management applications. Primarily, the assessment will support the Chesapeake Bay Program and its jurisdiction partners in detecting signals of change in the state-identified healthy watersheds, providing information useful to support strategies to protect and maintain watershed health. In particular, indicators of vulnerability may help to provide an "early warning" to identify factors that could cause future degradation, allowing for steps to be taken to head off these potential negative effects. The CHWA will also be integrated with other Bay Program efforts in support of stream and watershed health.

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Introduction – Purpose and Objectives

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

- 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 through 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 also 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 2020a).

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 2020a) identifies efforts underway and planned for achieving the intended outcome: that 100 percent of state-identified currently healthy waters and watersheds remain healthy.

This report documents the development of the Chesapeake Healthy Watersheds Assessment 2.0 (CHWA 2.0), which revisits and updates the original Chesapeake Healthy Watersheds Assessment. Through CHWA 2.0, the CBP aims to further improve and refine the calculations, analyses, and associated interactive mapping and reporting tool.

Background

CHWA 2.0 has its basis in the Chesapeake Healthy Watersheds Assessment, but additionally draws upon and applies the methodology presented in the Maryland Healthy Watersheds Assessment.

The Chesapeake Healthy Watersheds Assessment

The original 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 Baywide 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 conditions at future intervals, with the ability to integrate new data that becomes 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.

The Maryland Healthy Watersheds Assessment (MDHWA)

The MDHWA established a framework for watershed health and vulnerability metrics tailored to assessing Maryland waters and watersheds. Beyond providing a context-specific for understanding watershed health, the MDHWA demonstrated the ability of watershed metrics to predict watershed health.

Whereas the Chesapeake Healthy Watersheds Assessment bases its health metrics on index values that aggregate health metrics across various subcategories, the MDHWA takes a more holistic approach. 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, the MDHWA, considers stream biological condition not as a parameter of watershed health, but instead as a response variable to test the strength of other parameters. Biological data (FIBI and BIBI scores) from the MBSS were used to test the predictive power of other metrics.

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 subindices 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 provided 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). 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.

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. 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.

Chesapeake Healthy Watersheds Assessment 2.0

The overall goal of "Scope of Work 1: Chesapeake Healthy Watersheds Assessment 2.0" is to further improve, refine, and finalize the Chesapeake Healthy Watersheds Assessment (CHWA). The CHWA 2.0 will be used to determine if State-Identified Healthy Waters and Watersheds are being maintained which is a major gap identified in the Healthy Watershed's Management Strategy, "routine collection of information about the status of healthy waters and watersheds is often lacking." Better scientific and technical understanding of healthy watershed threats has also been identified as a key factor in meeting the Healthy Watersheds Goal. Refining and improving the CHWA and its vulnerability metrics information will allow for tracking through time and our more holistic understanding of progress toward this outcome.

The CHWA 2.0 implements the random forest methodology piloted in the MDHWA to predict a biological score as a proxy to watershed health, scaled to the entirety of the Chesapeake Bay watershed. CHWA 2.0 includes a refreshed interactive mapping tool, modelled after the original CHWA, to allow users to interact with over 100 metrics and understand the factors affecting their watershed. This report documents the methodology and metrics used to assess watershed health, the results of the predicted health scores, and the functionality of the interactive mapping tool.

State-Identified Healthy Watersheds

Each of the 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. This dataset is displayed in Figure 1 and can be found here: https://data-chesbay.opendata.arcgis.com/datasets/ChesBay::healthy-watersheds-2017-1/about

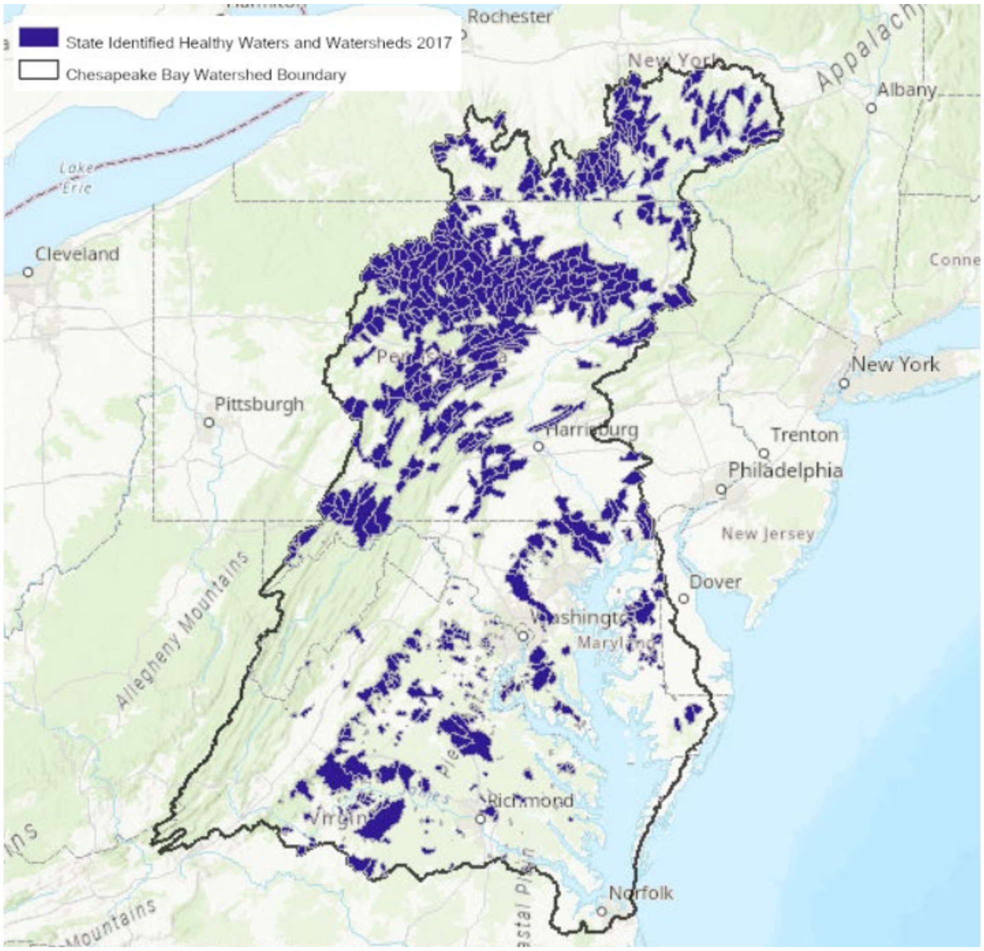

Figure 1. Map of the State Identified Healthy Watersheds in the Chesapeake Bay (2017).

Individual jurisdictions have defined their healthy waters and watersheds, as shown in Table 1. 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.

Table 1. Definition of a healthy watershed by jurisdiction, for the jurisdictions that make up the Chesapeake Bay Watershed.

Jurisdiction	Definition of Healthy Waters or Watersheds
New York	Waterbodies that have been categorized as "No Known Impact" because monitoring data

	and information indicate an absence of use restrictions are considered healthy.
Pennsylvania	Waters and watersheds that have been classified as High Quality or Exceptional Value are considered healthy.
Maryland	Tier II Waters: streams and their catchments are designated Tier II when their biological characteristics are significantly better than minimum water quality standards.
West Virginia	Waters that have been designated Tier 3 are known as outstanding national resource waters and are considered healthy.
Virginia	Waters and watersheds that are identified as having high aquatic integrity according to the Virginia Department of Conservation and Recreation's Division of Natural Heritage Healthy Waters Program are defined as ecologically healthy waters.
Delaware	Currently no healthy watersheds are defined. All of the state's tributaries to the Chesapeake Bay are impaired by nitrogen, phosphorus, sediment and/or bacteria, and will only be considered healthy when their Total Maximum Daily Loads (TMDLs) are achieved, and their surface water quality standards are met.
District of Columbia	Because the District primarily urbanized, it has not currently identified healthy watersheds.

Scale of Analysis

Although the national PHWA provided data at the 12-digit HUC scale, initial inspection of healthy watershed examples within the Chesapeake Bay Watershed indicated that a finer scale of analysis would be needed for the CHWA. Analysis needed to be appropriate for assessing the state-identified healthy watersheds, as many of these watersheds are themselves smaller than a 12-digit HUC. Even for larger healthy watersheds, managers of state programs had expressed interest in having access to environmental and landscape data on the particular sub-areas within those watersheds to inform management and decision-making processes, and especially, to help locate and address land-based stressors that may be affecting watershed health.

For the current analysis conducted for the Chesapeake Healthy Watersheds Assessment, the geographic units selected were catchments from the National Hydrography Dataset Plus Version 2 (NHDPlus) geospatial dataset developed by EPA and USGS. These NHDPlus catchments represent the direct drainage area of individual NHDPlus stream reaches and therefore allowed assessment of conditions at a finer scale than provided by the PHWA. Within the Chesapeake Bay Watershed, the average area of a 12-digit HUC is 89.97 square kilometers (34.74 square miles = 22,233.6 acres), while the average area of an NHDPlus catchment is 2.04 square kilometers (0.79 square miles = 505.6 acres). If needed, catchment data can be aggregated up to larger landscape units. Using the NHDPlus 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.

An initial step was to prepare a map representing the drainage areas of the healthy watersheds in Chesapeake Bay Watershed, created from the state-identified waters and watersheds provided by the Bay Program. A further step was to identify those NHDPlus 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. However, metrics were computed for all catchments across the entire Bay watershed, not only for those within healthy watersheds.

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) – both were based on NHDPlus catchments. Similarly, Wisconsin's statewide assessment of watershed health and vulnerability (Cadmus Group 2014b) employed state-specific boundaries at a catchment scale, using reach-scale watershed segments from the Wisconsin Department of Natural Resources 24K hydro geodatabase.

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 11 a complete picture of the hydrologic relationships between every catchment in the stream network at the 1:100,000 scale.
>
> The hydrologic relationships in NHDPlus allow for calculations of watershed characteristics (e.g., drainage area, stream length, land use) at both the incremental (within catchment boundaries) and cumulative scales (within all upstream catchments) for any stream reach. Cumulative values are included in the Assessment because of the potential for upstream conditions to influence the health of a given stream reach. For example, high percent imperviousness in the cumulative watershed is expected to influence downstream biological communities even though the incremental imperviousness for the catchment may be low. In addition to its analytical benefits, NHDPlus catchments can be aggregated to larger watershed scales. This allows for flexible

reporting of results at other watershed scales appropriate for multiple management or communication objectives.

Watershed health and vulnerability metrics were quantified on a catchment-by-catchment basis. The NHDPlus dataset supports aggregation of incremental-to-cumulative data by storing a unique numeric identifier for each catchment as well as upstream/downstream catchments.

For the Chesapeake assessment, working at the NHDPlus catchment scale provided the benefits described above and also enabled the leveraging of data and approaches from the EPA's Stream-Catchment (StreamCat) Dataset (Hill et al. 2016) in compiling catchment-scale metric data. Developed by EPA's Office of Research and Development (ORD), the StreamCat dataset (https://www.epa.gov/national-aquaticresource-surveys/streamcat) is an extensive collection of landscape metrics for 2.6 million streams and associated catchments within the conterminous U.S., including both natural and human-related landscape features. Of particular importance, StreamCat data are summarized both for individual stream catchments and for cumulative upstream watersheds, based on the NHDPlus Version 2 geospatial framework (EPA 2019b).

Using the same approach, most of the metrics included in the Chesapeake Healthy Watersheds Assessment were computed as integrating conditions throughout the entire upstream watershed. For certain applications of the data, use of catchment-specific (not watershed) data may also be of interest. For example, data on landscape conditions by individual catchments may be useful to help understand the various stressors acting in different parts of a watershed, whereas values that integrate conditions across the entire upstream watershed may blur or smooth these differences.

As in the national PHWA, certain CHWA metrics were computed for the riparian area only, defined as the area within approximately 100 meters on either side of the streamline. Other metrics were computed for slight variations of this defined riparian area, known as the hydrologically connected or hydrologically active zone, as defined in the PHWA. A table comparing the PHWA, CHWA 1.0 and CHWA 2.0 (Table 2) and a Figure showing the differences in scale between PHWA and CHWA (Figure 2) are both shown below.

Assessment	Scale	Analysis Methods	Date Completed
EPA Preliminary Healthy Watersheds Assessments (PHWA)	12-digit HUC	Sub-Index Method	2017, 2021
Chesapeake Healthy Watersheds Assessment 1.0	NHDPlus Catchment	Stepwise Regression Model and Sub-Index Method	2020
Chesapeake Healthy	NHDPlus Catchment	Random Forest Model; Spearman's Coefficient	2023

Watersheds Assessment 2.0		and Pearson's Correlation Coefficient	

Table 2. Comparison of PHWA, CHWA 1.0, and CHWA 2.0 based on scale, analysis method, and completion date.

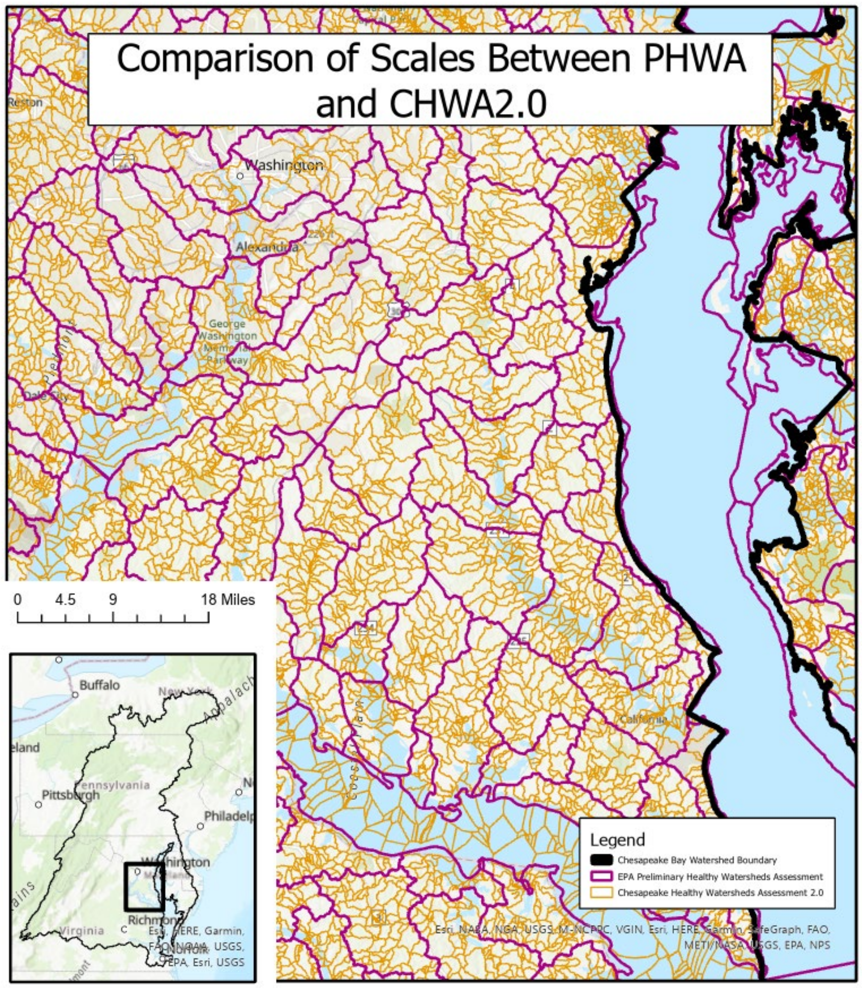

Figure 2: Map showing differences in scale between PHWA and CHWA 2.0.

