ALABAMA & MOBILE BAY BASIN
INTEGRATED ASSESSMENT OF WATERSHED HEALTH

A Report on the Status and Vulnerability of Watershed Health in Alabama and the Mobile Bay Basin

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Cover photos courtesy of Rick Dowling (Left: Hatchet Creek, Coosa County) and Randy Shaneyfelt (Upper Right: Pitcher plants in headwater sloped wetlands, Baldwin County; Lower Right: Barrow Creek, headwater coastal stream in Mobile County)

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EXECUTIVE SUMMARY

Healthy waters are a vital part of Alabama's identity and economy. The state's high-quality streams, lakes, and wetlands provide a wealth of recreational opportunities, clean drinking water, and other ecosystem services to residents and visitors alike. Their continued function and status as *healthy* aquatic ecosystems depends in large part on the implementation of protection measures to prevent direct impacts and to maintain key watershed features and processes. A more concerted effort to protect high-quality waters by state agencies and other organizations can support the effectiveness of current efforts to restore impaired waters and circumvent the need for costly restoration in the future.

The purpose of the Alabama and Mobile Bay Basin Integrated Assessment of Watershed Health (the Assessment) is to identify healthy watersheds and characterize relative watershed health across the state and Basin to guide future protection initiatives. A healthy watershed has the structure and function in place to support healthy aquatic ecosystems. It is characterized as having all or most of these key components:

- Intact and functioning headwaters, wetlands, floodplains, riparian corridors, biotic refugia, instream habitat, lake habitat, and biotic communities;
- Natural vegetation in the landscape; and
- Hydrology, sediment transport, fluvial geomorphology, and disturbance regimes expected for its location.

The goals of the Assessment were to:

1. Integrate multi-disciplinary data to both identify healthy watersheds and characterize the relative health of watersheds across the Alabama and the Mobile Bay Basin;
2. Make watershed health data and information readily available to a variety of state, federal, and local programs for watershed protection planning; and
3. Encourage inter-agency partnerships and collaboration to build upon previous efforts to assess watershed health and protect healthy watersheds.

This report presents the methods and results of the planning and analysis phases of the Assessment, and outlines proposed next steps and applications. The Assessment applies a *systems approach* that views watersheds and their aquatic ecosystems as dynamic and interconnected systems in the landscape connected by surface and ground water and natural vegetative corridors. Watershed health is quantified across the state at the catchment (or subwatershed) scale from existing statewide geospatial datasets and from predictive models derived from field monitoring data collected as part of existing statewide assessment programs. This information is synthesized into several indices that describe watershed health and vulnerability to future degradation.

An important facet of the Assessment is that it leverages existing efforts that have been undertaken to analyze the characteristics of watersheds and the aquatic ecosystems within them. Several agencies and organizations assess various aspects of watershed health at statewide and national scales and/or generate data or tools that facilitate watershed health assessment. This project has forged partnerships among these groups to gather and standardize disparate datasets and provide a more complete picture of watershed health across Alabama and the Mobile Bay Basin.

One outcome of the Assessment is a watershed health database that will be made available to groups involved in watershed protection and restoration planning. The database is intended to help identify healthy watersheds that are priorities for local-scale assessment of protection opportunities. Several immediate uses of the database have been identified by project partners.

A second, more enduring, outcome is the integrated assessment framework developed by project partners. This framework reflects our understanding of the interconnected nature of the physical, chemical, and biological condition of aquatic ecosystems; the significance of landscape and watershed scale processes on aquatic ecosystem health; and the need to view water bodies as connected parts within a larger system rather than as isolated units. At present, the framework serves as a starting point for agencies and organizations tasked with protecting healthy waters to collaborate and apply a unified approach rather than undertake disjointed efforts. Over the long term, the project partners envision that the existing framework will be updated as data gaps are filled and improved methodologies are identified.

1 INTRODUCTION

1.1 Purpose and Intended Use

Over the past several decades, considerable effort has been made to restore the impaired streams, rivers, and lakes of Alabama, and to improve the health of the state's largest estuary, Mobile Bay. While some success has been achieved, many miles of streams and acres of lakes remain degraded and new impairments continue to be identified. Degradation of Alabama's aquatic ecosystems has important economic and societal consequences. In addition to the large capital expenses associated with restoration, impaired waters often lose their ability to provide valuable ecosystem services to the public, such as recreation and supplies of clean water. Together, these issues call for the expanded use of watershed protection as a tool to preserve ecosystem services and preclude the need for costly restoration.

This report presents the methods, results, next steps, and applications of the Alabama and Mobile Bay Basin Integrated Assessment of Watershed Health (the Assessment). The overarching goal of the Assessment is to characterize the relative health of watersheds across Alabama and the Mobile Bay Basin for the purpose of guiding future initiatives to protect healthy watersheds. The Assessment synthesizes disparate data sets to depict current landscape and aquatic ecosystem conditions throughout the Alabama and Mobile Bay Basin assessment areas. It is framed around the recognition that the biological, chemical, and physical health of a waterbody are fundamentally connected to one another and to the maintenance of natural watershed processes. The Assessment further recognizes that the region's watersheds are dynamic, ever-changing systems, and characterizes the vulnerability of watershed health to future degradation. By integrating information on multiple ecological attributes at several spatial and temporal scales, a systems perspective on watershed health is provided.

Readers are asked to consider the following points regarding the scope of the Assessment as they review methods and interpret results:

- The term *watershed health* can have several connotations. Its use here refers to the holistic condition of *freshwater* ecosystems within a watershed. The condition of terrestrial, estuarine, and coastal ecosystems is not explicitly analyzed and results should not be used to infer the condition of these ecosystem types.
- The Assessment characterizes *relative* watershed health throughout Alabama and the Mobile Bay Basin using a collection of metrics that focus on the natural attributes of a watershed and its freshwater ecosystems. No statement on the *absolute* condition of any watershed or water body is made and results do not reflect the influence of factors not considered for analysis.
- Data and information on relative watershed health are intended to support a screening-level assessment of protection priorities across broad geographic areas (e.g., statewide or within regional planning units). As noted above, data generated for the Assessment are not intended to be used to determine the absolute condition of aquatic ecosystems (e.g., to assess attainment of designated uses). Further, Assessment data should not supplant in-depth, site-specific evidence of protection priorities and conclusions drawn for smaller-sized areas should be validated with site-specific information.

1.2 The Healthy Watersheds Program

The US Environmental Protection Agency (EPA) launched the Healthy Watersheds Program to motivate and support active protection of our nation's remaining healthy watersheds (US EPA, 2012). A cornerstone of the Program is the promotion of a strategic, systems approach (Beechie, Sear, & Olden, 2010) to watershed protection planning and implementation. The US EPA has proposed the use of *integrated assessments* of watershed health to assist states and others with identifying healthy watersheds and prioritizing candidate watersheds for protection and restoration. Integrated assessments synthesize information on landscape condition, hydrology, fluvial geomorphology, habitat, water chemistry, and biotic communities. By combining multidisciplinary data from multiple spatial scales, integrated assessments reflect our understanding of 1) the interconnected nature of the physical, chemical, and biological condition of aquatic ecosystems; 2) the significance of landscape and watershed scale processes; and 3) the need to view water bodies as connected parts within a larger system rather than as isolated units.

Learn More Online

Visit the US EPA Healthy Watersheds Program website to review background material and information on related projects: http://www.epa.gov/healthywatersheds

1.3 Overview of Alabama and Mobile Bay Basin Ecoregions

Alabama is home to a collection of freshwater ecosystems that is among the most diverse in the nation. From Appalachian headwaters to the broad, meandering rivers of the coastal plains, these waters support a greater number of fish and mollusk species than any other state in the US. Nearly 65% of Alabama's land area drains to Mobile Bay, with the remainder belonging to the Tennessee River and Gulf Coast drainage basins. An additional 10,000 square miles of Mississippi, Georgia, and Tennessee lie within the Tombigbee River, Coosa River, and Tallapoosa River portions of the Mobile Bay Basin.

Seven Level III Ecoregions have been delineated within Alabama and the Mobile Bay Basin (Omernik, 1987) (Figure 1). Each ecoregion contains a blend of small streams, medium and large rivers, lakes, wetlands, and other aquatic ecosystem types. Below is a brief description of these ecoregions with information adapted from Griffith et al. (2001) and the Alabama Comprehensive Wildlife Conservation Strategy (ADCNR, 2005).

- **Southeastern Plains** – Covers most of southern Alabama and the entire Mississippi portion of the Mobile Bay Basin. This ecoregion is separated from ecoregions to the north by the Fall Line, a key physiographic feature for aquatic species distributions. Above the Fall Line, streams are typified by fast currents and rocky bottoms, while slow, sandy bottomed streams dominate below. Terrain is flat to gently rolling and land cover is predominantly coniferous and hardwood forest. Agricultural lands are also common, notably in the Blackland Prairie subregion in central Alabama/eastern Mississippi and the Dougherty Plain subregion in southeastern Alabama. This ecoregion includes several large river systems that drain to the Gulf Coast, including the Tombigbee, Alabama, and Conecuh. The floodplains of these rivers harbor a large number of swamps, bogs, and riparian forests.
- **Southern Coastal Plain** – Covers a narrow band surrounding Mobile Bay northward to the border of Mobile County. This ecoregion is a transitional area between the freshwater ecosystems of the Southeastern Plains and the brackish/saltwater ecosystems found along the Gulf Coast. North of Mobile Bay are the wetlands, backwater ponds, and oxbow lakes of the Mobile River-Tensaw River Delta. The complex landscape created by these parallel flowing rivers provides an extensive and diverse assortment

of aquatic habitat types. Much of the Delta is under public land ownership and has been protected from development. In contrast, areas along the eastern and western shores of Mobile Bay are under urban or agricultural cover. Streams in these areas drain directly to Mobile Bay and have been subject to degradation as a result of human activity.

- **Piedmont** – Extends from central Alabama eastward into Georgia. Topography is characterized by rolling hills with higher relief along its northern boundary with the Ridge and Valley ecoregion. Land cover is mostly forest and pasture interspersed with some cropland. The heavily populated metropolitan Atlanta area extends into the Mobile Bay Basin in this ecoregion. The Piedmont ecoregion contains most of the Tallapoosa River watershed and middle and lower stretches of the Coosa River. Reaches of both rivers have been impacted by artificial impoundments (e.g., Harris, Martin and Lay, Mitchell, and Jordan Reservoirs).
- **Ridge and Valley** – Lies north of the Piedmont ecoregion from central Alabama into the Georgia and Tennessee portions of the Mobile Bay Basin. Named after the numerous parallel valleys and ridges that cover the landscape, the ecoregion contains a mix of forest, agriculture, and urban cover (particularly in the greater Birmingham area, the state's largest population center). Major rivers include the Coosa River and the Cahaba River. The Coosa River is impounded along much of its length and has experienced a substantial loss of biodiversity. The Cahaba River is mostly free-flowing, but has suffered from degradation due to heavy residential and commercial development in the Birmingham area.
- **Southwest Appalachians** – Extends from central Alabama northward to the state border. This ecoregion is composed of plateaus, mountain ridges, hills, and valleys. Dominant land cover is pine-oak, and to a lesser extent, oak-hickory forest. Most of the coal deposits in Alabama lie in this ecoregion, and large areas have been altered by strip mining.
- **Interior Plateau –** This ecoregion covers a portion of northern Alabama in the Tennessee River Basin. Terrain in the Interior Plateau is generally rolling to hilly. Much of the naturally dominant hardwood forests of the Interior Plateau have now been converted to agriculture. Springs are high in number, in part due to the limestone geology throughout the ecoregion. The Interior Plateau contains stretches of the Tennessee River where free-flowing riverine habitats have been virtually eliminated due to artificial impoundments.
- **Blue Ridge –** Comprises a small part of the Mobile Bay Basin in northern Georgia. Topography is diverse and includes narrow ridges, hilly plateaus, and mountain peaks. Land cover is mostly forest with some pasture and croplands on terraces and floodplains. The Blue Ridge ecoregion contains the headwaters of the Coosa River, including high-gradient cool water streams in more mountainous areas.

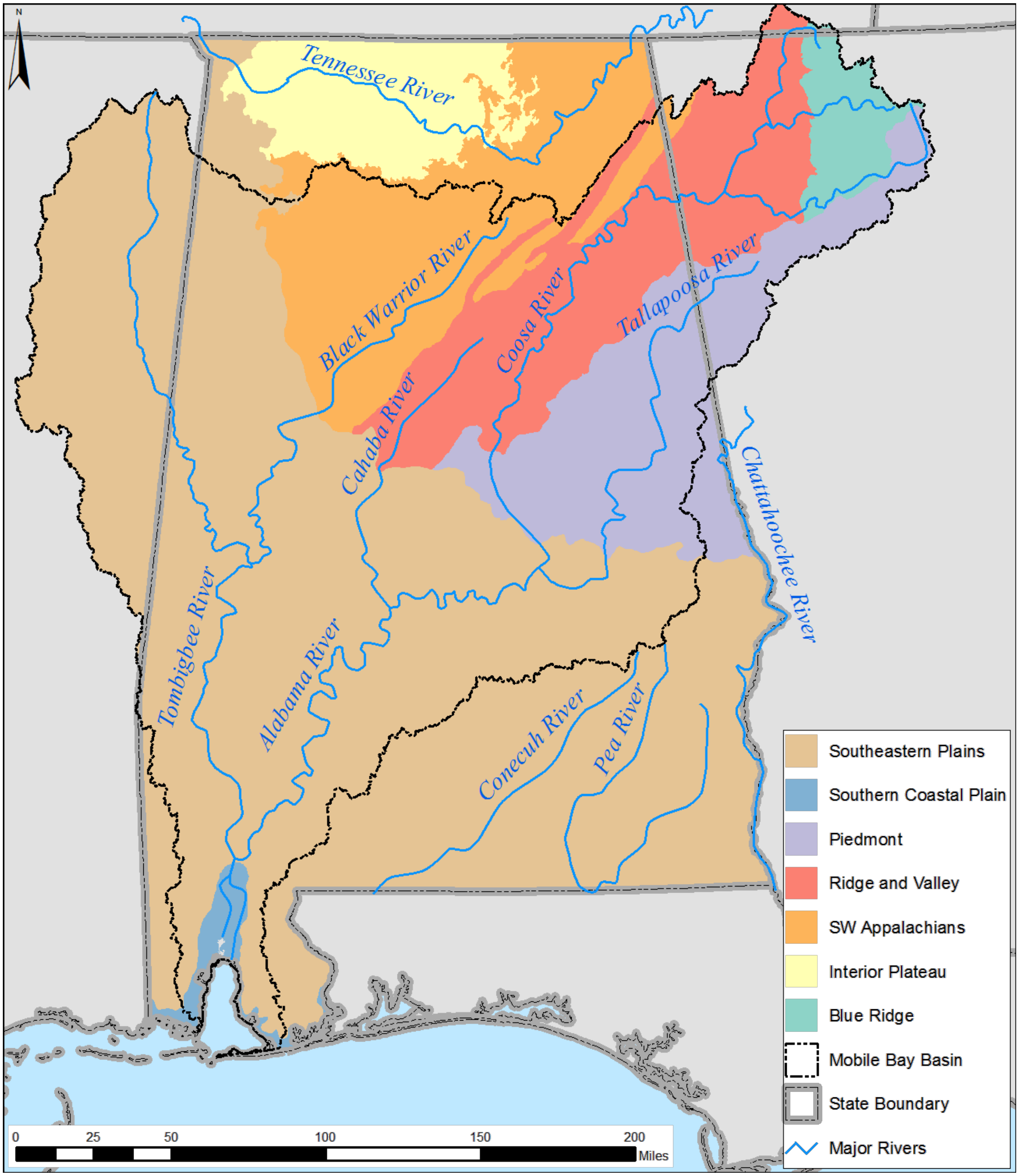


FIGURE 1. LEVEL III ECOREGIONS OF ALABAMA AND THE MOBILE BAY BASIN.

