Overview of the Preliminary Healthy Watersheds Assessments Project:
Evaluating Relative Health and Vulnerability of Conterminous US Watersheds

EPA Office of Water Healthy Watersheds Program, February 2017

1.0 Introduction

In 2009, the US Environmental Protection Agency (EPA) Office of Water created the Healthy Watersheds Program to help bring more emphasis to protecting high quality waters under the Clean Water Act. This program supports EPA's state, tribal and other partners by taking non-regulatory, collaborative approaches to maintaining high quality waters through assessing and protecting watershed health. A major part of this approach is providing technical analysis, tools and data to help identify healthy watersheds that may represent good prospects for protection.

This document provides an overview of the Preliminary Healthy Watersheds Assessments (PHWA) project, which was carried out during 2016-2017 to improve the availability of comprehensive, national information about watershed health and vulnerability. The goal of this project was to help our partners better target watershed protection efforts by systematically identifying where healthier and more vulnerable watersheds occur. In particular, this project was designed to:

- Ensure that states and other users have basic, statewide and ecoregionally based information on watershed condition that can help them identify and prioritize opportunities for healthy waters protection, communicate with protection partners, and support protection approaches;
- Provide a foundation of nationally available watershed condition data that can be built on and enhanced as better data become available;
- Support state efforts to implement the protection goal of the 303(d) Program Vision[1] and include healthy watersheds protection as part of their Integrated Reporting and nonpoint source pollution control strategies; and
- Support the Clean Water Act goal of "maintaining" as well as restoring the integrity of waters across the nation.

2.0 The Healthy Watersheds Assessment Framework

The PHWA's approach was based on the Healthy Watersheds Assessment Framework,[2] an analytical approach influenced by EPA's Science Advisory Board[3] writings that identified essential ecological attributes that support healthy ecosystems. The Healthy Watersheds Assessment Framework focuses on six key attributes of watershed health: Landscape Condition, Geomorphology, Habitat, Water Quality, Hydrology, and Biological Condition (Figure 1). This assessment approach was refined over several years through the completion of projects in 12 states, including in-depth statewide assessments of California, Wisconsin, Alabama and Tennessee. Whereas specific assessment objectives varied, each was generally aimed at developing a screening tool to evaluate *relative* watershed condition (i.e., in comparison to watersheds across the whole state) to help resource managers plan and target future watershed protection efforts. Because the Healthy Watersheds Assessment Framework is not designed to make a statement on the *absolute* condition of any watershed or water body, these assessments do not define a "healthy watershed" threshold. In addition to characterizing watershed health, some included estimates of relative

[1] USEPA (2013). New Vision for the CWA 303(d) Program – An Updated Framework for Implementing the CWA 303(d) Program Responsibilities. www.epa.gov/tmdl/new-vision-cwa-303d-program-updated-framework-implementing-cwa-303d-program-responsibilities Accessed 09 February 2017.
[2] USEPA (2012). Identifying and Protecting Healthy Watersheds: Concepts, Assessments, and Management Approaches. https://www.epa.gov/sites/production/files/2015-10/documents/hwi-watersheds-complete.pdf Accessed 09 February 2017. See also www.epa.gov/hwp generally.
[3] USEPA Science Advisory Board (2002). A Framework for Assessing and Reporting on Ecological Condition. https://yosemite.epa.gov/sab/sabproduct.nsf/7700D7673673CE83852570CA0075458A/$File/epec02009.pdf.

watershed vulnerability, defined as the potential for future degradation of watershed processes and aquatic system health.

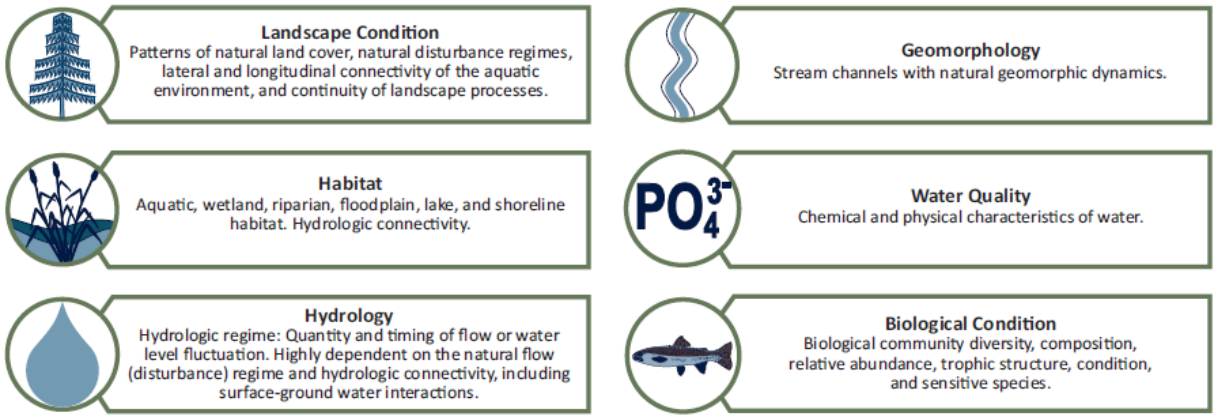

Figure 1. Six attributes of watershed health described in *Identifying and Protecting Healthy Watersheds: Concepts, Assessments, and Management Approaches* (USEPA 2012). Measurement of watershed indicators related to each attribute (i.e., "sub-index") provides the basis for the Watershed Health Index score.

Within the framework, key ecological and stressor attributes are combined to estimate overall watershed health and watershed vulnerability. *Watershed health* is characterized by the presence of natural land cover that supports hydrologic and geomorphic processes within their natural range of variation, good water quality, and habitats of sufficient size and connectivity to support healthy, native aquatic and riparian biological communities. An overall Watershed Health Index is calculated by first identifying measurable indicators closely associated with each of the six key attributes that appear in Figure 1, compiling sub-indices for each attribute, then developing the index from all sub-indices. *Watershed vulnerability* is scored by a similar process of indicator selection followed by sub-index and index calculation. Key terms are described in Table 1.

Table 1:
Key Terms Used in Healthy Watersheds Assessments

METRIC – a general term for any watershed raw data, indicator, sub-index, or index value.

INDICATOR – a measurable attribute of a watershed that is relevant to a component watershed health or vulnerability.

SUB-INDEX – a watershed score obtained by considering several indicators relevant to one primary component of watershed health or vulnerability.

INDEX – a major, overall score per watershed obtained by combining several sub-index scores. The Preliminary Healthy Watersheds Assessment calculates a *Watershed Health* and *Watershed Vulnerability* index score for each HUC12 watershed.

- **WATERSHED HEALTH INDEX –** an integrated measure of the current condition of an aquatic ecosystem and its surrounding watershed. The PHWA *Health Index* is comprised of landscape condition, habitat, hydrology, geomorphology, water quality, and biological condition sub-indices.
- **WATERSHED VULNERABILITY INDEX –** an integrated measure of the potential for future degradation of watershed processes and aquatic system health. The PHWA *Vulnerability Index* is comprised of land use change, water use, and wildfire risk sub-indices.