Methods to Develop an Assessment of Watershed Health

For the Chesapeake Healthy Watersheds Assessment, candidate metrics in each of the five categories describing ecological attributes of watershed health condition were considered and evaluated as potential indicators of watershed health. Input from CBP partners, HWGIT members, and state data contacts was gathered to inform the process of proposing and selecting candidate metrics. Candidates included the original suite of PHWA metrics, calculated at the catchment rather than HUC-12 scale, along with Chesapeake Bay Watershed-specific renditions of those metrics, based upon regional rather than national data sets, when available. In addition, new metrics were proposed and considered, including those based on additional demographic, geomorphic, habitat, and biological data, as well as nutrient load data from SPARROW and the Chesapeake Bay Watershed Model.

Random Forest (RF) modeling was used to predict BIBI classification scores for each watershed within the Chesapeake Bay watershed. 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 algorithm uses a bootstrap sample of training data to build a 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.

The Chessie BIBI macroinvertebrate index is a Chesapeake Bay watershed wide measure of biological index from sampled macroinvertebrate data (Smith et al, 2017). The Chessie BIBI point database (Figure 3) developed by Smith et al. (2017) contains a standardized, continuous biological index score from 0 to 100 and a categorical score, ranging from very poor to excellent, based on resampled diversity and species richness metrics driven by the sampled data for 1^{st}-4^{th} order streams at the 1:100k scale (Maloney et al, 2018). The database contains data from 100 runs of this process, including the mean, median, and standard deviation of the data. The Chesapeake Healthy Watersheds Assessment 2.0 utilizes the median categorical score.

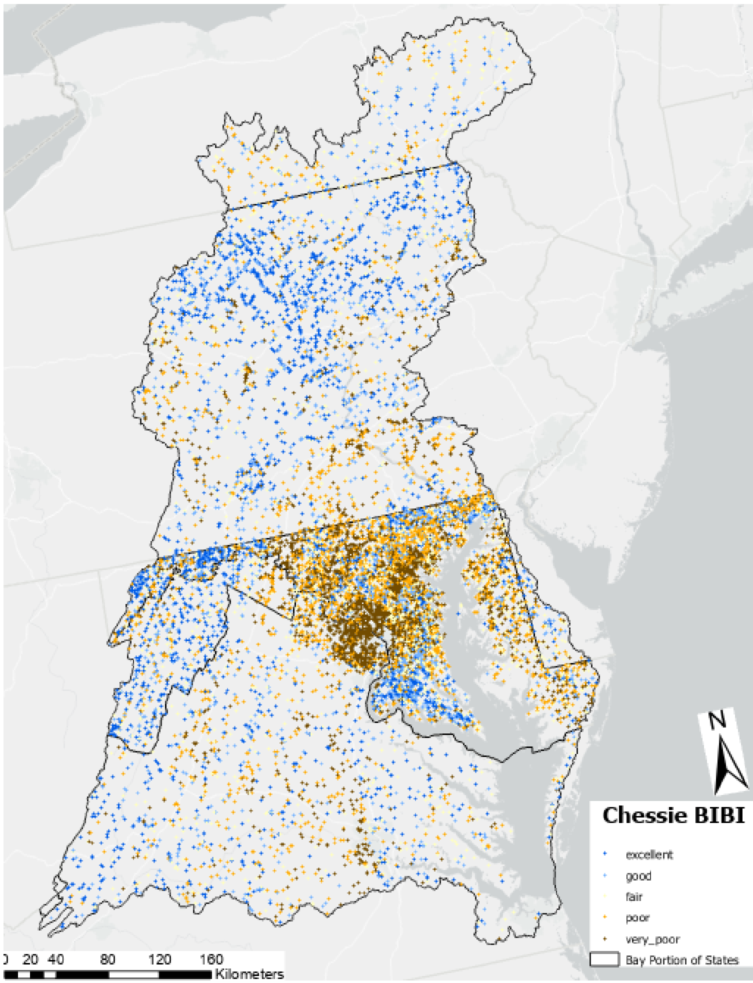

Figure 1 Chessie BIBI points representing the median rating of 100 runs for the raw 5-classes.

The Chessie BIBI data were related to the NHDv2.1 1:100k catchment scale, to match the scale of the predictive metrics, using a crosswalk table developed by Krause et al (2022). The crosswalk table denoted high confidence entries in which the spatial relationship matched the attributes of each dataset, including the stream names. The Chessie BIBI records not related to a catchment with high confidence were removed. Chessie BIBI records prior to 2010 were also removed. Each catchment related to a Chessie BIBI record was assigned the median categorical score. If a catchment contained more than one Chessie BIBI record, the score from the most recent record was assigned. If there was more than one record that shared the most recent date, the score was randomly selected from the most recent scores. This resulted in a training dataset of 2,353 catchments with reasonable distribution among the 5 classes (Table 3).

Table 1 The distribution of the 5 Chessie BIBI classes that were selected as training data.

Median Score	Count	% of Data
excellent	515	22%
good	449	19%
fair	368	16%
poor	589	25%
very poor	432	18%
Total	2,353	100%

The categorical scores were collapsed into 3 classes: good, fair, and poor, where excellent is merged with good and very poor is merged with poor. This resulted in an uneven distribution of training data across categories, with good and poor making up over 80% of the training data. This was rectified by randomly sampling 500 records with a "good" score and 500 records with a "poor" score and using all 368 "fair" records (Table 4, Figure 4).

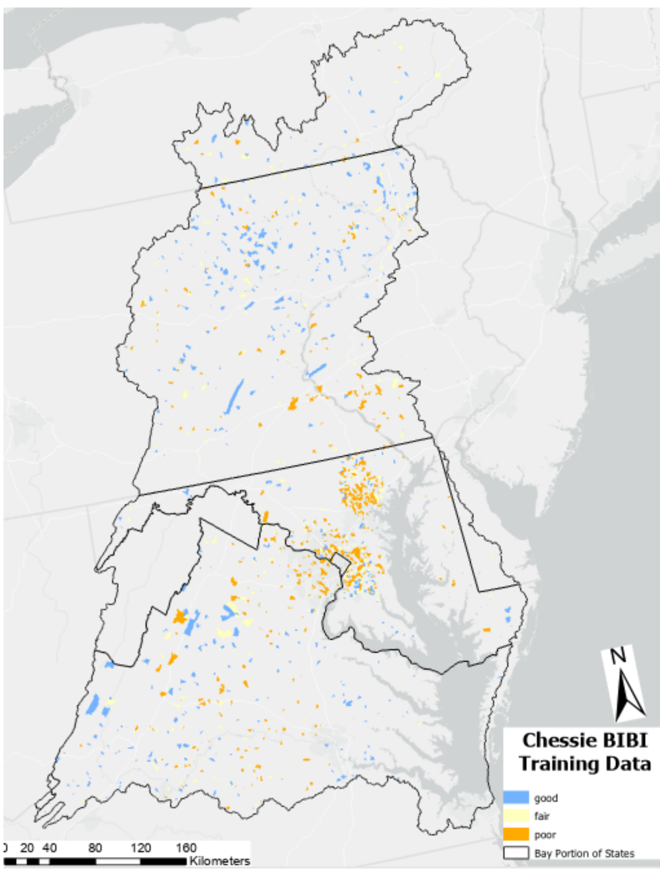

Figure 4 NHDv2.1 catchment Chessie BIBI median score used for training the random forest model. These data are filtered by date and randomly selected to ensure a reasonable class distribution.

Table 2 Distribution of training data for the collapsed 3-class schema. The "raw data" includes all data selected as possible training data and the "training data" are the number of records per class selected to train the model.

	Raw Data		Training Data	
Median Score	**Count**	**% of Data**	**Count**	**% of Data**
good	964	41%	500	37%
fair	368	16%	368	27%
poor	1,021	43%	500	37%
Total	2,353	100%	1,368	100%

The random forest modelling was executed in Python using the sklearn library. The parameters used to train the random forest model were selected using the RandomizedSearchCV function, which randomly tests a user-defined number of parameter combinations and assesses the "best" hyper-tuning parameters for the given training data by the parameters that give the highest cross-validation score. Cross-validation was used to assess the predictive ability of a model by using a subset of the training data to train the model and the remaining data to test the results of the trained model. In this case, 80% of the training data was used to build the random forest and 20% of the training data was used to test the results of the model. The hyper-tuning search randomly selected 100 parameter combinations, including n_estimators (number of classification trees), max_features (number of predictor variables to consider for the next split), max_depth (maximum depth of the tree), criterion (criteria that measures the quality of a split), min_samples_split (minimum number of samples required to split an internal node) and min_samples_leaf (minimum number of samples required to be at a leaf node). The "best" parameters had a mean cross-validation score of ~0.58 (Table 5).

Table 5 The hyper tune parameters tested for the "best" for the training data.

Parameter	Test Range	Best value
n_estimators	200-2,000, increments of 10	400
min_samples_split	2, 5, 10	10
min_samples_leaf	1, 2, 4	1
max_features	auto, sqrt, log2	sqrt
max_depth	None, 10-110 increments of 10	20
criterion	gini, entropy	gini

Predictive Metrics

The Chesapeake Healthy Watersheds Assessment 2.0 contains 106 metrics, 60 of which were used in the random forest model to assess their ability to predict watershed health via biological condition (see appendix). Metrics were selected for inclusion that provide a unique representation of conditions related to aquatic health. Only 8 of the water quality metrics were included in the random forest model which were chosen to represent conditions not described in other metrics, including measures of nitrogen and phosphorus due to fertilizer, manure, and wastewater treatment facilities. Metrics were excluded from the random forest model if they were duplicative, modeled (e.g., multiple water quality measures from SPARROW or the Phase 6 Watershed Model), or represent future conditions (e.g., vulnerability to development). No metrics were excluded purely due to high correlation to other metrics, although several were correlated to metrics that remained in the model. A table of all metrics is provided as an appendix to this report.

Watershed Health Metrics

Landscape Condition

% Tree Canopy in Riparian Zone – The % Tree Canopy in Riparian Zone metric was derived from Chesapeake Bay Program high-resolution land use/land cover data from 2017/2018 and the Chesapeake Bay Watershed 1:24k 100-foot Riparian Zone (McDonald et al., 2023). The catchment-level version of this metric reports tree canopy area as a percent of land area within the riparian zone in each catchment. The watershed level version of this metric reports tree canopy area as a percent of land area within the riparian zone in all upstream catchments.

Dataset fields:

- PcTC17Rp – % Tree Cover in Riparian Zone 2017/18 Catchment
- PcTCRpWs – % Tree Cover in Riparian Zone 2017/18 Watershed

Housing Unit Density – The Housing Unit Density metric was derived from SILVIS Lab data, based on the 2020 United States Census. To calculate housing unit density, census blocks were intersected with catchments, and the total housing unit counts were apportioned to each catchment based on the intersection proportion. These values were summed and divided by the area of the catchment. The catchment-level version of this metric reports the number of housing units per square kilometer within each catchment. The watershed-level version of this metric reports the number of housing units per square kilometer within all upstream catchments.

Dataset fields:

- THU2020 – Housing Unit Density 2020 Catchment (units/sq. Km)
- THU2020Ws – Housing Unit Density 2020 Watershed (units/ sq. Km)

Population Density – The Population Unit Density metric was derived from SILVIS Lab data, based on the 2020 United States Census. To calculate housing unit density, census blocks were intersected with catchments, and the total population counts were apportioned to each catchment based on the intersection proportion. These values were summed and divided by the area of the catchment. The catchment-level version of this metric reports the number of people per square kilometer within each catchment. The watershed-level version of this metric reports the number of people per square kilometer within all upstream catchments.

Dataset Fields:

- PopDens20 – Population Density 2020 Catchment (people/sq. Km)
- PopDens20Ws – Population Density 2020 Watershed (people/sq. Km)

% Extractive – The % Extractive 2017/2018 metric was derived from Chesapeake Bay Program high-resolution land use/land cover data from 2017/2018. The catchment-level version of this metric reports the percent of land area comprised of surficial mines mapped as extractive. The watershed-level version of this metric reports the percent of total upstream catchment land area mapped as extractive.

Dataset Fields:

- PcEXTR – % Extractive 2017/18 Catchment
- PcEXTRWs – % Extractive 2017/18 Watershed

% Forested Extent Loss to Development 2001-2013 – The % forested extent loss to development was derived from 30-meter resolution National Land Cover Database (NLCD) (2019 edition) land cover data. All 30-meter cells that were forested extent in 2001 (Evergreen Forest, Deciduous Forest, Mixed Forest, Woody Wetlands, Herbaceous, and Scrubland) and developed in 2013 (Low, Medium and High Intensity Development and Developed Open Space) were considered forested extent loss to development. The area of forest loss to development per catchment was calculated and accumulated downstream. The percentage of land area per catchment and upstream watershed was calculated.

Dataset Fields:

- PcForLss – % Forested Extent Loss to Development 2001-2013 Catchment
- PcForLssWs – % Forested Extent Loss to Development 2001-2013 Watershed

% Natural Land Cover in Riparian Zone – The % Natural Land Cover in Riparian Zone metric was derived from Chesapeake Bay Program high-resolution land use/land cover data from 2017/2018 and the Chesapeake Bay Watershed 1:24k 100-foot Riparian Zone (McDonald et al., 2023). The catchment-level version of this metric reports natural land *use (wetlands, forest, and regenerating forests)* area as a percent of *land* area within the riparian zone in each catchment. The watershed level version of this metric reports natural land *use* area as a percent of *land* area within the riparian zone in all upstream catchments.

Dataset Fields:

- PcNatRp – % Natural Land in Riparian 2017/18 Catchment
- PcNatRpWs – % Natural Land in Riparian 2017/18 Watershed

% Protected Lands – The % Protected Lands metric was derived from a data layer maintained by the Chesapeake Bay Program, which is compiled from authoritative federal and state data sources. “Protected lands” means lands permanently protected from development, whether by purchase or donation, through a perpetual conservation or open space easement or fee ownership for their cultural, historical, ecological, or agricultural value. The land area was divided by the summed area of 2018 protected lands dataset. The catchment-level version of this metric reports the percent of catchment

land area comprised of protected lands. The watershed-level version of this metric reports the percent of upstream catchment land area comprised of protected lands.

Dataset Fields:

- PcPL18 – % Protected Lands Catchment
- PcPL18Ws – % Protected Lands Watershed

% Tree Cover in Riparian Zone – The % Tree Cover in Riparian Zone metric was derived from Chesapeake Bay Program high-resolution land use/land cover data from 2017/2018 and the Chesapeake Bay Watershed 1:24k 100-foot Riparian Zone (McDonald et al., 2023). The catchment-level version of this metric reports tree cover area as a percent of land area within the riparian zone in each catchment. The watershed level version of this metric reports tree cover area as a percent of land area within the riparian zone in all upstream catchments.

Dataset Fields:

- PcTCRp – % Tree Cover in Riparian 2017/18 Catchment
- PcTCRp – % Tree Cover in Riparian 2017/18 Watershed

% Agriculture 2017/2018 – The % Agriculture metric was derived from Chesapeake Bay Program high-resolution land use/land cover data from 2017/2018. The catchment-level version of this metric reports the percent of catchment land area comprised of agricultural lands, including cropland, pasture/hay, and orchards/vineyards. The watershed-level version of this metric reports the percent of upstream catchment land area comprised of agricultural lands.