2 METHODS OVERVIEW

2.1 *Healthy Watersheds Assessment Process*

This report is the result of a collaboration between the US EPA, the Alabama Department of Environmental Management (ADEM), and the Mobile Bay National Estuary Program (MBNEP) to assess watershed health and vulnerability throughout Alabama and the Mobile Bay Basin. The Assessment was initiated with the formation of an Assessment Team with representation from US EPA and other organizations to develop the assessment methodology, review and communicate results, and implement next steps. The Assessment Team is comprised of members from:

- Participating State Agencies
    - Alabama Department of Environmental Management
    - Alabama Department of Conservation and Natural Resources
    - Alabama Department of Public Health
    - Geological Survey of Alabama
- Participating Federal Agencies
    - US EPA Office of Water
    - US EPA Region 4
    - US Fish and Wildlife Service
- Other Participating Organizations
    - Mobile Bay National Estuary Program
    - Alabama Rivers Alliance
    - Alabama Clean Water Partnership
    - The Nature Conservancy
    - Dauphin Island Sea Lab
    - Weeks Bay National Estuarine Research Reserve
    - National Fish and Wildlife Foundation
    - City of Mobile
    - City of Daphne

The first task undertaken by the Assessment Team was to prepare an inventory of available field monitoring data and geospatial data for assessing current landscape, habitat, hydrological, geomorphological, water quality, and biological condition throughout the assessment area and projected vulnerability to future degradation. From this inventory, a list of candidate watershed health and vulnerability metrics was generated.

The Assessment Team then refined the technical approach to the Assessment, examined and completed the data inventory, and discussed the candidate watershed health and vulnerability metrics. Also discussed were options for communicating results and a preliminary list of uses of the Assessment output. From this step, an Assessment Roadmap (Figure 2) was produced to serve as an outline for assessment planning, analysis, reporting, and implementation.

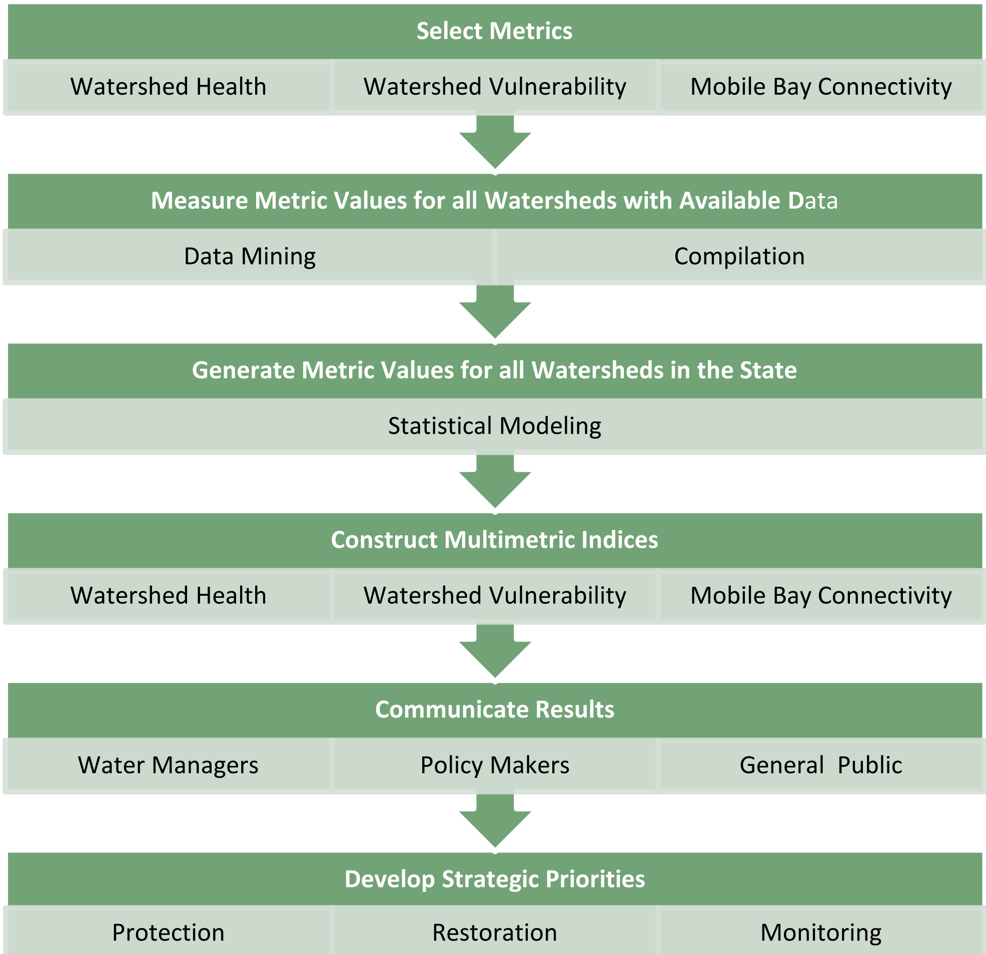


FIGURE 2. ROADMAP FOR THE ALABAMA & MOBILE BAY BASIN INTEGRATED ASSESSMENT OF WATERSHED HEALTH.

2.2 Geographic Scope

This assessment characterizes watershed health and vulnerability for two separate tiers: 1) throughout the state of Alabama (the *Statewide* tier); and 2) throughout the Mobile Bay Basin (the *Basin* tier). For the Statewide tier, watershed health and vulnerability are quantified for every watershed in Alabama and scored relative to other watersheds in the state to facilitate statewide prioritization of protection efforts. For the Basin tier, watershed health and vulnerability are quantified for every watershed in the Mobile Bay Basin and scored relative to other watersheds in the Basin to inform Basin-wide protection planning.

The Basin tier includes an analysis of hydrologic connectivity throughout the Mobile Bay Basin for the purpose of identifying areas that are both healthy and highly connected to Mobile Bay for protection consideration. A more focused analysis of hydrologic connectivity within the two 8-digit hydrologic units (HUC8s) adjacent to Mobile Bay is also completed (the *HUC8 tier*). The Mobile Bay HUC8 (HUC 03160205) and the Mobile-Tensaw HUC8 (HUC 03160204) lie immediately upstream of Mobile Bay and although they contribute a fraction of total freshwater, sediment, and solute inflow, their health is strongly tied to local scale conditions throughout the Bay.

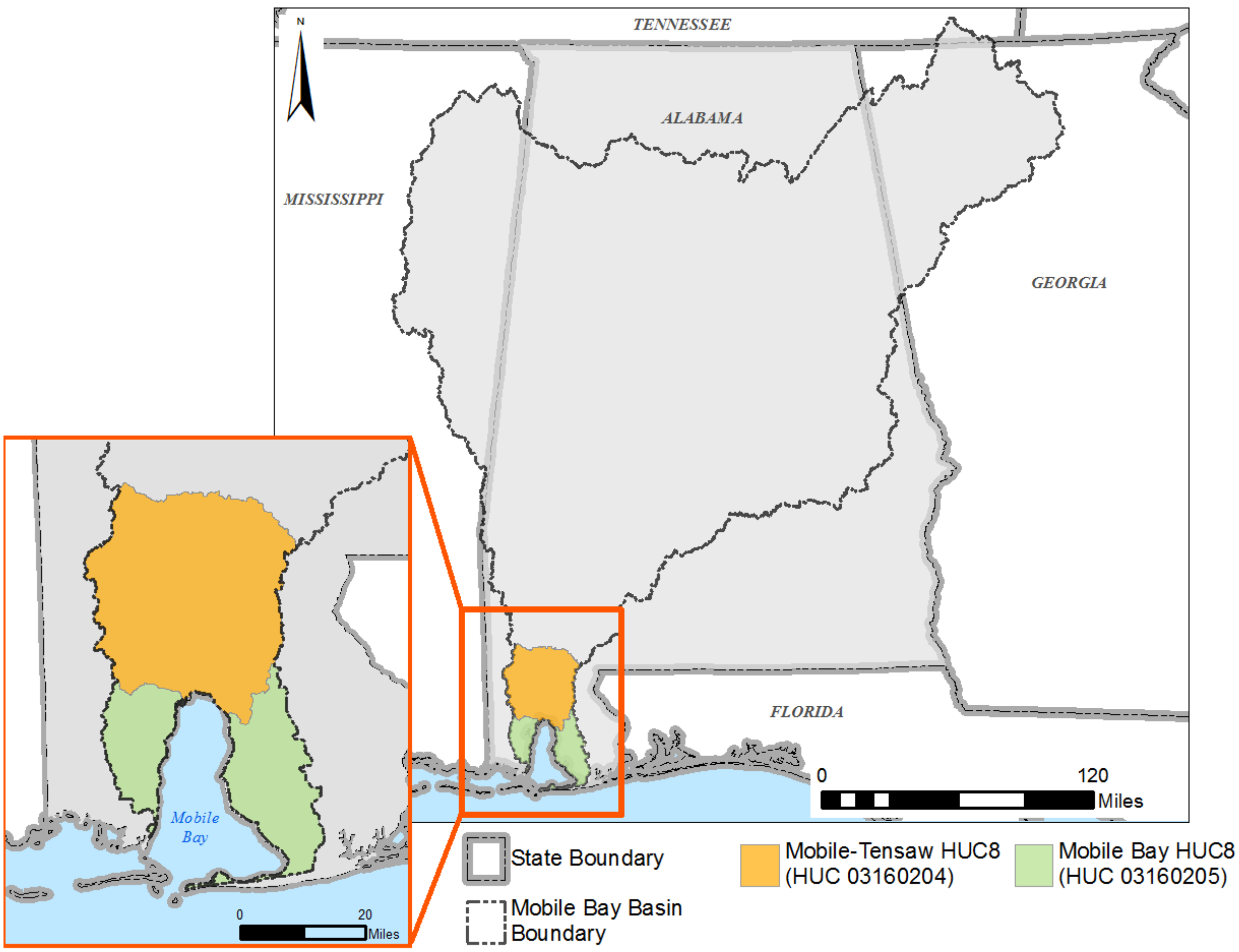


FIGURE 3. ILLUSTRATION OF THE GEOGRAPHIC TIERS OF THE ASSESSMENT. WATERSHED HEALTH AND VULNERABILITY ARE ASSESSED FOR ALABAMA (THE STATEWIDE TIER) AND FOR THE MOBILE BAY BASIN (THE BASIN TIER). AN ANALYSIS OF HYDROLOGIC CONNECTIVITY TO MOBILE BAY IS CONDUCTED AT THE BASIN TIER AND WITHIN THE MOBILE-TENSAW AND MOBILE BAY HUC8S (THE HUC8 TIER).

2.3 Conceptual Framework

The US EPA 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 supports native aquatic and riparian species; and water quality supports healthy biological communities" (US EPA, 2012). This definition encompasses six distinct but interrelated attributes of watersheds and the aquatic ecosystems within them: landscape condition; habitat; hydrology; geomorphology; water quality; and biological condition (Figure 4).

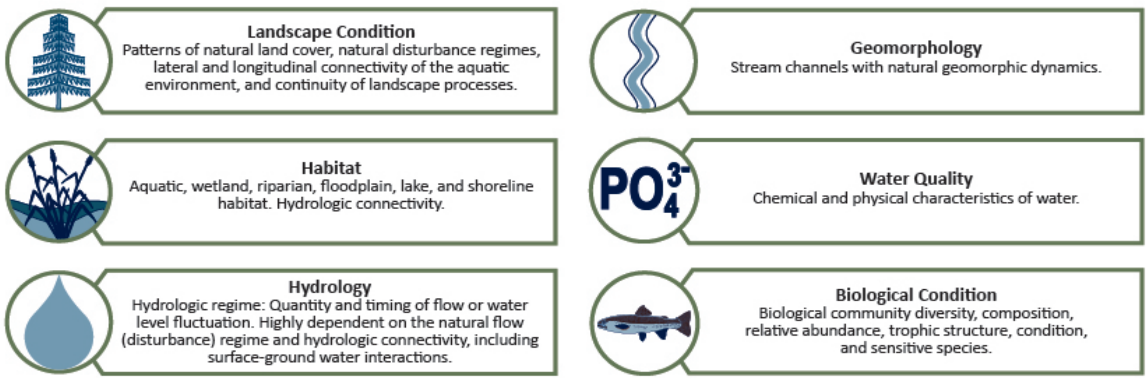


FIGURE 4. SIX ATTRIBUTES OF WATERSHED HEALTH DESCRIBED IN *IDENTIFYING AND PROTECTING HEALTHY WATERSHEDS CONCEPTS, ASSESSMENTS, AND MANAGEMENT APPROACHES* (US EPA, 2012).

An *integrated assessment* of watershed health sets out to evaluate each of these six attributes using a collection of *Watershed Health Metrics*. Watershed health metrics are specific measures of the six attributes that are quantified throughout the entire assessment area based on existing data.

Data used to quantify watershed health metrics are selected to depict present conditions. Because watershed health is a dynamic property that can vary with future changes in climate and human activity, the Assessment also evaluates the vulnerability of watershed health to future degradation. Vulnerability is quantified from a collection of *Watershed Vulnerability Metrics* that characterize potential exposure to future climate, land use, and water use change.

An additional component of the Assessment is an evaluation of hydrologic connectivity throughout the Mobile Bay Basin. The condition of Mobile Bay is linked, in large part, to the condition of its drainage basin. Healthy portions of the basin, for example, contribute to natural levels of water, nutrients, organic matter, and sediment inflow. The influence of any single watershed on Bay conditions is quantified in the Assessment from a group of *Mobile Bay Connectivity Metrics* that capture a watershed's potential for runoff generation and downstream attenuation of exported material and energy. Further discussion of metrics and data sources is provided in Sections 2.5, 2.6, and 2.7.

Two approaches are used to calculate metric values for every watershed in the Alabama and Mobile Bay Basin assessment area. Most metrics are quantified from existing geospatial datasets derived from remote sensing or other data collection methods that provide complete coverage across the state and Basin. The remaining metrics are quantified from a group of statistical models that relate instream conditions to landscape characteristics using existing field monitoring data. These models are built from existing field monitoring datasets and therefore incorporate information from stream sampling efforts that is otherwise not applicable for an assessment of every watershed in the state. See Sections 2.5, 2.6, and 2.7, and Appendix D for details of metric calculation methods.

A total of 19 metrics are used to characterize the relative health and vulnerability of watersheds in Alabama and the Mobile Bay Basin. To integrate this information for reporting and application, metrics are aggregated into a group of multimetric sub-indices and indices. Each index/sub-index combines related metrics into an overall score that ranges from 0 to 100. Methods for developing index and sub-index scores are further discussed in Section 2.9.

2.4 Spatial Framework

One objective of the Assessment is to characterize watershed health and vulnerability within a spatial framework that accommodates watershed protection planning across varied spatial scales and planning unit delineations. Toward this end, the geographic units selected for analysis are reach-scale watershed segments of the National Hydrography Dataset Plus Version 2 (NHDPlus) geospatial dataset (McKay, Bondelid, & Dewald, 2012). These watershed segments, termed *catchments* in NHDPlus documentation, comprise the direct drainage area of individual NHDPlus stream reaches. The NHDPlus stream network is a medium-resolution 1:100,000 scale geospatial representation of streams in the state and Basin.

NHDPlus catchments in Alabama and the Mobile Bay Basin are illustrated in Figure 5. A total of 77,482 catchments fall completely within Alabama, or on the state border, and are included in the Statewide tier of the Assessment. The Basin tier includes the 67,901 catchments located in the Mobile Bay Basin. The HUC8 tier includes the 1,966 catchments that lie within the Mobile-Tensaw and Mobile Bay HUC8s.