3.0 PHWA Methods Overview

3.1 Adapting the Healthy Watersheds Assessment Framework to the PHWA

EPA-assisted healthy watersheds assessments were originally designed and carried out as intensive, state-specific or basin-specific projects. This approach was too expensive, labor-intensive and data-limited for all but a few states given the limited resources available. Tradeoffs would be necessary for EPA to assist all states with basic watershed health and vulnerability information at a still-useful watershed scale. The substantial number and variety of datasets and indicators covering the lower 48 states presented an opportunity to advance the availability of healthy watersheds information for most states in one project. Toward these ends, the PHWA was designed and carried out to help all conterminous states obtain and use at least a basic level of healthy watersheds assessment data. The PHWA's design remained consistent with the Healthy Watersheds Assessment Framework while adapting the watershed scale, data sources, and products to provide more widespread state assistance within the available budget.

Watershed Scale

Healthy watersheds assessments address a specific watershed scale. Some of the past healthy watersheds assessments compiled scores at the catchment (1 to 2 sq mi in area on average) scale, which produced highly detailed but labor-intensive and data-limited assessments. The PHWA used the 12-digit hydrologic unit code[4] (HUC12) scale (36 sq mi on average). This scale was selected for three primary reasons: (1) most watershed planning efforts occur at the HUC12 level, as the area represents a geographic scope that is small enough to manage but large enough to address water quality problems and the concerns of stakeholders[5]; (2) this choice of scale made it possible to use already available data across the conterminous US; and (3) healthy watersheds data at this scale would be compatible with the wide variety of other data already at the same scale.

Data Sources

As a national project, use of nationally available datasets was not only efficient but also enabled the PHWA to assess watersheds in a consistent manner across states and ecoregions. Data sources included EPA's Watershed Index Online[6] and the Recovery Potential Screening[7] project, which together have compiled a database of several hundred HUC12 environmental indicators for the lower 48 states. The usefulness of these watershed indicators to states and others was largely demonstrated through state-specific tools for 48 states and projects in 28 states over a ten-year span. Many of these same indicators have been used in previous healthy watersheds assessments, and it was possible to characterize all key Healthy Watersheds Assessment Framework attributes in the PHWA using these national data sources and tools.

PHWA Products

Past healthy watersheds assessments (2011-2015) generated an extensive state-specific technical report, geodatabase, and project-specific workshop for each project. PHWA outputs for each state include a mix of generic and state-specific products. State-specific PHWA products include the geodatabase of map layers, including HUC12 watershed health and vulnerability indicators, sub-index and index scores, plus more user-friendly maps of high-scoring watersheds at risk and summary scores in data tables. Generic products include this overview and PHWA overview webinars that will be available upon request.

---

[4]Hydrologic Unit Codes (HUCs) in a hierarchical series of scales make up the national Watershed Boundary Dataset or WBD. Although the WBD undergoes continuous updates, the exact version used for the PHWA HUC12 boundaries is accessible at http://www.epa.gov/enviroatlas/enviroatlas-data-download-step-2

5 USEPA (2008). Handbook for Developing Watershed Plans to Restore and Protect Our Waters. https://www.epa.gov/sites/production/files/2015-09/documents/2008_04_18_nps_watershed_handbook_handbook-2.pdf. Accessed 09 February 2017.

[6] USEPA (2015). The Watershed Index Online. www.epa.gov/wsio. Accessed 09 February 2017.

[7] USEPA (2017). Recovery Potential Screening Tool. www.epa.gov/rps. Accessed 09 February 2017.

3.2 Statewide and Ecoregional Watershed Assessment

The PHWA is a national project, but is actually comprised of 48 statewide and 85 ecoregional assessments at the HUC12 watershed[8] scale. The PHWA scored each watershed in comparison to the gradients of scores in both the entire Omernik Level III Ecoregion[9] and the entire state in which it occurs (Figure 2). Whereas the healthier watersheds often score well both statewide and ecoregionally, the two scoring approaches occasionally contrast in useful ways.

The gradient of watershed health scores across a state allows for watershed comparisons across the political unit within which many watershed protection decisions take place. Statewide scores provide useful input to statewide planning processes that protect or avoid impacts to the state's healthier watersheds. These can include Clean Water Act Section 319 Nonpoint Source Program Plans and, under the Section 303(d) Vision, Statewide Prioritization Plans. However, top scoring watersheds at the statewide scale are sometimes clustered in one small region of the state due to exceptional conditions. Although it is certainly useful to identify and act on such areas, they can outshine the healthier watersheds in other areas when there is a need for a state program to more equitably recognize and act on healthier watersheds in other parts of the state as well. Further, statewide-only relative scoring misses the opportunity to compare in-state watersheds with similar watersheds in adjacent states when prioritizing limited resources and actions.

The PHWA dual scoring approach also assesses relative watershed health by ecoregion. There are multiple ecoregions in nearly all states, and examining top watersheds within each in-state ecoregion can reveal a more geographically distributed group of high scorers. Because most ecoregions cross multiple state lines, the ecoregionally based scores may reveal whether the in-state portion of one ecoregion is exceptional. For example, in Figure 2, the majority of Ecoregion 70's top-scoring HUC12s (darkest blue) occur within West Virginia despite that state containing less than a quarter of the ecoregion's total area. Yet, statewide scoring alone in this West Virginia example (Figure 2, left side) failed to detect Ecoregion 70's top scorers due to better relative scores from Ecoregion 67. Further, the ecoregional scoring alternative can help users explore partnering approaches with neighboring states, such as protecting large interstate high-scoring patches or restoring healthy watershed corridors across state lines.

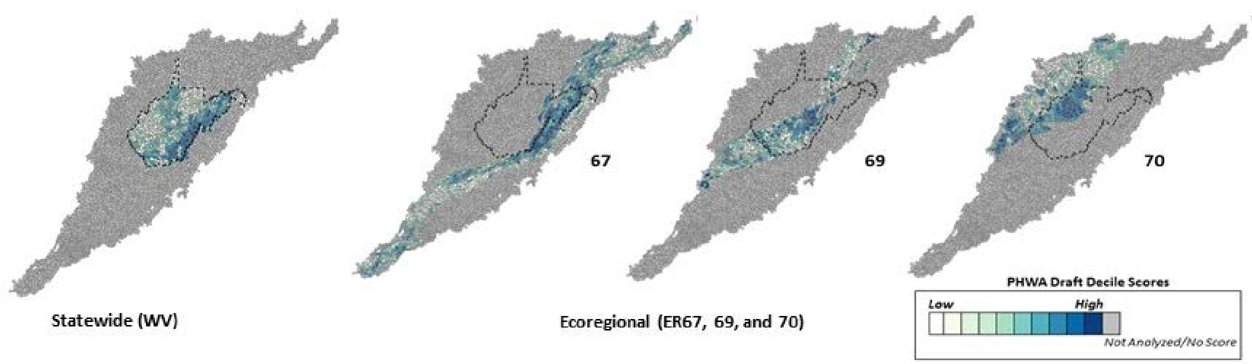

Figure 2. Watershed Health Index measured on West Virginia HUC12s statewide (left) and individually across whole, multi-state ecoregions (three maps at right). Each individual HUC12 has two watershed health scores: one relative to all HUC12s in its state and the other relative to all HUC12s in its ecoregion. Statewide and ecoregional scores are often similar but sometimes differ markedly (e.g., when a HUC12 scores high statewide but low ecoregionally, or vice versa). Both are provided to offer different perspectives on identifying the healthier watersheds for protection. (Draft data for demonstration purposes only)

---

[8] For brevity, the PHWA uses the terms watershed and HUC12 interchangeably. Although HUCs are delineated based on breaks between overland drainage patterns, many HUCs are not true, full watersheds.

