United States Environmental Protection Agency

This document contains one section of the EPA technical document, "Identifying and Protecting Healthy Watersheds," published in February 2012. You can find the entire document at: http://water.epa.gov/healthywatersheds

Identifying and Protecting Healthy Watersheds

Chapter 4. Healthy Watersheds Integrated Assessments

February 2012

4. Healthy Watersheds Integrated Assessments

Introduction

This chapter introduces the Healthy Watersheds Initiative, discusses the characteristics of a healthy watershed, and reviews the benefits of protecting healthy watersheds. This chapter also describes the purpose, target audience, and intended use of this document.

Overview of Key Concepts

This chapter describes the healthy watersheds conceptual framework. It then discusses, in detail, each of the six assessment components – landscape condition, habitat, hydrology, geomorphology, water quality, and biological condition. A sound understanding of these concepts is necessary for the appropriate application of the methods described in later chapters. This chapter concludes with a discussion of watershed resilience.

Examples of Assessment Approaches

This chapter summarizes a range of assessment approaches currently being used to assess the health of watersheds. This is not meant to be an exhaustive list of all possible approaches, nor is this a critical review of the approaches included. These are provided solely as examples of different assessment methods that can be used as part of a healthy watersheds integrated assessment. Discussions of how the assessments were applied are provided for some approaches. Table 3-1 lists all of the assessment approaches included in this chapter.

Healthy Watersheds Integrated Assessments

This chapter presents two examples for conducting screening level healthy watersheds integrated assessments. The first example relies on the results of a national assessment. The second example demonstrates a methodology using state-specific data for Vermont. This chapter also includes examples of state efforts to move towards integrated assessments.

Management Approaches

This chapter includes examples of state healthy watersheds programs and summarizes a variety of management approaches for protecting healthy watersheds at different geographic scales. The chapter also includes a brief discussion of restoration strategies, with focus on targeting restoration towards degraded systems that have high ecological capacity for recovery. The results of healthy watersheds integrated assessments can be used to guide decisions on protection strategies and inform priorities for restoration.

4.1 Integrated Assessment

The term "integrated assessment," as used in this document, refers to a holistic evaluation of system components and processes that results in a more complete understanding of the aquatic ecosystem, and allows for the targeting of management actions to protect healthy watersheds. Figure 4-1 shows the healthy watersheds integrated assessment and management framework. Collaboration with multiple partners is critical for framing the scale and context of the assessment and ensuring that all relevant data and expertise are identified and made available. These data are then used to evaluate each of the six healthy watersheds assessment components - landscape condition, habitat, hydrology, geomorphology, water quality, and biological condition. The results of the individual assessments are synthesized to provide an overall assessment of watershed health. Strategic watershed protection priorities can then be identified by evaluating vulnerability alongside the identified healthy watersheds. Examples of watershed protection strategies and the role of outreach and education are discussed in Chapter 5. It is also important to collect new data for demonstrating the effectiveness of watershed protection activities and to refine future assessments. Assessment and management of healthy watersheds is an adaptive and iterative process, with new data and improved methodologies providing better assessment results and more effective protection strategies over time.

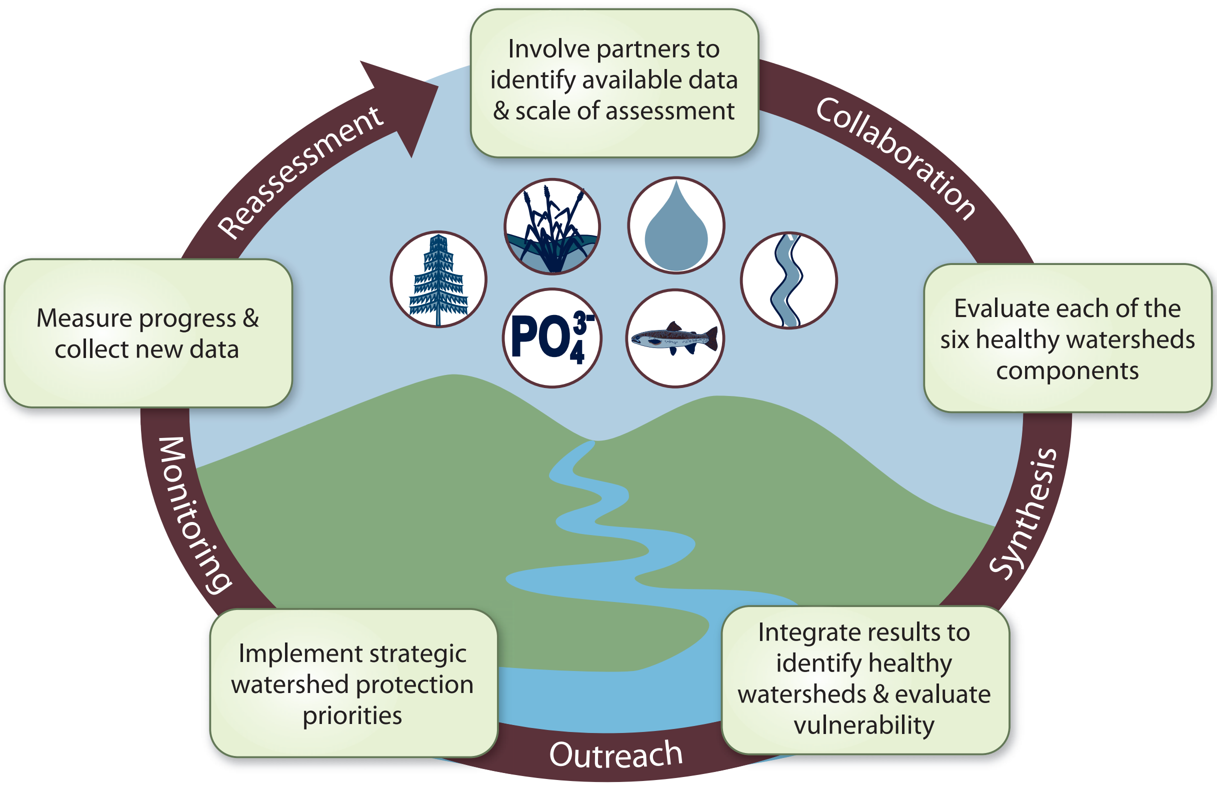

Figure 4-1 Healthy watersheds integrated assessment and management framework.

Numerous approaches are available for evaluating each healthy watersheds attribute, ranging from screening level analyses and desktop assessments to field assessments. The National Fish Habitat Assessment (NFHA) is an example of a screening level analysis that was conducted for the entire United States (National Fish Habitat Board, 2010). The assessment estimates relative fish habitat condition for all rivers at the reach, catchment, and HUC12 scale. The following fifteen human disturbance variables were calculated for all reaches represented in the NHDPlus dataset:

1. Population density
2. Developed open space
3. Road crossing density
4. Low intensity development
5. Road density
6. Medium intensity development
7. Dam density
8. High intensity development
9. Mine density
10. Impervious surfaces
11. Toxics Release Inventory site density
12. Pasture/hay
13. National Pollutant Discharge Elimination System site density
14. Cultivated crops
15. Superfund national priority site density

Canonical correspondence analysis and multiple linear regression were used to relate the best subset of the human disturbance variables to a fish community metric, percent intolerant species. The fish community data were available from 2,440 sites sampled since 1995. The NFHA results can be downloaded by state and used as a first pass for identifying healthy watersheds (http://ecosystems.usgs.gov/fishhabitat/). NFHA results for Vermont are shown in Figure 4-2.

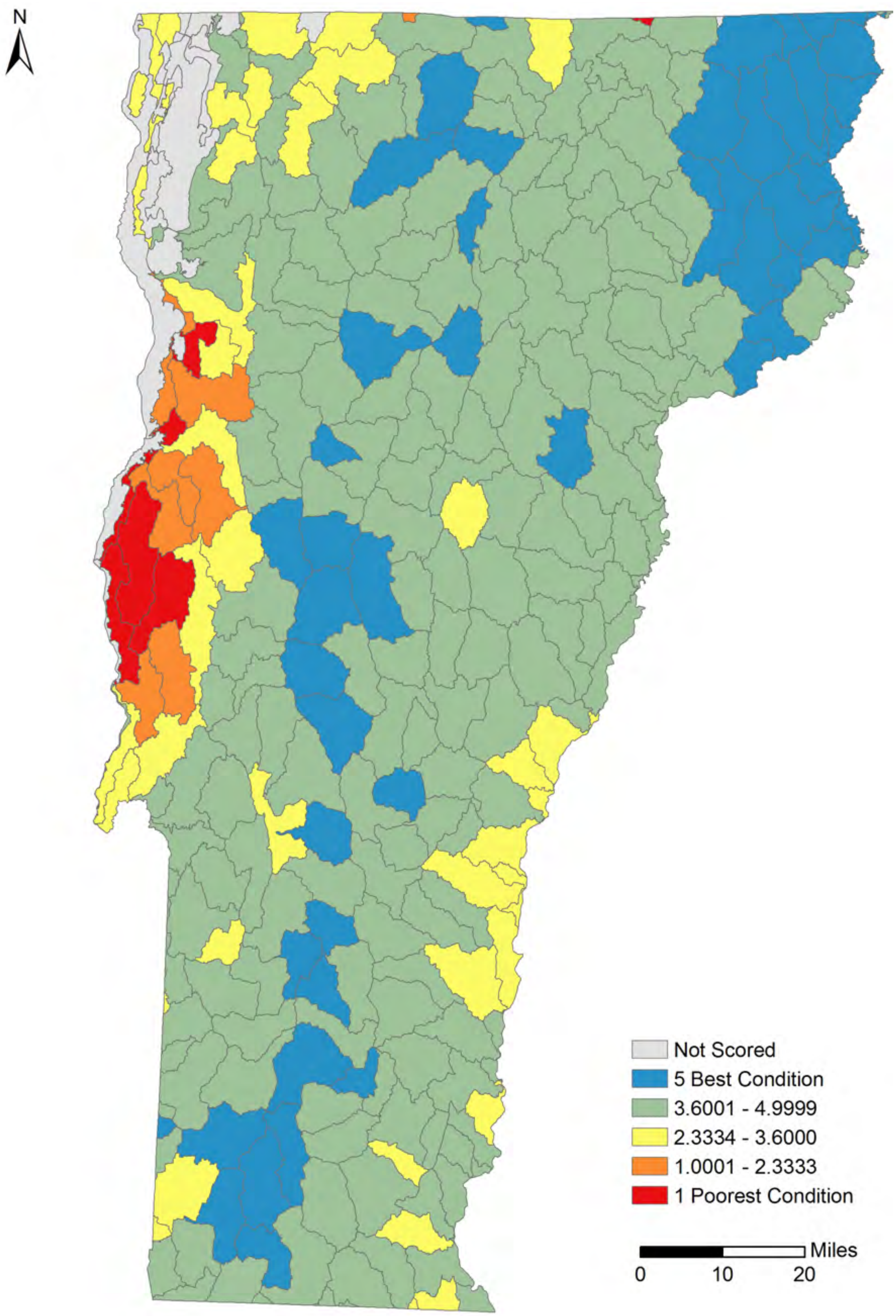

Figure 4-2 National Fish Habitat Assessment (NFHA) scores at the 12 digit hydrologic unit code (HUC) scale for Vermont (courtesy of the National Fish Habitat Board).

NFHA results provide one option for easily identifying potential healthy watersheds without the need to collect additional data or conduct an assessment. Many states have detailed datasets available that include more specific indicators of watershed health and consider additional attributes and habitats (e.g., lakes, wetlands, etc.). These states are in a good position to perform their own assessment and identify healthy watersheds. This chapter outlines one example of a GIS-based, screening level methodology for identifying healthy watersheds statewide. This assessment methodology uses an index approach for identifying healthy watersheds across the State of Vermont with existing data collected by state and national organizations. Indices are a convenient way to aggregate data and communicate complex information in a simplified manner. They are most useful for comparative purposes (e.g., healthy or degraded) and to communicate with the public or decision makers. By design, indices contain far less information than the raw data that they summarize; they do not convey information about underlying processes. Statistical methods can be used to better understand the relationships between individual metrics that make up an index. The results of such analyses can be helpful in estimating conditions in data-poor watersheds and can also help to set management goals. For example, multiple linear regression can be used to investigate relationships between different land cover classes in a watershed and indicators of biological condition such as macroinvertebrate species richness. Biological conditions can then potentially be estimated in similar watersheds that lack biomonitoring data by applying the regression equation to available land cover data. In addition, this type of analysis provides information on potential land cover thresholds that result in lowered biological condition. These thresholds can then be used to inform land use planning decisions.

Some of the datasets used in this example are unique to the State of Vermont, while others are available nationwide. Most states and tribes will find that they are able to gather sufficient existing data, from both internal sources and from national databases, to perform screening level assessments for identifying healthy watersheds. Screening level assessments allow early action to protect healthy watersheds and prioritization of future field data collection efforts that will be used to verify and refine the assessments of individual healthy watersheds components. It is important to work across programs and agencies in order to identify all potentially useful datasets. The datasets used in the assessment summarized in this chapter come from the organizations listed in Table 4-1. These data were used to calculate metrics for each of the six healthy watersheds assessment components (Table 4-2). The rest of this section describes how these metrics were calculated and integrated into an overall index of watershed health.

Table 4-1 Datasets used to identify healthy watersheds in Vermont.