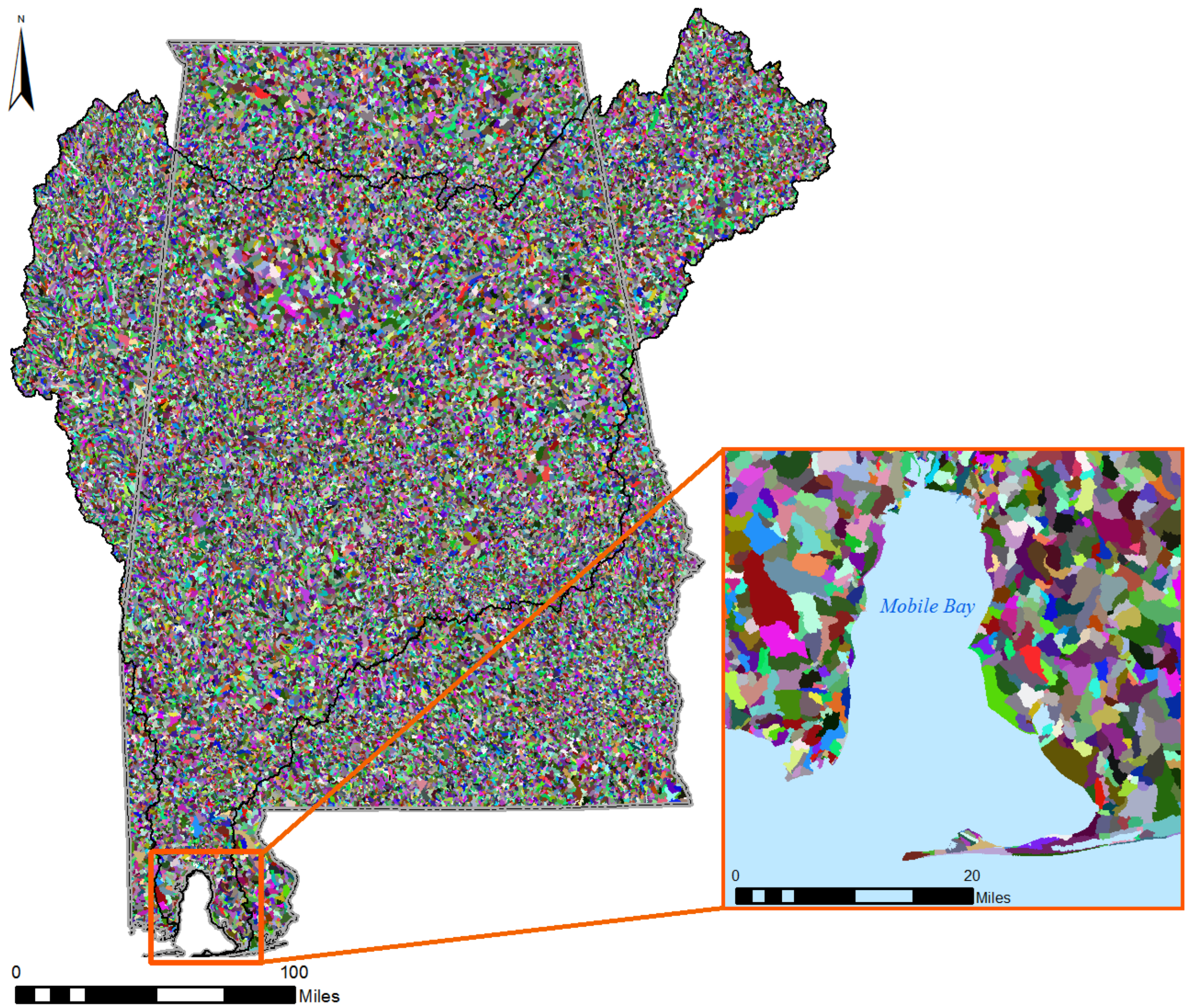


FIGURE 5. NHDPLUS CATCHMENTS OF ALABAMA AND THE MOBILE BAY BASIN. A DETAILED VIEW OF CATCHMENTS IN THE VICINITY OF MOBILE BAY IS SHOWN IN THE INSET.

Watershed health, vulnerability, and connectivity metrics are quantified on a catchment-by-catchment basis. Calculation of most metrics involved summarizing existing geospatial datasets to catchment-specific values. Other metrics were quantified from modeled relationships between stream condition and several landscape variables. These landscape variables describe channel, riparian, and watershed-wide characteristics (e.g., riparian forest cover or mean watershed slope) at both the incremental scale (within catchment boundaries) and cumulative scale (within all upstream catchments) (Figure 6). Cumulative values were included due to the potential for upstream conditions to influence the health of a given stream reach. The NHDPlus dataset supports aggregation of incremental-to-cumulative data by storing a unique numeric identifier for each catchment as well as upstream/downstream catchment IDs.

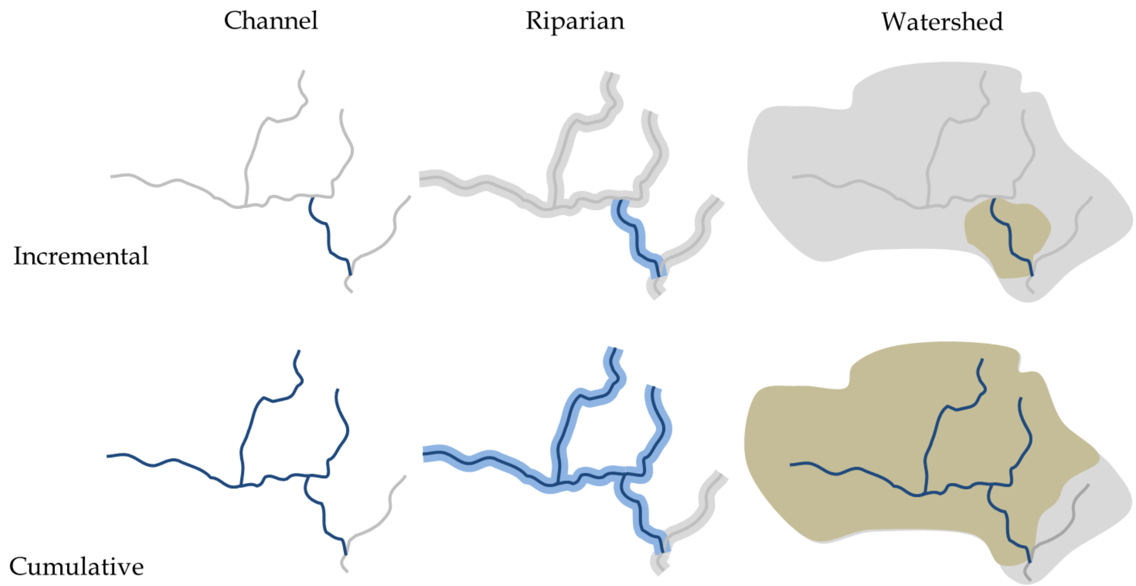


FIGURE 6. DIFFERENCE BETWEEN INCREMENTAL AND CUMULATIVE SCALES FOR QUANTIFYING LANDSCAPE VARIABLES. VARIABLES QUANTIFIED AT THE INCREMENTAL SCALE SUMMARIZE CONDITIONS WITHIN CATCHMENT BOUNDARIES ONLY. VARIABLES QUANTIFIED AT THE CUMULATIVE SCALE ALSO SUMMARIZE CONDITIONS THROUGHOUT ALL UPSTREAM CATCHMENTS.

A final note on the spatial framework of the Assessment relates to differences between the scale of analysis and the intended scale of interpretation. Although NHDPlus catchments serve as analysis units, results are not intended to be used to assess the condition of a single catchment. Rather, results should be viewed over broad geographic areas to identify patterns and prioritize watersheds for in-depth, site-specific assessments of protection needs.

2.5 Watershed Health Metrics and Data Sources

Twelve watershed health metrics were selected by the assessment team based on data availability, data quality, and the objectives of the Assessment (Figure 7). The selected metrics characterize the landscape condition, hydrology, habitat, geomorphology, water quality, and biological condition attributes of watershed health depicted in Figure 4 and described in EPA's *Identifying and Protecting Healthy Watersheds Concepts, Assessments, and Management Approaches* (US EPA, 2012). For the Assessment, they are grouped as Landscape Condition, Hydrologic Condition, Habitat Condition/Geomorphology, Water Quality, and Biological Condition metrics (note that the habitat and geomorphology attributes of watershed health in the EPA Healthy Watersheds framework are combined for this assessment because selected metrics are relevant to both attributes).

Landscape condition metrics describe the extent and connectivity of natural land cover throughout a catchment and within key functional zones such as floodplains, riparian areas, and wetlands. Hydrologic, habitat/geomorphology, water quality, and biological condition metrics focus on physical, chemical, and biological properties of streams and rivers. Data gaps prevented the selection of metrics that explicitly describe the condition of lakes, wetlands, or other non-stream freshwater aquatic ecosystems.

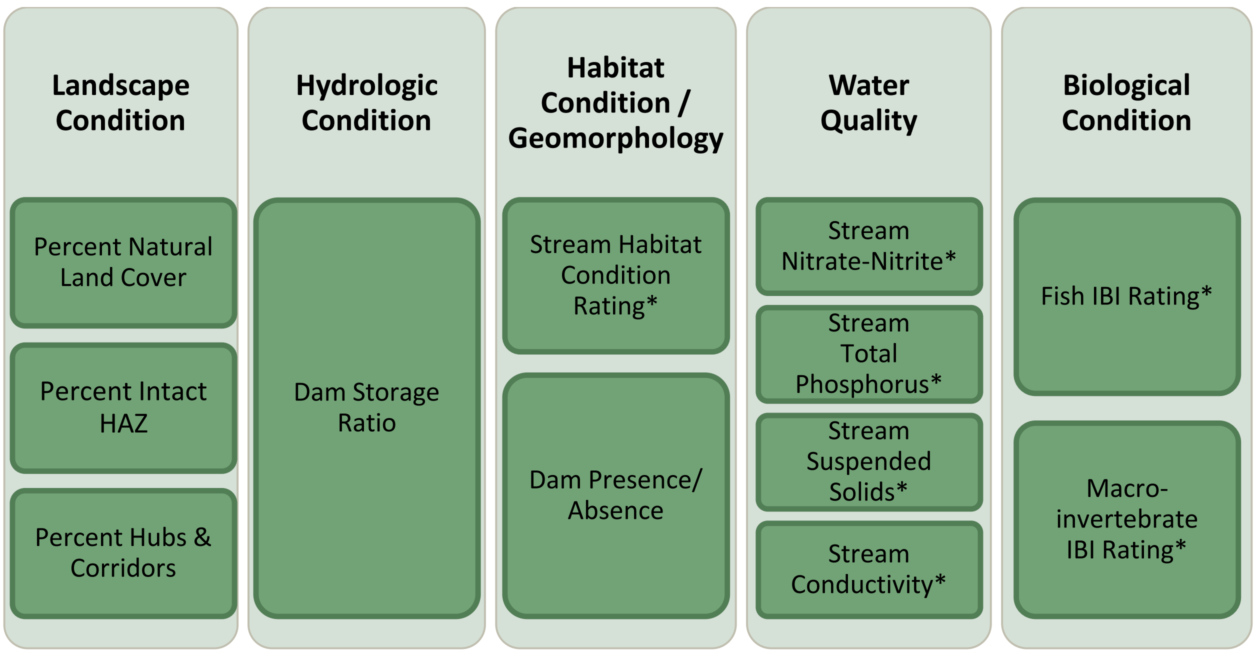


FIGURE 7. WATERSHED HEALTH METRICS. METRICS MARKED WITH AN ASTERISK (*) ARE QUANTIFIED FROM PREDICTIVE STATISTICAL MODELS. THE REMAINING METRICS ARE QUANTIFIED FROM PRE-EXISTING GEOSPATIAL DATA.

Two approaches are used to quantify watershed health metrics for all catchments in Alabama and the Mobile Bay Basin. One involves calculating metric values directly from existing geospatial data by summarizing state/basin-wide datasets to catchment-specific values. The second approach uses predictions from statistical models that relate landscape characteristics to stream conditions. The underlying sources of data for these modeled metrics are field samples collected across the assessment area through stream monitoring programs. A limitation of stream monitoring data for use in the Assessment is that samples are not available for all 77,482 catchments in Alabama and 67,901 catchments in the Mobile Bay Basin. For this reason, metrics are not quantified directly from observed values but rather from a group of statistical models that are developed and validated from field monitoring data.

The statistical models developed for the Assessment are regression models that predict representative values of seven stream health metrics for any NHDPlus catchment using landscape variables as predictors. Landscape variables describe land cover, soil characteristics, topography, etc., and are quantified at both the incremental and cumulative scales (see Figure 6). Landscape variables quantified for statistical modeling are listed in Table 1.

TABLE 1. LANDSCAPE VARIABLES CONSIDERED FOR PREDICTIVE STATISTICAL MODELS OF STREAM HEALTH.

Landscape Variables
Stream Channel Characteristics
Stream Density; Stream Slope; Stream Order
Basin Topography Characteristics
Mean Elevation; Mean Slope; Mean Wetness Index
Climatological Characteristics
Mean Annual Precipitation; Mean Annual Temperature; Mean Annual Potential Evapotranspiration
Soil Characteristics
Mean Soil Erodibility; Percent Hydrologic Soil Group A Soils; Percent Hydrologic Soil Group B Soils; Percent Hydrologic Soil Group C Soils; Percent Hydrologic Soil Group D Soils
Riparian Land Cover
Percent Natural Land Cover; Percent Agricultural Land Cover; Percent Urban Land Cover; Percent Impervious Cover
Hydrologically Active Zone (HAZ) Land Cover
Percent Natural Land Cover; Percent Agricultural Land Cover; Percent Urban Land Cover; Percent Impervious Cover; Percent Wetland Cover
Watershed Land Cover
Percent Natural Land Cover; Percent Agricultural Land Cover; Percent Urban Land Cover; Percent Impervious Cover; Percent Wetland Cover
Anthropogenic Characteristics
Dam Density; Road Density, Mean Empower Density

The models used for metric predictions are *Boosted Regression Tree* (BRT) models. BRTs are a relatively recent approach to modeling ecological relationships that combine two methods: 1) regression tree modeling; and 2) boosting (Elith, Leathwick, & Hastie, 2008). BRTs are well-suited for modeling complex ecological relationships. Example applications of BRTs for guiding management decisions include the prediction of water chemistry and stream condition scores in West Virginia watersheds (Merovich, Petty, Strager, & Fulton, 2013) and prediction of fish community condition scores and species presence throughout the Midwestern US (Clingerman, et al., 2012).

BRTs were selected for use in the Assessment because they have several advantages over other statistical methods (e.g., multiple linear regression or generalized linear modeling). Specifically, BRT models:

- Can be used to predict several data types (e.g., numeric, categorical, or binary);
- Are insensitive to outliers in response and predictor datasets and do not require a pre-processing step to evaluate data distributions and remove outliers;
- Capture interactions between individual predictors in the regression tree structure and do not require the use of "interaction terms" as possible predictor variables (e.g., the product of two predictors that together have an interaction effect);

- Have no assumption of a linear relationship between predictor and response variables and account for nonlinear relationships;
- Address overfitting without subjective determinations of "significant" predictors.

Refer to Appendix D for details of metric modeling methods and results. The remainder of this section describes watershed health metrics, the reasoning for their selection, the data sources, and an overview of metric calculation methods.

Landscape Condition Metrics

Landscape condition is described by the extent and connectivity of natural land cover throughout a watershed and within key functional zones such as floodplains, riparian areas, and wetlands. The assessment team selected three metrics to characterize landscape condition in the assessment area: *Percent Natural Land Cover; Percent Intact Hydrologically Active Zone* (HAZ); and *Percent Hubs and Corridors*. Metric data sources and calculation methods are summarized below.

Percent Natural Land Cover – Aquatic ecosystems are connected to the landscape through surface and subsurface drainage. Natural land cover throughout a watershed maintains hydrologic processes such as infiltration, evapotranspiration, and groundwater recharge, and protects aquatic ecosystems from nonpoint sources of pollution, including urban and agricultural runoff. Further, natural land cover in and around the riparian zone, floodplains, and wetlands serves as habitat for aquatic species and supports connectivity between habitat patches. Many aquatic organisms depend on the connections provided by natural corridors to migrate to and among suitable habitats as conditions vary over the short-term and seasonally.