[9] USEPA (2013). Level III and IV ecoregions of the continental United States. U.S. EPA, National Health and Environmental Effects Research Laboratory, Corvallis, Oregon, Map scale 1:3,000,000. Available online at: https://catalog.data.gov/dataset/omerniks-level-iii-ecoregions-of-the-conterminous-united-states

3.3 Index Calculation Methods Overview

The following processing steps are repeated for each statewide and ecoregional assessment:

Step 1: Select watershed indicators for assessment area (single state or ecoregion)

A core set of watershed health and vulnerability indicators served as the starting point for all ecoregional assessments. Indicator sets were sometimes modified at the ecoregional scale depending on ecological setting and the relevance of core indicators in the ecoregion. Statewide indicator selection included all indicators used in any of its component ecoregions. When a HUC12 watershed straddled more than one state or ecoregion, it was scored only in the state/ecoregion in which its majority by area resided.

Step 2: Calculate and normalize watershed indicator values

Directionality of indicator measurement was first configured to ensure that all health indicators have 'higher is healthier' values, and all vulnerability indicators have 'higher is more vulnerable' values. Watershed indicator values were calculated for each HUC12 watershed, then scores for each indicator were unity-normalized within a range of 0 to 1. Indicator values were normalized separately within each ecoregion or state to correct for differences among the indicators in unit of measurement and to ensure that each indicator received equal weighting later when calculating sub-index scores. Because scoring is relative to the geographic area being assessed, ecoregional and statewide scores for the same indicator in the same watershed can differ.

Step 3: Calculate Sub-Index scores

Watershed indicators were grouped into sub-indices according to the six attributes of watershed health or three attributes of vulnerability. A watershed's sub-index score was calculated as the mean of its normalized indicator values. If a watershed had no data for a given indicator, that indicator was not calculated as part of the sub-index scoring and the sub-index value reflected the mean of the remaining indicators. Watershed Health sub-indices included Landscape Condition, Hydrology, Geomorphology, Habitat, Water Quality, and Biological Condition. Watershed Vulnerability Sub-Indices include Land Use Change, Water Use, and Wildfire Risk. As with their component indicators, all sub-index scores potentially range from 0 to 1. Sub-indices were not normalized in order that raw sub-index scores more clearly show the actual range and distribution of scores among watersheds in the ecoregion or state.

Step 4: Calculate Index scores

An overall Watershed Health Index and Watershed Vulnerability Index score was calculated for each HUC12 as the mean of the sub-index values for that watershed. All sub-indices were equally weighted within each index. Index scores were presented within a potential maximum range from 0 to 1 where higher scores denote healthier or more vulnerable watersheds. Like the sub-indices, indices were not normalized in order that raw scores could more clearly show the actual range and distribution of scores among watersheds in the ecoregion or state.

3.4 Watershed Indicators

In total, the PHWA utilized 20 indicators representing 6 sub-indices of watershed health and 9 indicators representing 3 sub-indices of watershed vulnerability. Indicator usage involved a core, national set as well as limited addition or removal of specific indicators when necessary to address ecoregional differences. For example, for landscape condition indicators, ecoregion-specific determinations were made regarding the classification of 'Barren Land' as natural or human use land cover.

The PHWA utilized watershed indicators measured in three different spatial zones of HUC12s: (1) the **watershed** (Ws; used to identify properties measured throughout the entire HUC12); (2) the **riparian zone** (RZ; delineated by placing a 100-meter buffer around the surface water feature layer from the National Land Cover Dataset (NLCD) and flowline and waterbody features from the NHDPlus version2); and (3) the **hydrologically active zone** (HAZ; defined by the riparian corridor adjacent to surface waters conflated with areas of high topographic wetness potential that are contiguous to surface waters).

3.4.1 Watershed Health Indicators

Watershed health indicators selected for the PHWA (Figure 3) reflected the six sub-indices of watershed health previously discussed. Indicators that comprise each sub-index are described briefly below. Indicator choices included those with positive as well as negative effects on watershed health; metrics associated with negative effects were inverted to be directionally consistent with positive (i.e., higher score is healthier) metrics. Detailed descriptions and source metadata are available in the PHWA data table spreadsheets compiled for each of the lower 48 states.