Dataset	Organization
Dam inventory	Vermont Department of Environmental Conservation
Water quality monitoring data	Vermont Department of Environmental Conservation
Stream geomorphic assessment data	Vermont Department of Environmental Conservation
Significant Wetlands Inventory	Vermont Department of Environmental Conservation
Biological monitoring data	Vermont Department of Environmental Conservation
Draft results from Vermont's Habitat Blocks and Wildlife Corridors Analysis	Vermont Fish and Wildlife Department
National Hydrography Dataset Plus (NHDPlus)	U.S. Environmental Protection Agency
National Land Cover Dataset (NLCD) 2001 and 2006	U.S. Geological Survey
Active River Area delineation for the northeastern U.S	The Nature Conservancy
Climate change projections	Climate Wizard
Impervious cover change projections	U.S. Environmental Protection Agency
Water use change projections	U.S. Geological Survey

Table 4-2 Metrics calculated for each healthy watersheds assessment component.

Healthy Watersheds Assessment Component	Metric
Landscape Condition	Percent of watershed occupied by unfragmented natural land cover Percent natural land cover within the Active River Area
Habitat	Dam density (#/mi) Percent of watershed occupied by significant (i.e., high quality) wetlands
Hydrology	Dam storage ratio (days)
Geomorphology	Percent of assessed stream miles in reference condition
Water Quality	Percent of assessed sites in reference condition
Biological Condition	Percent of assessed sites in BCG Tiers I or II

Determine the Appropriate Scale

One of the first steps in any watershed assessment is to decide on the appropriate geographic scale. Depending on the specific objectives and the resources available, the assessment can be conducted at a number of scales. Watersheds have a hierarchical nature; every watershed is nested within a larger watershed and has smaller watersheds nested within it. The appropriate scale for conducting a healthy watersheds assessment depends on the user and their specific objectives, as well as the hydrologic characteristics of the region (e.g., larger watersheds in arid regions, smaller watersheds in regions with high precipitation). It is also important to consider the resolution of available datasets when choosing the appropriate scale for the assessment. For example, the NLCD layer has a resolution of 30 meters and should only be used in landscape scale analyses (not site-based). Ideally, field data will have been collected under a probabilistic monitoring design that allows for statistical estimates of aquatic ecosystem condition at the watershed scale. In the absence of probabilistic data, data gaps and uncertainties should be clearly stated. In this example, data were aggregated at the HUC12 scale to identify healthy watersheds throughout Vermont. Though the field data used here were not collected under a probabilistic design, the large amount of data collected in all areas of the state helps to minimize uncertainty. A refinement of this analysis would include statistically-based estimates of biological condition at the watershed scale using data collected under a probabilistic monitoring design.

Evaluate Landscape Condition

The percent natural land cover within a watershed can be an important indicator of watershed health. Land cover data are sometimes available from the state or county. When local data are not available, the NLCD can be downloaded for free from the Multi-Resolution Land Characteristics Consortium (http://www.mrlc.gov). This dataset contains land cover data for the years 1992, 2001, and 2006, as well as percent impervious data for the entire United States. Impervious surfaces are associated with roads and residential and urban areas, and can increase watershed runoff, leading to instream flow alteration, geomorphic instability, and increased pollutant loading. Less than 10% impervious cover throughout a watershed has been correlated with excellent or very good IBIs and is suggested as a threshold beyond which aquatic ecosystem health begins to decline (Schueler, 1994). Recent research has suggested that much lower levels of impervious cover may have significant impacts on the aquatic biota (King, Baker, Kazyak & Weller, 2011). A general trend of declining IBI scores has also been observed with increasing agricultural land use (Wang & Yin, 1997). However, generally applicable thresholds have yet to be determined and are likely to vary by region.

The extent and connectivity of natural land cover within a watershed are very important for ecological integrity. Natural land cover within the watershed, and especially within headwater areas and riparian corridors, helps to maintain the hydrologic regime, regulates inputs of nutrients and organic matter, and provides habitat for fish and wildlife. Assessing the connectivity of large core areas of natural vegetation involves a green infrastructure assessment such as those that have been conducted by Virginia, Florida, and Maryland (see Chapter 3). Green infrastructure assessments identify large core areas of unfragmented natural vegetation and corridors of sufficient width to allow for the migration of wildlife between the core areas. A number of GIS tools have been developed to assist with green infrastructure assessments, such as the University of Connecticut's Landscape Fragmentation Tool (University of Connecticut Center for Land Use Education and Research, 2009). This tool delineates areas of contiguous natural land cover, allowing for the identification of core areas or hubs. Typically, green infrastructure assessments then use GIS techniques to identify corridors that represent the easiest migration routes for wildlife to move from one core area to another. For the Vermont example, draft results from the Fish and Wildlife Department's Habitat Blocks and Wildlife Corridors analysis were used to identify contiguous blocks of natural land cover and calculate the percent of each watershed's area occupied by these blocks (Figure 4-3). The green infrastructure metric was calculated as follows:

$$\text{Green infrastructure metric} = \frac{\text{(Acres of contiguous natural land cover in watershed)}}{\text{(Total acres in watershed)}}$$

The amount of natural land cover within the Active River Area is another important indicator of landscape condition. The Active River Area framework was developed by The Nature Conservancy and includes the river channel, lakes and ponds, and the riparian lands necessary for the physical and ecological functioning of the aquatic ecosystem (see Chapter 3). This area is formed and maintained by disturbance events and regular variations in flow and water level within the dynamic environment of the water/land interface. The Active River Area focuses on five key processes: hydrology and fluvial action, sediment transport, energy flows, debris flows, and biotic actions and interactions (Smith et al., 2008). The analysis identifies the places where these processes occur based on valley setting, watershed position, and geomorphic stream type. The Active River Area has already been delineated by The Nature Conservancy for the entire northeastern United States (Arlene Olivero, The Nature Conservancy, Personal Communication). A set of GIS tools for delineating the Active River Area in other parts of the country can be obtained by contacting TNC's freshwater program. For the Vermont example, the percent natural land cover within the Active River Area was calculated for each watershed (Figure 4-4). The Active River Area metric was calculated as follows:

$$\text{Active River Area metric} = \frac{\text{(Acres of natural land cover in Active River Area)}}{\text{(Total acres in Active River Area)}}$$

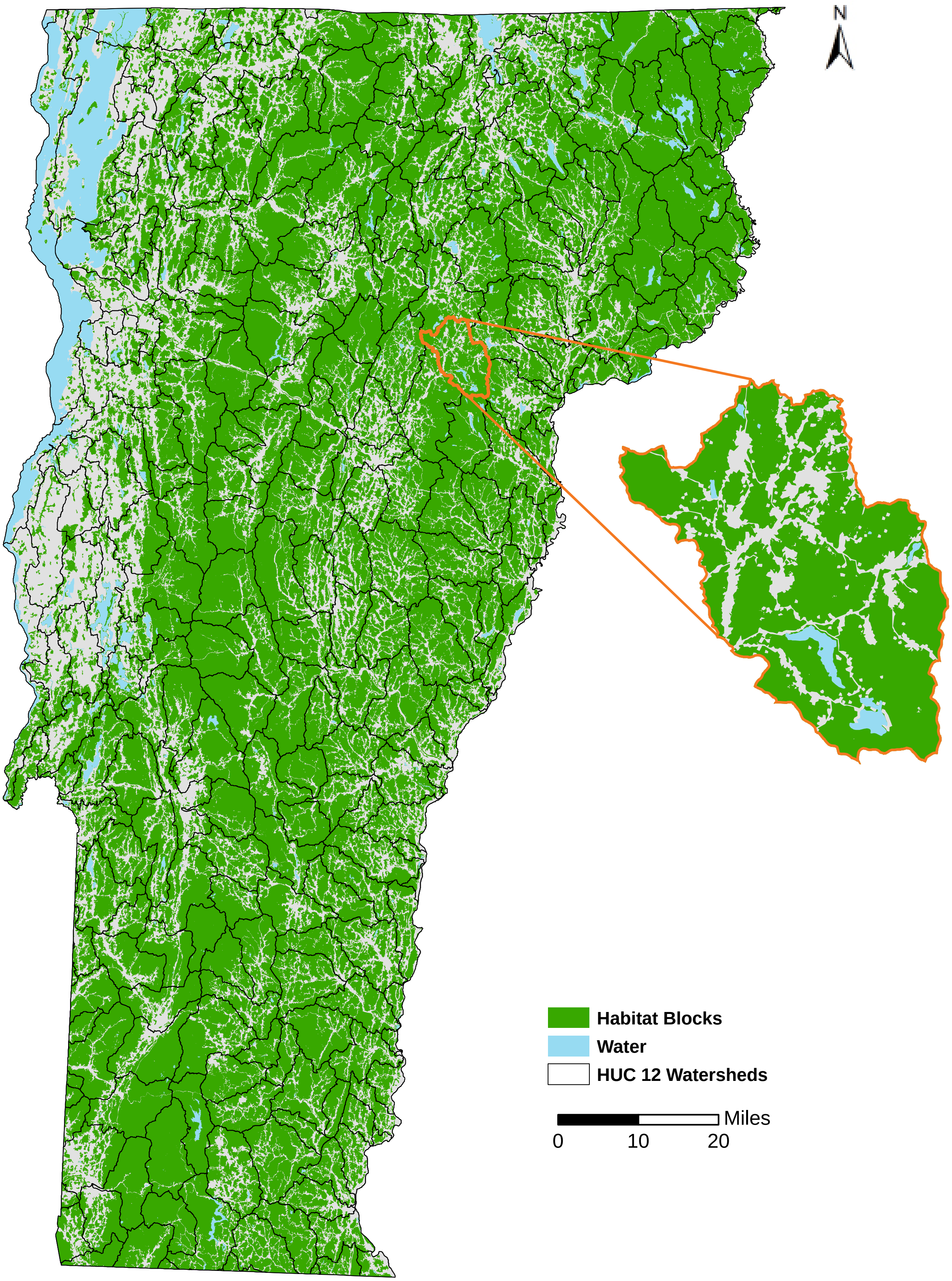

Figure 4-3 Blocks of contiguous natural land cover in Vermont (courtesy of Vermont Fish and Wildlife Department).

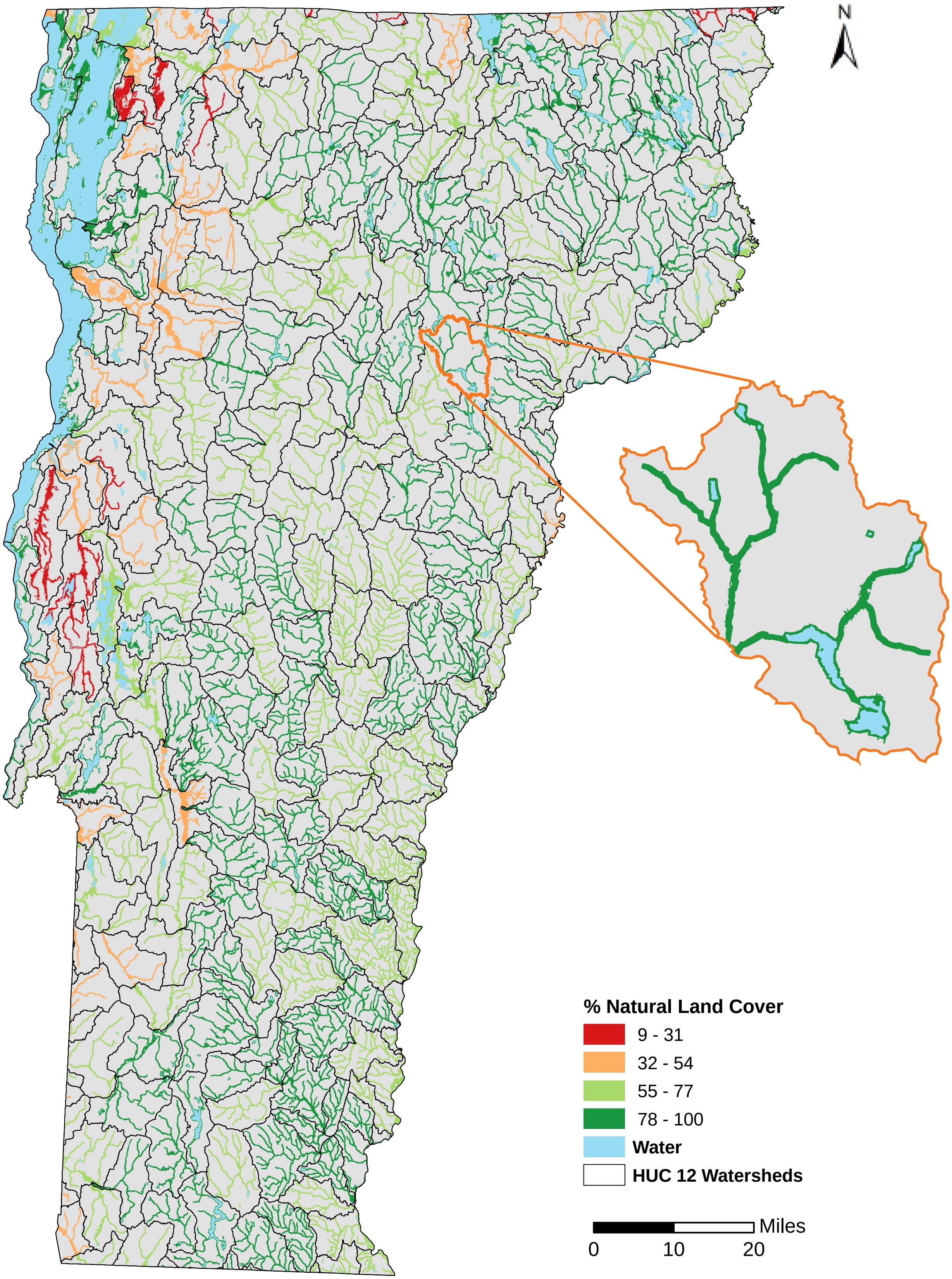

Figure 4-4 Percent natural land cover in the Active River Area of Vermont (Active River Area delineation courtesy of The Nature Conservancy)..