The significance of natural land cover on watershed health is captured in the Assessment with the *Percent Natural Land Cover* metric. Percent natural land cover is calculated from the 2006 National Land Cover Dataset (NLCD) (Fry, et al., 2011) as the area of natural NLCD cover types in a catchment divided by catchment area, multiplied by 100. A list of natural and non-natural NLCD cover types is provided in Table 2.

TABLE 2. CLASSIFICATION OF NATURAL AND NON-NATURAL NLCD COVER TYPES.

Class	NLCD Cover Type & Code[a]
Natural	Open Water (11); Deciduous Forest (41); Evergreen Forest (42); Mixed Forest (43); Shrub/Scrub (52); Grassland/Herbaceous (71); Woody Wetlands (90); Emergent Herbaceous Wetlands (95)
Non-Natural	Developed, Open Space (21); Developed, Low Intensity (22); Developed, Medium Intensity (23); Developed, High Intensity (24); Barren (31)[b]; Pasture/Hay (81); Cultivated Crops (82)

[a] NLCD classification codes are shown in parentheses.

[b] *Barren* is considered a non-natural cover type because mined areas are classified as Barren in the NLCD dataset.

Percent Intact Hydrologically Active Zone (HAZ) – The presence of natural land cover in the runoff and material contribution areas of a watershed supports natural flow, sediment, and water temperature regimes and maintains reference levels of nutrient and organic matter input to streams. Key functional zones for maintenance of natural land cover include riparian areas, areas with high runoff potential, and depressional areas, and are together referred to in this report as the *Hydrologically Active Zone* (HAZ).

The significance of HAZ land cover on watershed health is captured in the Assessment with the *Percent Intact HAZ* metric. It is quantified from the 2006 National Land Cover Dataset (NLCD) (Fry, et al., 2011) and the estimated HAZ area within each NHDPlus catchment. The HAZ was delineated by merging two geospatial datasets acquired from EPA Region 4 with nationwide coverage:

- A gridded dataset depicting a 100 meter riparian zone surrounding water bodies; and
- A gridded dataset depicting the extent of the wet zone, defined as any area with a wetness index greater than 550. The wetness index (Beven & Kirkby, 1979) is a function of flow accumulation and slope gradient, with high wetness index values corresponding to high flow accumulation, low slope, and high runoff potential.

Percent intact HAZ was then calculated for NHDPlus catchments by summing the area of natural NLCD land cover types in the HAZ of each catchment, dividing by HAZ area, and multiplying by 100. See Table 2 for a list of natural and non-natural NLCD cover types.

Percent Hubs & Corridors – The size and connectivity of intact vegetative patches are important to the health of a watershed's biological communities. Green infrastructure approaches to land conservation view landscapes as ecological networks consisting of linked landscape elements that are broadly classified as hubs (large patches of intact natural areas) and corridors (relatively undisturbed areas that allow for migration between hubs). Green infrastructure provides habitat of sufficient size and connectivity to support both aquatic and aquatic dependent species.

EPA Region 4 has developed the National Ecological Framework (NEF), a geospatial model of the connectivity of natural lands using the hub/corridor approach. The NEF defines hub locations throughout the nation based on the following:

- Location of Priority Ecological Areas (PEAs). PEAs include first order stream catchments, intact wetland and forest patches, roadless areas, strategic habitat conservation areas of the US Fish and Wildlife Service, protected lands in the USGS Protected Areas Database, and lands within the Nature Conservancy Ecoregional Portfolio Core Data Set;
- Extent of natural land cover in PEAs (based on 2001 NLCD land cover data); and
- Size of PEAs. A minimum hub size of 5,000 acres is used in the NEF.

The NEF corridors are delineated by identifying least-disturbed pathways between hubs, based on 2001 NLCD land cover data.

The *Percent Hubs and Corridors* metric is included in the Assessment to account for the role of hubs and corridors as biotic refugia and pathways for migration. It is calculated from NEF data acquired from EPA Region 4 for each NHDPlus catchment as the area of hubs and corridors within catchment boundaries, divided by catchment area, multiplied by 100.

Hydrologic Condition Metrics

A stream's flow regime refers to its characteristic pattern of flow magnitude, timing, frequency, duration, and rate of change (Poff, et al., 1997). The flow regime plays a central role in shaping aquatic ecosystems and the health of biological communities. Aquatic organisms have adapted to the range of physical and chemical conditions brought about by natural flow patterns. Alteration of natural flows can reduce the quantity and quality of aquatic habitat, degrade aquatic life, and result in the loss of ecosystem services.

The potential for altered streamflow due to upstream impoundments is characterized with the *Dam Storage Ratio* metric. Dam storage ratio is quantified for each NHDPlus catchment as the volume of water impounded by dams in or upstream of a catchment, divided by annual flow volume at the catchment outlet. Dam locations and impounded water volumes used for indictor calculations are those reported in the 2012 National Anthropogenic Barriers dataset (Ostroff, Wieferich, Cooper, & Infante, 2013). Estimates of annual flow volume at each NHDPlus catchment outlet are reported in the NHDPlus dataset (McKay, Bondelid, & Dewald, 2012).

Habitat Condition/Geomorphology Metrics

The term habitat encompasses a host of physical, chemical, and biological characteristics of aquatic ecosystems and the optimal set of conditions for aquatic life will vary from one species to another. Here, habitat condition is assessed from reach-scale stream habitat characteristics. Several of these directly or indirectly reflect aspects of fluvial geomorphology, such as channel shape or bed substrate. Selected metrics are therefore grouped as habitat condition *and* geomorphology metrics.

Two metrics are used to describe habitat condition and geomorphology: *Stream Habitat Condition Rating* and *Dam Presence/Absence*. Metric data sources and calculation methods are summarized below.

Stream Habitat Condition Rating – ADEM monitors several habitat and geomorphic characteristics in wadeable streams throughout the state as part of reach-scale habitat assessments. Monitored variables include the extent of pools, riffles, and bends, channel dimensions, and substrate properties. These characteristics are combined into an overall stream habitat score and rating (Optimal, Sub-optimal, Marginal, or Poor).

Stream Habitat Condition Rating is included as an integrated metric of stream habitat condition and geomorphology. Stream habitat data compiled for the Assessment were acquired from the ADEM (Lisa Huff, personal communication) and were processed to produce a single representative stream habitat rating for each monitored NHDPlus catchment. Ratings were available for 678 NHDPlus catchments throughout Alabama. Observed ratings were used to develop a BRT regression model to predict a representative stream habitat rating for every catchment in the assessment area. Several landscape variables listed in Table 1 were included as predictors of stream habitat rating. Refer to Appendix D for details of stream habitat monitoring data, modeling methods, and model results.

Dam Presence/Absence – Artificial impoundments can have a lasting impact on the quality and connectivity of stream and riverine habitat. Above dams, pooling of water results in a loss of lotic habitat, and changes in flow magnitude and velocity alter natural channel geomorphology below dam outfalls.

To account for the negative impacts of dams on stream habitat, *Dam Presence/Absence* is included as a metric of watershed health. The presence of man-made dams was evaluated for each NHDPlus catchment in the assessment area using dam locations reported in the 2012 National Anthropogenic Barriers Dataset (Ostroff, Wieferich, Cooper, & Infante, 2013). Note that dam presence/absence is used in place of other measures of dam prevalence, such as dam density, because of the small size of NHDPlus catchments, which typically have no more than one dam within their boundaries.

Water Quality Metrics

Under natural conditions, stream water chemistry varies within a characteristic range that is determined by a stream's geography, geology, topography, and other characteristics. Aquatic biota have adapted to such conditions and the presence of water quality parameters in their natural range is a key feature of healthy streams.

Stream water quality is monitored by several agencies and organizations in Alabama, with dozens of parameters sampled. For this Assessment, the focus is on parameters that represent natural water quality characteristics. Based on this objective and data availability, four water quality metrics were selected:

- *Stream Total Phosphorus Concentration;*
- *Stream Nitrate-Nitrite Concentration;*
- *Stream Total Suspended Solids Concentration; and*
- *Stream Conductivity*.

A water quality database for Alabama and the Mississippi, Georgia, and Tennessee portions of the Mobile Bay Basin was compiled for the above parameters using data acquired from the EPA and USGS Water Quality Portal (http://www.waterqualitydata.us/). Water quality data were processed to generate representative median growing season (March through October) concentrations of each parameter for monitored catchments. Table 3 lists the number of catchments with observed values of each water quality parameter.

TABLE 3.NUMBER OF NHDPLUS CATCHMENTS WITH WATER QUALITY MONITORING DATA.

Water Quality Metric	No. of Catchments
Stream Nitrate-Nitrite Concentration (Growing Season Median)	824
Stream Total Phosphorus Concentration (Growing Season Median)	776
Stream Suspended Sediment Concentration (Growing Season Median)	819
Stream Conductivity (Growing Season Median)	938

Observed water quality data were used to develop BRT models to predict median growing season stream total phosphorus, nitrate-nitrite, total suspended solids concentrations, and conductivity for every catchment in the assessment area. Several landscape variables listed in Table 1 were included as predictors of stream water quality. Refer to Appendix D for details of monitoring data, modeling methods, and model results.

Biological Condition Metrics

A stream's biological condition can be described by the abundance, diversity, and functional organization of fish, invertebrates, and other aquatic fauna. A healthy biotic community demonstrates a balance of native species that are integrated across trophic and functional levels and are able to adapt to short- and long-term variation in ecosystem conditions. Healthy watersheds support biotic communities with these characteristics due to hydrologic, geomorphic, and water quality regimes that provide habitat of sufficient size, variety, and connectivity.

The biological characteristics of aquatic ecosystems considered in this assessment are macroinvertebrate and fish community variables monitored in wadeable streams by ADEM and the Geological Survey of Alabama (GSA). These agencies sample the number and proportion of several taxonomic and functional macroinvertebrate and fish groups in streams throughout the state. For each monitored site, fish variables are combined into an overall *Fish Index of Biotic Integrity (FIBI)* rating (Excellent, Good, Fair, Poor, Very Poor) and macroinvertebrate variables are combined into an overall *Macroinvertebrate Index of Biotic Integrity (MIBI)* rating (Excellent, Good, Fair, Poor, Very Poor). These ratings are used as stream biological condition metrics for the Assessment.

Observed FIBI and MIBI data for wadeable streams in Alabama were acquired from GSA (Pat O'Neil, personal communication) and ADEM (Lisa Huff, personal communication), respectively, and were processed to produce a single representative FIBI rating and MIBI rating for each monitored catchment. Observed FIBI ratings were available for 460 catchments. Observed MIBI ratings were available for 450 catchments. Observations were used to develop BRT models to predict a representative MIBI rating and FIBI rating for every NHDPlus catchment in the assessment area. Several landscape variables listed in Table 1 were included as predictors of FIBI and MIBI ratings. Refer to Appendix D for details of monitoring data, modeling methods, and modeling results.

2.6 Watershed Vulnerability Metrics and Data Sources

Watershed vulnerability is defined as the potential for future degradation of watershed processes and aquatic ecosystem health. Vulnerability can be driven by a variety of factors. Here, three vulnerability attributes are considered: Climate Change Vulnerability, Land Use Vulnerability, and Water Use Vulnerability.

The assessment team selected watershed vulnerability metrics (Figure 8) based on the data availability, data quality, and the objectives of the Assessment. This section describes the watershed vulnerability metrics, the reasoning for their selection, data sources, and methods applied to calculate metric values.

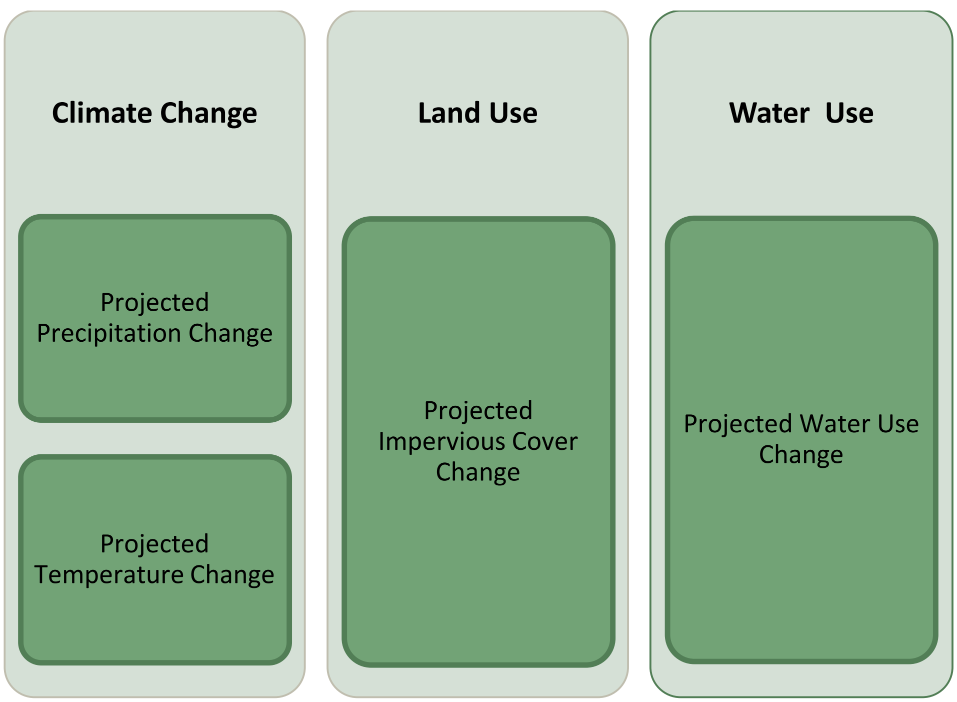


FIGURE 8. WATERSHED VULNERABILITY METRICS.

Climate Change Vulnerability Metrics

Changes in climate translate to a shift in material and energy inputs to aquatic ecosystems. The impact of climate-driven changes to aquatic ecosystem health can be significant and in line with those posed by large-scale landscape disturbance by humans.

With the availability of downscaled global climate model data, projected changes in temperature and precipitation can be evaluated for watersheds across a large region or state. This assessment incorporates projections of future climate to characterize the vulnerability of Alabama's watersheds to altered precipitation and temperature regimes. Two climate change vulnerability metrics are used: *Projected Precipitation Change* and *Projected Temperature Change*.

Climate change metrics are quantified from geospatial climate change data acquired from The Nature Conservancy's Climate Wizard website (http://www.climatewizard.org/). Gridded projections of the departure of 2040-2069 mean annual temperature and precipitation from 1961-1990 baseline means were averaged by NHDPlus catchment to estimate future changes in annual temperature and annual precipitation in each catchment. Climate Wizard precipitation and temperature projections used for metric calculations are an ensemble average of multiple general circulation models for a medium carbon emission scenario.

Land Use Vulnerability Metrics

As discussed in Section 2.5, the presence of natural land cover across a watershed maintains key hydrologic processes, protects aquatic ecosystems from nonpoint sources of pollution, provides habitat for aquatic biota, and supports connectivity between habitat patches. Although a watershed may presently contain large patches of natural vegetative cover, future land cover change will occur with the expansion of urban and agricultural lands.

The vulnerability of watersheds to future land cover change due to urban growth is characterized with the *Projected Impervious Cover Change* metric. Projections of future impervious cover from the EPA Integrated Climate and Land Use Scenarios (ICLUS) program serve as the source of data for the impervious cover change metric (US EPA, 2009). Gridded impervious cover projections for the years 2010 and 2050 were acquired from the ICLUS data website (http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=205305) for four population growth scenarios. Grids were used to calculate the percentage of impervious area in 2010 and 2050 in NHDPlus catchments under each growth scenario. The change in impervious cover was then calculated as the difference between 2050 and 2010 impervious area for each growth scenario. Values derived from the four growth scenarios were averaged to produce a single estimate of impervious cover change in NHDPlus catchments[1].

Water Use Vulnerability Metrics

Surface and groundwater withdrawals can greatly alter a watershed's natural hydrologic regime, and thus, the health of aquatic ecosystems. Future water demand will increase beyond current levels with population growth and expansion of agriculture, industry, and mining. The potential for increased water demand

[1] Land cover and water use projections for some catchments pointed to a loss of impervious cover/reduced water use due to future migration of human populations. For these catchments, projected impervious cover change and water use change was set to zero for vulnerability index calculations (described in Sections 2.7 and 2.9).

throughout Alabama and the Mobile Bay Basin due to a growing human population is captured in the Assessment with the *Projected Water Use Change* metric.