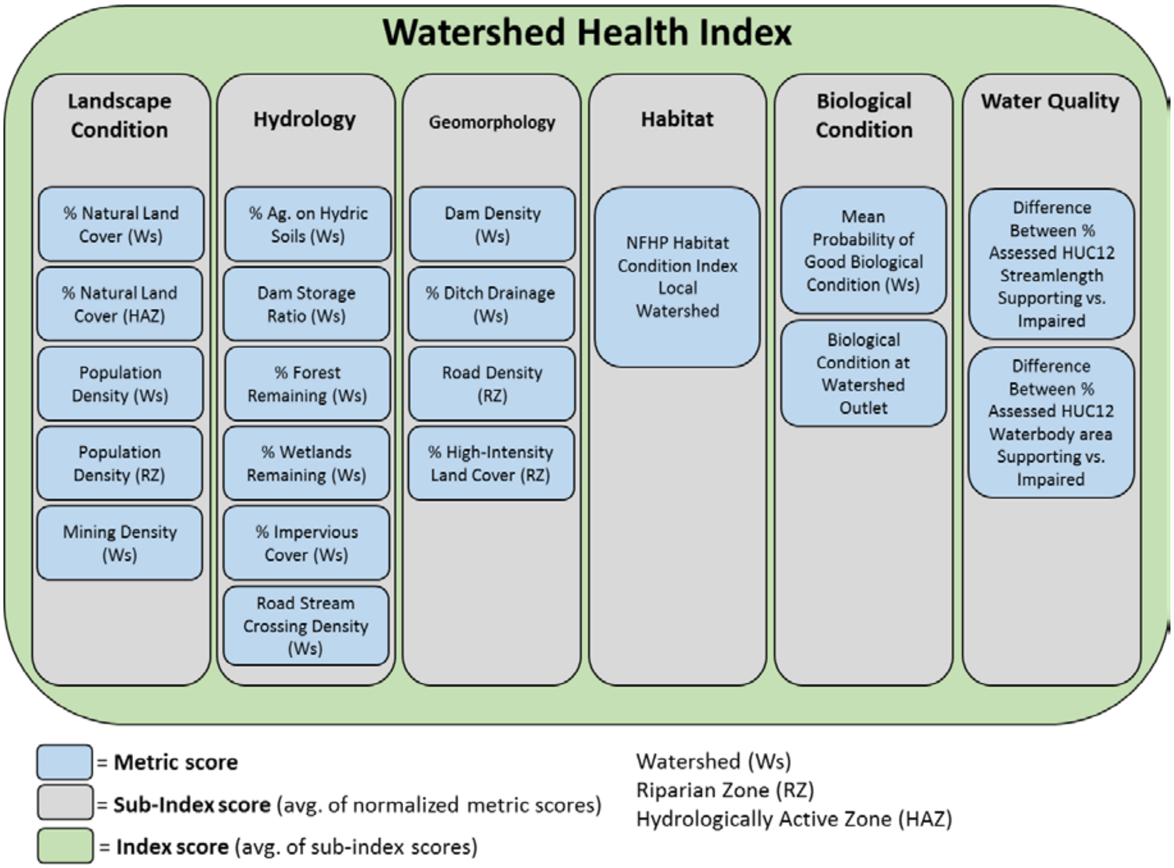

Figure 3. PHWA Watershed Health Index and Sub-Index structure with component indicators (blue boxes). Indicators measure watershed-wide (Ws), riparian zone (RZ) or hydrologically active zone (HAZ) attributes as marked.

Landscape Condition

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. Natural land cover supports watershed health by maintaining hydrologic and geomorphic processes and protecting aquatic ecosystems from nonpoint sources of pollution. Further, natural land cover in and around the riparian zone, floodplains, and wetlands filters pollutants, serves as habitat for aquatic and semi-aquatic species and supports connectivity between habitat patches.

Landscape condition indicators for the PHWA included direct measures of natural land cover extent and measures of anthropogenic sources of landscape alteration. The extent of natural land cover was measured throughout the entire HUC12 watershed and within the hydrologically active zone. Indicators of anthropogenic sources of landscape alteration measured the size of human populations in the watershed and riparian zone, and the number of mining operations in the watershed. Large human populations reduce natural vegetative cover through conversion to urban and agriculture lands, while human settlement in riparian corridors removes the buffer between waterbodies and upland development. Coal and mineral mining operations can alter the landscape through vegetation loss and excavation. Other common human influences on landscape condition such as agriculture and urbanization were reflected in the percent natural land cover metrics.

Hydrology

The flow regime refers to a stream's characteristic pattern of flow magnitude, timing, frequency, duration, and rate of change. 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. Yet, flow measurements and data are generally not consistently available across the country, or even across most states, requiring use of surrogate measurements of the factors that strongly influence flow.

Hydrology indicators in the PHWA characterized the maintenance of natural land cover types in the watershed that support natural flow regimes, and also characterized anthropogenic watershed features that have the potential to alter hydrologic processes on the landscape or within stream channels. Forest and wetland cover types help to maintain key hydrological processes such as canopy interception, soil infiltration rates, evapotranspiration, groundwater recharge, and flood storage within their natural range of variability. Impervious cover in a watershed can increase the flashiness of streamflow, with high rates of stormwater runoff, reduced infiltration, and reduced groundwater recharge. The presence of agriculture on hydric soils in place of wetland cover can also increase flow magnitudes through artificial drainage of wet soils. While the effects of dams on riverine hydrology vary with storage and release operations, alterations can include attenuation of high flows, augmentation of low flows, or an increase in the frequency of extreme low-flows. Road-stream crossings can alter stream velocity and depth above and below their culverts and interrupt upstream-downstream hydrologic connectivity.

Geomorphology

Stream channel shape, sinuosity, slope, and bed substrate reflect a dynamically stable balance between the stream's sediment supply and sediment transport capacity. This balance can be destabilized under altered flow and/or sediment regimes, resulting in a long-term change in channel form, such as incision or widening. While periodic changes to channel form occur naturally with disturbances such as floods, human activities often instigate and accelerate geomorphic change that can reduce the quality, extent, and connectivity of habitat for aquatic organisms. Like hydrology, geomorphically relevant data are not consistently available across the US and geomorphic condition is inferred through surrogate metrics.

Geomorphology indicators in the PHWA described watershed features that have the potential to alter geomorphic processes and stream channel form, including dams, artificial drainage ditches, near-stream roads, and high-intensity land use in the riparian zone. Dams can alter channel geomorphology by slowing water velocity and increasing sediment deposition above the dam and releasing sediment-deficient water below the dam outfall. Artificial drainage ditches increase water delivery to streams, resulting in changes to flow magnitudes and velocities that can drive geomorphic change. The presence of roads and high-intensity land use types (cropland and medium/high-density urban) in the riparian zone can alter channel forms through changes to flow patterns or through direct channel manipulations (i.e., channel straightening, bank armoring, or levee construction).

Habitat

The term aquatic 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. The PHWA characterized aquatic habitat using a national, multi-metric index of reach-scale fish habitat condition developed by the National Fish Habitat Partnership (NFHP)[10]. The 2015 NFHP Habitat Condition

---

[10] Crawford, S., Whelan, G., Infante, D.M., Blackhart, K., Daniel, W.M., Fuller, P.L., Birdsong, T., Wieferich, D.J., McClees-Funinan, R., Stedman, S.M., Herreman, K., and Ruhl, P. 2016. Through a Fish's Eye: The Status of Fish Habitats in the United States 2015. National Fish Habitat Partnership. Accessed on 09 February 2017, at http://assessment.fishhabitat.org/.

Index (HCI) scored fish habitat condition in stream reaches across the US according to the following characteristics of the local drainage area of each stream reach: extent of urban and agricultural land cover types, human population density, road length, number of road-stream crossings, number of dams, number of mine operations, number of facilities with National Pollutant Discharge Elimination System (NPDES) wastewater discharge permits, number of sites in the EPA Toxic Release Inventory program, and number of sites on the Superfund National Priorities List. Each of these measures were selected by the NFHP because they were determined to be meaningful for assessing fish habitat condition. NFHP Index calculation inputs and methods were validated by comparison with states and regional fisheries datasets across the country. The NFHP HCI was first calculated nationally in 2010 and recalculated in 2015.

Biological Condition

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. EPA's 2008-2009 National Rivers and Streams Assessment (NRSA)[11] evaluated the ecological condition of perennial rivers and streams in the conterminous United States by sampling 1,924 sites randomly selected based on a probability-based design. A multi-metric index based on measures of benthic macroinvertebrate community was used to represent overall biological condition. Biological condition at sampling sites was classified as "poor", "fair", or "good" by comparing scores to the distribution of scores observed as least-disturbed reference sites.