Evaluate Habitat Condition

The quality of aquatic habitat is dependent on the surrounding landscape, and hydrologic and geomorphic processes. Therefore, habitat condition is partly accounted for through indicators representing those assessment components. The potential for organisms to migrate upstream and downstream within a riverine system can also serve as an indicator of aquatic habitat condition. For the Vermont example, dam density (dams per stream mile) was calculated and used as an indicator of aquatic habitat connectivity (Figure 4-5). The habitat connectivity metric was calculated as follows:

$$\text{Habitat connectivity metric} = \frac{\text{(Number of dams in watershed)}}{\text{(Total stream miles in watershed)}}$$

Intact wetlands help to maintain natural hydrologic regimes, provide important habitat for fish and wildlife, and regulate water quality. The Vermont Department of Environmental Conservation has inventoried and classified wetlands in Vermont into one of three classes according to their overall condition and ability to provide important habitat or maintain important ecosystem functions. Class I and Class II wetlands are designated as significant wetlands based on the function and value they provide. For the Vermont example, the percent of the watershed occupied by Class I and Class II wetlands was calculated and used as an additional indicator of habitat condition for each watershed (Figure 4-6). The wetland metric was calculated as follows:

$$\text{Wetland metric} = \frac{\text{(Acres of Class I and Class II significant wetlands)}}{\text{(Total acres in watershed)}}$$

Evaluate Hydrologic Condition

Where long-term stream flow data are available, either from a USGS stream gage or a locally operated stream gage, and predevelopment flow data are available or have been modeled, the degree of hydrologic alteration can be rigorously evaluated. Where long-term flow data are not available, it can be estimated with a number of modeling techniques. For example, StreamStats is a web-based USGS application that will estimate monthly stream flow statistics at ungaged sites across the United States (U.S. Geological Survey, 2009e). The Massachusetts Sustainable Yield Estimator estimates daily stream flow at ungaged sites anywhere in Massachusetts (Archfield et al., 2010). The USGS is currently working to expand the approach developed in Massachusetts to estimate continuous, daily unimpacted stream flow at any ungaged location in the Connecticut River Basin (portions of MA, CT, NH, and VT). This will result in a seamless, multi-state GIS-based point-and-click application that will allow users to identify a stream reach of interest in the Connecticut River Basin and obtain estimated continuous daily, unimpacted or "natural" stream flow at the selected location.

The ratio of the volume of water impounded by dams and the average annual predevelopment stream flow can also serve as an indicator of potential hydrologic alteration.The National Inventory of Dams (NID), as well as many state dam inventories, contains the annual storage volume impounded behind each dam. Summing these values for an entire watershed gives the numerator of the dam storage ratio. Estimated average annual predevelopment stream flow can be obtained for any watershed in the country from the National Hydrography Dataset Plus (NHDPlus). Dividing the dam storage volume by the predevelopment stream flow yields the storage ratio. It is important to keep in mind that these values are only coarse estimates and that this indicator does not represent the important hydrologic processes that drive aquatic ecosystem condition. More sophisticated analyses of hydrologic condition should be conducted when feasible. For the Vermont example, the dam storage ratio was calculated for each watershed and used as a metric of hydrologic alteration. The hydrologic alteration metric was calculated as follows:

$$\text{Hydrologic alteration metric} = \frac{\text{(Dam storage volume)}}{\text{(Predevelopment annual stream flow)}}$$

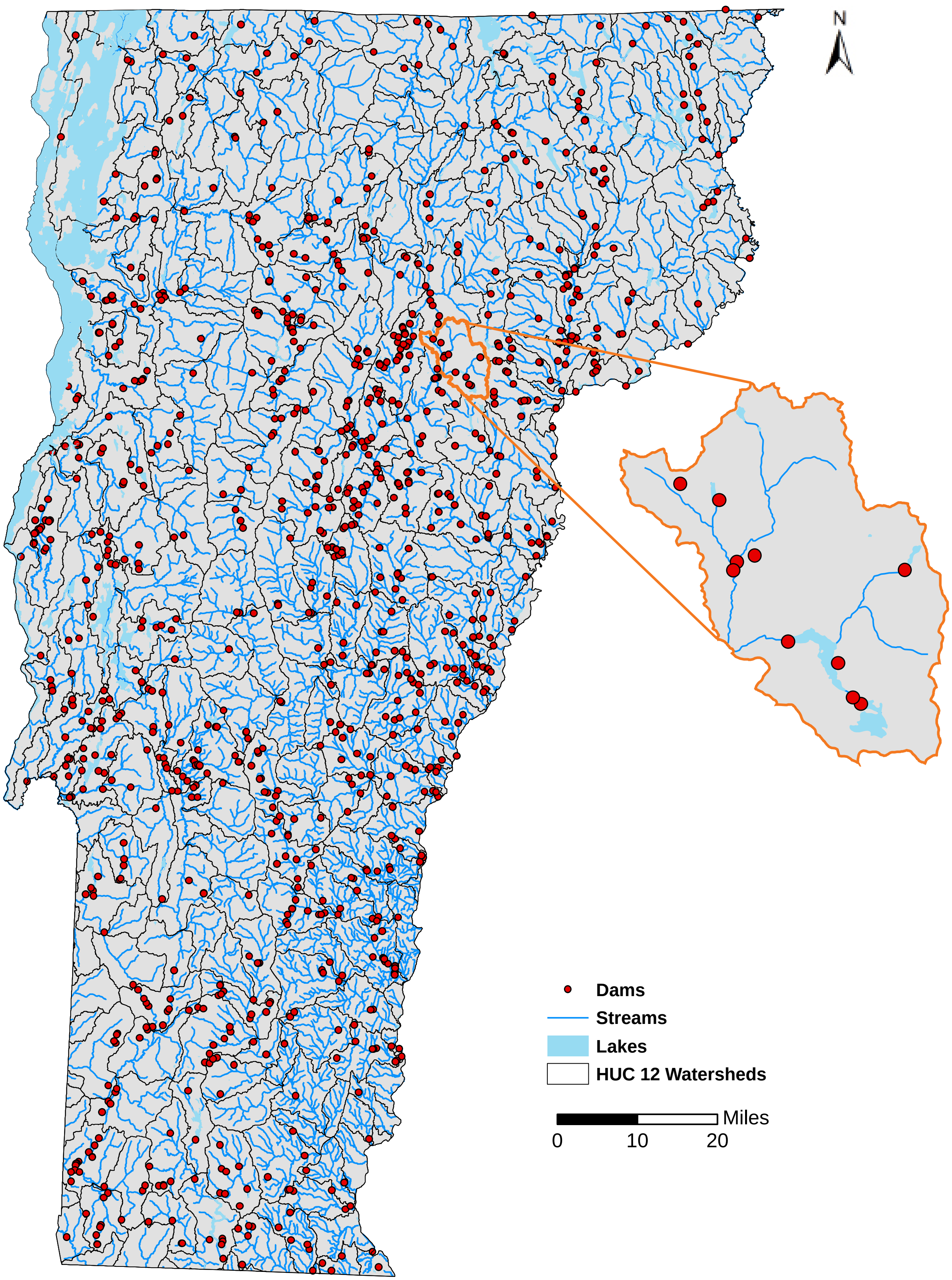

Figure 4-5 Location of dams in Vermont (courtesy of Vermont Department of Environmental Conservation).

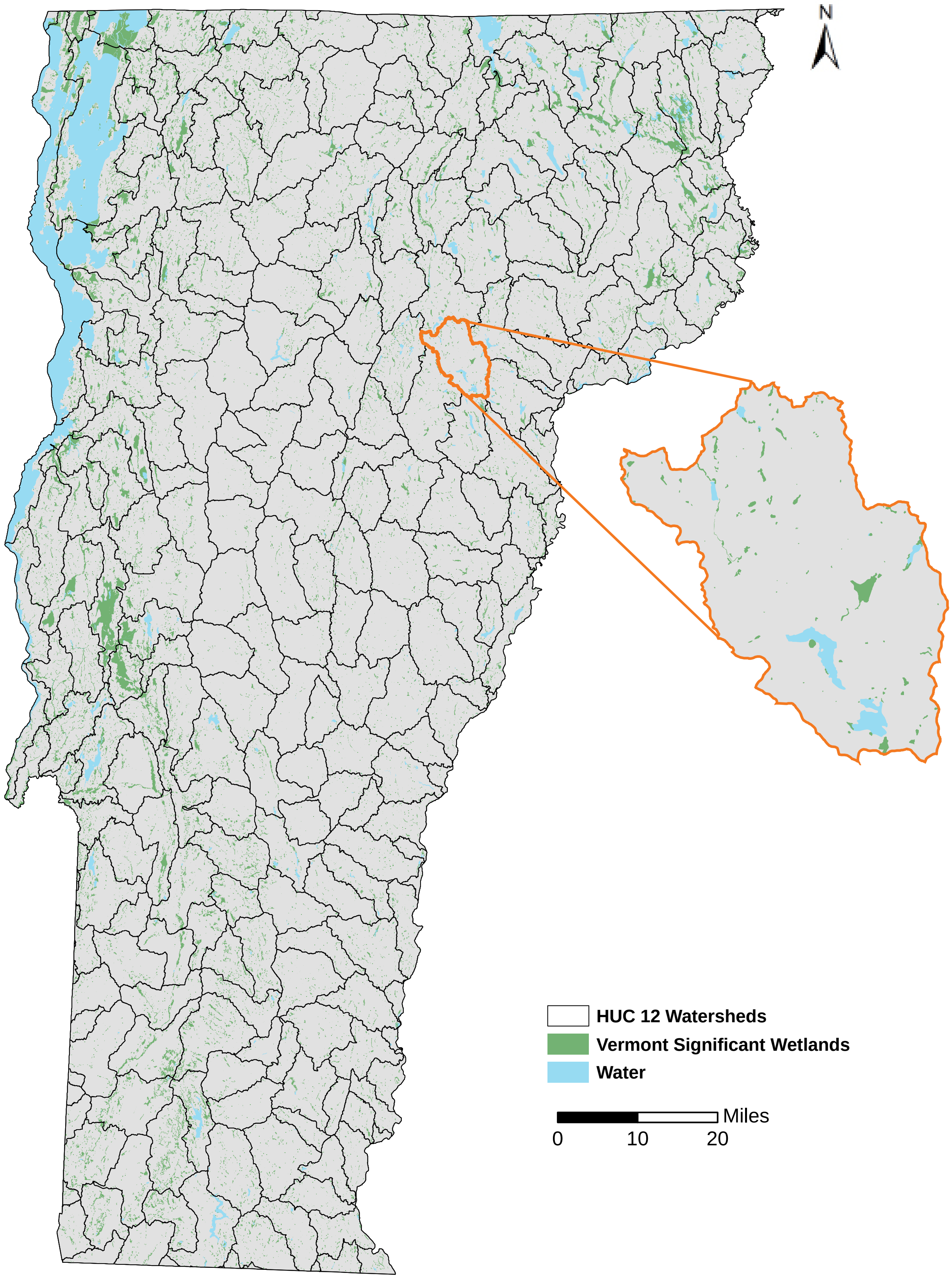

Figure 4-6 Class I and Class II significant wetlands in Vermont (courtesy of Vermont Department of Environmental Conservation).

Evaluate Geomorphic Condition

Built infrastructure can fragment both terrestrial and aquatic habitat throughout a watershed and can modify natural stream geomorphology. In the absence of data on stream geomorphology, the percent natural land cover in the Active River Area can be used as a potential indicator of geomorphic condition. Detailed assessments of stream geomorphic condition can be performed using procedures such as the Massachusetts River and Stream Continuity Project protocols (Massachusetts Department of Fish & Game, 2011), Vermont's Stream Geomorphic Assessment protocols (Kline, Alexander, Pytlik, Jaquith, & Pomeroy, 2009), or other similar, region-specific protocols. Most of these protocols typically begin with a desktop based analysis (Phase 1) of geomorphic condition and are often followed up with detailed field assessments.

Phase 1 stream geomorphic assessments have been conducted for a large number of watersheds in Vermont using techniques described in Chapter 3 (Figure 4-7). Phase 1 assessments are GIS-based analyses using elevation, land cover, and stream network data layers to classify stream types and evaluate the condition of individual reaches based on a comparison to reference conditions for that stream type. Additional data used to evaluate stream reach condition include locations of flow regulations and water withdrawals (including dams, bridges, culverts, etc.), USGS topographic maps, and historical information concerning dredging, gravel mining, and bank armoring. The Phase 1 geomorphic condition is determined primarily through a stream impact rating based on channel, floodplain, and land use modifications. Low stream impact ratings indicate reaches that are in good to excellent condition and may be candidate reference reaches. The specific methods used to determine stream geomorphic condition are described in detail in the Vermont SGA protocols. Table 4-3 describes the stream geomorphic condition categories that are determined through the stream impact rating. For the Vermont example, the percent of assessed stream miles in reference condition was calculated for each watershed and used as an indicator of geomorphic condition. The geomorphology metric was calculated as follows:

$$\text{Geomorphology metric} = \frac{(\text{Stream miles in reference condition})}{(\text{Total stream miles assessed in watershed})}$$

Table 4-3 Descriptions of the stream geomorphic condition categories (Kline et al., 2009).