The following steps were applied to calculate projected water use change for each NHDPlus catchment:

- Estimate present-day public water use and private domestic water use in NHDPlus catchments from 2005 county totals reported by the USGS (2009). For each county, total water use was distributed to NHDPlus catchments based on the ratio of catchment impervious surface area to county impervious surface area. To ensure consistency with projections of future water use, impervious surface data used in this step were 2010 impervious cover projections from EPA's ICLUS program (US EPA, 2009).
- Estimate future public water use and private domestic water use by county from 2005 county totals (USGS, 2009), 2005 county populations, and 2050 county population projections from EPA's ICLUS program (US EPA, 2009). Future water use was calculated by multiplying 2005 water use by the ratio of 2050 county population to 2005 county population.
- Estimate future public water use and private domestic water use in NHDPlus catchments from 2050 county water use totals (calculated in the previous step). For each county, total water use was distributed to NHDPlus catchments based on the ratio of catchment impervious surface area to county impervious surface area. Impervious cover data used in this step were 2050 projections from EPA's ICLUS program (US EPA, 2009)[1].
- Calculate water use change in NHDPlus catchments by subtracting present-day water use from future water use.

2.7 Mobile Bay Connectivity Metrics and Data Sources

Hydrologic connectivity refers to the water-mediated transport of material and energy between elements of a hydrologic system (Freeman, Pringle, & Jackson, 2007). Within the Mobile Bay Basin, watersheds are hydrologically connected to one another and to Mobile Bay through surface and subsurface flowpaths. The condition of Mobile Bay is therefore linked, in large part, to the condition of its drainage basin. Healthy portions of the basin, for example, contribute to natural levels of water, nutrients, organic matter, and sediment inflow. To explore hydrologic connectivity throughout the Mobile Bay Basin, the assessment team selected three Mobile Bay connectivity metrics that describe the potential for runoff and downstream attenuation of exported material and energy (Figure 9).

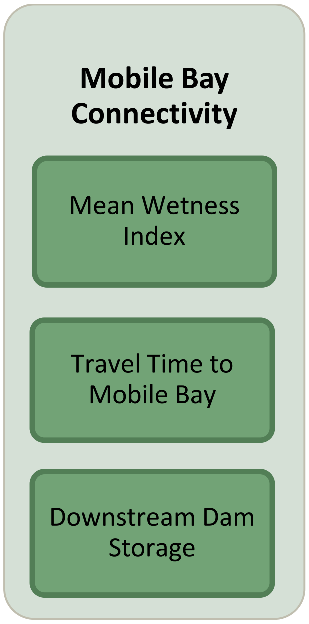


FIGURE 9. MOBILE BAY CONNECTIVITY METRICS.

Mobile Bay connectivity metrics are quantified for each NHDPlus catchment in the Mobile Bay Basin. Together, these metrics characterize a catchment's relative contribution to material and energy input to Mobile Bay. A brief description of connectivity metrics and calculation methods is provided below.

- *Mean Wetness Index* describes the potential for runoff production from a catchment, with higher runoff potential corresponding to higher connectivity to Mobile Bay. The wetness index (Beven & Kirkby, 1979) is a commonly used measure of runoff potential and is a function of flow accumulation and slope gradient. The mean wetness index of each NHDPlus catchment is quantified from a gridded wetness index dataset acquired from EPA Region 4.
- *Travel Time to Mobile Bay* describes the potential for downstream material and energy attenuation, with higher travel times corresponding to lower connectivity to Mobile Bay. Travel time to Mobile Bay is quantified for each NHDPlus catchment using flowpath lengths and flow velocities reported in the NHDPlus dataset (McKay, Bondelid, & Dewald, 2012).
- *Downstream Dam Storage* also describes the potential for downstream material and energy attenuation, with high storage volumes corresponding to lower connectivity to Mobile Bay. Downstream dam storage is quantified for each NHDPlus catchment using dam locations and storage volumes reported in the 2012 National Anthropogenic Barriers dataset (Ostroff, Wieferich, Cooper, & Infante, 2013).

2.8 Metric Rank-Normalization

Metrics of watershed health, vulnerability, and hydrologic connectivity to Mobile Bay are *rank-normalized* for reporting and for index calculations (discussed in Section 2.9). Normalization provides a dataset that is both unitless and on a shared scale, typically 0 to 100. Normalizing by rank (rank-normalization) provides a dataset with uniform scale *and* uniform distribution (Figure 10). The benefits of standardizing metric distributions are discussed further in Section 2.9.

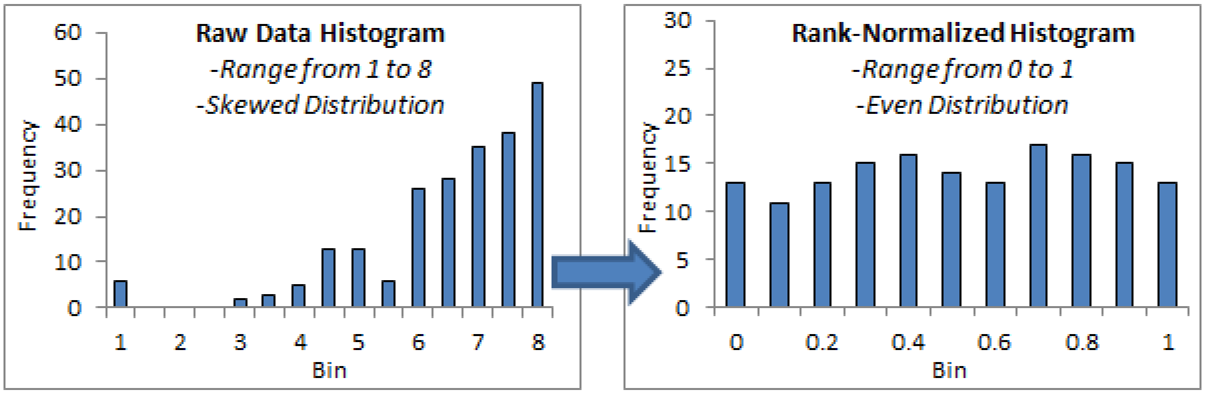


FIGURE 10. EXAMPLE HISTOGRAMS FOR RAW (LEFT) AND RANK-NORMALIZED (RIGHT) DATA. NOTE THAT RANK-NORMALIZATION STANDARDIZES BOTH THE SCALE AND DISTRIBUTION OF COMPONENT METRIC DATA.

Rank-normalization of watershed health and vulnerability metrics is performed separately at the Statewide and Basin tiers by:

1. Ranking all catchments in Alabama (for the Statewide tier) or the Mobile Bay Basin (for the Basin tier) on the basis of raw metric values.
    - Catchments are ranked in ascending order if higher metric values correspond to higher watershed health, vulnerability, or connectivity.
    - Catchments are ranked in descending order if higher metric values correspond to lower watershed health, vulnerability, or connectivity.
2. Applying the following formula to calculate a catchment's rank-normalized score:

$$Rank\text{-}Normalized\ Score = \frac{Catchment\ Rank - 1}{Maximum\ Rank - 1} * 100$$

The above steps are also applied to calculate rank-normalized scores for connectivity metrics. Two groups of rank-normalized connectivity metric scores are calculated, one for all catchments in the Mobile Bay Basin (Basin tier scores) and another for just those catchments in the Mobile-Tensaw and Mobile Bay HUC8s (HUC8 tier scores).

Rank-normalization provides metric scores ranging from 0 to 100 with consistent *directionality*. Directionality refers to the relationship between metric scores and watershed health, vulnerability, or connectivity (i.e., whether high scores correspond to higher or lower watershed health). Table 4 lists the original directionality of each metric. Rank-normalized scores are directionally aligned so that:

- Higher scores for watershed health metrics correspond to higher watershed health;

- Higher scores for watershed vulnerability metrics correspond to higher watershed vulnerability; and
- Higher scores for connectivity metrics correspond to higher hydrologic connectivity to Mobile Bay.

Note that rank-normalization was not required for the Dam Presence/Absence metric since only two values are possible (1 for dam presence, 0 for dam absence). For consistency, this metric was "normalized" to a 0-to-100 scale by multiplying by 100.

TABLE 4. ORIGINAL DIRECTIONALITY OF WATERSHED HEALTH AND VULNERABILITY METRICS. RANK-NORMALIZED METRIC SCORES RANGE FROM 0 TO 100 AND ARE DIRECTIONALLY ALIGNED SO THAT HIGHER SCORES CORRESPOND TO HIGHER WATERSHED HEALTH, WATERSHED VULNERABILITY, OR HYDROLOGIC CONNECTIVITY TO MOBILE BAY.

Metric Category	Metric Name	Original Directionality
Watershed Health	Percent Natural Land Cover Percent Intact Hydrologically Active Zone Percent Hubs and Corridors Stream Habitat Condition Rating Fish IBI Rating Macroinvertebrate IBI Rating	Higher Value = Higher Watershed Health
	Dam Presence/Absence Dam Storage Ratio Stream Nitrate-Nitrite Concentration Stream Total Phosphorus Concentration Stream Total Suspended Solids Concentration Stream Conductivity	Lower Value = Higher Watershed Health
Watershed Vulnerability	Projected Precipitation Change Projected Temperature Change Projected Impervious Cover Change Projected Water Use Change	Higher Value = Higher Watershed Vulnerability
	Percent Protected Lands	Lower Value = Higher Watershed Vulnerability
Mobile Bay Connectivity	Mean Wetness Index	Higher Value = Higher Connectivity
	Travel Time to Mobile Bay Downstream Dam Storage	Lower Value = Higher Connectivity

2.9 Multimetric Index Development

Multimetric Index Descriptions

This assessment uses twenty metrics to characterize watershed health, vulnerability, and hydrologic connectivity to Mobile Bay. To integrate this information for reporting and application, metrics are aggregated into several *multimetric indices*. A multimetric index synthesizes information from several component metrics into a single composite value. For example, the Assessment includes a *Landscape Condition* multimetric index that combines the three metrics selected to characterize landscape condition in order to provide an integrated view of the condition of a watershed's natural infrastructure.

Two "levels" of multimetric indices are distinguished for watershed health and watershed vulnerability. Metrics are first combined into a set of *sub-indices* based on groupings depicted in Figure 7 and Figure 8. Each watershed health sub-index describes one attribute of watershed health. These include the *Landscape*

Condition Sub-Index, *Hydrologic Condition Sub-Index*, *Habitat Condition/Geomorphology Sub-Index*, *Water Quality Sub-Index,* and *Biological Condition Sub-Index*. Similarly, each watershed vulnerability sub-index describes one attribute of watershed vulnerability. These include the *Climate Change Vulnerability Sub-Index*, *Land Use Vulnerability Sub-Index*, and *Water Use Vulnerability Sub-Index*.

Watershed health and vulnerability sub-indices are combined into two composite index scores: the *Watershed Health Index* and the *Watershed Vulnerability Index*. The Watershed Health Index is calculated from the six watershed health sub-indices (Landscape Condition, Hydrologic Condition, Habitat Condition/Geomorphology, Water Quality, and Biological Condition) to provide an integrated view of landscape and aquatic ecosystem health. The Watershed Vulnerability Index is calculated from the three vulnerability sub-indices (Climate Change, Land Use, and Water Use).

The purpose of the sub-index/index hierarchy is to balance the influence of each watershed health and vulnerability attribute on overall index scores. Without this step, index scores can be biased toward attributes that have the highest number of metrics. For example, the Assessment uses four metrics to characterize stream water quality, while a single metric is used to characterize hydrologic condition. Without an intermediate step to calculate a *Water Quality Sub-Index* and a *Hydrologic Condition Sub-Index,* Watershed Health Index scores would be more reflective of water quality than hydrologic condition.

Table 5 lists each of the multimetric indices generated for the Assessment and their component metrics.

TABLE 5. LIST OF COMPONENT METRICS FOR EACH SUB-INDEX AND INDEX CALCULATED FOR THE ASSESSMENT.

Index Name	Sub-Index Name	Metric(s)
Watershed Health Index	Landscape Condition Sub-Index	Percent Natural Land Cover Percent Intact Hydrologically Active Zone Percent Hubs & Corridors
	Habitat Condition/Geomorphology Sub-Index	Stream Habitat Condition Rating Dam Presence/Absence
	Hydrologic Condition Sub-Index	Dam Storage Ratio
	Water Quality Sub-Index	Stream Nitrate-Nitrite Concentration Stream Total Phosphorus Concentration Stream Total Suspended Solids Concentration Stream Conductivity
	Biological Condition Sub-Index	Fish IBI Rating Macroinvertebrate IBI Rating
Watershed Vulnerability Index	Climate Change Vulnerability Sub-Index	Projected Precipitation Change Projected Temperature Change
	Land Use Vulnerability Sub-Index	Projected Impervious Cover Change Percent Protected Lands
	Water Use Vulnerability Sub-Index	Projected Water Use Change
Mobile Bay Connectivity Index	*None*	Mean Wetness Index Travel Time to Mobile Bay Downstream Dam Storage

Multimetric Index Calculations

Index and sub-index scores range from 0 to 100 and are calculated as the average of rank-normalized component metrics. Normalization is a customary step in multimetric index development that standardizes the scale of component metrics. Rank-normalization also standardizes component metric distributions (see Section 2.7). This eliminates the potential for any one component metric to dominate index scores due to varied scales and distributions. Note, however, that the effects of standardizing the scale and distribution of component metrics are not always positive, particularly when the values of a metric are predominantly in a range considered to be "good" or predominantly "poor". Rank-normalization can also be problematic when a large number of catchments share the same value of a given metric.

The rank-normalization methodology described in Section 2.7 provides metric scores that are directionally aligned (i.e., higher rank-normalized scores correspond to higher watershed health, watershed vulnerability, or hydrologic connectivity to Mobile Bay). Index scores follow the same directionality:

- High Watershed Health Index scores correspond to high watershed health;
- High Watershed Vulnerability Index scores correspond to high watershed vulnerability; and
- High Connectivity Index scores correspond to high hydrologic connectivity to Mobile Bay.

As noted above, index and sub-index scores are calculated by averaging rank-normalized component metric. These averaged values are also subsequently rank-normalized for reporting. This ensures that scores for each index/sub-index range from 0 to 100. Further, rank-normalization eases interpretation by providing scores that correspond to percentiles. For example:

- A Watershed Health Index score of 0 corresponds to the lowest condition in the state;
- A Watershed Health Index score of 25 corresponds to the 25th percentile condition;
- A Watershed Health Index score of 50 corresponds to the 50th percentile condition;
- A Watershed Health Index score of 75 corresponds to the 75th percentile condition;
- A Watershed Health Index score of 100 corresponds to the highest condition in the state.

Watershed health and vulnerability index and sub-index scores are calculated separately at the Statewide tier and the Basin tier. A catchment can therefore have multiple scores for a given index if it falls within the boundary of more than one tier. For example, a catchment located in both Alabama and the Mobile Bay Basin will have one Watershed Health Index score for the Statewide tier and one Watershed Health Index score for the Basin tier. An index score should be interpreted relative to scores for other catchments in that tier.

Connectivity Index scores are calculated at both the Basin tier and the HUC8 tier. Basin tier scores reflect a catchment's connectivity to Mobile Bay relative to all other catchments in the Mobile Bay Basin. HUC8 tier scores reflect connectivity relative to other catchments in the Mobile-Tensaw and Mobile Bay HUC8s only.

Correlation Analysis

After calculating sub-index scores, the strength of correlation between the Landscape Condition Sub-Index and the Habitat/Geomorphology, Biological Condition, and Water Quality sub-indices was evaluated. Component metrics for the Habitat/Geomorphology Sub-Index, Biological Condition Sub-Index, and Water

Quality Sub-Index are quantified from statistical models that relate stream health observations to several landscape variables (see Section 2.5), including those which describe the amount and distribution of natural land cover in a catchment. Because these same properties are captured in Landscape Condition metrics, there is potential for redundancy between the Landscape Condition Sub-Index and sub-indices derived from modeled metrics. Correlation analysis was undertaken to assess whether redundancy was significant enough to prohibit combining sub-indices into the Watershed Health Index.