Whereas nationally consistent data estimating biological condition has long been desired but unavailable, modeled estimates are now emerging. The PHWA characterized biological condition using data from a landscape metric-based model of NRSA biological condition, developed by EPA's Office of Research and Development (ORD)[12]. ORD modeled the probability of "good" biological condition in perennial stream reaches using local (catchment surrounding stream reach) and cumulative (total upstream contributing area) watershed-scale landscape predictor metrics from EPA's Stream-Catchment (StreamCat) dataset.

The Mean Probability of Good Biological Condition per HUC12 offered an area-weighted average of all NHDPlus perennial stream catchments that have a 'probability of good condition' value calculated by the ORD model. Catchments without a score in the HUC12 do not affect this indicator, which is sensitive only to what has been modeled. The second metric, Biological Condition Score at Watershed Outlet, reflected the 'probability of good condition' score for the most downstream NHDPlus perennial stream catchment receiving flow from upstream portions of the HUC12. As the outlet or 'pour point' integrates much of the stresses and responses from upstream, it differs from and complements the first metric. Due to the reliance on perennial streams for this sub-index, HUC12s with no perennial waters did not receive a sub-index score.

Water Quality

Under natural conditions, water chemistry in a waterbody varies within a characteristic range that is determined by geography, geology, topography, and other characteristics. Aquatic biota adapted to such conditions and the presence of water quality parameters in their natural range are key features of healthy streams. The PHWA characterized water quality using assessment data generalized from EPA's Assessment and Total Maximum Daily Load Tracking and Implementation System (ATTAINS) database[13], which contains nationwide data on assessed and impaired waters assembled from state-specific biennial assessment reports. Like the Biological Condition sub-index, the development of Water Quality indicators was challenging because of state-to-state differences in assessment and reporting, as well as limitations in data availability across the conterminous U.S. For this reason, the Water Quality indicators focused only

[11] USEPA (2017). National Rivers and Streams Assessment. https://www.epa.gov/national-aquatic-resource-surveys/nrsa. Accessed February 9, 2017.

[12] Hill, R.A., E.W. Fox, S.G. Leibowitz, A.R. Olsen, D.J. Thornbrugh, and M.H. Weber. Predictive mapping of the biotic condition of conterminous-USA rivers and streams. *Ecological Applications* (submitted).

[13] USEPA (2017). Assessment and Total Maximum Daily Load Tracking and Implementation System (ATTAINS). https://ofmpub.epa.gov/waters10/attains_index.home Accessed July 2015.

on summarizing extent of assessed and impaired versus unimpaired waters in general rather than attempting to represent pollutant-specific conditions.

PHWA water quality indicators were developed using ATTAINS data on the lengths and areas of assessed and impaired waters within each HUC12 watershed. The first indicator measured the percent of the HUC12's assessed stream length fully supporting Designated Uses minus the percent of assessed stream length that was listed as impaired. By representing the extent of fully supporting stream length as a proportion of total assessed stream length in the HUC12, this indicator controlled for variability in extent of assessed waters among watersheds while also considering impairments and attainments. The second indicator measured the percent of assessed waterbody area (lakes, ponds, etc.) fully supporting Designated Uses minus the percent of assessed waterbody area that was listed as impaired. Because state-to-state differences in assessment were substantial in some areas, this sub-index was not calculated in some of the ecoregional assessments. It was used in every statewide assessment. As with the Biological Condition sub-index, the Water Quality sub-index may be a good candidate for refinement using state-specific data.

3.4.2 Watershed Vulnerability Indicators

The impact of stressors on different ecosystems in different regions of the United States depends on the vulnerability of those systems and their ability to adapt to the changes imposed on them. A wide variety of factors can be related to watershed vulnerability, and the most relevant factors can vary substantially from region to region around the country; national data on some of these factors is also limited. As a result, a very limited number of vulnerability factors could be assessed nationally in the PHWA, and the Vulnerability Index should not be considered inclusive of all major forms of watershed vulnerability. Consideration of individual vulnerability sub-indices may be more appropriate than the overall index in many areas. The PHWA's approach characterized vulnerability to future degradation based on direction and magnitude of recent change in combination with selected traits relevant to likelihood of future change. The PHWA included three vulnerability sub-indices: Land Use Change, Water Use, and Wildfire Risk (Figure 4).

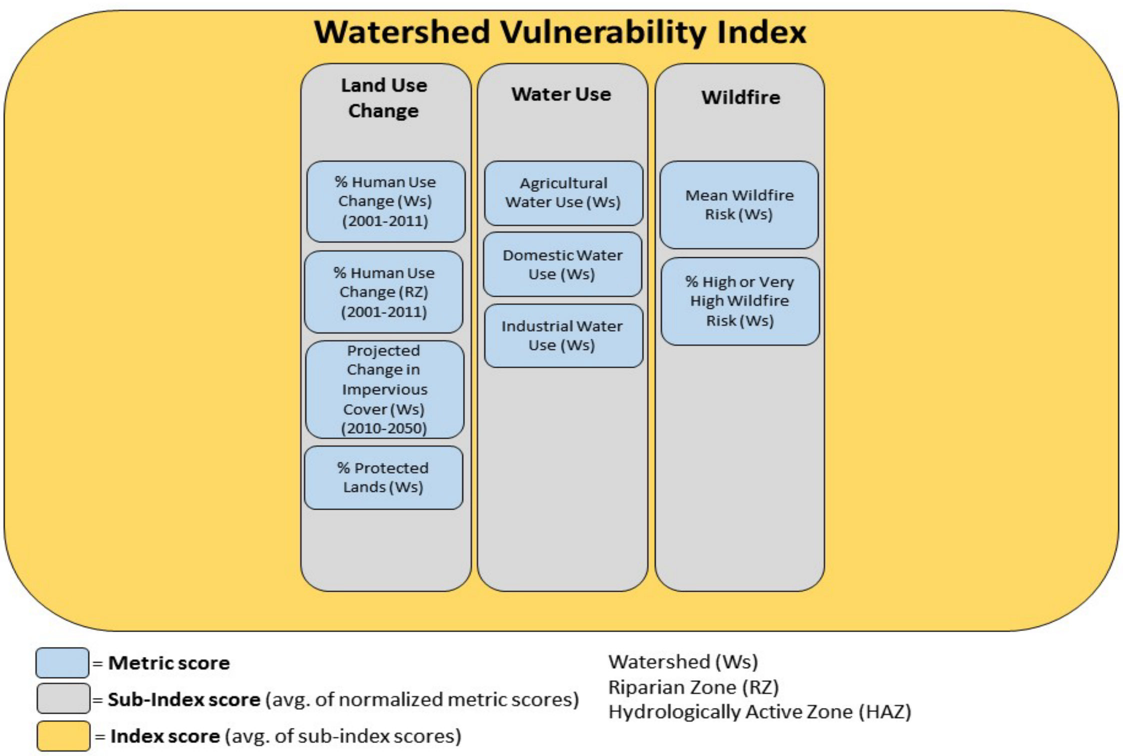

Figure 4. PHWA Watershed Vulnerability Index and Sub-Index structure with component indicators (blue boxes). Indicators measure watershed-wide (Ws) or riparian zone (RZ) attributes as marked.