Dataset Fields:

- PcAG – % Agriculture 2017/18 Catchment
- PcAGWs – % Agriculture 2017/18 Watershed

Hydrology

% Non-forested Wetlands – The % Non-forested Wetlands metric was derived from Chesapeake Bay Program high-resolution land use/land cover data from 2017/2018. The catchment-level version of this metric reports the percent of catchment land area comprised of non-forested wetlands. The watershed-level version of this metric reports the percent of upstream catchment land area comprised of non-forested wetlands.

Dataset Fields:

- PcWL – % Non-forested Wetlands 2017/18 Catchment
- PcWLWs – % Non-forested Wetlands 2017/18 Watershed

% Tree Canopy with Managed Understory – The % Tree Canopy with Managed Understory metric was derived from Chesapeake Bay Program high-resolution land use/land cover data from 2017/2018 and includes tree canopy over turf grass and impervious surfaces. The catchment-level version of this metric

reports the percent of catchment land area comprised of tree canopy with managed understory. The watershed-level version of this metric reports the percent of upstream catchment land area comprised of tree canopy with managed understory.

Dataset Fields:

- PcTCm – % Tree Canopy with Managed Understory 2017/18 Catchment
- PcTCmWs – % Tree Canopy with Managed Understory 2017/18 Watershed

Road Stream Crossing Density – The Road Stream Crossing Density metric was derived from StreamCat data from 2010. The total area was divided by a summed length of road segments crossing streams. The catchment-level version of this metric reports the density of road stream crossings within each catchment in kilometers per square kilometer. The watershed-level version of this metric reports the density of road stream crossings within all upstream catchments in kilometers per square kilometer.

Dataset Fields:

- RdStrX – Road Stream Crossing Density Catchment (km/sq. Km)
- RdStrXWs – Road Stream Crossing Density Watershed (km/sq. Km)

Flow Alteration Intensity Score – The Flow Alteration Intensity Score metric is derived from a USGS publication (Maloney et al. 2021), based on the hydrologic metrics of Eng et al. 2019. The metric reports the flow alteration intensity score within each catchment.

Dataset Field:

- FlowAlter – Flow Alteration

Geomorphology

% Impervious in Riparian Zone – The % Impervious in Riparian Zone metric was derived from Chesapeake Bay Program high-resolution land use/land cover data from 2017/2018 and the Chesapeake Bay Watershed 1:24k 100-foot Riparian Zone (McDonald et al., 2023). The catchment-level version of this metric reports impervious land cover area as a percent of land area within the riparian zone in each catchment. The watershed level version of this metric reports impervious land cover area as a percent of land area within the riparian zone in all upstream catchments.

Dataset Fields:

- PcISRp – % Impervious in Riparian 2017/18 Catchment
- PcISRpWs – % Impervious in Riparian 2017/18 Watershed

Dam Density – The Dam Density metric was derived from StreamCat data from 2013. The total area was divided by a count of georeferenced dams. The catchment-level version of this metric reports the density of dams within each catchment in dams per square kilometer. The watershed-level version of this metric reports the density of dams within all upstream catchments in dams per square kilometer.

Dataset Fields:

- DamDens – Dam Density Catchment (dams/sq. Km)
- DamDensWs – Dam Density Watershed (dams/sq. Km)

Road Density – The Road Density metric was derived from US Tiger Line data from 2010. The total area was divided by a sum of road segment lengths. The catchment-level version of this metric reports the density of roads within each catchment in kilometers per square kilometer. The watershed-level version of this metric reports the density of roads within all upstream catchments in kilometers per square kilometer.

Dataset Fields:

- RdDens – Road Density Catchment (km/sq. Km)
- RdDensWs – Road Density Watershed (km/sq. Km)

Road Density in Riparian Zone – The Road Density in Riparian Zone metric was derived from US Tiger Line data from 2010. The total area was divided by a sum of road segment lengths within the riparian zone. The catchment-level version of this metric reports the density of roads within the riparian zone in each catchment in kilometers per square kilometer. The watershed-level version of this metric reports the density of roads within the riparian zone in all upstream catchments in kilometers per square kilometer.

Dataset Fields:

- RdDensRp – Road Density Riparian Catchment (km/sq. Km)
- RdDensRpWs – Road Density Riparian Watershed (km/sq. Km)

Streambank lateral erosion – The Streambank Lateral Erosion metric is provided by USGS (Noe et al. 2020), derived from FACET (USGS 2019). 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). Predictions were made from a Random Forest regression model that used predictors including FACET geomorphometry in the stream reach and the hydrogeology, soils, topography, and land use of the upstream drainage area. Data were summarized to the NHDPlus V2 catchment scale. This metric reports the predicted streambank lateral erosion rate within each catchment (cm yr-1).

Dataset Field:

- SBLatEros – Streambank lateral erosion

Streambank erosional change – The Streambank Erosional Change metric is provided by USGS (Noe et al. 2020), derived from FACET (USGS 2019). 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). Predictions were made from a Random Forest regression model that used predictors including FACET geomorphometry in the stream reach and the hydrogeology, soils, topography, and land use of the upstream drainage area. Data were summarized to the NHDPlus V2 catchment scale. This metric reports streambank cross-sectional lateral erosion area change within each catchment as a product of bank height x lateral erosion (m2 yr-1).

Dataset Field:

- SBErosChg – Streambank erosional change

Streambank sediment flux – The Streambank Sediment Flux metric is provided by USGS (Noe et al. 2020), derived from FACET (USGS 2019). 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). Predictions were made from a Random Forest regression model that used predictors including FACET geomorphometry in the stream reach and the hydrogeology, soils, topography, and land use of the upstream drainage area. Data were summarized to the NHDPlus V2 catchment scale. This metric incorporates bank height, lateral erosion, and bulk density, reporting the predicted streambank sediment flux within each catchment (kg-sed m-1 yr-1).

Dataset Field:

- SBSedFlux – Streambank sediment flux

Streambed D50 – The Streambank D50 metric is provided by USGS (Noe et al. 2020), derived from FACET (USGS 2019). 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). Predictions were made from a Random Forest regression model that used predictors including FACET geomorphometry in the stream reach and the hydrogeology, soils, topography, and land use of the upstream drainage area. Data were summarized to the NHDPlus V2 catchment scale. This metric reports the predicted streambed D50 particle size within each catchment (mm).

Dataset Field:

- SbedD50 – Streambed Particle Size D50

Streambank fine sediment flux – The Streambank Fine Sediment Flux metric is provided by USGS (Noe et al. 2020), derived from FACET (USGS 2019). 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). Predictions were made from a Random Forest regression model that used predictors including FACET geomorphometry in the stream reach and the hydrogeology, soils, topography, and land use of the upstream drainage area. Data were summarized to the NHDPlus V2 catchment scale. This metric incorporates bank height, lateral erosion, and bulk density, and the percent of streambank sediment < 63 microns, reporting the predicted streambank fine sediment flux within each catchment (kg-finesed m-1 yr-1).

Dataset Field:

- SBFSFlux – Streambank Fine Sediment Flux

Streambed fine sediment + sand cover – The Streambed Fine Sediment + Sand Cover metric is provided by USGS (Noe et al. 2020), derived from FACET (USGS 2019). 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). Predictions were made from a Random Forest regression model that used predictors including FACET geomorphometry in the stream reach and the hydrogeology, soils, topography, and land use of the upstream drainage area. Data were summarized to the NHDPlus V2 catchment scale. This metric reports streambed percent fine sediment and sand cover within each catchment.

Dataset Field:

- SBFSSFlux – Streambed fine sediment and sand cover

Habitat

% Tree Cover with Unmanaged Understory – The % Tree Cover with Unmanaged Understory metric was derived from Chesapeake Bay Program high-resolution land use/land cover data from 2017/2018 and represents forests whose understory is not expected to be fertilized or compacted. The catchment-level version of this metric reports the percent of catchment land area comprised of tree cover with unmanaged managed understory. The watershed-level version of this metric reports the percent of upstream catchment land area comprised of tree cover with unmanaged understory.

Dataset Fields:

- PcTCu – % Tree Cover with Unmanaged Understory 2017/18 Catchment
- PcTCuWs – % Tree Cover with Unmanaged Understory 2017/18 Watershed

Fish Habitat Condition Index – The Fish Habitat Condition Index metric was derived from the National Fish Habitat Partnership (NFHP), 2015 National Assessment. The base version of the metric reports the mean habitat condition index (HCI) score for each catchment. The cumulative version of the metric reports the cumulative habitat condition index (HCI) score for each catchment. The network version of the metric reports the mean habitat condition index (HCI) score for the network.

Dataset Fields:

- FshHCI – Fish Habitat Condition Index Catchment
- FshHCICum – Fish Habitat Condition Index Cumulative
- FshHCINwrk – Fish Habitat Condition Index Network (Watershed)

Nature's Network Connectivity – The Natures Network Connectivity metric is derived from Nature Network's Conservation Design composite layer, which depicts an interconnected network of lands and waters (Imperiled Species, Terrestrial Core-Connector Network, Grassland Bird Core Areas, Lotic Core Areas, and Lentic Core Areas) based on 2017 data with some updates in the underlying datasets in 2022. The metric reports percent connectivity within each catchment.

Dataset Field:

- PcCnnctvty – Nature's Network Connectivity

Water Quality

% Impaired Stream – The % Impaired Stream metric is derived from EPA ATTAINS 2015 data (EPA 2022b). 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. The metric reports on the length of streams within each catchment categorized as impaired as a percentage of total stream length within each catchment.

Dataset Field:

- PcImprd – % Impaired Stream Catchment

Incremental Suspended-Sediment, Total Phosphorous, and Total Nitrogen Loads by Sector – The sector-specific incremental suspended-sediment (SS), total phosphorous (TP), and total nitrogen (TN) suite of metrics is derived from the USGS regional SPARROW model, Chesapeake Bay Program 2018. 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. The metric for each particle type (SS, TP, TN) is reported for each sector as kilograms per year.

Dataset Fields:

- Ss_is – Incremental suspended-sediment load
- Ss_is_afin – Incremental suspended-sediment load from agricultural uplands with fine sediment

- Ss_is_ares – Incremental suspended-sediment load from agricultural uplands with medium or coarse sediment or residuum
- Ss_is_othr – Incremental suspended-sediment load from non-agricultural and non-urban uplands
- Ss_is_strm – Incremental suspended-sediment load from streambank erosion
- Ss_is_ufin – Incremental suspended-sediment load from urban uplands with fine sediment
- Ss_is_umed – Incremental suspended-sediment load from urban uplands with medium or coarse sediment
- Ss_is_ures – Incremental suspended-sediment load from urban uplands with residuum
- Tn_in_fert – Incremental total nitrogen load from fertilizer applications (kg/yr)
- Tn_in_manu – Incremental total nitrogen load from manure applications (kg/yr)
- Tn_in_urb – Incremental total nitrogen load from other urban non-point sources (kg/yr)
- Tn_ in_ sept – Incremental total nitrogen load from septic system effluent (kg/yr)
- Tn_in_poin – Incremental total nitrogen load from wastewater treatment facility point sources (kg/yr)
- Tn_in – Incremental total nitrogen load (kg/yr)
- Tp_ip_fert – Incremental total phosphorus load from fertilizer applications (kg/yr)
- Tp_ip_manu – Incremental total phosphorus load from manure applications (kg/yr)
- Tp_ip_poin – Incremental total phosphorus load from point-source wastewater treatment facilities (kg/yr)
- Tp_ip_urb – Incremental total phosphorus load from urban non-point sources (kg/yr)
- Tp_ip – Incremental total phosphorus load (kg/yr)

Total Nitrogen, Phosphorus, and Suspended-Sediment Load, by Sector (Developed Land, Agriculture, Wastewater, Septic, and CSO) – The sector-specific total suspended-sediment (SS), total phosphorous (TP), and total nitrogen (TN) suite of metrics is derived from the Chesapeake Bay Program Phase 6 Watershed Model (2019). The metric for each particle type (SS, TP, TN) is reported for each sector as pounds per acre per year.

Dataset Fields:

- TN – Total nitrogen (SPARROW)
- TN_AG – Total nitrogen on agriculture
- TN_CSO – Total nitrogen on CSO
- TN_Dev – Total nitrogen on development
- TN_Sep – Total nitrogen on septic
- TN_WW – Total nitrogen on wastewater
- TP – Total phosphorus (SPARROW)
- TP_AG – Total phosphorus on agriculture
- TP_CSO – Total phosphorus on CSO
- TP_Dev – Total phosphorus on development
- TP_Sep – Total phosphorus on septic

- TP_WW – Total phosphorus on wastewater
- TSS – Accumulated suspended-sediment load (SPARROW)
- TSS_AG – Total suspended sediment on agriculture
- TSS_CSO – Total suspended sediment on CSO
- TSS_Dev – Total suspended sediment on development
- TSS_Sep – Total suspended sediment on septic
- TSS_WW – Total suspended sediment on wastewater

Metric data by catchment were assembled into the project geodatabase. Each catchment (designated with a unique identifier, COMID) has data for all of the selected metrics, as well as other attributes such as catchment area, a flag indicating whether the catchment is located within a healthy watershed, whether located at its outlet, and the identity of that healthy watershed. Metrics were organized under the six topic areas described above. Data are available for all catchments, not just those within state-identified healthy watersheds.

Watershed Vulnerability Metrics

One of the main objectives of the CHWA was to provide information about the vulnerability of healthy watersheds to future degradation. Candidate vulnerability metrics were proposed based on previous work done on the MDHWA and on recommendations from the project core team and advisors. These metrics include land use change, climate change metrics, wildfire risk, and water use. These metrics, particularly land use change, provide an outlook on future changes to stream condition and water quality. Land Use Change

% Change in Forested Extent *2013-18* – The % Change in Forested Extent 2013-18 metric was derived from Chesapeake Bay Program high-resolution land use/land cover change data from 2013/2014 to 2017/2018. The % forested extent refers to Tree Cover with an unmanaged understory and regenerating forest lands, such as harvested forests and natural succession. The catchment-level version of this metric reports the percentage of net forested extent change by catchment land area between 2013/14 and 2017/8. The watershed-level version of this metric reports the percentage of net forested extent change per upstream catchment land area between 2013/14 and 2017/8.

Dataset Fields:

- PcFEch – % Change in Forested Extent 2013-18 Catchment
- PcFEchWs – % Change in Forested Extent 2013-18 Watershed

% Change in Impervious Cover 2013-18 – The % Change in Impervious Cover 2013-18 metric was derived from Chesapeake Bay Program high-resolution land use/land cover change data from 2013/2014 to 2017/2018. The catchment-level version of this metric reports the net impervious change as a percent of catchment land area. The watershed-level version of this metric reports the impervious change as a percent of upstream catchment land area.

Dataset Fields:

- PcISch – % Change in Impervious Cover 2013-18 Catchment

- PcISchWs – % Change in Impervious Cover 2013-18 Watershed

% Impervious Projected to 2055 – The % Impervious Projected to 2055 metric was derived from the USGS Chesapeake Bay Land Change Model (CBLCM), which is an urban growth model used to forecast forest and agricultural land conversion under varying land management scenarios. The CBLCM forecasts land change by summary unit, including NHDPlus catchments. The forecasted impervious area (cumulative) in the year 2055 under the current zoning scenario is represented as a percentage of catchment land area.

Dataset Field:

- PcIS55 – % Impervious Projected to 2055 Catchment

% Forest Harvesting 2013-18 – The % Forest Harvesting 2013-18 metric was derived from Chesapeake Bay Program high-resolution land use/land cover data from 2013/2014 to2017/2018. The catchment-level version of this metric reports the percent of catchment land area that experienced the clearance of tree cover with an unmanaged understory for harvesting from within the catchment between 2013 and 2018. The watershed-level version of this metric reports the percent of upstream catchment land area that experienced tree cover with an unmanaged understory cleared for harvesting within upstream catchments between 2013 and 2018.