R-squared values (calculated as the square of Pearson correlation coefficients) for the Landscape Condition Sub-Index and the Habitat/Geomorphology, Biological Condition, and Water Quality sub-indices are displayed in Table 6. Values range from 0.003 to 0.34 at the Statewide tier and 0.0004 to 0.37 for Basin tier. For reference, R-squared values are also shown for the Hydrologic Condition Sub-Index, which does not include modeled metrics.

Weak to moderate correlation exists between the Landscape Condition Sub-Index and other sub-indices. R-squared values are below redundancy limits that have been reported for biological multimetric index development. For example, Stoddard et al. (2008) use a correlation threshold of 0.71 (R-squared = 0.50) to distinguish redundant metrics, Emery et al. (2003) use a threshold of 0.75 (R-squared = 0.56), and Hering et al. (2006) use a threshold of 0.80 (R-squared = 0.64). Correlation analysis results support the aggregation of the Landscape Condition, Habitat/Geomorphology, Biological Condition, and Water Quality sub-indices into one overall Watershed Health Index.

TABLE 6. R-SQUARED VALUES FOR THE LANDSCAPE CONDITION SUB-INDEX AND THE REMAINING WATERSHED HEALTH SUB-INDICES. VALUES ARE CALCULATED AS THE SQUARE OF PEARSON CORRELATION COEFFICIENTS.

	Landscape Condition Sub-Index (Statewide Tier)	Landscape Condition Sub-Index (Basin Tier)
Hydrologic Condition Sub-Index	0.003	0.0004
Habitat/Geomorphology Sub-Index	0.01	0.04
Biological Condition Sub-Index	0.34	0.37
Water Quality Sub-Index	0.28	0.32

3 RESULTS & DISCUSSION

This section presents maps illustrating scores for the Watershed Health Index, Watershed Vulnerability Index, and Mobile Bay Connectivity Index (full page maps of all indices, sub-indices, and metrics are provided in Appendix A through Appendix C). When reviewing index maps, recall that scores depict relative conditions across Alabama and the Mobile Bay Basin for the purpose of screening priority areas for protection and restoration planning.

3.1 Watershed Health Index

Watershed Health Index scores for the Statewide and Basin tiers are displayed in Figure 11 and Figure 12, respectively. High scoring patches are scattered throughout much of Alabama and the Mobile Bay Basin and are fragmented by areas with moderate to low Watershed Health Index scores, notably along large river corridors. Low scoring areas are also prominent in urbanized regions such as Huntsville, Birmingham, Montgomery, and Mobile, and across the Black Belt region in central Alabama/eastern Mississippi where agriculture is concentrated.

Watershed Health Index scores are based on a collection of metrics that describe catchment land cover and the physical, chemical, and biological attributes of stream ecosystems. Scores are quantified from measured values of watershed health metrics (e.g., percent natural land cover, dam storage ratio) and from statistical models of stream conditions (e.g., stream habitat rating). Modeled metric values are based on a set of predictors that characterize both natural and anthropogenic watershed features across multiple scales. Watershed Health Index scores therefore reflect ecological condition gradients shaped by: 1) natural variation in soils, topography, geology, hydrology, etc.; 2) anthropogenic stressors that have influenced measured metric values; and 3) incremental and cumulative scale anthropogenic stressors determined to be relevant to watershed health through regression modeling. High scoring areas possess natural watershed characteristics that are shared by healthy aquatic ecosystems and lack anthropogenic features associated with degraded ecosystem health.

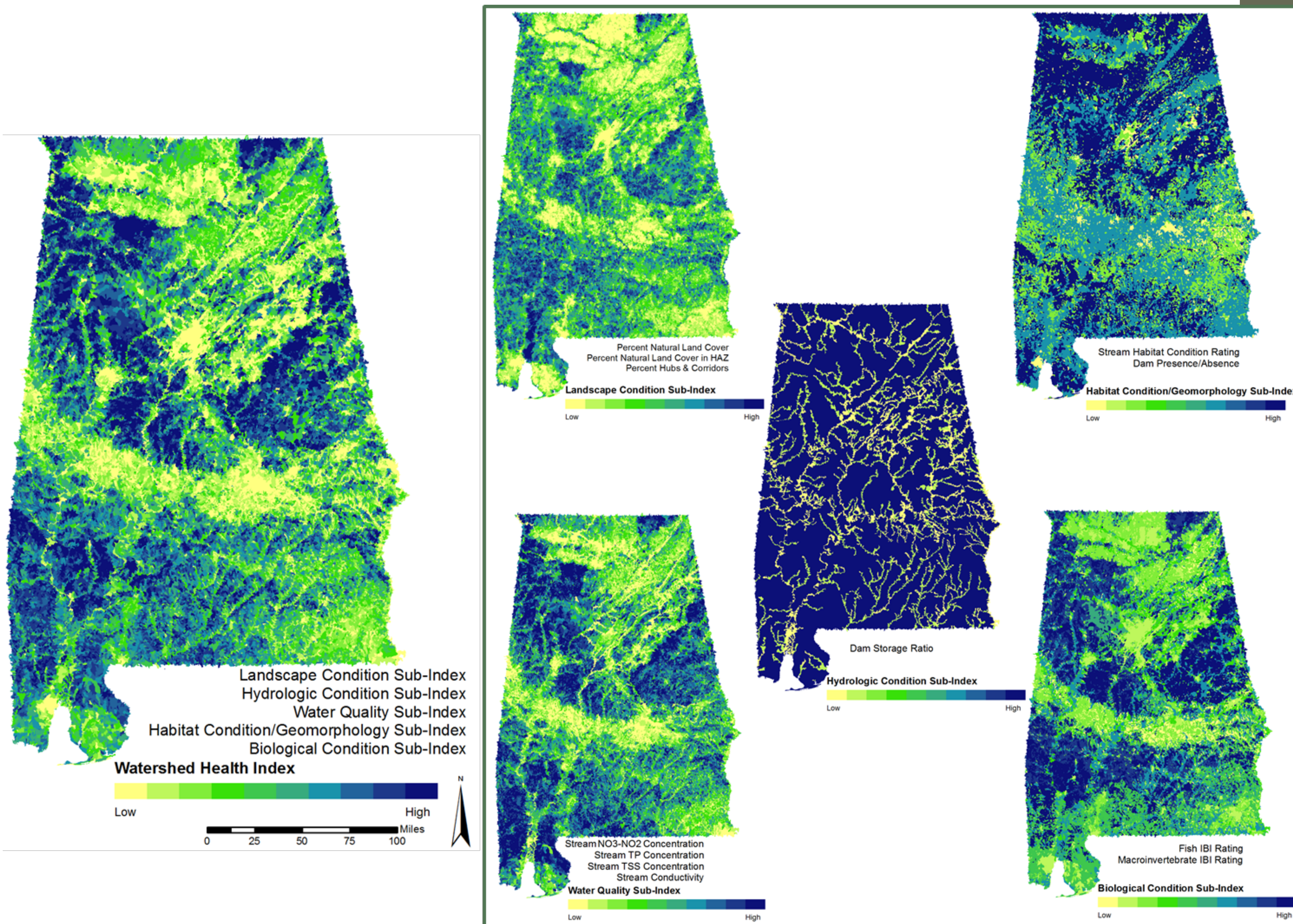


Figure 11. Watershed Health Index and Sub-Index scores for Alabama catchments.

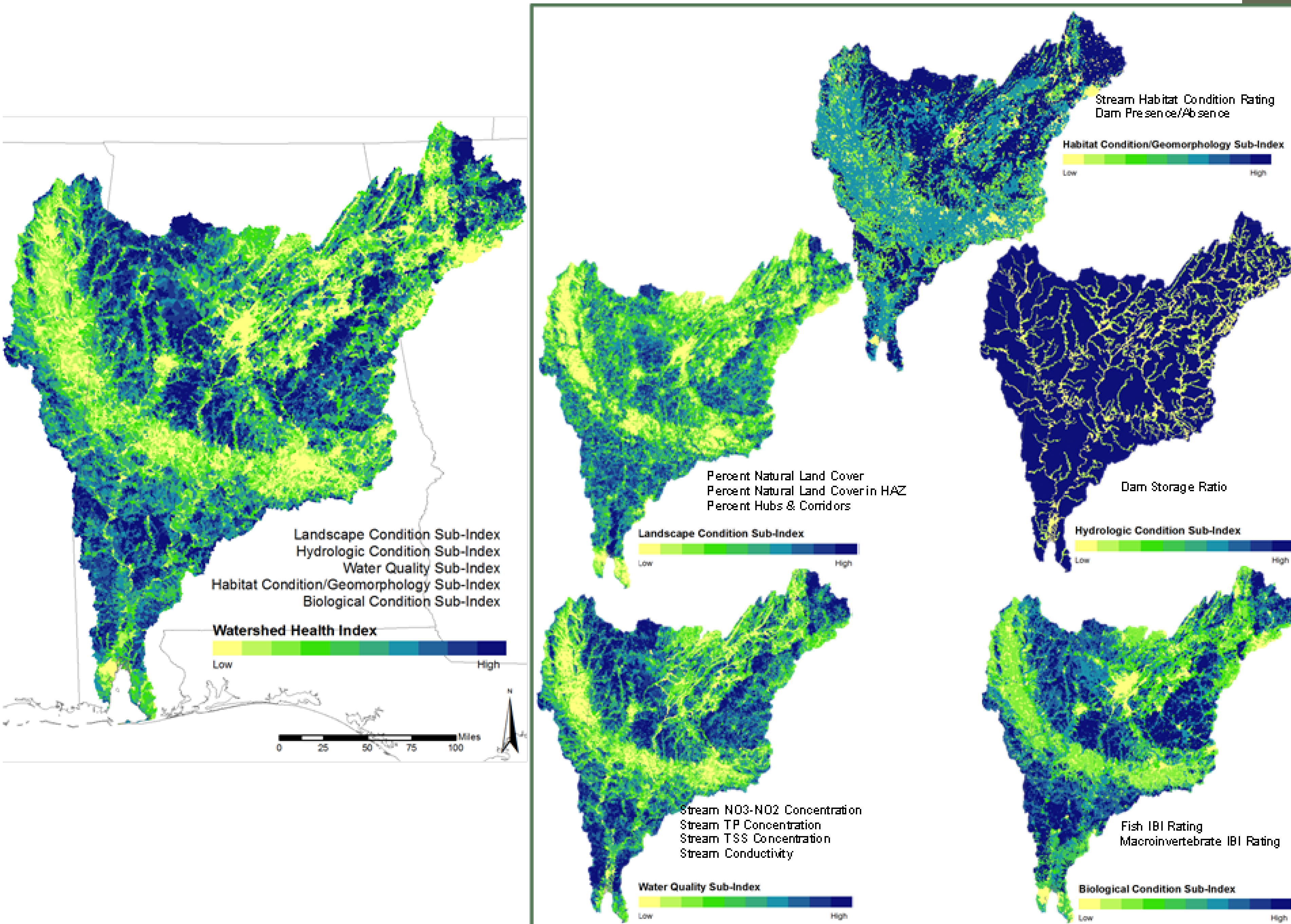
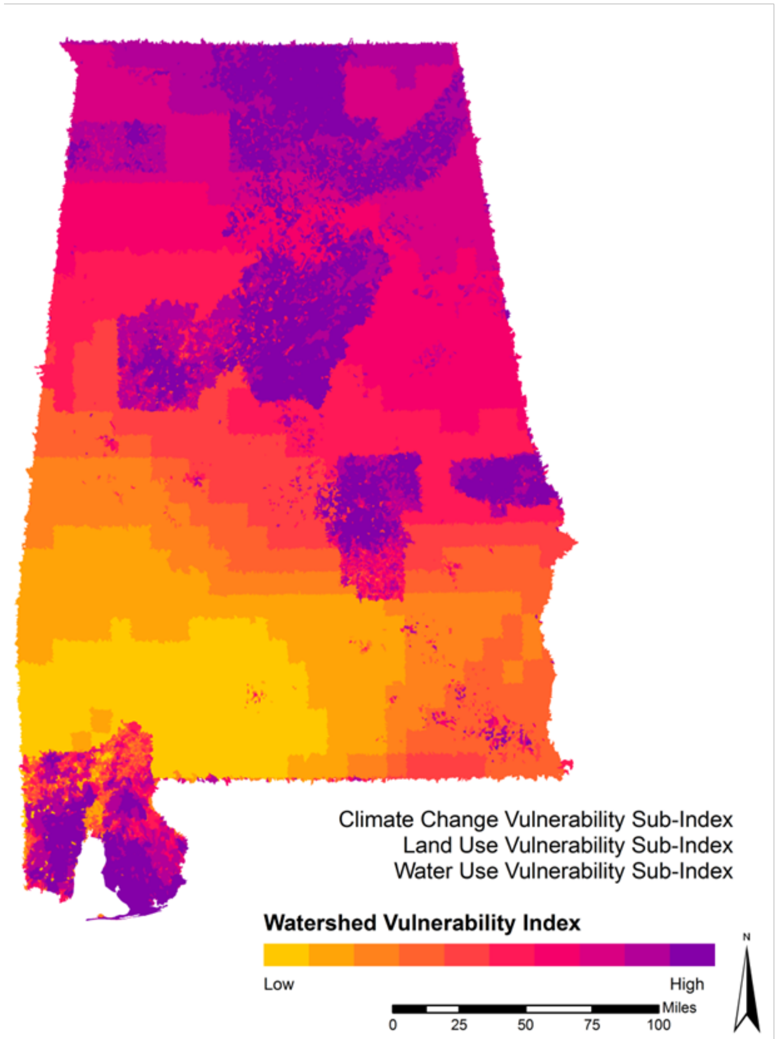


FIGURE 12. WATERSHED HEALTH INDEX AND SUB-INDEX SCORES FOR MOBILE BAY BASIN CATCHMENTS.

3.2 Watershed Vulnerability Index

Watershed Vulnerability Index scores for the statewide and Basin tiers are displayed in Figure 13 and Figure 14, respectively. The north-south gradient in Watershed Vulnerability Index scores reflects projections of greater changes in annual precipitation and temperature in northern Alabama relative to southern Alabama. Patches of high Watershed Vulnerability Index scores occur in densely populated regions where impervious cover and water use are expected to increase with future population growth.

Watershed Vulnerability Index scores present an approximation of the potential for future degradation of aquatic ecosystem health. They depict projected exposure to climate, land use, and water use change but do not explicitly quantify how projected exposure translates to changes in the physical, chemical, and biological makeup of a waterbody. The index is intended to be used in conjunction with Watershed Health Index scores to identify areas that are at present healthy but vulnerable and most in need of protection.