Indicator choices included those with positive as well as negative effects on watershed vulnerability; some metrics (such as percent protected land) were inverted to be directionally consistent with "higher score is more vulnerable" sub-indices and indices. Detailed descriptions and source metadata are available in the PHWA data tables spreadsheets compiled for each of the lower 48 states.

Land Use Change

Although a watershed may presently contain large patches of natural vegetative cover, future land cover change may occur with the expansion of urban and agricultural lands. PHWA land use change indicators described the vulnerability of watersheds to future land use change. Indicators included measures of recent increases in urban and agricultural cover in the watershed and in the riparian zone, projected future impervious cover in the watershed, and the extent of lands with protections in place to moderate impacts from future land uses.

Water Use

Surface and groundwater withdrawals can greatly alter a watershed's natural hydrologic regime. In many areas, future water demand will increase beyond current levels as a result of population growth and expansion of agriculture, industry, and mining. Water use indicators in the PHWA were drawn from EPA's EnviroAtlas[14] and characterized current agricultural, domestic, and industrial water use in the watershed as an available surrogate measure for future water demand.

Wildfire

As a result of vegetation loss, wildfires can cause changes in hydrologic processes such as overland flow, interception, evapotranspiration, and as a result can increase runoff, erosion, and sediment delivery. Characterization of wildfire vulnerability used a measure of wildfire risk from the USDA Forest Service Wildfire Hazard Potential dataset.[15] Areas mapped with higher values represent fuels with a higher probability of experiencing torching, crowning, and other forms of extreme fire behavior under conducive weather conditions, based primarily on 2010 landscape conditions.

4.0 PHWA Products

Although the PHWA was national in scope, products were compiled per individual state and include both statewide and in-state ecoregional results. Each PHWA state package includes this overview document, a state-specific watershed data file, and a file geodatabase containing PHWA map layers.

Watershed Data File

This Microsoft Excel file was formatted to include user-friendly products such as maps (Figure 5) and data summaries (Figure 6), as well as all the PHWA data tables and metadata, in a single file format that would be more accessible to a broader user audience than the geodatabase. These PHWA products can be used to answer some critical questions:

- Where are the top-scoring watersheds?
- Among the healthiest watersheds, which are most vulnerable?
- Statewide, are watersheds generally high-scoring, low-scoring, or varied?
- Are there spatial patterns (e.g. basin clustering, high scoring corridors, one high-scoring ecoregion) across the state?
- Where might in-state protection efforts be focused? How about interstate collaborative efforts?
- How similar or different are the sets of healthiest watersheds from within-state compared to the best from within their respective ecoregions?

Each state-specific PHWA watershed data file includes several tabbed worksheets as described in Table 2.

[14] USEPA (2017). EnviroAtlas website. https://www.epa.gov/enviroatlas Accessed February 9, 2017.

[15] https://www.landfire.gov/ Accessed July 2016.

File Geodatabase

A state-specific ArcGIS file geodatabase was also produced for each state in order to facilitate easier integration of PHWA results with other state datasets and, if desired, further modification of state-specific index calculation and data sources. Each state geodatabase includes the HUC12, state and ecoregional boundaries, with values from all PHWA indicators, sub-indices, and indices as attributes of the HUC12s.

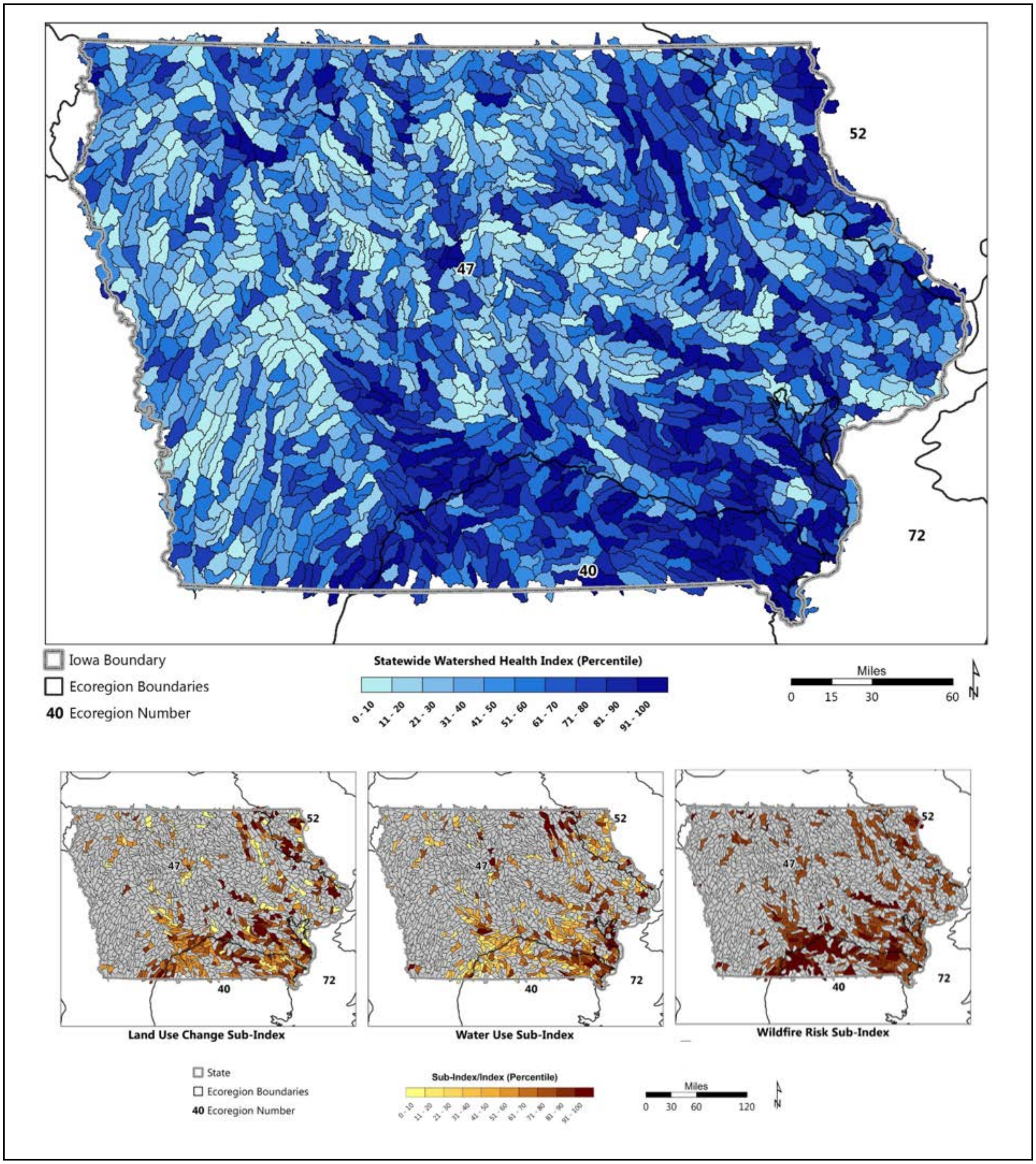

Figure 5. Example interpretive maps of Iowa watersheds from a state PHWA Watershed Data File show statewide Watershed Health Index scores for all HUC12s (above), and three different sub-indices of vulnerability for only the top 25% based on statewide watershed health (below). Percentile cutoffs represent relatively higher-scoring watersheds and do not imply an absolute healthy or vulnerable threshold.