Dataset Fields:

- PcHarv – % Forest Harvesting 2013-18 Catchment
- PcHarvWs – % Forest Harvesting 2013-18 Watershed

% Non-forested Wetland Conversion to Development 2013-18 – The % Non-forested Wetland Conversion to Development 2013-18 metric was derived from Chesapeake Bay Program high-resolution land use/land cover data from 2013/2014 and 2017/2018. Forested wetland loss to development is captured in the % Forested Extent Conversion to Development metric. The catchment-level version of this metric reports the percent of catchment land area that experienced non-forested wetlands lost to development between 2013/14 and 2017/18. The watershed-level version of this metric reports the percent of upstream catchment land area that experienced non-forested wetlands lost to development between 2013/14 and 2017/8.

Dataset Fields:

- PcNFWDv – % Non-forested Wetland Conversion to Development 2013-18 Catchment
- PcNFWDvWs – % Non-forested Wetland Conversion to Development 2013-18 Watershed

Housing Unit Density Change – The Housing Unit Density Change metric was derived from SILVIS Lab data, based on the 1990 United States Census and the 2020 United States Census. Housing unit density calculated from the year 1990 was subtracted from housing unit density calculated for the year 2020. The catchment-level version of this metric reports the difference in the number of housing units per square kilometer within each catchment between 1990 and 2020. The watershed-level version of this metric reports the difference in the number of housing units per square kilometer within upstream catchments between 1990 and 2020.

Dataset Fields:

- THUchg – Housing Unit Density Change Catchment
- THUchgWs – Housing Unit Density Change Watershed

Water Use

Agricultural Water Use – The Agricultural Water Use metric was derived from the EPA EnviroAtlas 2018. 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, a new zonal summary was run based on updated catchment boundary and land use land cover analysis to inform downscaling to catchment scale. The metric reports daily agricultural water use (million gallons per day) in the HUC12.

Dataset Field:

- AgWatUse – Agriculture Water Use

Domestic Water Use – The Domestic Water Use metric was derived from the EPA EnviroAtlas 2018. 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, a new zonal summary was run based on updated catchment boundary and land use land cover analysis to inform downscaling to catchment scale. The metric reports daily domestic water use (million gallons per day) in the HUC12.

Dataset Field:

- DomWaterUse – Domestic Water Use

Industrial Water Use – The Industrial Water Use metric was derived from the EPA EnviroAtlas 2018. The metric reports daily industrial water use (million gallons per day) in the HUC12.

Dataset Field:

- IndWatUse – Industrial Water Use

Wildfire Risk

% Wildland Urban Interface – The % Wildland Urban Interface metric was derived from 2010 data provided by the University of Wisconsin - Madison SILVIS lab, 2017. The wildland-urban interface (WUI) is defined as the area where houses meet undeveloped wildland vegetation. The metric reports the percent of total area comprised of wildland-urban interface within the catchment.

Dataset Field:

- PcWUIIntfc – % Wildland Urban Interface

% Wildland Urban Intermix – The % Wildland Urban Intermix metric was derived from 2010 data provided by the University of Wisconsin - Madison SILVIS lab, 2017. The wildland-urban interface (WUI) is defined as the area where houses intermingle with undeveloped wildland vegetation. The metric reports the percent of total area comprised of wildland-urban interface within the catchment.

Dataset Field:

- PcWUIIntmx – % Wildland Urban Intermix

Climate Change

% Resilient Lands – The % Resilient Lands metric was derived from The Nature Conservancy data on resilient lands, 2016. This metric reports the percent of catchment land area comprised of resilient lands within the catchment.

Dataset Field:

- PcResLands – % Resilient Lands

Climate Stress – The Climate Stress metric was derived from North Atlantic Landscape Conservation Cooperative (NALCC) data, Nature's Network, 2017. The metric is reported as the climate stress value for the habitat.

Dataset Field:

- ClmtStrs – Climate Stress

Probability of Brook Trout Occurrence – The Probability of Brook Trout Occurrence metric was derived from North Atlantic Landscape Conservation Cooperative (NALCC), Nature's Network, USGS Conte Lab, 2017. The metric reports the probability of brook trout occurrence within each catchment, under various climatic conditions (current conditions and 2, 4, and 6 degrees Celsius hotter than current conditions).

Dataset Fields:

- BTOccCrnt – Probability of Brook Trout (current)
- BTOcc2C – Probability of Brook Trout (2-degree Celsius increase)
- BTOcc4C – Probability of Brook Trout (4-degree Celsius increase)
- BTOcc6C – Probability of Brook Trout (6-degree Celsius increase)

Correlation

Correlated metrics provide pros and cons to modelling watershed health. Random forests can handle correlated metrics by producing numerous trees using a random selection of variables each time. Correlated metrics remained present in the random forests model if they provided additional explanation of macrobenthic conditions somewhere in the watershed and thereby improved the overall predictive power of the model. For example, percent impervious in local catchments and percent impervious in upstream watershed were correlated but provided context of local versus upstream conditions. The downside of including correlated metrics is that they hinder direct interpretation of the predictive power of each metric. Following the same example, the percent impervious in local catchments of headwater catchments was equal to the percent impervious upstream watershed and the local values were a subset of the upstream values. The decision trees were built using a random sample of metrics, therefore how many times percent impervious in catchment was selected versus percent impervious in watershed versus both being selected affects the feature importance of each. The presence of correlated metrics in CHWA 2.0 means the metrics may not be distinct enough to accurately represent the ranking of metric importance in predicting watershed health. The metric importance values are still useful, however, in determining the relative importance of each metric. The metrics used in the random forest model were continuous data and one categorical dataset. The type of datasets must be considered when assessing correlation between data. Two approaches were used to assess correlation between continuous variables: (1) Pearson's correlation coefficient (R^2) and (2) Spearman's rank correlation coefficient (rho aka ρ). Pearson's correlation coefficient can be used to identify linear relationships between 2 variables, where 1 is a perfect positive correlation, 0 is no correlation, and -1 is a perfect negative correlation. Spearman's coefficient can be used to identify monotonic relationships between continuous variables, where 1 is a perfect positive correlation, 0 is no correlation, and -1 is a perfect negative correlation. For example, population density in the watershed and housing unit density in the watershed are positively, linearly correlated with a 0.97 R^2 and 0.95 ρ (Figure 5). Percent impervious in the watershed and tree cover with an unmanaged understory (forests) have a 0.51 R^2 and a 0.61 ρ (Figure 6). Heatmaps are used to visualize the correlation of continuous variables using these two methods (Figures 7 and 8).

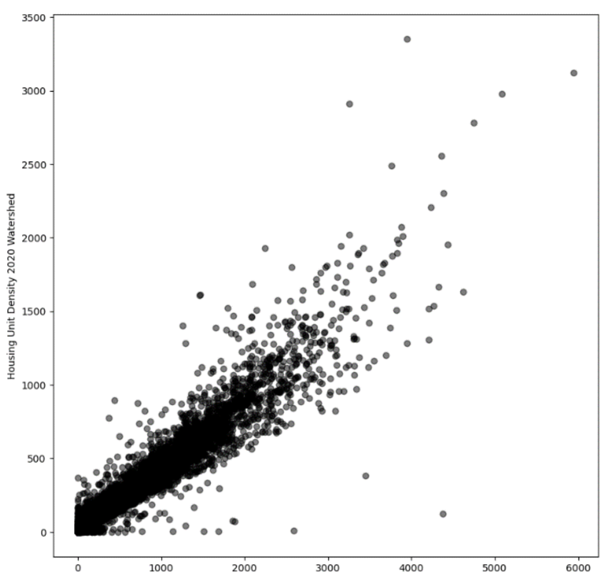

Figure 2 Plot of population density in the upstream watershed and housing unit density in the upstream watershed, showing a strong, positive, linear relationship.

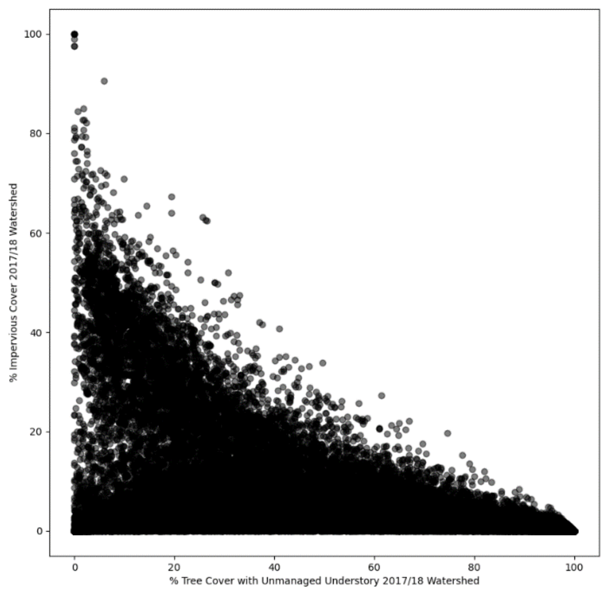

Figure 3 Plot of percent forested in the upstream watershed and percent impervious cover in the upstream watershed, showing a non-linear relationship.

Figure 4 A heatmap of Pearson's correlation coefficient for all continuous metrics used in the random forest model. Reds are a positive linear correlation and blues are a negative linear correlation. The darker the color, the stronger the correlation.

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Figure 5 A heatmap of Spearman's rho, or Spearman's Rank Correlation coefficient for all continuous metrics used in the random forest model. Reds are a positive linear correlation and blues are a negative linear correlation. The darker the color, the stronger the correlation.

To assess correlation between the categorical variable (bioregion) and the continuous variables, an Analysis of Variance (ANOVA) was performed for each combination of metrics. ANOVA produces a p-value, which can be used to assess if the differences in the means of the continuous variables between categories occurred by chance or not. Bioregion provided additional context not captured in the continuous variables, so it remained included.

The metrics with a correlation of 0.9 or above for Pearson or Spearman are in Table 6.

Table 3 Correlated metrics with an R^2or rho of 0.9 or better.

Metric 1	Metric 2	Pearson	Spearman
Incremental total phosphorus load from point-source wastewater treatment facilities (kg/yr)	Incremental total nitrogen load from wastewater treatment facility point sources (kg/yr)	0.812	1.000
Housing Unit Density 2020 Watershed	Population Density 2020 Watershed	0.973	0.950
Streambank sediment flux	Streambank erosional change	0.965	0.946
Incremental total phosphorus load from manure applications (kg/yr)	Incremental total nitrogen load from manure applications (kg/yr)	0.781	0.959
Road Density Watershed	Road Density Riparian Watershed	0.954	0.915
Incremental total phosphorus load from fertilizer applications (kg/yr)	Incremental total nitrogen load from fertilizer applications (kg/yr)	0.853	0.941
Road Density Riparian	Road Density	0.937	0.912
Streambed fine sediment and sand cover	Streambed D50	-0.770	-0.930
Housing Unit Density 2020	Population Density 2020	0.928	0.921

Results

The predicted watershed health categories are poor, fair, and good. About 65% of the watershed area is predicted to be healthy (good and fair), with 52% predicted as “good” and 13% predicted as “fair” (Table 7). Healthy areas generally appear in forested areas along the watershed's western and northern parts. The “poor” predicted watersheds appear in developed areas, focused on the eastern parts of the watershed containing major cities like Washington D.C., Baltimore, and Harrisburg (Figure 9).

Table 4 Model results per class. Number of catchments and total area of the watershed.

Predicted Score	Count	% Count	Area (km^2)	% Area
Good	36,858	44%	88,683	52%
Fair	10,371	12%	22,124	13%
Poor	36,399	44%	59,664	35%

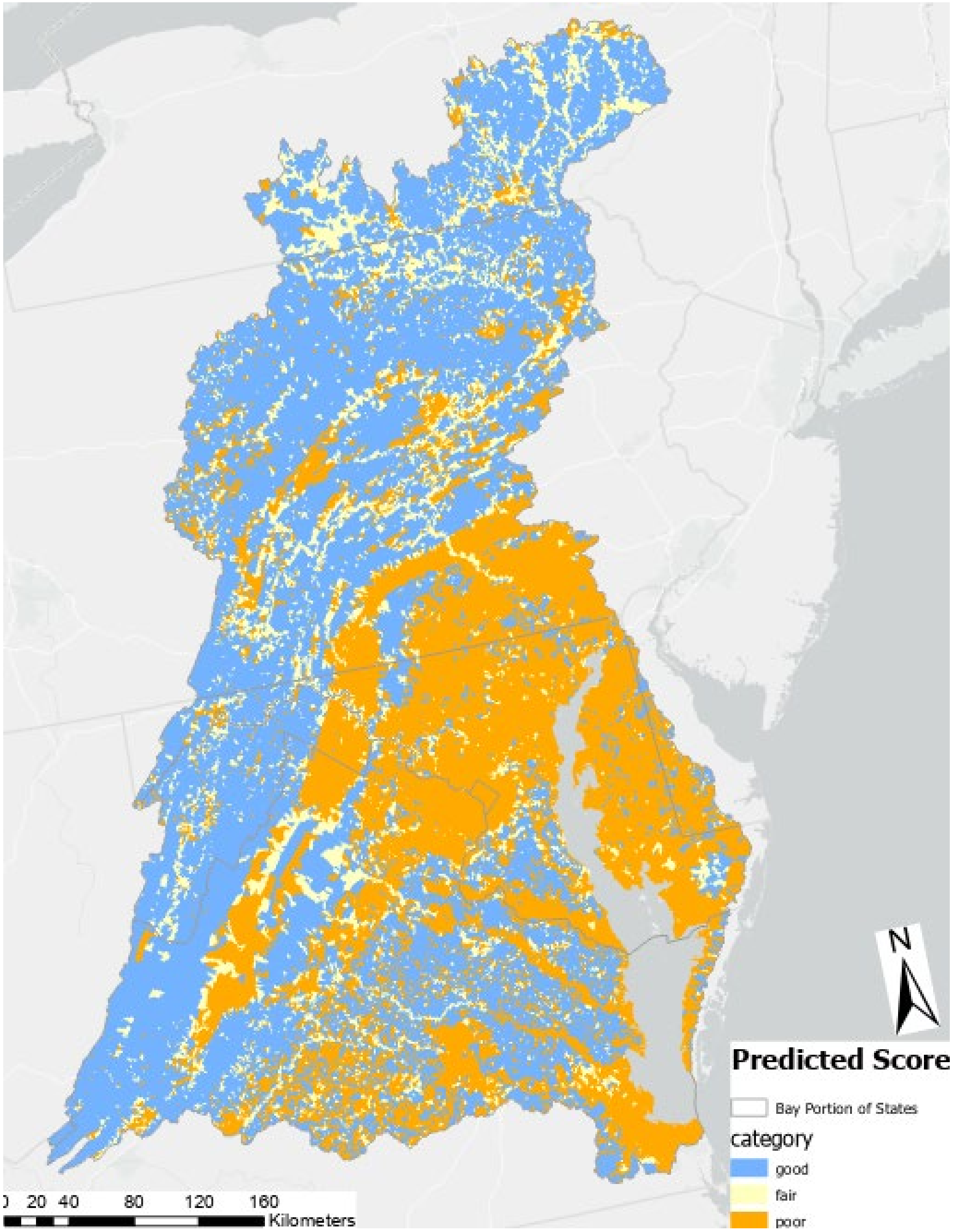

Figure 6 Results of the random forest model showing the predicted score at the NHDv2.1 catchment scale.