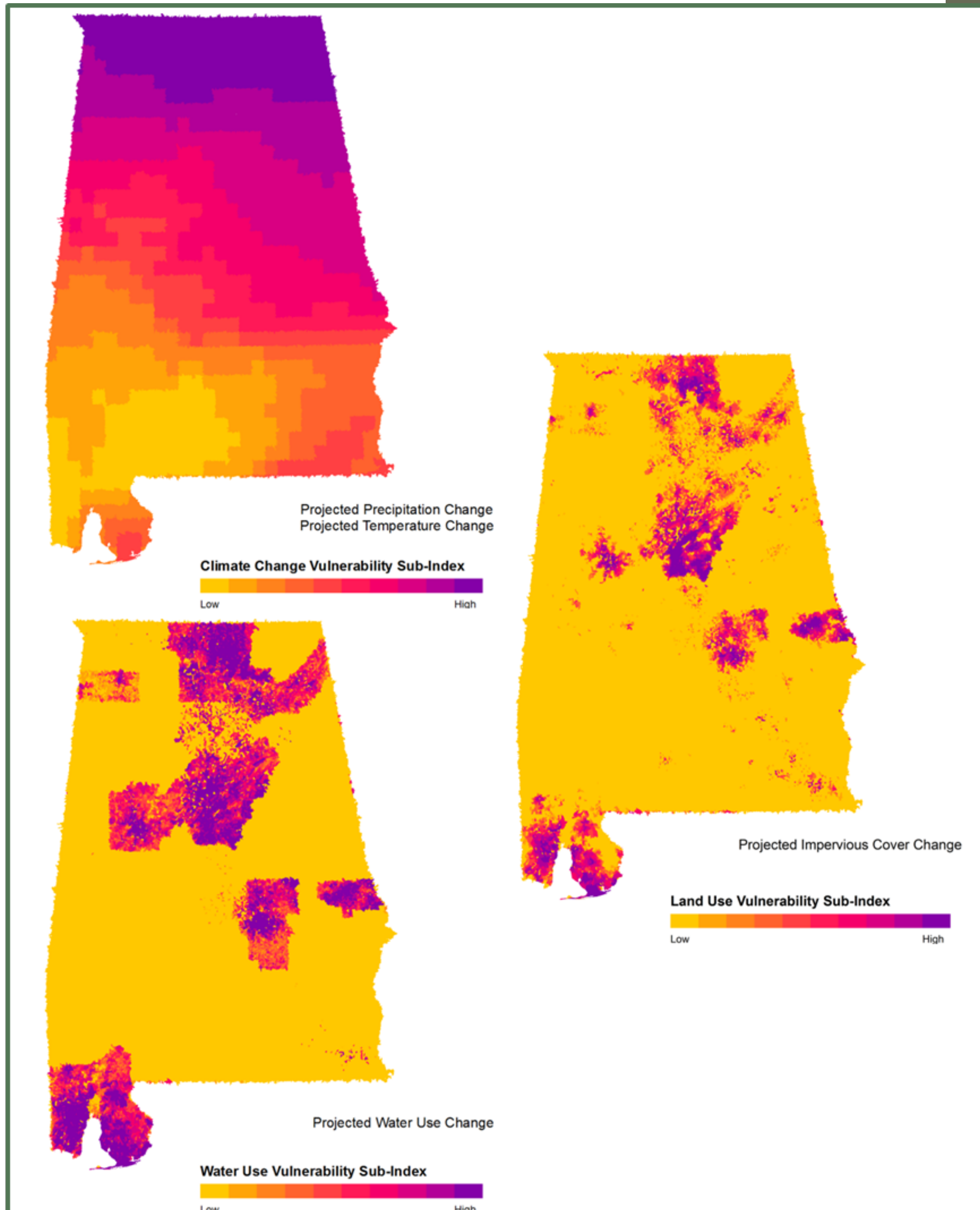


FIGURE 13. WATERSHED VULNERABILITY INDEX AND SUB-INDEX SCORES FOR ALABAMA CATCHMENTS.

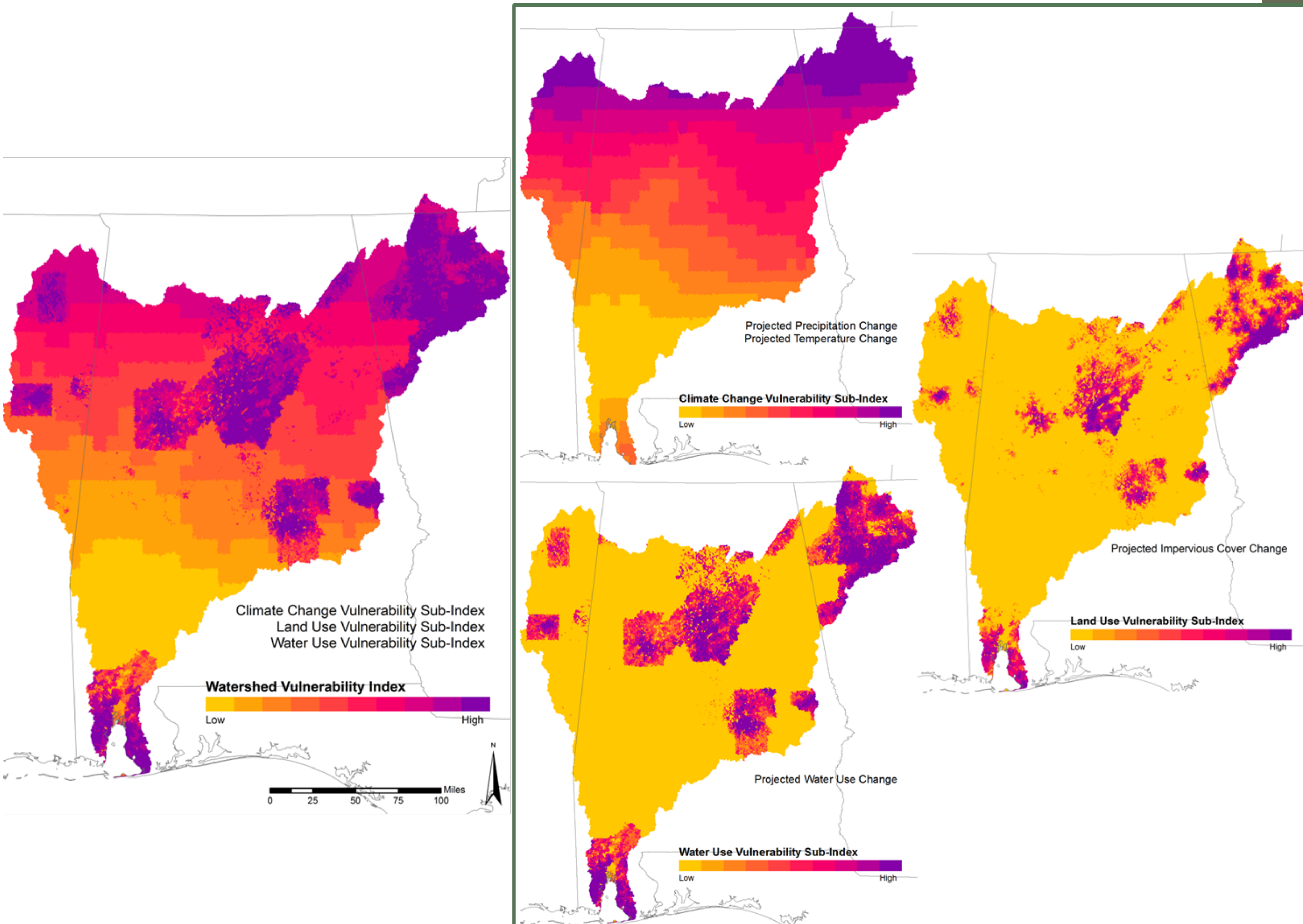


FIGURE 14. WATERSHED VULNERABILITY INDEX AND SUB-INDEX SCORES FOR MOBILE BAY BASIN CATCHMENTS.

3.3 Mobile Bay Connectivity Index

Mobile Bay Connectivity Index scores for the Basin tier and HUC8 tier are displayed in Figure 15 and Figure 16, respectively. Connectivity Index scores are highest in close proximity to Mobile Bay and decrease upstream. Connectivity in the Tombigbee River (western) portion of the Mobile Bay Basin is generally higher than connectivity in the Alabama River (eastern) portion of the Basin, due in part to extensive impoundment along the Coosa and Tallapoosa Rivers.

Mobile Bay Connectivity Index scores provide insight into the spatial pattern of hydrologic connectivity throughout the Mobile Bay Basin. The index can be incorporated into watershed protection planning efforts whose goals include the protection and restoration of Mobile Bay. For example, areas with high Watershed Health Index scores and high Mobile Bay Connectivity Index scores may be deemed priorities for protection because they have the potential to exert a greater influence on Mobile Bay relative to areas with low Connectivity Index scores.

One aspect of hydrologic connectivity not captured in Connectivity Index scores is the *cumulative* effect of headwater streams on the ecological health of Mobile Bay. First and second order stream catchments make up 75% of the total number of NHDPlus catchments in the Mobile Bay Basin (see Figure 17). Together, headwater catchments help to maintain natural levels of water, sediment, and nutrient inflow to receiving waters, and their degradation can contribute to coastal eutrophication and alteration of natural hydrologic regimes (Freeman, Pringle, & Jackson, 2007). Watershed protection initiatives that aim to maintain and improve the health of Mobile Bay may therefore benefit from a headwater protection strategy. Given the large area covered by headwater watersheds in the Mobile Bay Basin, protection could be implemented incrementally, starting with headwaters that are healthy and highly connected to Mobile Bay. Figure 18 illustrates a potential application of assessment data to screen headwaters for these characteristics. The map displays Watershed Health Index scores for headwater catchments that have a high Connectivity Index score (greater than 75[2]). Watersheds with high Watershed Health Index scores can be further evaluated for prioritizing protection actions.

[2] In this example, the Connectivity Index threshold of 75 was selected without an in-depth review of other alternatives.

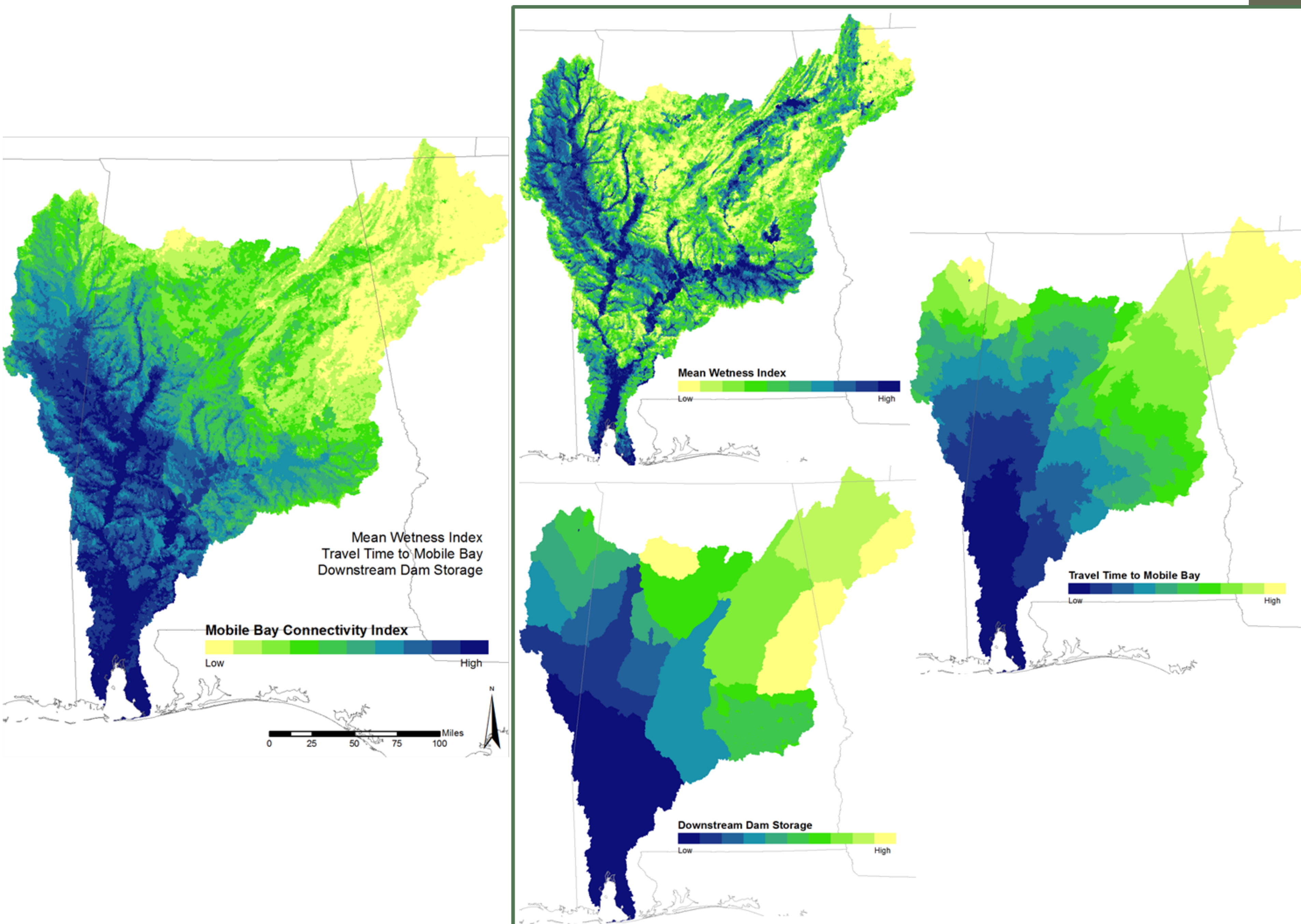


FIGURE 15. MOBILE BAY CONNECTIVITY INDEX SCORES FOR MOBILE BAY BASIN CATCHMENTS.

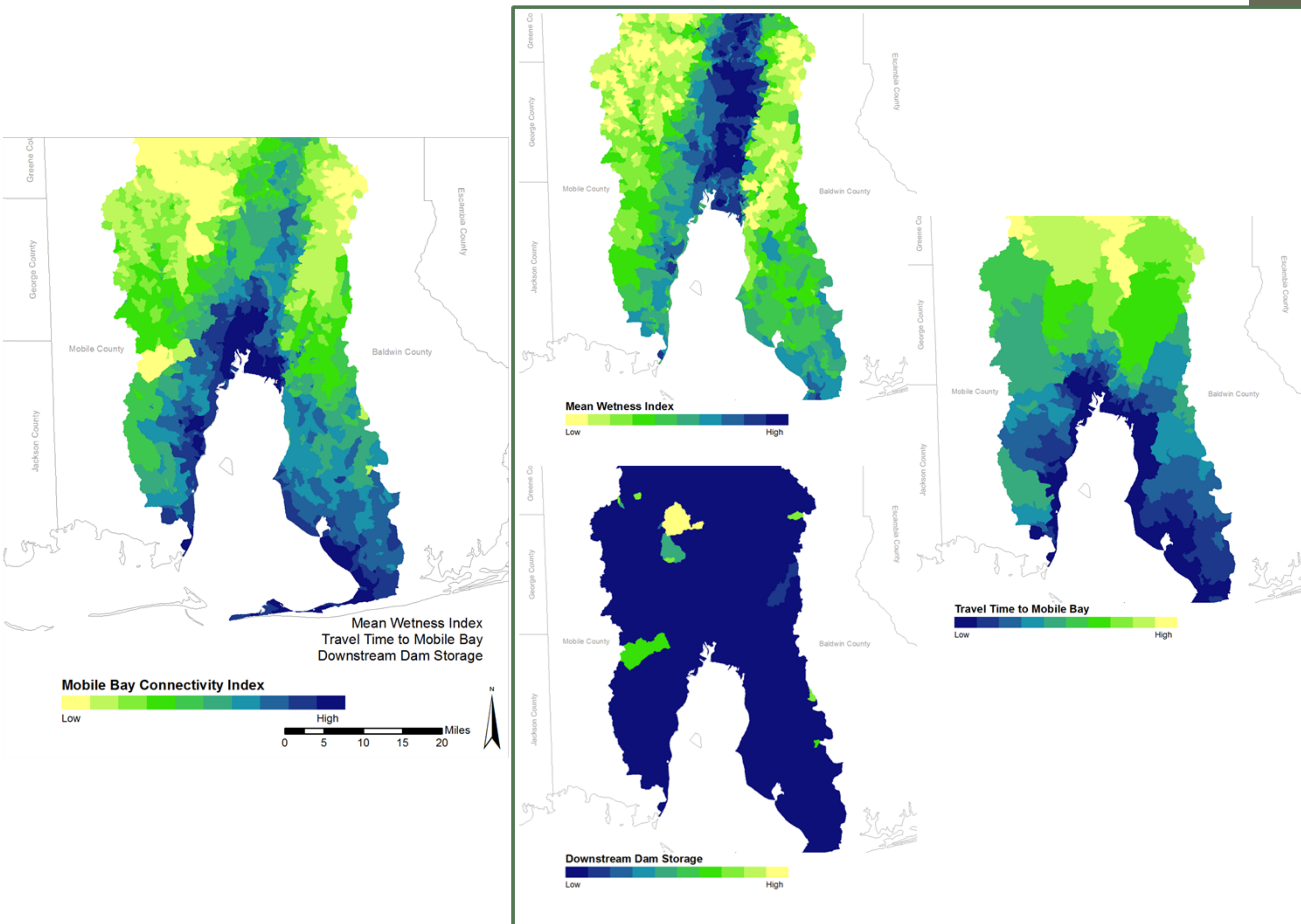


Figure 16. Mobile Bay Connectivity Index scores for catchments in the Mobile Bay HUC8 and Mobile-Tensaw HUC8.