Table 2: **Worksheets and their content in each state-specific PHWA watershed data file.**	
Introduction	Key to contents of the file and several common terms.
Index Summary by Watershed	A user-friendly summary of each HUC12 watershed's overall health and vulnerability index scores. Highlights watersheds that are top-scorers and high-scoring watersheds that are also vulnerable. Searchable by watershed name.
Health and Vulnerability Map Series	A set of seven statewide maps that provide a visual summary of PHWA results. Includes ecoregions, statewide health index (raw and by percentile), top 25% state health index, top 25% ecoregional health index, top 10% and 25% by both state and ecoregional health index, and four vulnerability maps for watersheds in the top 25% state health index.
State Health Index and Sub-Index Scores	Full dataset of HUC12 statewide watershed health index and six component sub-index scores. Each HUC12's score is relative to the gradient of scores statewide (max range 0.0 to 1.00). State border HUC12s are limited to those with >50% of total area in-state.
State Vulnerability Index and Sub-Index Scores	Full dataset of HUC12 statewide watershed vulnerability index and three component sub-index scores. Each HUC12's score is relative to the gradient of scores statewide (max range 0.0 to 1.00). State border HUC12s are limited to those with >50% of total area in-state.
ER Health Index and Sub-Index Scores	Full dataset of HUC12 ecoregional watershed health index and six component sub-index scores. Each HUC12's score is relative to the gradient of scores ecoregion-wide (max range 0.0 to 1.00), although only HUC12s within this state appear in this table. Ecoregional border HUC12s are assigned only to the ecoregion containing the majority of the HUC12's total area.
ER Vulnerability Index and Sub-Index Scores	Full dataset of HUC12 ecoregional watershed vulnerability index and three component sub-index scores. Each HUC12's score is relative to the gradient of scores ecoregion-wide (max range 0.0 to 1.00), although only HUC12s within this state appear in this table. Ecoregional border HUC12s are assigned only to the ecoregion containing the majority of the HUC12's total area.
Raw Indicator Scores	Raw indicator values per HUC12 for all indicators used in sub-index and index calculation. These data are provided in order to support any future effort to revise and recalculate sub-indices or indices using new indicators, different combinations, or different weights.
Metadata and Definitions	Definitions and sources of indicators, and their usage per ecoregion and state. Also includes basic field definitions and a glossary of frequently used terms about the data sources.

Colorado's Preliminary Healthy Watersheds Assessment (PHWA) evaluated the relative watershed health and vulnerability of Colorado's 2,988 12-digit hydrologic unit code (HUC12) watersheds. Watersheds were assessed at both the statewide and ecoregional scale, resulting in paired *Watershed Health* and *Watershed Vulnerability* scores per HUC12 watershed (i.e., one set of statewide scores and one set of ecoregional scores per watershed). Together, these scores provide insights on a watershed's condition relative to others within the state, as well as those watersheds sharing similar ecological characteristics across the ecoregion.

Statewide and ecoregional index scores are presented below as both raw scores ("Score", between 0 and 1) and percentiles (0 to 100%). The "Top 10%" and "Top 25%" columns denote watersheds scoring in the top percentiles of watershed health, both within the state and their ecoregion.

Blue-highlighted watershed names indicate those scoring in the Top 25% of watershed health both within the state and their ecoregion. Among these Top 25% "healthiest" watersheds, yellow-highlighted watershed names indicate those that also have an elevated (> 75th percentile) statewide vulnerability score. This information helps distinguish between healthy watersheds and healthy watersheds most at risk to degradation.

Please note that the full PHWA dataset, including indicator and sub-index scores that comprise each overall index, is available in other worksheets of this file.

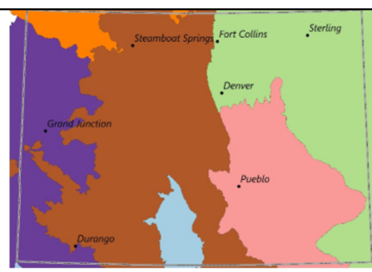

Figure: Colorado includes parts of six Omernik Level III ecoregions

PHWA Watershed Index Summary				WATERSHED HEALTH INDEX						WATERSHED VULNERABILITY INDEX			
				STATEWIDE		ECOREGIONAL		Top Scoring Watersheds		STATEWIDE		ECOREGIONAL	
Watershed Name	HUC12	ECOREGION	STATE	Score	Percentile	Score	Percentile	Top 10%	Top 25%	Score	Percentile	Score	Percentile
Bronco Canyon-Purgatorie River	110200101604	26	CO	0.66	17.7	0.82	63.8	No	No	0.13	49.0	0.13	30.4
Browns Canyon	110200010708	21	CO	0.76	41.0	0.74	52.3	No	No	0.11	35.1	0.12	34.8
Browns Creek	110200010704	21	CO	0.81	59.2	0.75	55.5	No	No	0.13	49.6	0.14	47.3
Browns Draw	140500020605	20	CO	0.90	90.7	0.90	84.0	No	Yes	0.35	96.7	0.32	90.0
Brumley Valley-Disappointment Creek	140300020506	20	CO	0.91	94.4	0.91	87.7	No	Yes	0.25	86.0	0.23	69.9
Brunker Creek	102500020101	25	CO	0.81	58.4	0.78	45.1	No	No	0.19	75.1	0.19	76.5
Brush Creek	110200011001	21	CO	0.79	52.6	0.73	48.2	No	No	0.06	6.8	0.07	13.9
Brush Creek	140100050904	20	CO	0.86	76.6	0.83	54.1	No	No	0.23	83.4	0.25	75.4
Brush Creek	140100051106	21	CO	0.77	45.9	0.75	57.2	No	No	0.15	59.4	0.17	54.6
Brush Creek	140200010202	21	CO	0.89	88.5	0.88	96.0	No	Yes	0.05	4.1	0.05	6.4
Brush Creek-Cedar Creek	101900120807	25	CO	0.94	98.0	0.91	89.1	No	Yes	0.11	37.9	0.10	11.5
Brush Creek-Roaring Fork River	140100040602	21	CO	0.66	16.5	0.47	1.7	No	No	0.17	67.0	0.25	75.9
Brush Hollow Creek-Arkansas River	110200020408	26	CO	0.64	14.3	0.59	5.2	No	No	0.16	62.7	0.20	66.6
Buck Canyon-Two Butte Creek	110200130106	26	CO	0.89	87.3	0.85	77.6	No	Yes	0.16	66.6	0.17	54.2
Buck Creek	101900130404	25	CO	0.71	27.5	0.70	25.3	No	No	0.12	40.6	0.11	25.9
Buck Creek-Hermosa Creek	140801040407	21	CO	0.87	81.5	0.83	84.3	No	Yes	0.20	75.8	0.23	73.4
Bucktail Creeks-San Miguel River	140300030702	20	CO	0.88	83.9	0.84	58.6	No	No	0.28	90.6	0.26	77.1
Buffalo Creek	101900020303	21	CO	0.74	36.4	0.79	70.8	No	No	0.16	65.7	0.18	60.2
Buffalo Gulch	101900010302	21	CO	0.80	55.2	0.73	47.9	No	No	0.07	9.7	0.07	14.3

Figure 6. Example PHWA Watershed Index Summary from Colorado offers watershed health and vulnerability index scores that are searchable by watershed name. Higher-scoring watersheds in health alone and health plus vulnerability are highlighted.