Condition	Description
Reference	In Equilibrium – no apparent or significant channel, floodplain, or land cover modifications; channel geometry is likely to be in balance with the flow and sediment produced in its watershed.
Good	In Equilibrium but may be in transition into or out of the range of natural variability – minor erosion or lateral adjustment but adequate floodplain function; any adjustment from historic modifications nearly complete.
Fair	In Adjustment – moderate loss of floodplain function; or moderate to major plan-form adjustments that could lead to channel avulsions.
Poor	In Adjustment and Stream Type Departure – may have changed to a new stream type or central tendency of fluvial processes or significant channel and floodplain modifications may have altered the channel geometry such that the stream is not in balance with the flow and sediment produced in its watershed.

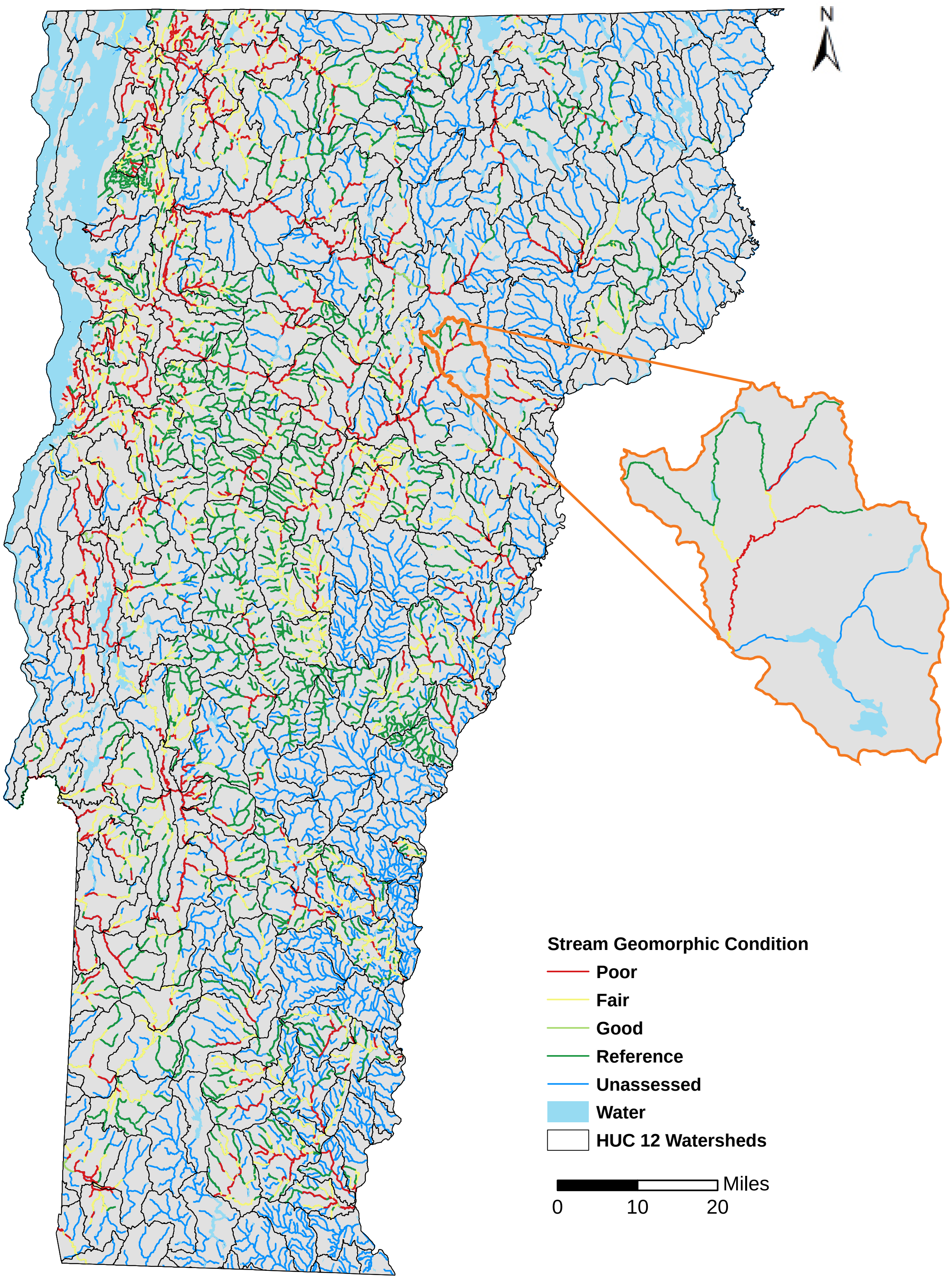

Figure 4-7 Phase 1 stream geomorphic assessment results for Vermont (courtesy of Vermont Department of Environmental Conservation).

Evaluate Water Quality

Water quality can be evaluated in a number of ways, ranging from statewide probabilistic monitoring to the use of complex watershed loading models and empirical analyses of the relationship between landscape characteristics and water quality. As part of the National Wadeable Streams Assessment and National Lakes Assessment, EPA has specified ecoregional water quality criteria for identifying least-disturbed sites throughout the United States (Herlihy, et al. 2008; in-review manuscript by Herlihy, A., Banks Sobota, J., McDonell, T., Sullivan, T., Lehmann, S., and Tarquinio, E. "An a priori process for selecting candidate reference lakes for a national survey"). For the Vermont example, these criteria were used to identify streams and lakes that are likely to be in reference condition based on total phosphorus, total nitrogen, turbidity, and chloride concentrations (Table 4-4; Figure 4-8). The water quality metric was calculated as follows:

$$\text{Water quality metric} = \frac{\text{(Number of sites with all parameters less than reference criteria)}}{\text{(Total number of sites assessed in watershed)}}$$

Table 4-4 Ecoregional water quality criteria used to screen for reference sites in Vermont (Herlihy, et al. 2008; in-review manuscript by Herlihy, A., Banks Sobota, J., McDonell, T., Sullivan, T., Lehmann, S., and Tarquinio, E. "An a priori process for selecting candidate reference lakes for a national survey").

Ecoregion/Ecoarea	Total Phosphorus (µg/L)	Total Nitrogen (µg/L)	Turbidity (NTU)	Chloride (µe/L)
Northern Appalachian Ecoregion (Streams)	20	750	5	250
New England Highlands Ecoarea (Lakes)	10			20
New York Lowlands Ecoarea (Lakes)	20			100

Evaluate Biological Condition

In areas where IBIs have been developed, these data can be overlain in GIS to identify healthy instream conditions in the context of the other healthy watersheds attributes. Healthy watersheds should have IBI scores close to reference conditions. Where such indices have not been developed, biological data can be used to create them. Examples of approaches for developing IBIs are summarized in Chapter 3.

The Vermont Department of Environmental Conservation uses the Biological Condition Gradient (BCG) to characterize biological condition statewide (See Chapter 3). Each assessed stream is placed into one of six tiers (biological condition categories) based upon the IBI scores from fish and/or macroinvertebrate assessments. Tiers I and II can be considered to be least or minimally disturbed. Where the fish and macroinvertebrate scores differ for the same stream, the lower score is used to represent biological condition. This is a conservative approach for estimating overall biological condition. For the Vermont example, the percent of Tier I and Tier II sites in each watershed was used as a metric to represent overall biological condition (Figure 4-9). The biological condition metric was calculated as follows:

$$\text{Biological condition metric} = \frac{\text{(Number of Tier I and Tier II sites)}}{\text{(Total number of sites assessed in watershed)}}$$

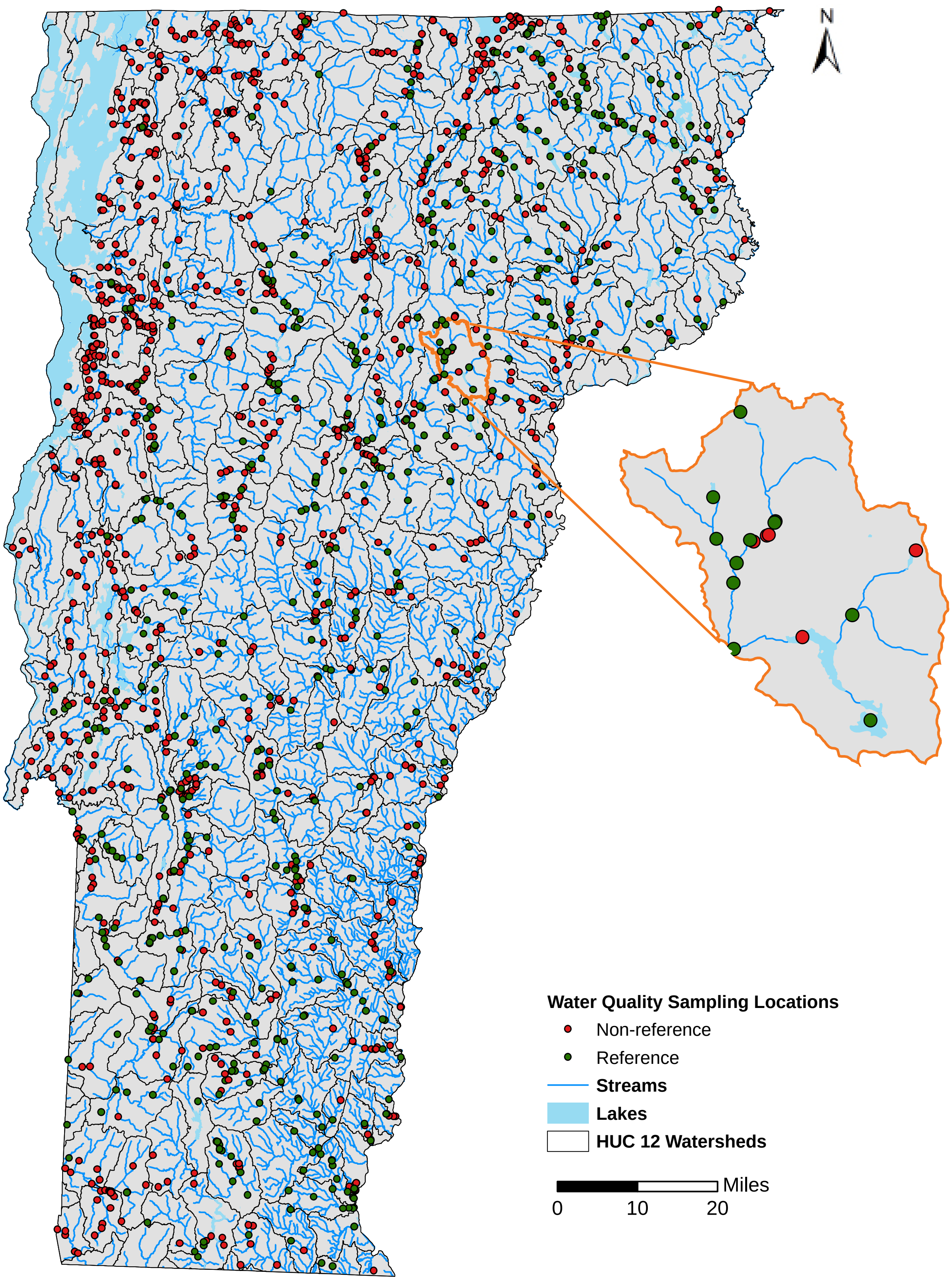

Figure 4-8 Reference and non-reference water quality sites in Vermont (courtesy of Vermont Department of Environmental Conservation).