Model Accuracy

There are several methods to assess model accuracy. All methods are dependent on 20% of the training data that are used to test the accuracy of the model predictions. The overall accuracy score, or the percentage of correctly classified test data, is 59%. The out-of-bag score is a measure of average error from each decision tree using the portion of training data that was not part of the bootstrap sample to build each tree. The out-of-bag score is 0.56. The balanced accuracy is the average of recall per class, which measures the ability for the model to correctly identify positive samples. The balanced accuracy is 0.58. Cohen's kappa is a score that assesses the level of agreement while considering chance agreement. The kappa score is 0.38, which is considered fair agreement. These accuracy metrics can be seen in Table 8. Precision is a measure of the ability to not classify positive matches as negative (non-matches). F1-score is the harmonic mean of precision and recall, where 1 is the best score and 0 the worst. See Table 9 for precision, recall, and F1-score per class.

Table 5 Series of model accuracy scores.

Accuracy Type	Value
Accuracy Score	0.59
Out-Of-Bag Score	0.56
Balance Accuracy	0.58
Cohen's Kappa	0.38

Table 6 Model accuracy scores.

Class	Precision	Recall	f1-score	Support
Fair	0.55	0.26	0.35	84
Good	0.59	0.77	0.67	103
Poor	0.60	0.70	0.65	87

Another approach to assessing accuracy is to identify where the predictions are incorrect, or which classes are being confused. Building a confusion matrix of measured values (Chessie BIBI) and predicted values for each class is one way to analyze accuracy (Tables 10 and 11). In the test data, 77% of "good" catchments were predicted as good, 70% of "poor" catchments were predicted as poor, and 26% of "fair" catchments were predicted as fair. The largest area of confusion is the 43% of "fair" catchments predicted as good. Another approach is to review the Area Under the Curve (AUC) of the Receiver Operating Characteristics (ROC) curve. ROC is a probabilistic curve comparing the rate of true positive predictions and the rate of false positive predictions on the test dataset (Narkhede, 2021). The AUC score is used to identify how well the model can distinguish classes (Narkhede, 2021). An AUC score of 1 is perfect distinction between classes, 0.5 is no distinction between classes, and 0 is inverse distinction of classes (e.g., all good is classed as poor). The average AUC score of the 3 predicted classes is 0.73, with poor at 0.80, good at 0.78, and fair at 0.60. This is visualized in Figure 10. To go a step further, the ROC can be plotted for each combination of classes to assess specifically which classes are being confused and in which direction, like the confusion matrix. In Figure 11, the most confusion is "fair" being classified as good and poor, while the least confusion is between good and poor.

Table 7 Confusion matrix of test data, where each row is the "true" value (Chessie BIBI), and the columns are predicted values from the model.

	Good	Fair	Poor
Good	79	10	14
Fair	36	22	26
Poor	18	8	61

Table 8 confusion matrix of test data, where each row is the "true" value (Chessie BIBI), and each column is the predicted values from the model. This table is converted to show the percentage of each "true" class captured in each predicted category. For example, the 77% of "true" good predicted as good means that 77% of the "true" goods were predicted as true. Of the "true" good predictions, 10% were predicted as fair and 14% predicted as poor.

	Good	Fair	Poor	Total
Good	77%	10%	14%	103
Fair	43%	26%	31%	84
Poor	21%	9%	70%	87
Total	133	40	101	274

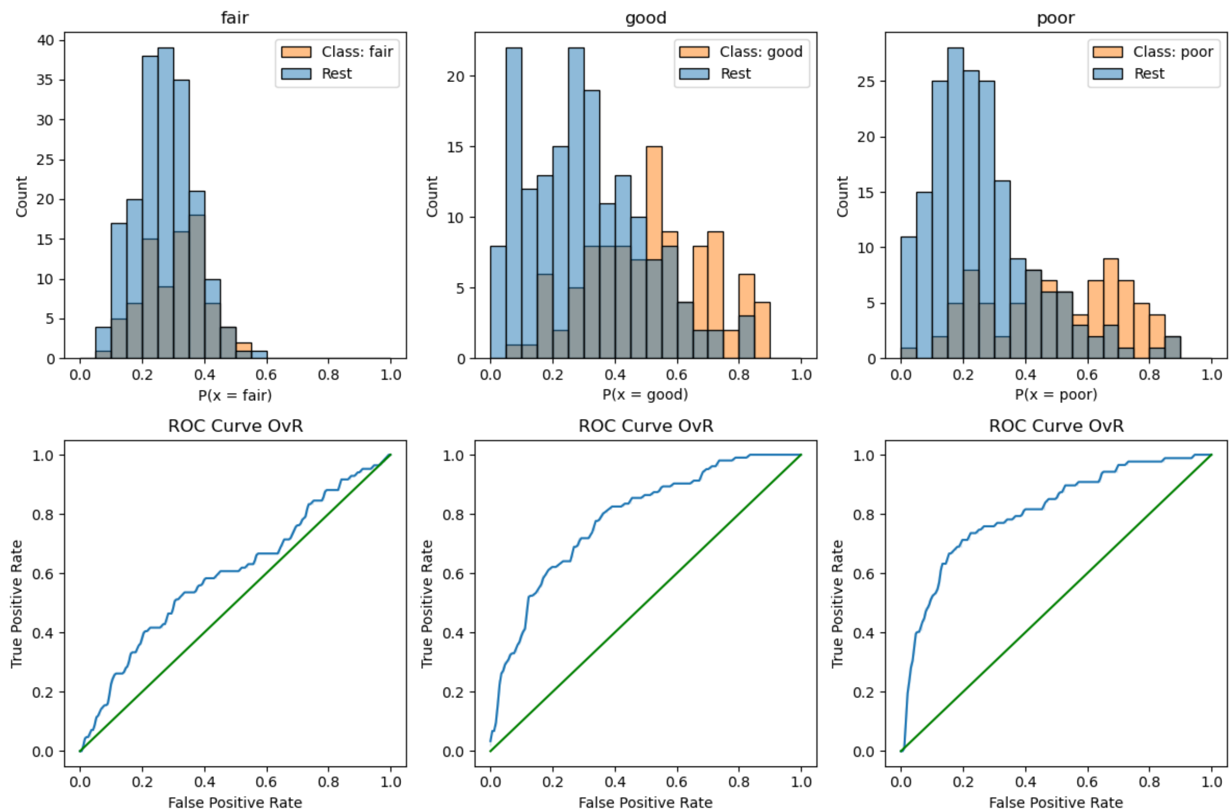

Figure 7 The ROC curves and histograms for each class. The orange in the histograms represents the class, the blue represents the other 2 classes, and the grey represents overlap. The ROC for each class represents the model's ability to correctly identify the class on the test data.

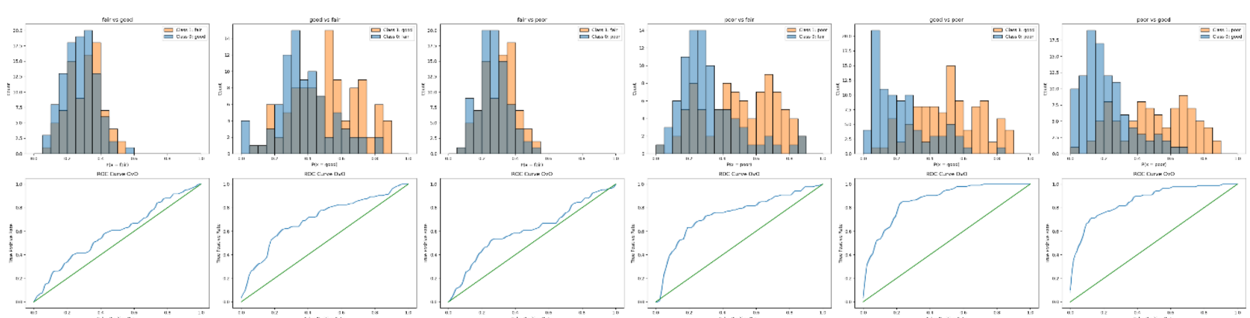

Figure 8 The ROC curves for each combination of classes, where orange is the "true" class and blue is the predicted class.

Metric Importance

A feature importance plot was developed to identify the relative importance of any feature within the random forest classification (Figure 12). 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, a feature importance plot can provide a good relative indication of what metrics the model used to derive the highest accuracy. Some metrics were found to be consistently important, specifically tree cover with unmanaged understory, 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, population density, and housing density. These hold constant with previous research and are intuitively the types of metrics typically associated with assessing watershed health.

The top 7 most important metrics in predicting watershed health are all watershed metrics, in that they include data from upstream of the given catchment (Figure 12). This result implies that in many cases, upstream factors play a significant role in watershed health and particularly biological health.

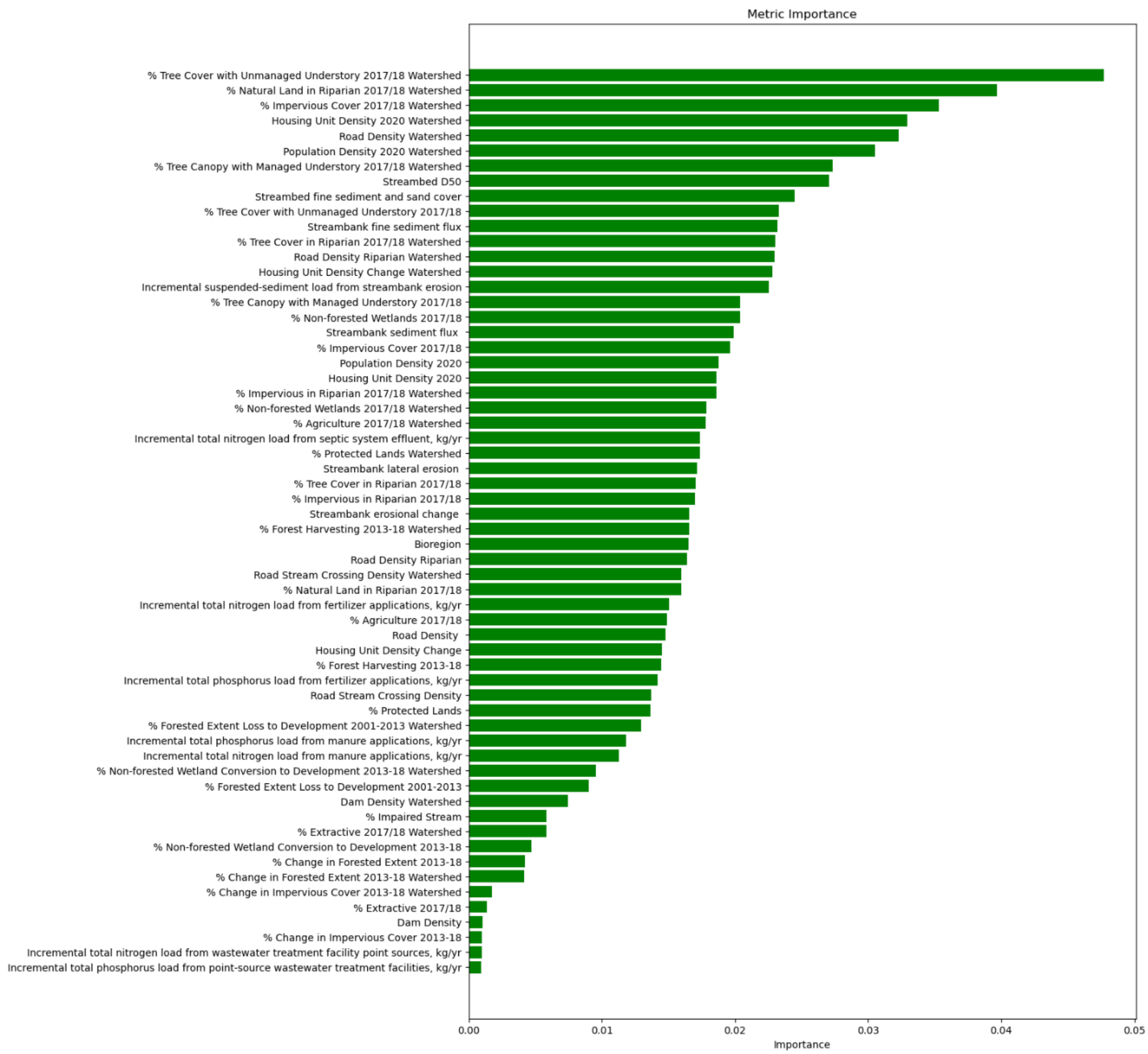

Figure 9 Metric importance plot of all metrics included in the random forest model.

Next Steps

The Chesapeake Healthy Watersheds Assessment 2.0 is an excellent framework to assess the importance of metrics in watershed health and in its predictive power of distinguishing watersheds in good vs poor condition. Improvements can be made by incorporating new metrics, including measured temperature and conductivity data, and assessing if the predictive power of the model improves. Some metrics in this report can be used as proxies for these metrics, including percent impervious and percent forested in the riparian zone. The CHWA 2.0 framework can be used to both include these new metrics to predict watershed health and assess the ability of these "proxy" metrics to predict these measured data. Another improvement is to further reduce redundancy in metrics to expand the interpretation of metric importance. One approach could be to remove local catchment data and use upstream watershed metrics, like Maloney et al (2018) did in their efforts to predict biological conditions. Another approach is to experiment with tools, like the LassoCV function in the sklearn library, which can be used to identify a reduced list of metrics that has a similar predictive power to the full list of metrics. The training data used for this project included a random sample of "good" and "poor" catchments to even out the distribution of training data among classes. Future iterations of the CHWA 2.0 framework should use a stratified sampling approach to ensure the training data is distributed amongst classes and spatially. This may be alleviated by predicting raw scores as opposed to 3-classes. Finally, additional research should be done to assess the local and upstream conditions and whether one or the other is a better proxy for watershed health. Finally, biotic health is only one aspect of a healthy watershed. Identifying other response variables, such as salinity or habitat, is necessary to truly determine if a watershed is "healthy".

CHWA 2.0 Data Exploration Tool

In addition to presenting an updated suite of metrics and a more sophisticated analytical method for assessing overall watershed health, the Chesapeake Bay Healthy Watersheds Assessment 2.0 launched a new, updated interactive data exploration application. The application contains numerous tools that can be leveraged to view, interact with, filter, and download the datasets associated with the Chesapeake Bay Healthy Watersheds Assessment 2.0.

Development

Stakeholder Feedback

Prior to revamping the application and interface, HWGIT Team sought stakeholder feedback to understand the user experiences of those who interact with the tool. Feedback collection mechanisms included satisfaction surveys, live focus groups, and targeted one-on-one interview sessions with stakeholders that represent key user groups (state natural resource managers, land trust planners, environmental scientists). Key takeaways from the stakeholder feedback sessions included:

- Application users fall into two groups: lay users (who might have limited scientific or technical background, and who want a simplified, "boiled down" interface that shows which watersheds are healthy/unhealthy, protected/unprotected, vulnerable/resilient at a glance) and scientific power users (who might have a deep technical knowledge, and who want to freely slice and dice individual metrics, in order to augment their own analyses).
- Given the volume of information from multiple data sources presented in the application, as well as the numerous possibilities for interacting with the interface and data, the application components and data would benefit from ample descriptive context.
- Application users desired easy access to training materials on both the application overall, as well as pre-defined use cases for walking through the application.
- Stakeholders wanted the incorporation of additional information that could enrich decision support activities (e.g., diversity, equity, inclusion, and justice (DEIJ) information, land management boundary information, best management practices (BMP) location information, and comparisons of watershed health through time).