5.0 Using PHWA Results

The PHWA was developed to help EPA and state partners protect high quality waters and maintain their benefits to society and the environment, by identifying healthier and more vulnerable watersheds and making this information available to others involved in watershed protection. Potential uses include:

Support state actions to prioritize, protect and maintain high quality waters.

The PHWA was supported by EPA's CWA Section 303(d) Listing and Impaired Waters Program and the Section 319 Nonpoint Source Control Program, because both programs have encouraged states to more actively protect high quality waters in recent years. Under the Section 303(d) Vision initiative, states have systematically identified priority waters and watersheds, including healthy watersheds priorities for protection over the next several years. Although healthy watersheds assessments exist in some states, the PHWA supports the Vision's protection goal by nationally improving the basic level of information about watershed health and the location of high quality watersheds in all the conterminous states. Similarly, the nonpoint source control programs in states may be able to utilize PHWA information in developing statewide protection strategies and targeting protection efforts. The PHWA may also prove useful to other protection-oriented programs within and beyond the Clean Water Act. The PHWA can complement case-by-case approaches to protecting high quality waters with a more comprehensive, statewide characterization of watershed health and vulnerability.

Raise awareness of where the healthiest watersheds occur.

One of the most important objectives of the PHWA was to identify the healthier watersheds throughout the country, and it remains equally important to communicate those findings effectively. In addition to generating and delivering geospatial data in commonly-used formats including Excel data tables and a file geodatabase, the PHWA results were packaged in more user-friendly forms. A map series was developed for each state including statewide maps of watershed health and vulnerability scores, the highest-scoring watersheds, and the relative vulnerability of those watersheds. The Index Summary sheet of the PHWA Watershed Data File includes health and vulnerability index scores, and is searchable by individual watershed name. Overall state summary statistics were also compiled. These PHWA materials can be useful in raising public awareness of healthy watersheds and their beneficial effects.

Raise awareness that healthy watersheds are sometimes highly vulnerable.

It may come as a surprise that even some of the healthiest watersheds are vulnerable to degradation and the loss of their beneficial qualities. The PHWA provides insights into which healthy watersheds may be vulnerable to specific threats and pressures, including land use change, water use, and wildfire. Better understanding these specific vulnerabilities can help identify good HUC12 candidates for management efforts, like conservation easement programs, water conservation efforts, and fuel reduction treatments. This information can also help educate watershed managers, protection partners, and the general public about the importance of watershed health and resilience to disturbances, such as fires, floods, and droughts. Broader understanding of vulnerability can help avoid the loss of benefits that healthy watersheds provide to communities and the environment.

Improve communication and coordination among states, EPA and other partners by providing nationally-consistent measures of watershed health and vulnerability.

As partners in implementing the Clean Water Act, EPA headquarters, regional offices and states all interact and communicate about their respective geographic areas of responsibility. Having nationally consistent sources of watershed condition information can help EPA and the states better understand others' protection options, plans, and priorities.

Provide a basis for EPA, states and others to promote high quality waters protection in cross-program interactions and partnering with other landscape management efforts.

Large-scale planning activities such as utilities or transportation routing often seek information on environmentally sensitive or high quality areas to avoid or minimize impacts. A common concern is avoiding impacts to waterways. A watershed-based dataset on health and vulnerability may be more useful to such efforts than waterbody-based data because it addresses the whole landscape rather than just the waters themselves. Further, the PHWA's orientation toward protection of high quality waters makes it potentially complementary to more terrestrial-oriented landscape protection efforts such as federal, state and private wildlife management plans. Because all watersheds are scored in the PHWA, it provides a basis to find locations of mutual interest with other programs.

Provide an initial dataset upon which others can build better watershed condition information. To some extent, developing the PHWA needed to sacrifice some data richness and variety to establish a nationally consistent dataset. Thus, the PHWA should be considered a limited, initial dataset on watershed health and vulnerability that has great potential to be improved and enhanced with more data at statewide or other scales. For example, an individual state may have extensive bioassessment data that could improve health index and sub-indices well beyond the more basic data available nationally. A state may choose to identify thresholds of health or vulnerability score that are appropriate to their watersheds and priorities. Further, whereas the PHWA used impairments in general to score the Water Quality Sub-index, a single state may be better-suited to use data on impairment from several specific pollutants to score this attribute in a more informative manner. Vulnerability assessment as well was able to address just three sub-indices due to national data limitations, but potential exists to develop and score additional vulnerability factors where state or other data can support the analysis. As the PHWA assigned equal weights to all indicators and sub-indices, weighting could also be changed on a statewide or ecoregional basis to match environmental conditions or program priorities. The full PHWA dataset for each state is provided to facilitate whatever improvements might be considered over time. As resources permit, EPA's Healthy Watersheds Program may be able to help states' and others' efforts to build on and improve PHWA data.

6.0 Contact Information and Disclaimer

The Preliminary Healthy Watersheds Assessments project (PHWA) was carried out during 2016 and early 2017 by the US Environmental Protection Agency Office of Water, Healthy Watersheds Program, with contractual assistance from The Cadmus Group, Inc. Questions, comments and requests pertaining to the PHWA should be routed through the online "contact us" form available at https://www.epa.gov/hwp/forms/contact-us-about-healthy-watersheds-protection .

Disclaimer

The information compiled in the Preliminary Healthy Watersheds Assessments project (PHWA) and presented in this document and related data files is intended to support screening-level assessments to inform potential watershed protection priorities and is based on modeled and/or aggregated data that may have been collected or generated for other purposes. Results should be considered in that context and do not supplant site-specific evidence of watershed health or vulnerability. Scores represent relative gradients from lowest to highest with reference to watersheds statewide and ecoregion-wide, and no absolute threshold values of health or vulnerability are implied.

At times, this document refers to statutory and regulatory provisions, which contain legally binding requirements. This document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus, it does not impose legally binding requirements on EPA, states, authorized tribes, or the public and may not apply to a particular situation based on the circumstances.

Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government. The views and opinions of authors herein do not necessarily state or reflect those of the U.S. Government and shall not be used for advertising or product endorsement purposes.