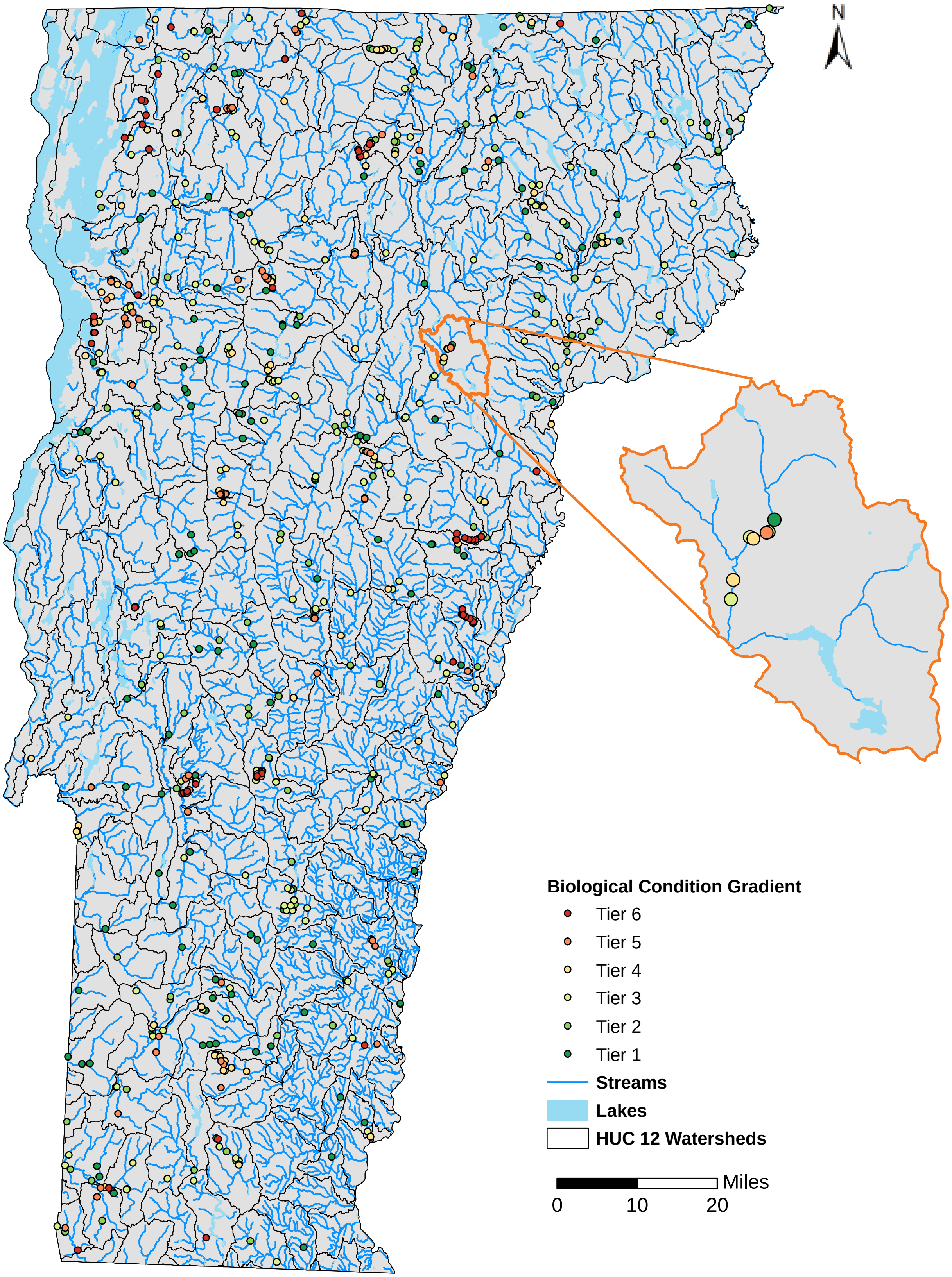

Figure 4-9 Combined results of fish and macroinvertebrate bioassessment scores at stream monitoring sites in Vermont (courtesy of Vermont Department of Environmental Conservation).

Evaluate Overall Watershed Health

Watershed health was evaluated by normalizing the metric scores to integrate the data on multiple healthy watershed attributes into a composite score. Normalization converts indicator scores into a common scale in order to avoid potential bias introduced by the units in which each variable is measured. Normalization can be as simple as defining a threshold for the indicator score that is considered healthy. Scores above this threshold may receive a one and scores below it, a score of zero. Defining "healthy" thresholds for each indicator can be a difficult process that may require input from multiple programs or agencies. Alternatively, the indicator scores may be scaled to a value between zero and one by dividing the observed value for a given watershed by the reference value or maximum value for all watersheds in a state, essentially representing the condition as a percentage. The indicator scores must also be directionally aligned, meaning that higher scores should equate to "better" ecological conditions for each metric. For metrics that are not directionally aligned (e.g., dam storage ratio) in their original units, the inverse (1/X) of each value can be taken.

For the Vermont example, a composite index of watershed health was constructed by averaging the normalized indicator scores for each attribute (Figure 4-10). For attributes with more than one indicator, a sub-index was first calculated. The sub-indices were then averaged to obtain the overall health index score. Depending on the specific management objectives, it may be appropriate to place more weight on some ecological attributes than on others. At that point, the process becomes subjective and a logical decision framework can be used for soliciting and documenting expert opinion (see Smith, Tran, & O'Neill, 2003). Weighting was not used in the Vermont assessment. The normalized metrics and sub-index were calculated as follows:

$$\text{Normalized metric value} = \frac{(\text{Observed metric for watershed x})}{(\text{Maximum metric value for all watersheds in state})}$$

$$\text{Sub-index} = \frac{(\text{Normalized metric 1} + \text{Normalized metric 2} + \ldots + \text{Normalized metric x})}{(\text{Total number of metrics})}$$

$$\text{Watershed health index} = \frac{(\text{Sub-index 1} + \text{Sub-index 2} + \ldots + \text{Sub-index x})}{(\text{Total number of Sub-indices})}$$

The final sub-index and watershed health scores for the Vermont HUC12s span varying ranges. For example, the habitat condition scores range from a minimum value of 0.001 to a maximum value of 0.516. For communication purposes, it can be useful to normalize the final sub-index and watershed health index scores to range from 0 to 1. This allows for comparison of attribute scores between different HUC12s, as well as allows for direct comparison of one attribute score to another. Figure 4-11 displays the normalized scores for each of the six attribute sub-indices and the normalized score for watershed health in three example HUC12s.

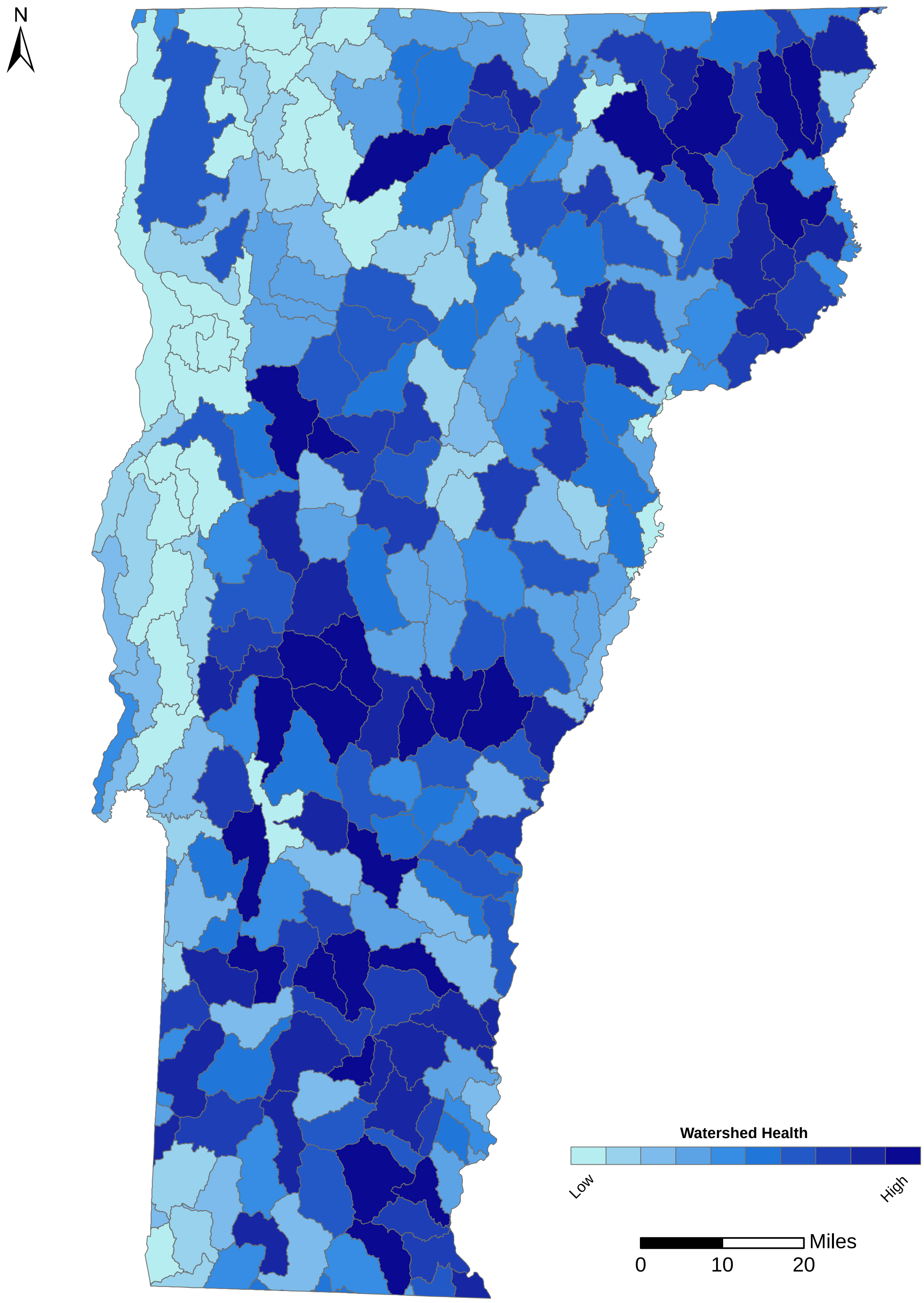

Figure 4-10 Relative watershed health scores for Vermont.

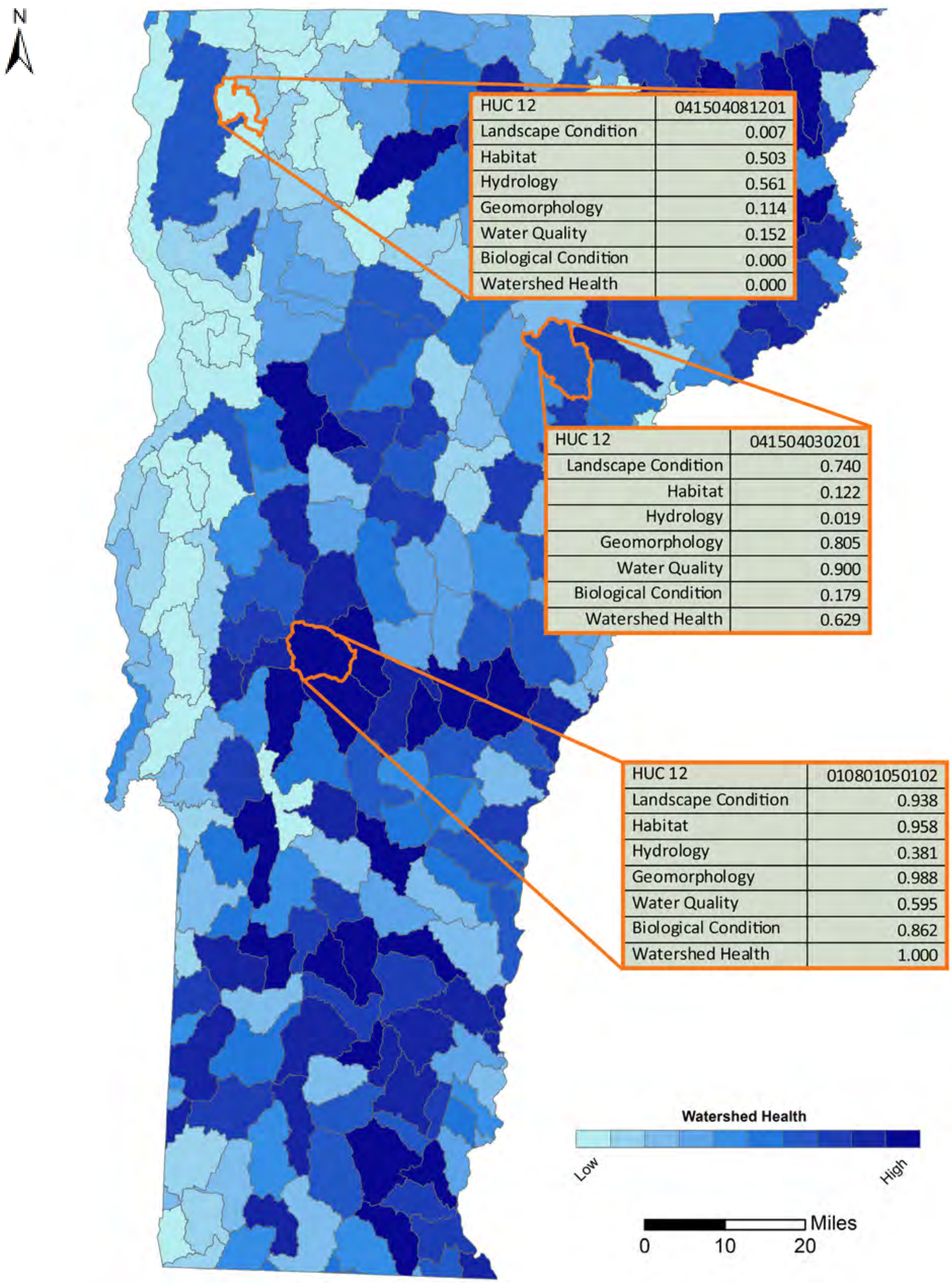

Figure 4-11 Normalized watershed health scores for Vermont, with normalized attribute scores displayed for select HUC12s. To facilitate communication of the results, all scores were normalized to range from 0 to 1. The final watershed health index scores, for example, were transformed from a minimum value of 0.071 and a maximum value of 0.598 to a minimum value of 0 and a maximum value of 1.