The stakeholder feedback was compiled and transformed into a list of action items. These action items were assessed on the basis of feasibility (whether they would be possible given available data and technological constraints) and universality (whether they would apply broadly to users or pertain to just a select few). The boiled down and prioritized list of action items is provided as an appendix (Appendix B) to this document.

Technologies Used

The original Chesapeake Bay Healthy Watershed Assessment data viewer utilized the Environmental Research Systems Institute (ESRI) suite of technologies, with the interface itself built using ArcGIS WebApp Builder Developer Edition SDK. CHWA 2.0 continues to utilize ESRI technologies but transitioned to the newer ArcGIS Experience Builder Developer Edition SDK, in order to modernize the application infrastructure and allow for a larger degree of customization.

Features

Custom Widgets

The Chesapeake Bay Healthy Watersheds 2.0 Data Exploration tool includes two custom-built widgets to improve the data exploration experience, in line with user feedback. First, the Catchment Report Widget (built and updated by Innovate! Inc.) provides an enriched attribute display experience. When a catchment is selected on the map, the catchment report widget displays the attribute values for each metric, grouped by category (health or vulnerability) and sub-category. Hovering over each reported metric displays a tooltip containing explanatory and reference information and links directly to the source data, if applicable. Users may also download a PDF version of the catchment report.

Second, the metric selection widget (modified by Innovate! Inc. based on a widget scaffold provided by XX on GitHub), allows users to have more specificity when viewing metrics on the map. In the previous version of the application, all metrics loaded in the map layer widget, with nested levels of visibility, which increased the complexity of locating and toggling between layers. With the metric selection widget, a user may navigate through the metric options, adding only those metrics that they would like to visualize to the map. This streamlines the metric exploration experience and provides a more intuitive interface for non-GIS savvy users.

Cross-Outcome Goals Analyses

"Easy Button" Views

The "Filters" widget allows users to toggle composite filters for various high-interest, multi-metric filters. These have pre-set criteria, based on scientific thresholds where available and statistical distribution thresholds (e.g., top or bottom decile) where scientific thresholds do not exist. When an "Easy Button" view is applied, the catchments that meet the criteria will be shown on the map, while catchments that do not meet the criteria will be removed from the map view (Figure X).

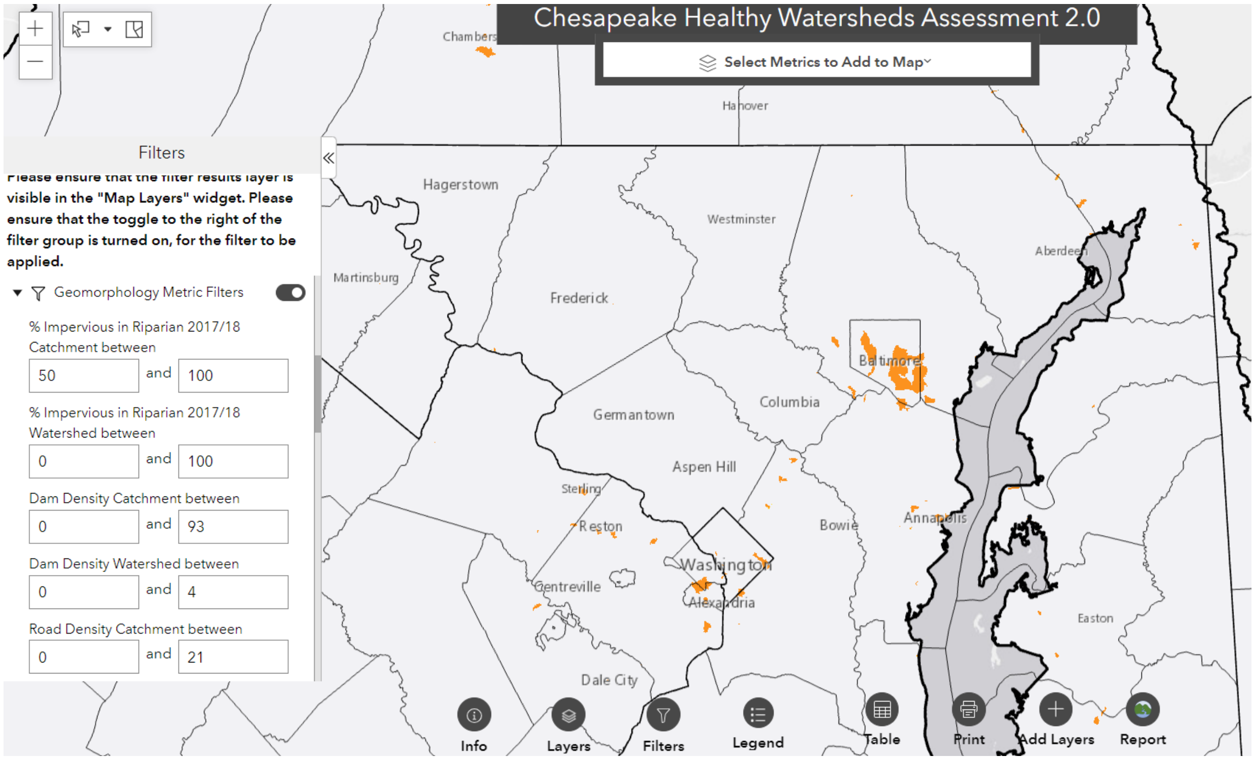

Figure 13. Watershed catchments that have a percent impervious cover between 50 and 100 % are displayed in the map view.

Bi-Variate Analysis Layers

The application provides a series of bi-variate analysis layers that allow for the quick comparison of two key metrics. These maps can be used to address CBP outcomes, such as the Fish Habitat Outcome and Forest Buffers Outcome, as well as assess vulnerability, including resilient lands vulnerable to development or climate stress. An example is provided in Figure 14.

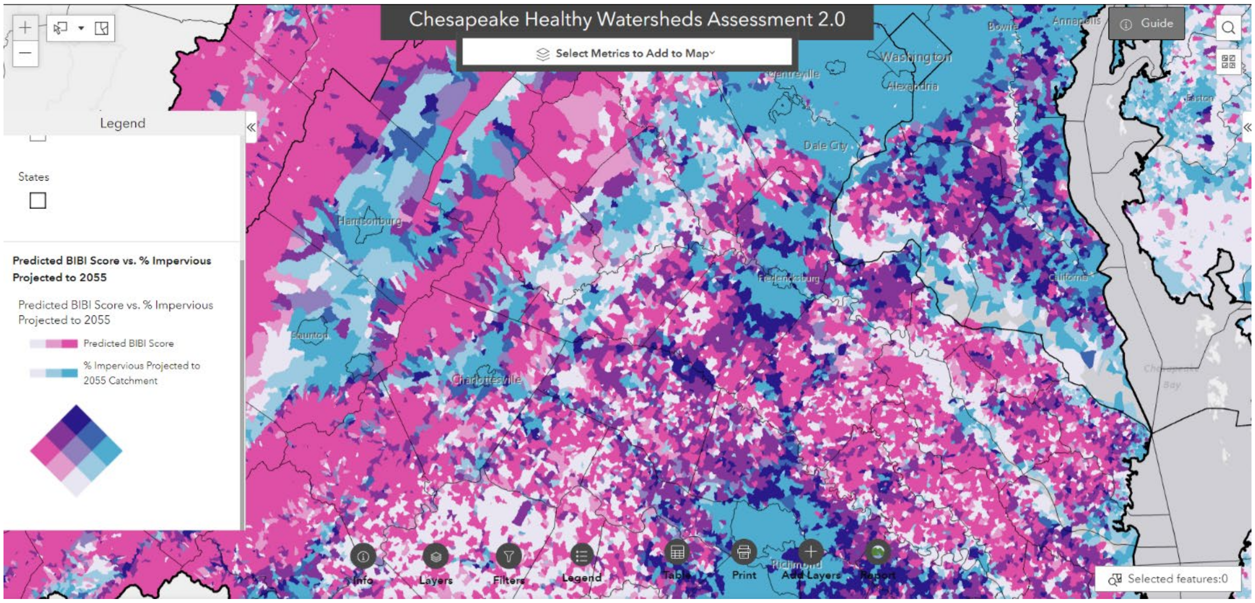

Figure 14. Bivariate layer comparing predicted BIBI scores versus percent impervious lands projected to 2055.

Overlay Layers

The application makes a selection of overlay layers available, to provide additional context in support of cross-outcome goals analysis.

Diversity, Equity, Inclusion, and Justice (DEIJ) Data – DEIJ overlay layers come from the Chesapeake Bay Program Environmental Justice and Equity Dashboard (Beta), 2021. The specific DEIJ layers provided in the application interface are: % persons of color, % low-income population, % linguistically isolated, and social vulnerability index.

Protected Lands – The Protected Lands overlay is a data layer maintained by the Chesapeake Bay Program Office, showing the spatial extent of protected lands. “Protected lands” means lands permanently protected from development, whether by purchase or donation, through a perpetual conservation or open space easement or fee ownership for their cultural, historical, ecological, or agricultural value. The underlying data are compiled from authoritative federal and state data sources.

Habitat Protection – The Habitat Protection overlays come from Black Duck Joint Venture, Ducks Unlimited, Atlantic Coast Joint Venture Black Duck Decision Support Tool (2022). The layers include priority conservation and restoration watersheds based on availability of food energy to support Black Duck population objectives.

Change in Stream Temperature – The Change in Stream Temperature comes from the Chesapeake Bay Program Open Data Portal (2020). The layer shows the change in stream water temperature in the Chesapeake Bay Watershed between 1960 and 2014.

Chessie BIBI – The macroinvertebrate index is a Chesapeake Bay watershed wide measure of biological index from sampled macroinvertebrate data used as a proxy for watershed health for the purpose of this assessment.

Limitations

Esri Experience Builder, while a robust tool, currently has limitations on various functionality. For example, the table view does not honor rounding or precision of numbers, so values that would typically be rounded to the hundredth are displayed several decimal places further than desired. There are also limitations to the filtering widget, as some filter settings are currently built to return a maximum of 100 features. Since the number of catchments is far greater than this value, those type of filters could not be implemented as-is. The filtering widget does not currently show the filtered selection as selected records in the table view either. Finally, in the previous version of Esri app-builder software, it was possible to add shapefiles to the application map; however, this is currently unavailable in this version of Experience Builder. These issues all will likely be resolved in future updates to the product or functionality could be built out in custom tools if necessary. These updates could then be implemented in future versions of the CHWA application. Other future enhancements to the application could include increasing efficiency of the catchment report widget and adding tooltips to widgets for a more intuitive user experience.

Further items were identified in stakeholder interviews that could not be implemented due to time limitations, more research being required, or additional data needed. These include enhancements to show where Best Management Practices (BMPs) are currently being implemented and where BMPs could be placed to provide the most benefit. Data limitations were the main impedance to inclusion in CHWA 2.0. Additionally, users felt it could be beneficial to be able to select area on the map and for the analysis layers to recalculate based on the selection; however, more technological research is required, and scientific input needed on how to best implement a solution. Other data that was not available at the time of development that should be added in later iterations include updated riparian data, updated FIBI score data, and conductivity data.

Recommendations for Tracking Watershed Health and Vulnerability

Using CHWA metrics, watershed health and vulnerability 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 CHWA offers another way to characterize conditions, detect change, and target future monitoring if needed.

The Chesapeake Bay metrics for watershed health and vulnerability compiled here represent a first 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, whether available throughout the Bay watershed or within a subarea.

Some metrics lend themselves to being updated with new versions of datasets that are scheduled or likely to be updated. Table 5 summarizes future data updates that are expected. 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 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.

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 CHWA 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, to build models for predicting stream and watershed health applicable elsewhere. In addition to CHWA's regional data, available state-specific data should be integrated into further diagnostic investigations. Further statistical evaluations of the watershed health and vulnerability metrics and their relationships with independent measures will be an important next step to establish a framework for evaluating when a statistically significant change is occurring (or about to occur) and to provide signals of change to understand when conditions are likely to fall short of expectations for healthy watersheds. Predictive models can inform the selection of watershed health metrics for assessing and tracking conditions, individually or within a combined watershed health index.

Management Applications and Availability of Chesapeake Healthy Watersheds Assessment 2.0 and Data

The assessment framework, metrics, and geodatabase created for the Chesapeake Healthy Watersheds Assessment (CHWA) 2.0 are intended to be useful for a variety of management applications. Primarily, the assessment will support the Chesapeake Bay Program and its jurisdiction partners in detecting signals of change in the state-identified healthy watersheds, providing information useful to support strategies to protect and maintain watershed health. In particular, indicators of vulnerability may help to provide an "early warning" to identify factors that could cause future degradation, allowing for steps to be taken related to communication and management actions to head off these potential negative effects.

The CHWA will be integrated with other Bay Program efforts in support of ecosystem health. For one, the CBP Stewardship, Habitat, Healthy Watersheds, and Water Quality Goal Implementation Teams (GITs) want to better understand key stressors or "risk factors" impacting stream health and aquatic habitats beyond nutrient and sediment impairments. Online tools can be utilized to better communicate watershed and aquatic habitat health, vulnerability, and resilience to decisionmakers and other stakeholders. For example, The Planning for Change Module of the Watershed Data Dashboard and Chesapeake Open Data Portal can be further developed to better visualize and communicate:

- Which streams, watersheds, and vital lands are most vulnerable and resilient to future impacts from land use and climate change?
- How do landscape patterns and hydrologic connectivity affect the impact of historic and future land use change on stream and aquatic health?

The CHWA will support a number of strategies and actions outlined in the Chesapeake Bay Program's recently updated Management Strategy for the Healthy Watersheds Outcome (CBP 2020a) and 2020-2021 Logic and Action Plan (CBP 2020b). The CHWA will provide information in support of federal and state efforts in assessing watershed status and characterizing watershed vulnerability to future risks. The geospatial data provided by the CHWA will be useful in conveying information to local governments and other decision makers for the protection of healthy watersheds. In addition, the CHWA will assist in understanding and addressing specific healthy watershed vulnerabilities.

CHWA 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 CHWA, 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.

The CHWA can contribute to watershed assessment and protection efforts within an overall management framework (CBP 2020a) that includes:

1. maps of state-identified healthy watersheds,
2. the best available assessments of the vulnerability of those watersheds,
3. the most current information on protections that are in place to ensure the long-term sustainability of watershed health, and
4. analyses on land use change or other landscape characteristics to track the health and viability of the watersheds over time.

As outlined in the Management Strategy (CBP 2020a), the CHWA can support the Healthy Watersheds GIT in its interactions with other Bay Program efforts, including the following:

- Coordination with the Scientific and Technical Assessment and Reporting Team in developing approaches for identifying, assessing, and monitoring the condition of existing healthy watersheds.
- Collaborate with the Sustainable Fisheries Goal Implementation Team and Fish Habitat Action Team in integrating CHWA findings with the regional Fish Habitat Assessments being developed for non-tidal and tidal waters that will inform habitat restoration and conservation efforts. The groups should investigate opportunities to integrate online visualization of the CHWA and the ongoing work related to the Fish Habitat Assessment to better understand landscape and instream stressors to both healthy watersheds and fish habitat.

- Coordination with the Habitat Goal Implementation Team and the Stream Health Workgroup, as those groups apply Bay-wide stream assessment tools (such as the Chesapeake basin-wide index of biotic integrity, Chessie BIBI) to track stream health and compile additional research findings about stressors affecting stream and watershed health in the Bay watershed.
- Work with the Enhancing Partnering, Leadership and Management Goal Implementation Team and Local Leadership Workgroup to engage with local organizations on conservation measures that support and maintain watershed health.
- Integrating with the Climate Resiliency workgroup to better understand the vulnerability and resilience of healthy watersheds to the impacts of climate change.
- Help with communication efforts to convey information about healthy watersheds to local stakeholders.