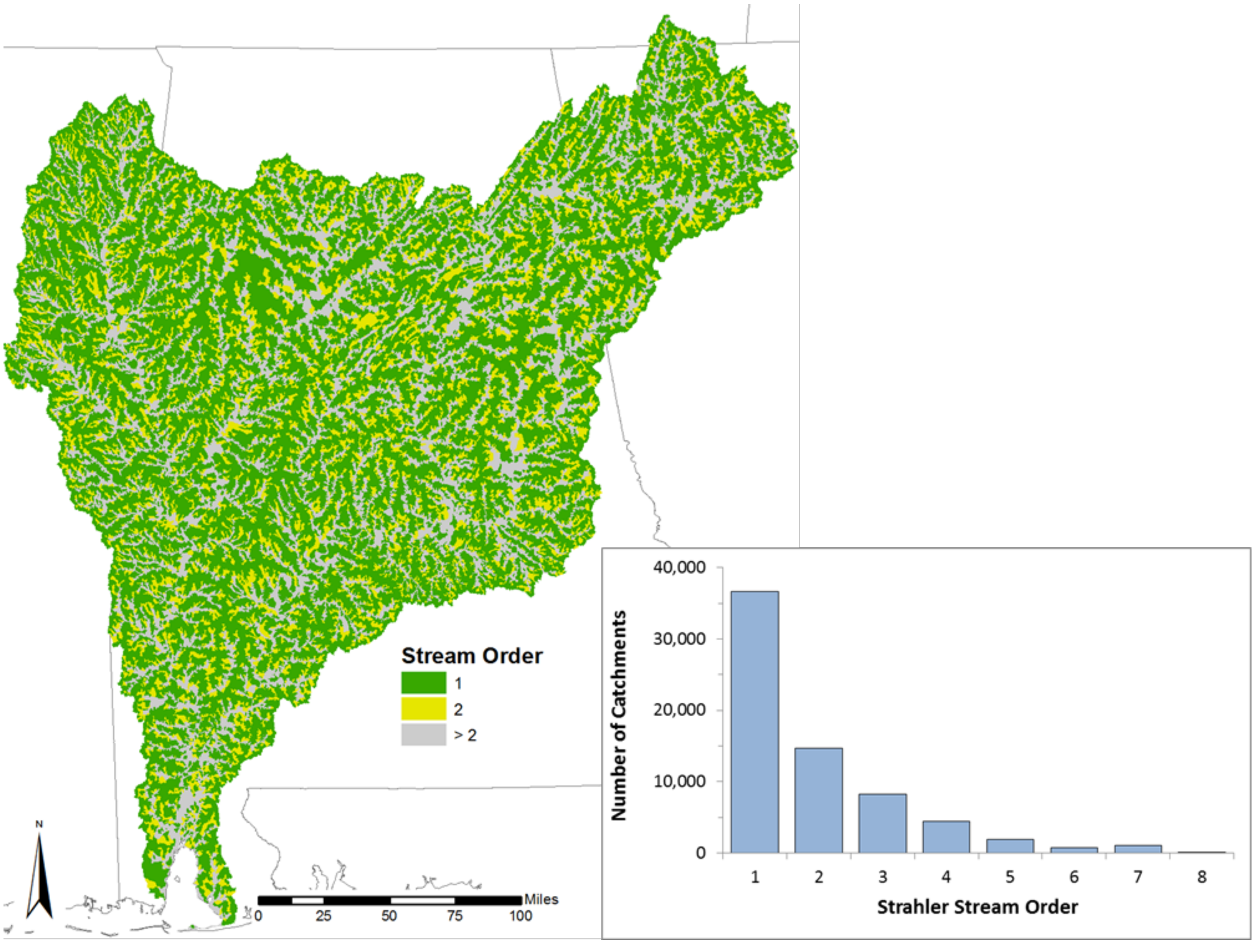


Figure 17. Map and bar plot of Strahler stream order (Strahler, 1957) for NHDPlus catchments in the Mobile Bay Basin.

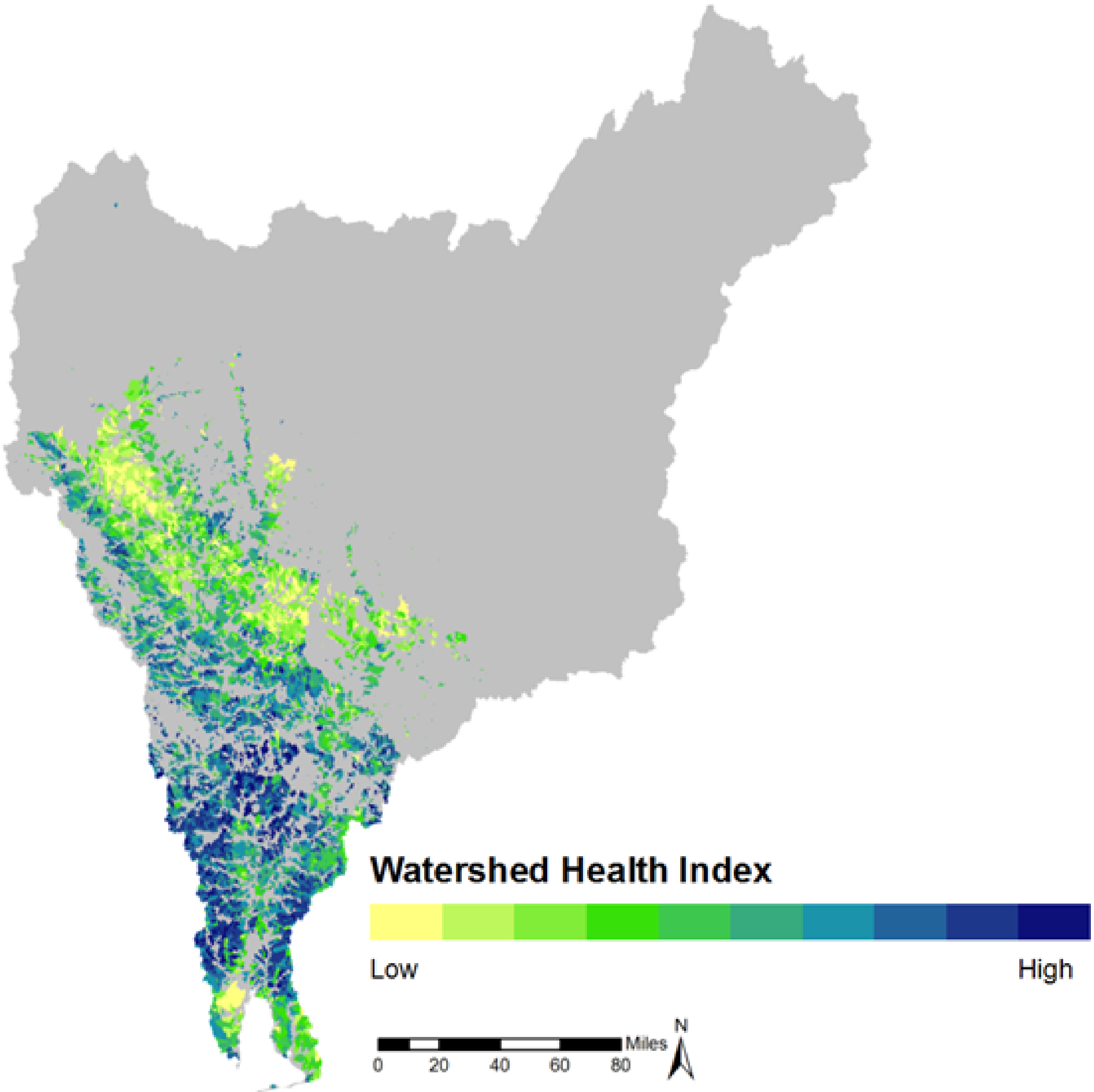


Figure 18. Watershed Health Index scores for headwater catchments (stream order 1 or 2) with high Mobile Bay Connectivity (Connectivity Index > 75).

4 ASSUMPTIONS & LIMITATIONS

Assumptions were made throughout the assessment process that may impose limitations on the use of results for certain watershed protection planning efforts. These assumptions should be recognized by users of Assessment output and are described below.

- **Spatial Framework**
  - The NHDPlus stream network is a medium resolution (1:100,000) representation of water body locations in Alabama and the Mobile Bay Basin. While the accuracy of the NHDPlus stream network and catchment delineations was not verified as part of this project, they were determined to be sufficient for statewide and regional screening of watershed protection priorities.
  - Metric and index scores describe overall or average conditions within a given NHDPlus catchment. Assessment results do not supply information at a resolution finer than the catchment scale.
- **Watershed Health Metrics and Indices**
  - Watershed health metrics were selected on the basis of data availability, data quality, and expert judgment of relevance to watershed health. Index scores do not account for aspects of watershed health beyond those represented by selected metrics. For example, the metrics selected to characterize the hydrologic, habitat/geomorphology, water quality, and biological attributes of watershed health all focus on conditions in freshwater stream ecosystems. Watershed Health Index scores therefore do not explicitly reflect the condition of other aquatic ecosystem types such as lakes, freshwater wetlands, and tidally-influenced systems.
  - The 2012 National Anthropogenic Barrier Dataset (NABD) was used to quantify the "*Dam Storage Ratio*" and "*Dam Presence/Absence*" metrics. The NABD is derived from the US Army Corps of Engineers National Inventory of Dams and includes most medium to large dams but does not include small impoundments such as farm pond dams.
  - Several watershed health metrics are quantified from statistical models that relate stream conditions to landscape variables. Error and uncertainty in model predictions can result from error/uncertainty in both model structure and predictor data. Model predictive error was reviewed through two validation methods (k-fold cross-validation and independent validation; see Appendix D). However, a detailed error and uncertainty analysis was not undertaken as part of this effort (e.g., calculation of prediction intervals or quantification of uncertainty). The suitability of modeled metrics for use in statewide and regional screening of watershed protection priorities was determined from model performance statistics, predictor-response relationships, and expert judgment of model predictions.
  - Monitoring data used to model habitat/geomorphology and biological metrics characterize conditions in single-channel, wadeable streams only. Observations for other waterbodies (non-wadeable streams, delta rivers with braided channels, etc.) were not available for use in the Assessment and model predictions may be prone to higher error where these waterbodies dominate.

- Monitoring data used to model habitat/geomorphology and biological metrics were available for Alabama streams only. Biological and habitat/geomorphology monitoring data for the Mississippi, Georgia, and Tennessee portions of the Mobile Bay Basin were not available or not comparable to Alabama data. Because the out-of-state portions of the Basin lie in ecoregions that also extend into Alabama (with the exception of the Blue Ridge Ecoregion; see Figure 1), models were applied to predict conditions throughout the entire Mobile Bay Basin. However, predictions may be prone to higher error in the out-of-state portions of the Basin.
- Recommendations for improving the accuracy of predictive models of watershed health metrics include refining response variable data by evaluating and accounting for sampling bias and expanding predictor data to account for factors not represented by the present set of predictors.
- Correlation among metrics was not factored into the metric selection process. Correlation can suggest that one metric supplies "redundant" information that is already provided by another metric, thus resulting in biased index scores.

- **Watershed Vulnerability Metrics and Indices**
  - Metrics of watershed vulnerability were selected on the basis of data availability, data quality, and expert judgment of relevance to watershed vulnerability. Index scores do not account for aspects of watershed vulnerability beyond those represented by selected metrics.
  - Climate change metrics are quantified from an ensemble average of output from multiple Global Climate Models. The uncertainty of model projections (e.g., minimum and maximum projected changes) was not evaluated.
  - Values of the "*Projected Impervious Cover Change*" metric reflect estimated changes in impervious cover due to urban expansion only. Land use changes resulting from agricultural expansion are not accounted for in the Assessment due to a lack of data.
  - Values of the "*Projected Water Use Change*" metric reflect estimated changes in public water use and private domestic water use only. Water use changes resulting from expansion of agriculture, industry, mining, etc. are not accounted for in the Assessment due to a lack of data.
  - The "*Projected Water Use Change*" metric is calculated from county-scale water use estimates. County values were disaggregated to NHDPlus catchments based on an assumed relationship between catchment impervious cover and catchment water use.
  - Correlation among metrics was not factored into the metric selection process. Correlation can suggest that one metric supplies "redundant" information that is already provided by another metric, thus resulting in biased index scores.
- Mobile Bay Connectivity Metrics and Index
  - The "*Downstream Dam Storage*" metric is calculated from the 2012 National Anthropogenic Barrier Dataset (NABD). The NABD is derived from the US Army Corps of Engineers National Inventory of Dams and includes most medium to large dams but does not include small impoundments such as farm pond dams.

5 NEXT STEPS & APPLICATIONS

This Assessment integrates disparate datasets to characterize watershed health, vulnerability, and hydrologic connectivity across Alabama and the Mobile Bay Basin. Results can be used to inform the prioritization and targeting of efforts to protect healthy watersheds in Alabama and the Mobile Bay Basin. Results also serve as a baseline dataset for evaluating changes in watershed health over time and to assess the effectiveness of existing protection strategies. The following is a summary of potential applications of Assessment results proposed by the Alabama Department of Environmental Management, the Mobile Bay National Estuary Program, the US Fish and Wildlife Service, and other partners.

Watershed Planning – Watershed plans developed by ADEM, MBNEP, and other groups outline watershed conditions and define specific protection and restoration needs. Assessment results can be used to prioritize watersheds that may benefit from having a plan conducted in the near-term. Results can also be used in conjunction with field observations of aquatic ecosystem conditions to help determine appropriate management actions throughout a watershed as part of the planning process.

Monitoring and Assessment – Assessment results can help inform aquatic ecosystem monitoring programs that aim to collect data across a broad range of watershed conditions. Results can be used to evaluate the range of watershed conditions currently monitored and to screen priority watersheds for expanded monitoring. Results can also guide the selection of reference watersheds for biological condition gradient development and tracking change in reference watersheds over time to validate the effectiveness of watershed protection actions.

Nonpoint Source Management – Results of the Assessment can be used to evaluate priority watersheds for implementing actions that prevent nonpoint source pollution in healthy watersheds. Example nonpoint source management efforts that can incorporate Assessment results include ADEM's Section 319 grant program, Alabama Clean Water Partnership projects, and the USDA National Water Quality Initiative.

Strategic Habitat Units – The Strategic Habitat Unit (SHU) effort is a partnership between the US Fish and Wildlife Service, the Alabama Department of Conservation and Natural Resources, and ADEM to identify high-quality rivers and streams for focusing conservation activities. Assessment results can inform the selection of new SHUs and priority SHUs for intensive assessment, as well as inform protection and restoration planning within each SHU.

Alabama Water Management Plan – Alabama Governor Robert Bentley has charged the Alabama Water Agencies Working Group with the task of developing a recommended statewide water management plan that takes into account the many demands on the state's water resources. Assessment results can help inform decisions related to water management in Alabama. For example, results can be used for preliminary screening of the ecological effects of proposed water withdrawals or to prioritize dam removal projects initiated by the Alabama chapter of The Nature Conservancy.

Outreach and Communication – Watershed health data generated by the Assessment can be incorporated into outreach materials to engage citizens and local groups in watershed health protection.

Addressing Data Gaps – The Assessment results reflect a comprehensive inventory of available data for characterizing watershed health, vulnerability, and connectivity. This process highlighted several data gaps that can be addressed through research, monitoring, and analysis. Example gaps include an understanding of ecological flow needs in Alabama, particularly for freshwater inflow to Mobile Bay for protecting oyster populations and other biota, and data to characterize the biological condition of lakes and large rivers.

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