Assess Vulnerability

Though not essential to identifying healthy watersheds and their intact components, a vulnerability assessment facilitates the prioritization of protection and restoration strategies. Future projections of impervious surface cover for the year 2050 from EPA's Integrated Climate and Land Use Scenarios (ICLUS) project (U.S. Environmental Protection Agency, 2010) were compared with current impervious surface cover in the same dataset to calculate a percent change metric for each watershed. The threats may include expected population growth and urban and suburban development, impacts from climate change, increased water withdrawals, industrialization, agriculture, etc. Vulnerability assessments can be conducted based on urban growth models, climate change predictive models, water use forecasts, invasive species threats, pollutant threats and models, best professional judgment, and other methods.

Areas of vulnerability can be identified on a map, and the healthy areas that fall within those "vulnerable boundaries" can be prioritized for protection. For example, a build-out analysis is a mapping method for assessing vulnerability to future growth. Build-out analyses identify areas of potential development based on current zoning regulations and can be instructive to the public and local governments. Many people are unaware of the potential risks that their local zoning regulations (or lack thereof) create. Build-out analyses and the predicted ecological and social effects of complete development can prompt action to revise zoning regulations and implement other environmental protection ordinances. Some of these potential actions are discussed in Chapter 5. To complete a build-out analysis, a GIS layer(s) of current zoning for the watershed(s) is required. Zoning designates legally allowable land uses for districts within a community. A copy of the land cover layer used in the landscape condition evaluation can be modified using GIS to reflect these potential future land uses.

For the Vermont example, vulnerability was calculated using data for future projections of impervious cover, climate change projections, future water use, and recent changes in anthropogenic cover (Figure 4-12). Future projections of impervious surface cover for the year 2050 were obtained from EPA's Integrated Climate and Land Use Scenarios (ICLUS) project (U.S. Environmental Protection Agency, 2010). The projected values of impervious surface cover were compared with current impervious surface cover in the same dataset to calculate a percent change metric for each watershed. The impervious change metric was calculated as follows:

$$\text{Impervious change metric} = \frac{(\text{Impervious area in 2050 - Impervious area in 2010})}{(\text{Impervious surface acres in 2010})}$$

Similarly, the percent change between current temperature and precipitation and projected temperature and precipitation for the year 2050 were also calculated for each watershed in Vermont. These climate projections are available for download from climatewizard.org (Maurer, Brekke, Pruitt, & Duffy, 2007). The temperature and precipitation change metrics were calculated as follows:

$$\text{Temp. change metric} = \text{Avg. annual temp.in 2050 - Avg. annual temp. for period of 1961 to 1990}$$

$$\text{Precip. change metric} = \text{Avg. annual precip.in 2050 - Avg. annual precip. for period of 1961 to 1990}$$

Projected water use estimates are available for Vermont from the USGS for the year 2020 (Medalie & Horn, 2010). In cases where detailed water use projections are not available, population growth estimates can be obtained from the U.S. Census Bureau. Future water use can be estimated based on these population projections and a per capita water use rate. Projected water use estimates from USGS were used to calculate the water use change metric as follows:

$$\text{Water use change metric} = \frac{(\text{Water use in 2020 - Water use in 2005})}{(\text{Water use in 2005})}$$

The percent change in anthropogenic (e.g., urban and agricultural) land cover between 2001 and 2006 was also calculated for each watershed. This metric represents recent landscape alteration, an important indicator of aquatic ecosystem degradation (Schueler, 1994; King, Baker, Kazyak & Weller, 2011). While impervious surface cover is projected to decrease in many watersheds throughout Vermont by 2050, recent land cover data indicate that anthropogenic land uses have continued to increase throughout Vermont in recent years. Therefore, this metric was included to provide a more balanced representation of landscape threats to aquatic ecosystem health. The recent land cover change metric was calculated as follows:

$$\text{Recent land cover change metric} = \frac{(\text{Anthropogenic land cover in 2006 - Anthropogenic land cover in 2001})}{(\text{Anthropogenic land cover in 2001})}$$

Similar to the method used to calculate the watershed health index, the vulnerability index was calculated by normalizing and combining the individual metric scores as follows:

$$\text{Normalized metric value} = \frac{(\text{Observed metric value for watershed x})}{(\text{Maximum metric value for all watersheds in the state})}$$

$$\text{Vulnerability index} = \frac{(\text{Normalized metric 1 + Normalized metric 2 + ... + Normalized metric x})}{(\text{Total number of metrics})}$$

Three additional examples of vulnerability assessment approaches include Virginia's Vulnerability Assessment Model, EPA's Regional Vulnerability Assessment (ReVA), and Wyoming's Ground Water Vulnerability Assessment. Case studies of these examples are provided on pages 4-26 through 4-30.

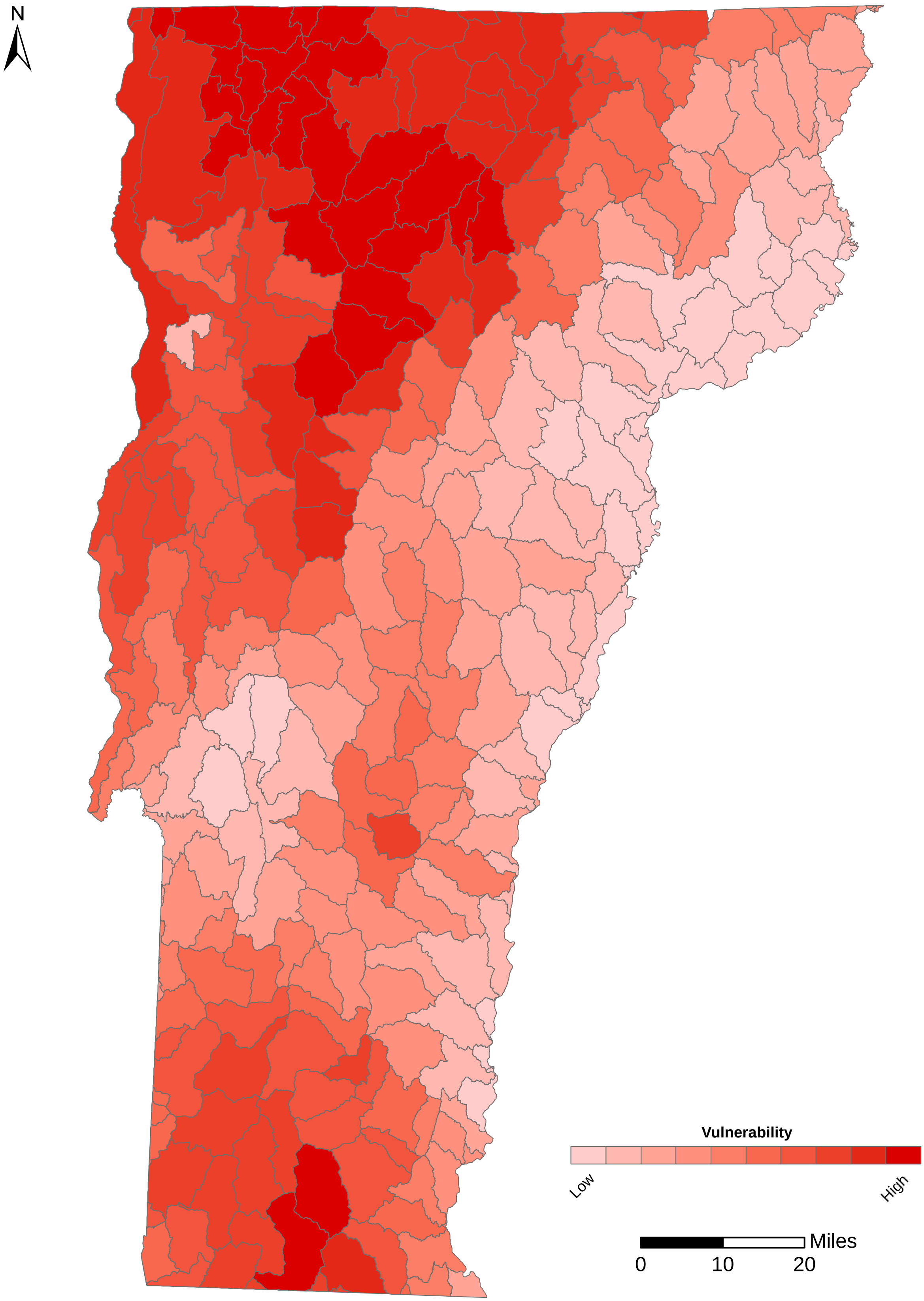

Figure 4-12 Relative watershed vulnerability scores for Vermont.

Set Strategic Management Priorities

The results of watershed health and vulnerability assessments can be used to set strategic management priorities at the watershed scale. Figure 4-13 illustrates one way to assign relative priorities statewide. The median watershed health score for the state splits the X-axis in half and the median watershed vulnerability score for the state splits the Y-axis in half. These two median lines create four quadrants that can be used to classify watersheds according to their relative restoration and protection needs. Other quantiles or break points (e.g., 90%) can also be used for classifying the watersheds as healthy or vulnerable. These break points should be carefully defined, and may require input from multiple programs or agencies. Healthy watersheds with high vulnerability can be considered a priority for protection actions before they become degraded. Healthy watersheds with low vulnerability should still be protected, but the need may not be as urgent. Degraded watersheds with low vulnerability can be considered a priority for restoration due to their high potential for recovery while degraded watersheds with high vulnerability can be considered less of a priority when the emphasis is on achieving results and demonstrating management effectiveness. In all of these cases, but especially when health and vulnerability scores are within intermediate ranges, site-specific determinations should be used to verify that the management action is appropriate for the watershed. Figure 4-14 displays the results of this management prioritization process for the State of Vermont. The individual scores for each of the metrics and sub-indices can also help guide the selection of specific management actions for a given watershed. For example, a watershed identified as a protection priority might have a high geomorphology score, but a relatively low water quality score. This indicates the need for both protection (e.g., river corridor easements) and restoration (e.g., TMDL implementation) actions.

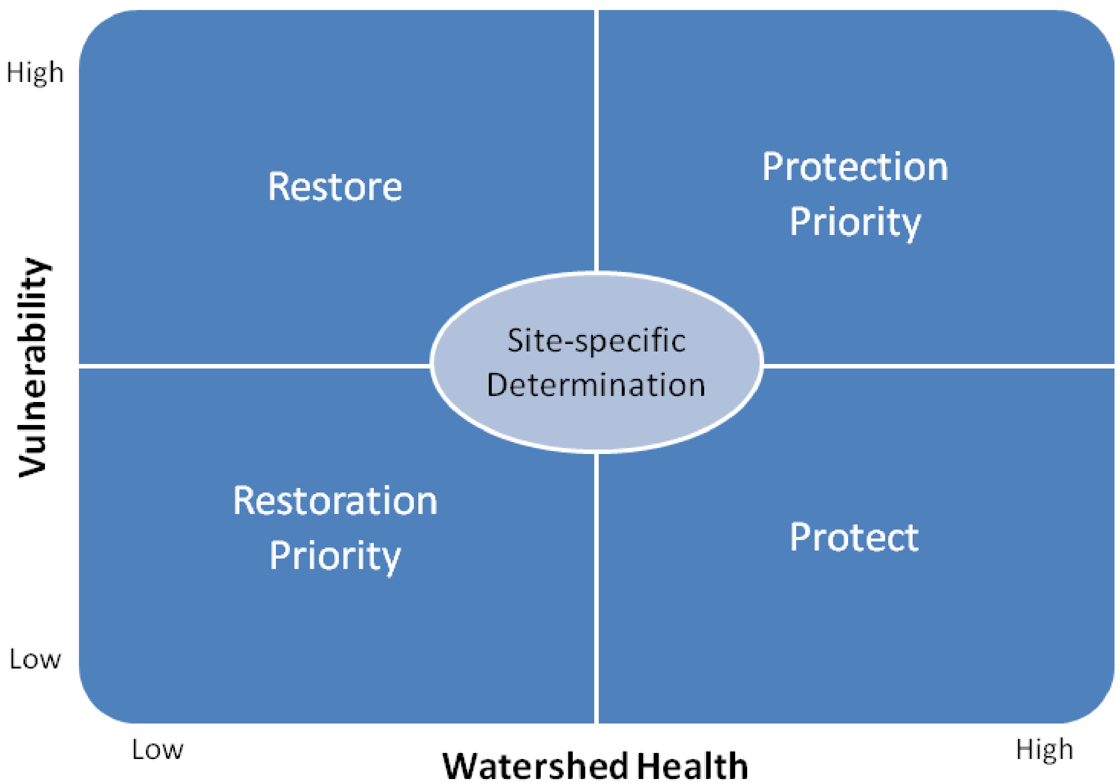

Figure 4-13 Example of a management priorities matrix for setting protection and restoration priorities using watershed health and vulnerability scores.