State-level healthy watershed program managers and state agencies can use the information from the CHWA 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, Maryland Department of Environment can use CHWA data to track conditions in its Tier II waters to identify and evaluate potential threats to watershed health and to 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 CHWA provides a flexible framework that can be updated periodically and can be augmented with new or more specific local data.

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

Other potential management applications of the CHWA include:

- Examining/quantifying stressors affecting stream health (not just in healthy watersheds)
- Assessing landscape factors affecting fish habitat in non-tidal and tidal watersheds, in coordination with CBP's Fish Habitat Assessments
- 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 (drinking water)
- Examining spatial patterns of population density and land use change in association 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 Catchment (with identifier "COMID"). The structure is simple, presenting the CHWA watershed health metrics organized within the six topic areas, vulnerability metrics within the four topic areas, values for sub-indices, and the watershed health index. In addition, the geodatabase includes attributes for each catchment such as state, HUC, and whether within state-identified healthy watersheds 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 for a variety of users including state and local governments and watershed groups. Further development of data analysis and visualization components through a user-friendly interface would help users in exploring and accessing data to address new management questions at a variety of scales, from regional to statewide to local. Statistics such as rankings and percentiles (either Bay-wide or by state) or comparisons of local catchment scores to regional distributions can be developed and displayed. Data visualization functions can be built into a web-based mapping application, allowing users online access to view maps, graphs, and other data summaries. It is recommended that the Healthy Watersheds GIT work with others at CBP to share information and develop an online platform that meets multiple end user needs.

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Appendix A – Full Metric List

Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
% Agriculture in 2017/18 in catchment	% Agriculture 2017/18	PcAG	Agricultural Water Use (mil gal/day)	AgWaterUse
% Agriculture in 2017/18 in watershed	% Agriculture 2017/18 Watershed	PcAGWs		

Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
Probability of Brook Trout (6-degree increase)	Probability of Brook Trout (6-degree Celsius increase)	BTOcc6C	% Probability of Brook Trout Occurrence @ 6 deg. C Increase in Water Temperature	Brook_Trout_Occur_6CTemp Chang
Probability of Brook Trout (2-degree increase)	Probability of Brook Trout (2-degree Celsius increase)	BTOcc2C		
Probability of Brook Trout (4-degree increase)	Probability of Brook Trout (4-degree Celsius increase)	BTOcc4C		
Probability of Brook Trout (current)	Probability of Brook Trout (current)	BTOccCrnt	% Current Probability of Brook Trout Occurrence	Brook_Trout_Occur_Current
Total nitrogen on agriculture	Total nitrogen on agriculture	TN_AG	Nitrogen Load Agricultural Sources (lbs./ac)	CBPModAGN
Total phosphorus on agriculture	Total phosphorus on agriculture	TP_AG	Phosphorus Load Agricultural Sources (lbs./ac)	CBPModAGP
Total suspended sediment on agriculture	Total suspended sediment on agriculture	TSS_AG	Sediment Load Agricultural Sources (lbs./ac)	CBPModAGS
Total nitrogen on CSO	Total nitrogen on CSO	TN_CSO	Nitrogen Load CSO Sources (lbs./ac)	CBPModCSON

Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
Total phosphorus on CSO	Total phosphorus on CSO	TP_CSO	Phosphorus Load CSO Sources (lbs./ac)	CBPModCSPOP
Total nitrogen on development	Total nitrogen on development	TN_Dev	Nitrogen Load Development Sources (lbs./ac)	CBPModDEVN
Total phosphorus on development	Total phosphorus on development	TP_Dev	Phosphorus Load Development Sources (lbs./ac)	CBPModDEVP
Total suspended sediment on development	Total suspended sediment on development	TSS_Dev	Sediment Load Development Sources (lbs./ac)	CBPModDEVS
Total suspended sediment on CSO	Total suspended sediment on CSO	TSS_CSO	Sediment Load CSO Sources (lbs./ac)	CBPModCSOS
Total nitrogen on septic	Total nitrogen on septic	TN_Sep	Nitrogen Load Septic Sources (lbs./ac)	CBPModSEPN
Total phosphorus on septic	Total phosphorus on septic	TP_Sep	Phosphorus Load Septic Sources (lbs./ac)	CBPModSEPP
Total suspended sediment on septic	Total suspended sediment on septic	TSS_Sep	Sediment Load Septic Sources (lbs./ac)	CBPModSEPS
Total nitrogen on wastewater	Total nitrogen on wastewater	TN_WW	Nitrogen Load Wastewater Sources (lbs./ac)	CBPModWWN

Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
Total phosphorus on wastewater	Total phosphorus on wastewater	TP_WW	Phosphorus Load Wastewater Sources (lbs./ac)	CBPModWWP
Total suspended sediment on waste water	Total suspended sediment on wastewater	TSS_WW	Sediment Load Wastewater Sources (lbs./ac)	CBPModWWS
Climate Stress indicator in Catchment	Climate Stress	ClmtStrs	Climate Stress (Habitat)	ClimateStress
DamDensityCat	Dam Density	DamDens		
DamDensityWs	Dam Density Watershed	DamDensWs	Dam Density (dams/sq. km)	DamDensityWs
Domestic Water Use in Catchment	Domestic Water Use	DomWatUse	Domestic Water Use (mil gal/day)	DomesticWaterUse
Fish Habitat Condition Index: cumulative	Fish Habitat Condition Index Cumulative	FshHCICum		
Fish Habitat Condition Index: local catchment	Fish Habitat Condition Index	FshHCI	Fish Habitat Condition Index: Local Catchment	HabConditionIndexLC
Fish Habitat Condition Index: network	Fish Habitat Condition Index Network	FshHCINwrk		
Housing Unit Density 2020	Housing Unit Density 2020	THU2020		
Housing Unit Density 2020 in Watershed	Housing Unit Density 2020 Watershed	THU2020Ws	Housing Unit Density (housing/sq. km)	HousingUnitDensWs

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Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
Industrial Water Use in Catchment	Industrial Water Use	IndWatUse	Industrial Water Use (mil gal/day)	IndustrialWaterUse
% of Stream Length Impaired in Catchment	% Impaired Stream	PcImprd	% Impaired Streams within Catchment	Pct303dImpairedCat
% Historic Forested Extent Loss to Development 2001-2013 in catchment	% Forested Extent Loss to Developme nt 2001-2013	PcForLss		
% Historic Forested Extent Loss to Development 2001-2013 in upstream watershed	% Forested Extent Loss to Developme nt 2001-2013 Watershed	PcForLssWs	% Average Forest Loss	PctForestLoss
% Impervious in Riparian Zone 2017/18 in catchment	% Impervious in Riparian 2017/18	PcISRp		
% Impervious in Riparian Zone 2017/18 in upstream watershed	% Impervious in Riparian 2017/18 Watershed	PcISRpWs	% Forest Cover in the Riparian Zone	PctImpRZWs
% Impervious Cover 2017/18 in catchment	% Impervious Cover 2017/18	PcIS		
% Impervious Cover 2017/18 in upstream watershed	% Impervious Cover 2017/18 Watershed	PcISWs	% Imperviousne ss in Watershed	PctImpWs

Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
Nature's Network Conservation Habitats in Catchment	Nature's Network Connectivit y	PcCnnctvty	% Natural Connectivity (Nature's Network Conservation Habitats)	PctNatlConnectivity
% Natural Land in Riparian Zone 2017/18 in catchment	% Natural Land in Riparian 2017/18	PcNatRp		
% Natural Land in Riparian Zone 2017/18 in upstream watershed	% Natural Land in Riparian 2017/18 Watershed	PcNatRpWs	% Natural Land Cover (% Forest + % Wetland)	PctNaturalLandWs
% Protected Lands in Catchment	% Protected Lands	PcPL18		
% Protected Lands in Watershed	% Protected Lands Watershed	PcPL18Ws	% Protected Lands	PctProtLandsWs
% Non-forested Wetlands 2017/18 in catchment	% Non-forested Wetlands 2017/18	PcWL		
% Non-forested Wetlands 2017/18 in upstream watershed	% Non-forested Wetlands 2017/18 Watershed	PcWLWs	% Wetlands in Watershed	PctWetlandsWs
Population Density	Population Density 2020	PopDens20		
Population Density in Watershed	Population Density 2020 Watershed	PopDens20 Ws	Mean Population Density (people/sq. km)	PopDensityWs
RoadDensityCat	Road Density	RdDens		
RoadDensityRiparianZoneCat	Road Density Riparian	RdDensRp		

Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
RoadDensityRiparianZoneWs	Road Density Riparian Watershed	RdDensRpWs	Riparian Zone (km/sq. km)	RoadDensityRZWs
RoadDensityWs	Road Density Watershed	RdDensWs		
Road and Stream Intersection Density	Road Stream Crossing Density	RdStrX		
Road and Stream Intersection Density Watershed	Road Stream Crossing Density Watershed	RdStrXWs	Road Stream Crossings Density (crossings/sq. km)	RoadStreamXingDens
Total nitrogen (SPARROW)	Total nitrogen (SPARROW)	TN	SPARROW - Total Nitrogen (lbs./ac/yr)	SPARROWTN
% Wildland Urban Interface	% Wildland Urban Interface	PcWUIIntfc	% Wildfire Risk	WildfireRiskUrbInterface
% Wildland Urban Intermix	% Wildland Urban Intermix	PcWUIIntmx		
% Change in Forested Extent 2013/14-2017/18 in catchment	% Change in Forested Extent 2013-18	PcFEch		
% Change in Forested Extent 2013/14-2017/18 in upstream watershed	% Change in Forested Extent 2013-18 Watershed	PcFEchWs		
% Change in Impervious Cover 2013/14-2017/18 in catchment	% Change in Impervious Cover 2013-18	PcISch		

Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
% Change in Impervious Cover 2013/14-2017/18 in upstream watershed	% Change in Impervious Cover 2013-18 Watershed	PcISchWs		
% Extractive 2017/18 in catchment	% Extractive 2017/18	PcEXTR		
% Extractive 2017/18 in upstream watershed	% Extractive 2017/18 Watershed	PcEXTRWs		
% Forest Harvesting 2013/14-2017/18 in catchment	% Forest Harvesting 2013-18	PcHarv		
% Forest Harvesting 2013/14-2017/18 in upstream watershed	% Forest Harvesting 2013-18 Watershed	PcHarvWs		
% Future Impervious (2055)	% impervious projected to 2055	PcIS55	% Increase in Development (projected through 2050)	FutureDev
% Non-forested Wetland Conversion to Development 2013/14-2017/18 in catchment	% Non-forested Wetland Conversion to Development 2013-18	PcNFWDv		
% Non-forested Wetland Conversion to Development 2013/14-2017/18 in upstream watershed	% Non-forested Wetland Conversion to Development 2013-18 Watershed	PcNFWDvWs		
% Tree Canopy with Managed Understory 2017/18 in catchment	% Tree Canopy with Managed	PcTCm		

Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
	Understory 2017/18			
% Tree Canopy with Managed Understory 2017/18 in upstream watershed	% Tree Canopy with Managed Understory 2017/18 Watershed	PcTCmWs		
% Tree Cover in Riparian Zone 2017/18 in catchment	% Tree Cover in Riparian 2017/18	PcTCRp	% Forest Cover in the Riparian Zone	PctForestRZWs
% Tree Cover in Riparian Zone 2017/18 in upstream watershed	% Tree Cover in Riparian 2017/18 Watershed	PcTCRpWs	% Forest Cover in the Riparian Zone	PctForestRZWs
% Tree Cover with Unmanaged Understory 2017/18 in catchment	% Tree Cover with Unmanaged Understory 2017/18	PcTCu	% Natural Land Cover (% Forest + % Wetland)	PctNaturalLandWs
% Tree Cover with Unmanaged Understory 2017/18 in upstream watershed	% Tree Cover with Unmanaged Understory 2017/18 Watershed	PcTCuWs	% Natural Land Cover (% Forest + % Wetland)	PctNaturalLandWs
Accumulated suspended-sediment load	Accumulate d suspended-sediment load (SPARROW)	TSS		
Agricultural Water Use in Catchment	Agriculture Water Use	AgWatUse	Agricultural Water Use (mil gal/day)	AgWaterUse
Bioregion	Bioregion	bioregion		

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Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
Change in Housing Unit Density 1990-2020	Housing Unit Density Change	THUchg		
Change in Housing Unit Density 1990-2020 in Watershed	Housing Unit Density Change Watershed	THUchgWs		
FlowAlterationIntensity Score	FlowAlteration	FlowAlter		
Incremental suspended-sediment load	Incremental suspended-sediment load	ss_is		
Incremental suspended-sediment load from agricultural uplands with fine sediment	Incremental suspended-sediment load from agricultural uplands with fine sediment	ss_is_afin		
Incremental suspended-sediment load from agricultural uplands with medium or coarse sediment or residuum	Incremental suspended-sediment load from agricultural uplands with medium or coarse sediment or residuum	ss_is_ares		
Incremental suspended-sediment load from non-agricultural and non-urban uplands	Incremental suspended-sediment load from non-agricultural and non-	ss_is_othr		

Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
	urban uplands			
Incremental suspended-sediment load from streambank erosion	Incremental suspended-sediment load from streambank erosion	ss_is_strm		
Incremental suspended-sediment load from urban uplands with fine sediment	Incremental suspended-sediment load from urban uplands with fine sediment	ss_is_ufin		
Incremental suspended-sediment load from urban uplands with medium or coarse sediment	Incremental suspended-sediment load from urban uplands with medium or coarse sediment	ss_is_umed		
Incremental suspended-sediment load from urban uplands with residuum	Incremental suspended-sediment load from urban uplands with residuum	ss_is_ures		

Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
Incremental total nitrogen load from fertilizer applications, kg/yr	Incremental total nitrogen load from fertilizer applications, kg/yr	tn_in_fert		
Incremental total nitrogen load from manure applications, kg/yr	Incremental total nitrogen load from manure applications, kg/yr	tn_in_manu		
Incremental total nitrogen load from other urban non-point sources, kg/yr	Incremental total nitrogen load from other urban non-point sources, kg/yr	tn_in_urb		
Incremental total nitrogen load from septic system effluent, kg/yr	Incremental total nitrogen load from septic system effluent, kg/yr	tn_in_sept		
Incremental total nitrogen load from wastewater treatment facility point sources, kg/yr	Incremental total nitrogen load from wastewater treatment facility point sources, kg/yr	tn_in_poin		

Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
Incremental total nitrogen load, kg/yr	Incremental total nitrogen load, kg/yr	tn_in		
Incremental total phosphorus load from fertilizer applications, kg/yr	Incremental total phosphorus load from fertilizer applications, kg/yr	tp_ip_fert		
Incremental total phosphorus load from manure applications, kg/yr	Incremental total phosphorus load from manure applications, kg/yr	tp_ip_manu		
Incremental total phosphorus load from point-source wastewater treatment facilities, kg/yr	Incremental total phosphorus load from point-source wastewater treatment facilities, kg/yr	tp_ip_poin		
Incremental total phosphorus load from urban non-point sources, kg/yr	Incremental total phosphorus load from urban non-point sources, kg/yr	tp_ip_urb		
Incremental total phosphorus load, kg/yr	Incremental total phosphorus load, kg/yr	tp_ip		