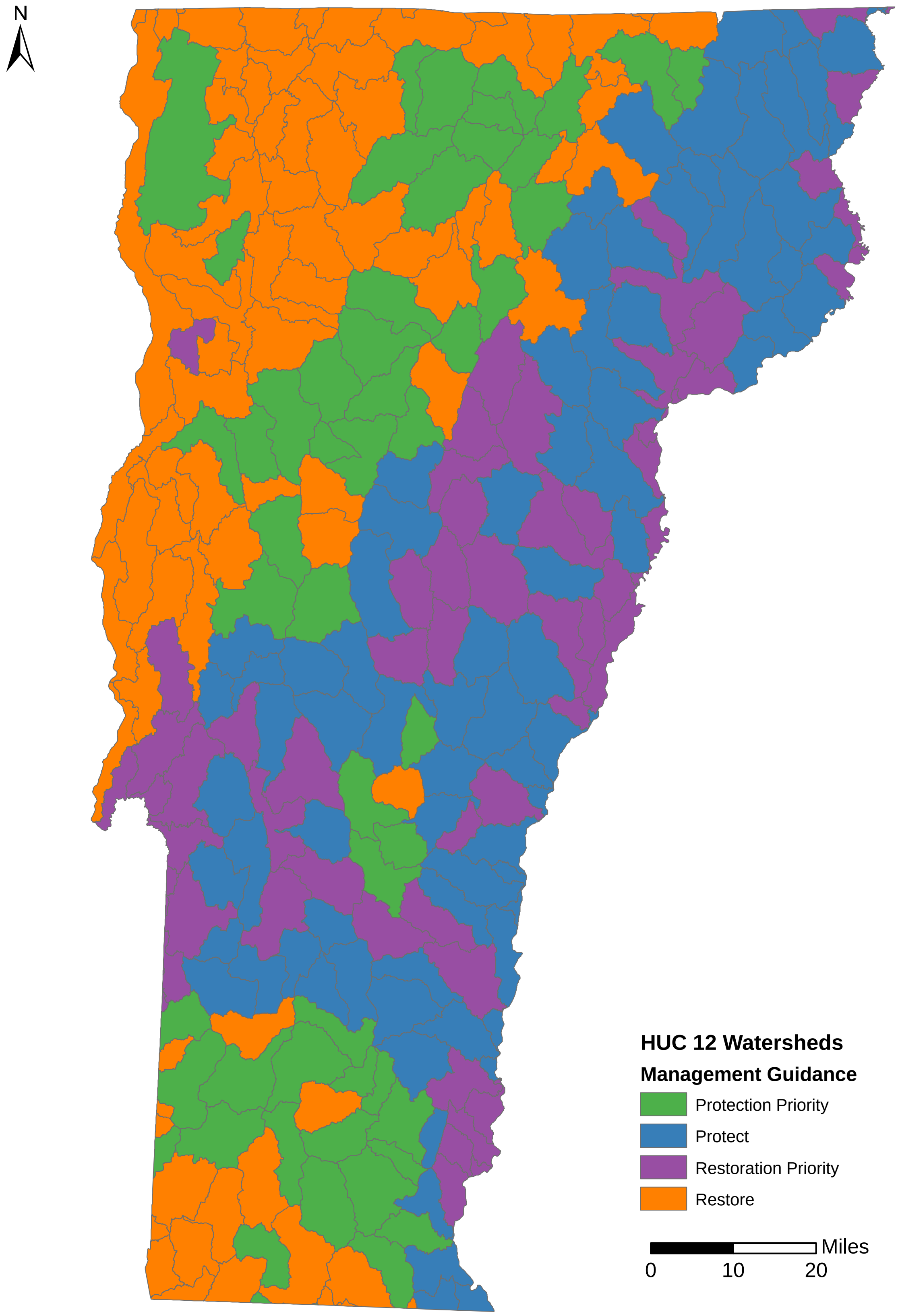

Figure 4-14 Example of potential management guidance based on combined watershed health and vulnerability scores for Vermont.


Case Study

Virginia Conservation Lands Needs Assessment Vulnerability Model

More Information: http://www.dcr.virginia.gov/natural_heritage/vclnavulnerable.shtml

The Virginia Conservation Lands Needs Assessment (VCLNA) is a flexible, widely applicable GIS tool for integrated and coordinated modeling and mapping of land conservation priorities and actions in Virginia. The VCLNA is currently composed of seven separate, but interrelated models: 1) Natural Landscape Assessment Model, 2) Cultural Model, 3) Vulnerability Model, 4) Forest Economics Model, 5) Agricultural Model, 6) Recreation Model, and 7) Watershed Integrity Model. Together, these models are used to identify and assess the condition of Virginia's green infrastructure. Additional models can be built to analyze other green infrastructure and natural resource-related issues. The Natural Landscape Assessment Model is described in Chapter 3 and the Watershed Integrity Model is described in Chapter 4.

The Vulnerability Model informs land conservation priorities in the Virginia Conservation Lands Needs Assessment by identifying those areas most at risk from development pressures and other factors. The Vulnerability Model uses three submodels to evaluate growth pressures in urban, urban fringe, and suburban or rural areas. A composite model integrates all three of the submodels to provide a complete picture of potential growth areas.

Based on the Chesapeake Bay Program's model, the Vulnerability Model used Rural Area Community Codes (U.S. Department of Agriculture Economic Research Service, 2005) to distinguish between urban, urban fringe, and suburban areas. The model used land cover, slope, census (housing and population), roads, travel time, and parcel data to predict future growth across the state.

The outputs of the Vulnerability Model provide an opportunity for local communities to proactively plan for growth. The results of the assessment can be used to guide a community's master planning process and can be combined with any of the other models in the VCLNA program, such as the Landscape Assessment Model or Watershed Integrity Model for use in determining priority conservation areas. GIS data, hardcopy, and digital maps are available for the Vulnerability Model's results in the Commonwealth of Virginia and can be combined with other data or analyses. The Vulnerability Model can be used for targeting and prioritization of conservation sites, guiding local planning and growth assessment, land management, and public education. Figure 4-15 shows how the vulnerability assessment results can be combined with a healthy waters assessment to identify high quality streams for protection priorities at a regional scale.

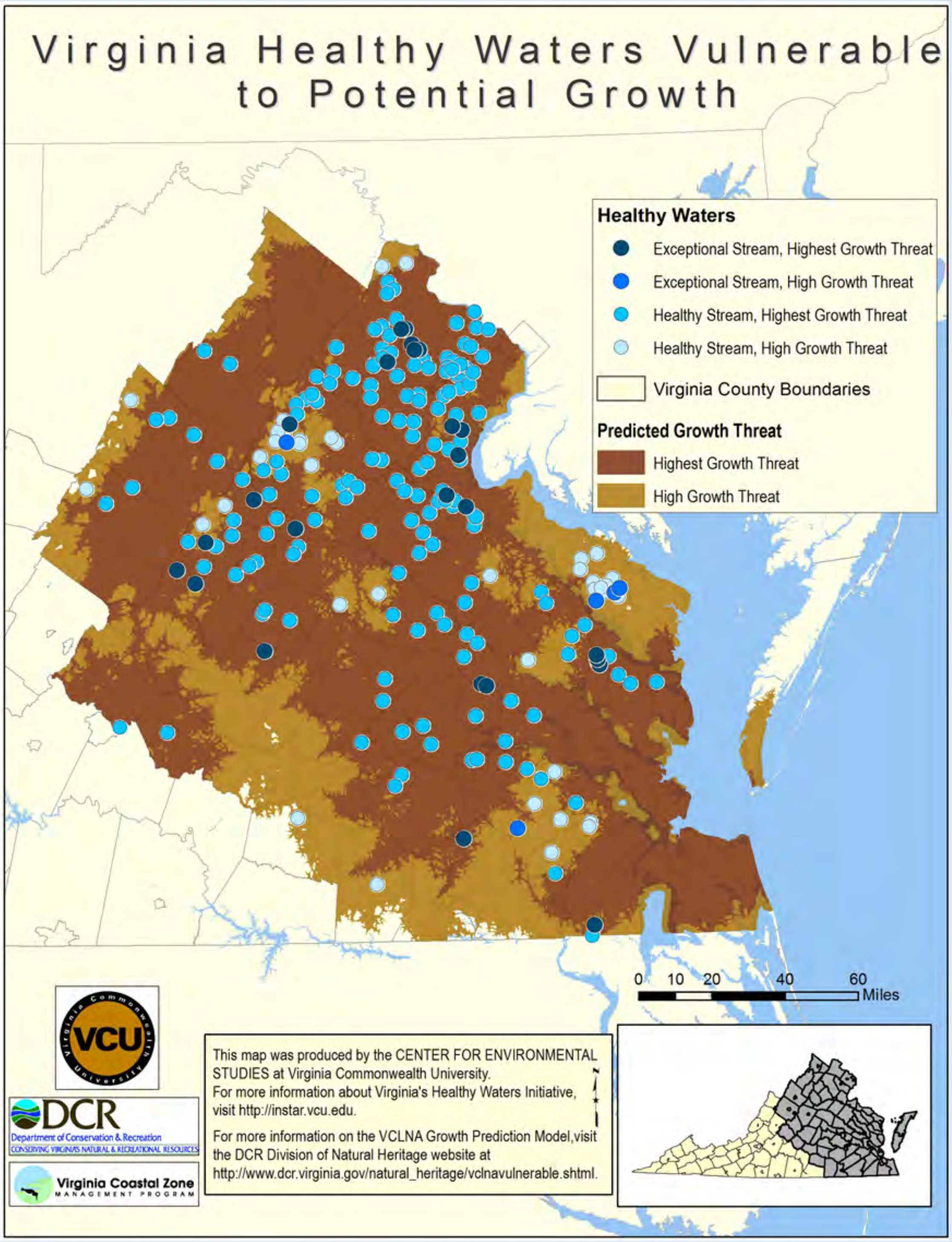

Figure 4-15 Regional results of the VCLNA Vulnerability Model overlain with results from Virginia's Healthy Waters program (Greg Garman, Virginia Commonwealth University, Personal Communication).


Case Study

EPA Regional Vulnerability Assessment Program

More Information: http://www.epa.gov/reva/

The goal of EPA's Regional Vulnerability Assessment (ReVA) Program is to develop and demonstrate an approach to comprehensive, regional-scale assessments that effectively inform decision makers as to the magnitude, extent, distribution, and uncertainty of current and anticipated environmental vulnerabilities. By identifying ecosystems within a region that are most vulnerable to being lost or harmed in the next five to 25 years, and determining which stressors are likely to pose the greatest risks, ReVA serves as an early warning system for identifying environmental changes that can be expected over the next few decades. The objectives of the ReVA program are to:

1. Provide regional scale, spatially explicit information on the extent and distribution of stressors and sensitive resources.
2. Develop and evaluate techniques to integrate information on exposure and effects so that decision makers can better assess relative risk and prioritize management actions.
3. Predict potential consequences of environmental changes under alternative future scenarios.
4. Effectively communicate economic and quality of life trade-offs associated with alternative environmental policies.
5. Develop techniques to prioritize areas for ecological restoration.
6. Identify information gaps and recommend actions to improve monitoring and focus research.

Current science indicates that future environmental protection efforts must address problems that are just emerging or are on the horizon. Many of these problems are subtle and cumulative, with widespread, regional effects and poorly understood implications. The research approach advocated by ReVA differs from typical ecological research in that it seeks to integrate many different types of information from many different sources into a cohesive product.

Much of the last 100 years of ecological research has focused on examining the effects of single components of ecosystems one by one. Many of the issues facing the environment are chronic conditions such as the impairment of our nation's waters being affected by point sources (e.g., waste water treatment facilities), nonpoint sources (pollution generated by activities such as agriculture), water usage, and climate.

ReVA uses four interacting functions to develop regional assessments that address current and future (projected) chronic environmental problems:

1. Landscape: Data on stressors and effects from many sources must be placed into spatial context and synthesized using GIS techniques.
2. Research Gaps: Research must fill critical gaps in our ability to apply the data at landscape and regional scales, and to understand how socioeconomic factors affect environmental conditions.
3. Real World: An assessment component must keep the project grounded in the "real world" by applying the data and risk assessment techniques to specific regions.
4. Data and Analytical Tools: This final step is critical to ensuring that the results of the research can be applied to continuing regional assessments. The data and analytical tools must be transferred into the hands of regional managers; ReVA accomplishes this final step by developing web based demonstration projects.

ReVA developed a web-based environmental decision toolkit for the Mid-Atlantic region that allows decision makers to evaluate potential changes to ecosystems in response to various management decisions under various future development scenarios (e.g., population increase, land-use change, climate change, intensity of resource extraction) out to the year 2020. The toolkit is now being used by states and EPA Region 3 to develop integrated management decisions. For example, ReVA has tailored the environmental decision toolkit to fit the local conditions found within the 15 counties of the Charlotte/Gastonia/Rock Hill region in North and South Carolina. This region is projected to see an 85% growth in its population by 2030, with concomitant increases in sprawl, air quality problems, and associated concerns of decreased quality of life if the growth is not carefully managed. ReVA has helped to integrate the pieces and provide insights into cumulative impacts associated with alternative patterns of growth and land development by explicitly considering factors such as air quality, amenities, water quality, infrastructure costs, and human health factors. Economic impacts of alternative growth scenarios were evaluated, along with the effects on health and natural resources. Many of the region's environmental concerns, such as air quality, will be driven by options chosen for future transportation needs. Thus, partners envisioned an alternative future scenario that would encourage both mass transit and distributed economic development built around city centers (Figure 4-16). ReVA worked closely with its partners to develop a spatially detailed model of land use change that reflected realistic challenges and options. At the same time, local leaders have formed an alliance to allow strategic planning to take place across regional boundaries. Individual jurisdictions are now able to consider land use and other issues on a more regional basis, not just by each locality. Now, questions of land use and other issues that impact the environment are being looked at on a broader scale.