Metric	CHWA 2.0 Alias	CHWA 2.0 Field Name	CHWA 1.0 Alias	CHWA 1.0 Field Name
Percent Resilient Lands	% Resiliant Lands	PcResLands		
Streambank erosional change	Streambank erosional change	SBErosChg		
Streambank fine sediment flux	Streambank fine sediment flux	SBFSFlux		
Streambank lateral erosion	Streambank lateral erosion	SBLatEros		
Streambank sediment flux	Streambank sediment flux	SBSedFlux		
Streambed D50	Streambed D50	SbedD50		
Streambed fine sediment + sand cover	Streambed fine sediment and sand cover	SBFSSFlux		
Total phosphorus (SPARROW)	Total phosphorus (SPARROW)	TP		

Appendix B – Application Enhancements Derived from User Feedback

Stakeholder Feedback	Task	Status
CHWA survey response: I find the various metrics associated with the watershed model output to be fairly cryptic (abbreviations) and in some cases inconsistent with other representations of watershed model output (e.g.,	Clarify abbreviations where present in the application	Implemented

Stakeholder Feedback	Task	Status
Watershed Data Dashboard). **Testing of the interface:** **There are a few abbreviations that could benefit from explanatory text for those who might be less familiar with the data (e.g., HUC12, COMID)**		
CHWA survey response: **Get rid of excessive decimal places in some of the attribute pop-ups, and in the watershed report. One or two decimal places would suffice and be easier to read. I don't need or want to know percent natural land cover out to 6 decimal places, nor metric scores beyond 2 decimals.** **Testing of the interface:** **There are fields in the pop-up and pdf report that have too many decimal points (e.g. HUC12 Acres has 6 decimal points; metrics in the catchment report all have 4 decimal places)**	Adjust popups and report to use fewer decimal points where precision isn't necessary	Implemented (in Report)

Stakeholder Feedback	Task	Status
CHWA survey responses: **1. Could we have a brief explanation of each of the sub-indices, maybe when you click on the 3 dots? I cannot figure out what biological condition (change) means, nor water quality (change) and I think those are the 2 I would be most interested in. I skimmed the accompanying report and used the ""find"" function but could not figure it out.** **2. I would like an easy link from the tool to an explanation of the dataset. Maybe that is just a link back to the source documentation or maybe that is a few sentences that appear when you hover over the data name.** **3. When I click in the layer list, it would be great to be able to click on a layer and see what is included in a metric.** **4. I am sure the CHWA describes the metrics/methods/calculations, but I would like a short summary or a page number that pops up with the layer so that I don't have to go searching through the 95-page document.** **5. I find the various metrics associated with the watershed model output to be fairly cryptic (abbreviations) and in some cases inconsistent with other representations of watershed model output (e.g., Watershed Data Dashboard). How were these loads**	Incorporate tooltip or popup with explanation of each subindex and indicator	Implemented

Stakeholder Feedback	Task	Status
converted to a catchment-scale metric? **CHWA 2.0 Activity Meeting Feedback** **1. What does the data mean? Where does it come from? What is the relationship between the data and the question being asked?** **Testing of the interface:** **It's not readily apparent that the watershed report contains the tooltips, nor that the sections can be clicked/expanded**		
Stakeholder interview feedback: **Allow users to bring their own data into the map** **CHWA 2.0 Activity Meeting Feedback:** **The ability to add related data is an important feature.** **ESRI products are not familiar to everyone. There needs to be a very specific and step by step for those who are not familiar**	Change "Add Data" icon so its purpose is clearer to non-GIS users	Implemented

Stakeholder Feedback	Task	Status
with the tool. **It might be the case that people don't realize they can already add data, because they are not familiar with the icon; clearly it is important functionality that users look for.**		
CHWA survey response: **I would add a description or some kind of call out box that tells you that you need to have the category selected in order for a dataset to appear.** **Wondering if there is a cleaner way to display all the embedded data layers so that it's easier to remember where you are/what you selected** **I would change the way the layers list is displayed. The hierarchy makes sense in terms of using a GIS mapping tool but is somewhat complicated to use for a basic user. I would suggest considering listing all layers rather than having them hidden hierarchically.** **CHWA 2.0 Activity Meeting Feedback:** **Confusion on layers and how to show a specific thing you are looking for. Are layers scale dependent? general confusion on making layers appear.** **Will need to learn the data organization before I can really use the tool** **Stakeholder Interviews:**	Add text in layer list widget to clarify how it works	Implemented

Stakeholder Feedback	Task	Status
Keep state and watershed layers included but separate **Making it easier for folks to find the data they want** **More intuitive/ less overwhelming application**		
CHWA survey response: **Enable opening tabular data so you don't have to click around to see attributes, and so you can select polygons based on attributes from the table.**	Enable attribute table	Implemented
CHWA survey response: **When searching for a common stream name, the list of options provides numbers that are not useful (COMIDs I assume). The search dropdown should have stream names and counties concatenated, or something to distinguish the unique streams with the same name. (Feedback from CHWA Survey)** **Testing of the interface:** **Connection between the search bar and the watershed feature**	Improve functionality and clarity of watershed/catchment search	Implemented

Stakeholder Feedback	Task	Status
service used for searching seems to be broken		
CHWA survey responses: **In the info box, provide a link to a feature service (NOT map image service) and/or polygon data download, for those of us who actually query and analyze data in desktop applications, and don't just want to look at/click around in online apps. Ideally, you could have the option to download the entire dataset, by state or other geographic unit, or by view extent. The app is great to visualize the general trends and to dig down and see what types of info are available, but after I've looked it over, I want the actual data on my desktop!** **CHWA2.0 Activity Meeting Feedback:** **Ability to export filtered data in a table or map would be helpful** **Stakeholder Interviews:** **Mostly uses the underlying data rather than the interface** **Data download to utilize and make decisions** **Do think there is a need for data to be accessible to be pulled into their own GIS**	Add in data export/download functionality	Implemented

Stakeholder Feedback	Task	Status
MDHWA Feedback (HWGIT Menti): **Can we download a flat file instead of a report?** **Make it easy to quickly download a subset of data from the app.**		
MDHWA Feedback (HWGIT Menti): **Contain diversity and equity data** **Stakeholder Interviews:** **Include DEIJ data to get the rural perspective – places that have less administrative capacity to protect land and prevent development** **Social and environmental justice perspective should be considered and potentially incorporated** **MDHWA Feedback (User Needs Research RTI CBP Staff):** **"Emphasis on climate and diversity will continue to increase –how do we include**	Provide diversity/equity data	Implemented

Stakeholder Feedback	Task	Status
data layers to represent these underserved and exacerbated regions due to climate?" – Healthy Watersheds Interviewee"		
MDHWA Feedback (HWGIT Menti): **Summarizing the amount of protected land in each watershed/catchment. Protected land is part of Land Use which is part of Vulnerability.** **Stakeholder Interviews:** **Contextual layer showing things already protected (green infrastructure, parks, conservation easements) What does it mean to protect these watersheds? What are the tools be used to protect the watersheds that you are putting in place that could impact vulnerability. (Ex. A large easement.)**	Summarize amount of protected land in each watershed + show protected areas?	Implemented

Stakeholder Feedback	Task	Status
CHWA2.0 Feedback (this is how the source is listed, but I'm not sure where this feedback actually came from): **Needing to integrate mandated data sources, i.e. flooding - use case for adding data to the application (ex. state-specific layers)** **Stakeholder Feedback:** **Uses Maryland Healthy Watershed Assessment more often (likes the specificity; Chesapeake-wide indicator is not necessarily directly applicable to each state)** **Keep state and watershed layers included but separate (State-identified healthy watersheds)** **Potential use case would be for state employees in states that make up the Chesapeake watershed, but don't have comprehensive data or similar tools**	Add layers for State-defined Healthy Watershed metrics (e.g., MDHWA) - nesting state-specific data by state; show index maps from MDHWA as layer, refer to Maryland data and report if they want to dig deeper. Could be solved by communication, messaging in-app? Reference the MDHWA and provide link and/or contact information for MD. Communication could solve this.	Implemented
Stakeholder Interviews: **Cost-effective BMP modeling (if BMPs are enacted here, how will things improve?)** **Adding BMPs would be a huge selling point/draw** **Contextualizing ""protection"" - what tools can be used and how can those tools contribute to protection** **Add BMPs/ way to evaluate BMPs** **BMPs – way to show these are providing benefits – habitat, economic, water quality / show where these can be**	Include BMP Layer - have small list of BMPs, but still needs work. Privacy concerns, would need to be summarized at the HUC-12 level or something similar. Could be included in future versions.	Future Enhancement

Stakeholder Feedback	Task	Status
strategically deployed to increase climate resiliency Comprehensive picture of green infrastructure would be helpful in the application. Might be out of scope for the application but something to consider if it is possible to include some component.		
Stakeholder Interviews: Making connections between groups doing conservation and restoration. Land trust service areas layer doesn't currently exist, but it is in progress. Could eventually be added a reference overlay layer. Chesapeake Bay team will research. This could be helpful in places where there are places where land trusts partner and get money from states.	Incorporate watershed stakeholder boundaries and information - add land trust layer information as a reference layer - need to research what exists.	Future Enhancement

Stakeholder Feedback	Task	Status
CHWA survey responses: **I would like an easy link from the tool to an explanation of the dataset. Maybe that is just a link back to the source documentation or maybe that is a few sentences that appear when you hover over the data name.** **CHWA 2.0 Activity Meeting Feedback:** **What does the data mean? Where does it come from? What is the relationship between the data and the question being asked?** **MDHWA Feedback (HWGIT Menti):** **Would be good to have the dates for the LU data right there (esp. now that we have multiple time points for the high-res datasets)** **Testing of the interface:** **It's not readily apparent that the watershed report contains the tooltips, nor that the sections can be clicked/expanded** **Stakeholder Interviews** **Would like to see the original data and/or publications behind the application (tooltips)**	Incorporate tooltip or popup with indicator underlying dataset sources, dates, resolution	Implemented

Stakeholder Feedback	Task	Status
CHWA Survey Response: **I have personally faced this challenge with the Integrated Report and came to the conclusion that several tools are needed. One for communication, one for data acquisition, and one to provide instruction. I think the watershed tool has a lot of potential to meet the data acquisition need. I definitely like the report feature. It might be good to eventually work on the communication and instructional pieces at some point.** **It is understandable that they want to include all information—it might be better to have multiple map applications dedicated to specific stories that they want to tell in order to make this easier for the intended audience to follow and utilize.** **MDWHA Feedback (HWGIT Menti):** **Identify watersheds contiguous to designated healthy watersheds with same or higher rating (could be one of the preset filters)** **CHWA2.0 Activity Meeting Feedback:** **Can you save filters?** **Would be good if the filter screen was broken up with headings or something similar to help find the various attributes faster. Some of the**	Implement pre-set filters and/or other means of creating stories/ pathways through the application	Partially Implemented

Stakeholder Feedback	Task	Status
labels are similar, so with all of it What is the relationship between the data and the question being asked? Stakeholder Interviews: Preset filters like ""fish health filter"" Build stories for those who use the tool, making it easier for folks to find the data they wanted a more intuitive/ less overwhelming application Application use and which data are emphasized depend on which stakeholders are being targeted for funding (‘you’re going to bait the hook for the fish you’re trying to catch’) Bake in some watershed thresholds into these filters to make the user experience easier		

Stakeholder Feedback	Task	Status
MDHWA Feedback (HWGIT Menti): **Periodic updates to allow for tracking of change over time. Updates could be announced with an accompanying scorecard of some sort to indicate those changes.** **More current data (<1 year old), frequent updates to the data** **Stakeholder Interviews:** **Identify watersheds that are currently healthy, degrading (and watershed that are improving)** **Always a time-lag with processing, but if we can get recurring snapshots that would be great but not sure of solution** **User Needs Research:** **This tool was developed for the state leads of the Healthy Watershed GIT to identify signals of change within state-identified healthy watersheds." –Healthy Watersheds Interviewee - interpretation and analysis solution - answering big questions like ""where are healthy or vulnerable watersheds""?**	Dataset showing score changes over time (CHWA 1.0, 2.0, and future periodic data updates) would require to identify metrics that are 1:1 (land cover change (forest and impervious change) metrics it is already baked in). The methodology has completely changed, so holistically comparing would be really difficult.	Future Enhancement

Stakeholder Feedback	Task	Status
CHWA survey response: **I would add a description or some kind of call out box that tells you that you need to have the category selected in order for a dataset to appear. Wondering if there is a cleaner way to display all the embedded data layers so that it's easier to remember where you are/what you selected** **I would change the way the layers list is displayed. The hierarchy makes sense in terms of using a GIS mapping tool but is somewhat complicated to use for a basic user. I would suggest considering listing all layers rather than having them hidden hierarchically.** **CHWA 2.0 Activity Meeting Feedback:** **Confusion on layers and how to show a specific thing you are looking for. Are layers scale dependent? general confusion on making layers appear.** **Will need to learn the data organization before I can really use the tool** **Stakeholder Interviews:** **Keep state and watershed layers included but separate, making it easier for folks to find the data they want, more intuitive/ less overwhelming application**	Discuss and potentially revamp the organization of the data within the layer list/ application	Implemented

Stakeholder Feedback	Task	Status
Stakeholder Interviews: **Bake in standards/ thresholds for better interpretation of the map** **Incorporate thresholds for protection** **Dashboard/ Indicators might be helpful for some stakeholders** **Notion of watershed thresholds – if CHWA was able to get a consensus on those thresholds, might be easier to gage how watersheds and catchments are doing.**	Re-design color ramps and labels to incorporate scientific threshold values where applicable	Implemented Color-ramps Instead

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CHWA Survey Response: **While the CHWA application is interactive, it really doesn't seem to be more accessible than the 95-page report. This seems to be designed to speak to people like us and not the intended audience. Like eMapPA, this provides a lot of data and is rather overwhelming. The quick start information is a good idea, but again has a large amount of information, which can be confusing and overwhelming to users. The video is helpful, but it is long and should have a brief and quick overview of the application, then focus on a couple specific actions that a user is likely to take.** **I have personally faced this challenge with the Integrated Report and came to the conclusion that several tools are needed. One for communication, one for data acquisition, and one to provide instruction. I think the watershed tool has a lot of potential to meet the data acquisition need. I definitely like the report feature. It might be good to eventually work on the communication and instructional pieces at some point.** **CHWA2.0 Activity Meeting Feedback:** **ESRI products are not familiar to everyone. There needs to be a very specific and step by step**	Refine/ streamline "Quick Start Information" widget	Implemented

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Stakeholder Feedback	Task	Status
for those who are not familiar with the tool. This could help with increasing confidence in using the tool. Need tutorials, webinar, user manual Will need to learn the data organization before I can really use the tool The diverse format of generating data is great. Great tool but smaller jurisdictions or jurisdictions with limited capacity might have the ability to use the tool due to complexity. MDHWA Feedback (HWGIT Menti): I think the generate report function is very useful. Having an accompanying guide or video walkthrough, as discussed, would be helpful Additional training to help me better understand the purpose and scope of the application. How can it be used to help target project areas for our nonpoint section 319 grant and/or Chesapeake Bay Implementation Grant (CBIG) for water quality project Stakeholder Interviews: Make a presentation, provide training and support User Needs Research RTI CBP Staff: The Heathy watersheds assessment is a good tool but would be more useful if it had		

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an accompanying video explaining how to use it or attached an example case study of how it was used to make a decision." –Habitat Interviewee		

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Bi-weekly meetings with CHWA team; can help answer the questions raised by stakeholders on local data; using Arcade to use dynamic symbology - this is based on the table filtering, not the map view. Examples - Innovate has done some custom coding, will think on this solution.	Allow users to select an area and re-filter / symbolize values based on selection	Future Enhancement