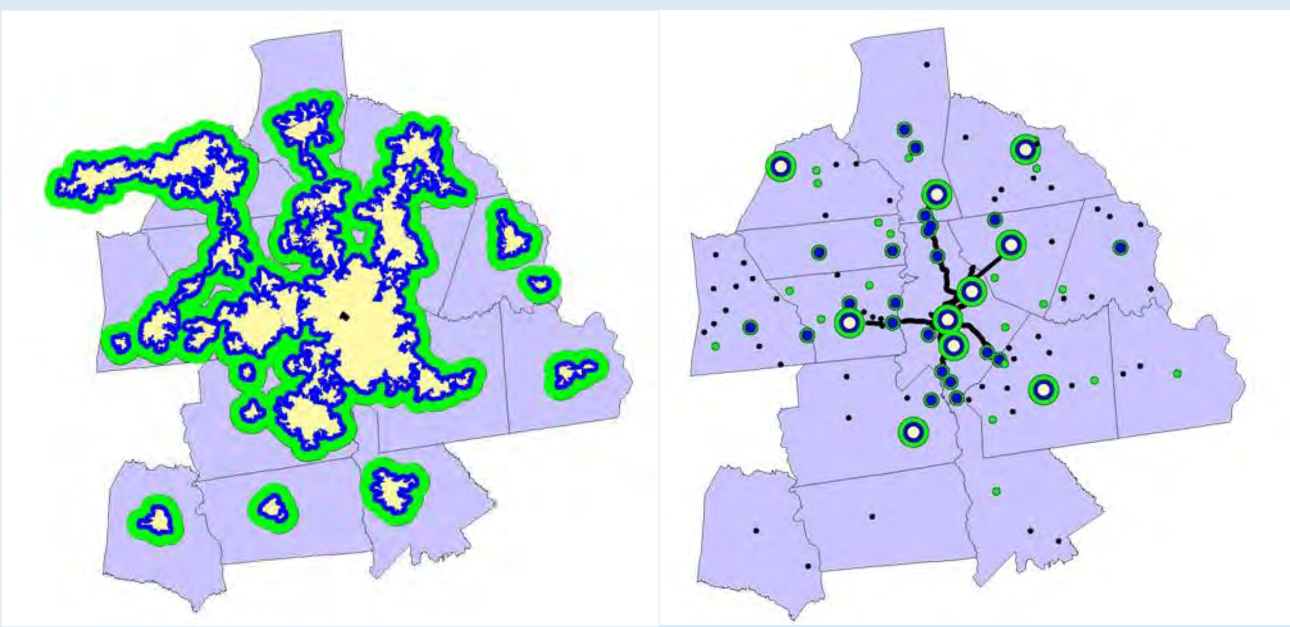

Figure 4-16 Business as usual development pattern (left) and compact center scenario (right) used for the alternative growth scenario evaluations (U.S. Environmental Protection Agency, 2011e).

Case Study

Wyoming Aquifer Sensitivity and Ground Water Vulnerability Assessment

More Information: http://waterplan.state.wy.us/plan/green/techmemos/swquality.html

The threat of ground water contamination is a major concern for Wyoming citizens, as well as local, state, tribal, and federal water management agencies. Use of industrial and agricultural chemicals, resource development activities (mining and oil and gas development), and urban development can potentially cause contamination of underlying ground water resources. In 1998, the University of Wyoming Water Resources Research Center, in partnership with the Wyoming Department of Environmental Quality and EPA, completed a statewide assessment of aquifer sensitivity and ground water vulnerability for the shallow aquifers in Wyoming. Aquifer sensitivity is defined as the relative ease with which contaminants can move from the land surface to the water table based on hydrogeologic characteristics of the land surface, the vadose zone, and the aquifer. Ground water vulnerability is defined as the relative ease with which contaminants can move from the land surface to the water table based on aquifer sensitivity and the physical and chemical properties of the contaminant.

The Wyoming statewide aquifer sensitivity/ground water vulnerability assessment was developed using the EPA DRASTIC model. The DRASTIC model uses seven environmental parameters (Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, and hydraulic Conductivity) to characterize the hydrogeologic setting and evaluate aquifer vulnerability. For the Wyoming Assessments, detailed statewide datasets were developed for the hydrogeologic (bedrock geology, surficial geology, well locations and logging information, elevation, and precipitation) and land use parameters used for the assessment (agricultural, urban, oil and gas exploration areas, etc.). GIS software was used to generate a statewide aquifer sensitivity map and individual county level aquifer sensitivity and ground water vulnerability maps. These maps are used for a variety of ground water management activities, including prioritizing ground water monitoring and land use planning and management of agricultural chemicals. Aquifer sensitivity and ground water vulnerability maps can be used to assess the vulnerability of ground water dependent ecosystems.

4.2 Moving Towards Integrated Assessments

The following assessment approaches represent state and EPA efforts to move towards integrated evaluations of watershed health. A summary of each approach is provided in the subsequent pages. Table 4-5 lists the healthy watersheds assessment components addressed by each approach, and pages 4-55 through 4-64 contain tables listing the indicators used in each assessment approach. These tables can be useful for identifying similarities and differences between approaches. States, tribes, and other organizations may also find these useful in developing their own lists of indicators for assessing watershed health. For example, the tables can form the basis of a "scorecard" for evaluating: a) which components to include in an integrated assessment, b) an appropriate classification system, c) indicators for which there are available data, and d) indicators that may require additional monitoring.

Virginia Watershed Integrity Model

The Virginia Watershed Integrity Model uses a green infrastructure approach to evaluate landscape condition across the watershed and in the riparian corridor specifically. It incorporates a terrestrial habitat evaluation and a modified IBI for identifying ecologically important catchments across the landscape. Although it does not address hydrology, geomorphology, or water quality directly, the IBI serves as an integrating indicator of the condition of these attributes, and the landscape condition is a characteristic that has a large effect on the condition of these attributes.

Minnesota's Watershed Assessment Tool

Minnesota's Watershed Assessment Tool is an online map viewer that lets users evaluate landscape, habitat, biology, water quality, hydrology, and geomorphology in an integrated context. Currently, it only supports online overlay analyses. However, efforts are underway to create a watershed health index that will use these data to evaluate the condition of Minnesota's watersheds.

Oregon Watershed Assessment Manual

The Oregon Watershed Assessment Manual addresses landscape, habitat, biology, water quality, hydrology, and geomorphology through field assessments and follow-up analyses based on a classification and condition assessment of channel habitat types. The classification system is based on the expected biota of a stream and its surrounding land uses. Management opportunities are prioritized to protect, restore, or collect additional data based on the condition evaluation.

California Watershed Assessment Manual

The California Watershed Assessment Manual presents an organizational framework for integrated assessments of California watersheds. The framework is based on recommendations from EPA's Science Advisory Board to evaluate the six essential ecological attributes of landscape condition, hydrology/geomorphology, biotic condition, chemical/physical condition, natural disturbance regimes, and ecological condition. A variety of assessment approaches and management options are presented.

Pennsylvania Aquatic Community Classification

The Pennsylvania Aquatic Community Classification approach is based on biological and environmental variables that categorize watersheds across Pennsylvania to identify the least disturbed streams and set watershed conservation, restoration, and enhancement priorities.

Connecticut Least Disturbed Watersheds

Connecticut's Least Disturbed Watersheds approach identified the least disturbed watersheds in Connecticut based on an impervious surface and natural land cover analysis, an IBI approach, water quality, flow modifications, and water withdrawals. The assessment identified watersheds of exceptional quality that can be used as reference sites in the development of a biological condition gradient for the state and that can be prioritized for protection.

Kansas Least Disturbed Watersheds

Kansas' Least Disturbed Watersheds approach identified the least disturbed watersheds in Kansas using a landscape alteration index and taxonomic richness data. The assessment identified candidate reference streams in each of Kansas' five ecoregions and condition ratings for all other streams.

EPA Recovery Potential Screening Tool

EPA's Recovery Potential Screening Tool uses a wide variety of landscape datasets, impaired waters attributes reported by states to EPA, and monitoring data to evaluate ecological, stressor, and social indicators to prioritize watersheds for protection or restoration. This approach allows for targeting of limited resources to protect those watersheds that are of the highest ecological integrity and restore watersheds with highest ecological capacity for recovery.

Table 4-5 Healthy watersheds assessment components addressed in each of the eight assessments summarized in this section.

Healthy Watersheds Assessment Component	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Landscape Condition	✔	✔	✔	✔	✔	✔	✔	✔
Habitat		✔	✔	✔	✔		✔	✔
Hydrology		✔	✔	✔	✔	✔	✔	✔
Geomorphology		✔	✔	✔	✔			✔
Water Quality		✔	✔	✔	✔	✔	✔	
Biological Condition	✔	✔	✔	✔	✔	✔	✔	✔

VA WIM: Virginia Watershed Integrity Model
MN WAT: Minnesota's Watershed Assessment Tool
OR WAM: Oregon Watershed Assessment Manual
CA WAM: California Watershed Assessment Manual
PA ACC: Pennsylvania Aquatic Community Classification
CT LDW: Connecticut Least Disturbed Watersheds
KS LDW: Kansas Least Disturbed Watersheds
EPA RPST: EPA Recovery Potential Screening Tool

Virginia Watershed Integrity Model

Author or Lead Agency: Virginia Department of Conservation and Recreation – Division of Natural Heritage

More Information: http://www.dcr.virginia.gov/natural_heritage/vclnawater.shtml

The Virginia Conservation Lands Needs Assessment (VCLNA) is a flexible, widely applicable GIS tool for integrated and coordinated modeling and mapping of land conservation priorities and actions in Virginia. The VCLNA is currently composed of seven separate, but interrelated models: 1) Natural Landscape Assessment Model, 2) Cultural Model, 3) Vulnerability Model, 4) Forest Economics Model, 5) Agricultural Model, 6) Recreation Model, and 7) Watershed Integrity Model. Together, these models are used to identify and assess the condition of Virginia's green infrastructure. Additional models can be built to analyze other green infrastructure and natural resource-related issues. The Natural Landscape Assessment is described in Chapter 3 and the Vulnerability Model is described in Section 4.3.

The VCLNA Watershed Integrity Model identifies the terrestrial resources that should be conserved to maintain watershed integrity and water quality. The relationship between land use and aquatic health is well documented. For example, it is well-known that as the area of impervious surface in a watershed increases, water quality declines. This is due to the decreased infiltration capacity of the land and the rapid accumulation of pollutants, such as heavy metals and salts, on these impervious surfaces. When it rains, these pollutants are rapidly washed off of the roads and parking lots directly into the nearest stream or storm drain, which often empties into a stream some distance away. Other examples of land use characteristics that affect water quality include erosion and sediment loading from decreased forest cover in a watershed, nutrient loading as a result of intensive agriculture, and decreased water quality as a result of loss of riparian vegetation.

The Watershed Integrity Model combines GIS layers representing a modified Index of Biotic Integrity (mIBI), an Index of Terrestrial Integrity (ITI), slope, source water protection zones, ecological cores, and riparian areas to derive a final weighted overlay grid that identifies the relative value of land in the watershed as it relates to water quality. The relative weights for the overlay analysis are as follows:

- mIBI – 25%
- ITI – 30%
- Slope – 10%
- Source water protection zones – 10%
- Ecological cores – 15%
- Riparian areas – 10%

The mIBI was developed by Virginia Commonwealth University Center for Environmental Studies (Virginia Commonwealth University, 2009) to evaluate aquatic health and is computed from six metrics:

1. Number of intolerant species.
2. Species richness.
3. Number of rare, threatened, or endangered species.
4. Number of non-indigenous species.
5. Number of critical/significant species.
6. Number of tolerant species.

The ITI is calculated based on the percent natural cover of the watershed, percent riparian corridor vegetation remaining, proportion of habitat fragmentation due to roads, and percent impervious surface cover in the watershed. Areas with steep slopes are included in the model as an indicator of where small headwater streams are likely to occur. Riparian areas and source water protection zones are also identified and included in the Watershed Integrity Model. Ecological cores are large patches of natural land cover that provide significant interior habitat and are an output of the VCLNA Natural Landscape Assessment Model. Inclusion of these large forested areas provides the Watershed Integrity Model with a method for prioritizing forested lands that provide water quality benefits in addition to critical wildlife habitat.

The final output of the Watershed Integrity Model is a weighted overlay grid identifying areas most critical for maintaining watershed health (Figure 4-17). Lands with a watershed integrity value of 5 are the most important areas for maintaining water quality, while lands with a value of 1 do not have a significant impact on maintaining water quality. The Watershed Integrity Model can be used alone or with other models, such as the VCLNA Vulnerability Model to identify those lands most important for water quality and most at risk from development pressures. The Virginia DCR identifies the following as potential uses of the Watershed Integrity Model:

- Targeting – to identify areas important for maintaining or improving water quality.
- Prioritizing – to provide justification for key conservation land purchases and other protection activities.
- Local planning – guidance for comprehensive planning and local ordinance and zoning development.
- Assessment – to review proposed projects for potential impacts.
- Land management – to guide property owners and public and private land managers in making land management decisions.
- Public education – to inform citizens about the importance of land use and the effect on water quality and watershed integrity.

A number of municipalities, counties, land trusts, and other organizations are beginning to use the methods and results from the Watershed Integrity Model to identify and prioritize conservation and preservation opportunities. For example, the Richmond Regional Planning District Commission and the Crater Planning District Commission are using the results of the Watershed Integrity Model and other VCLNA models in their planning process. Combined with an intensive public involvement process, these maps are being used by the Commissions to guide land use planning and conservation actions.

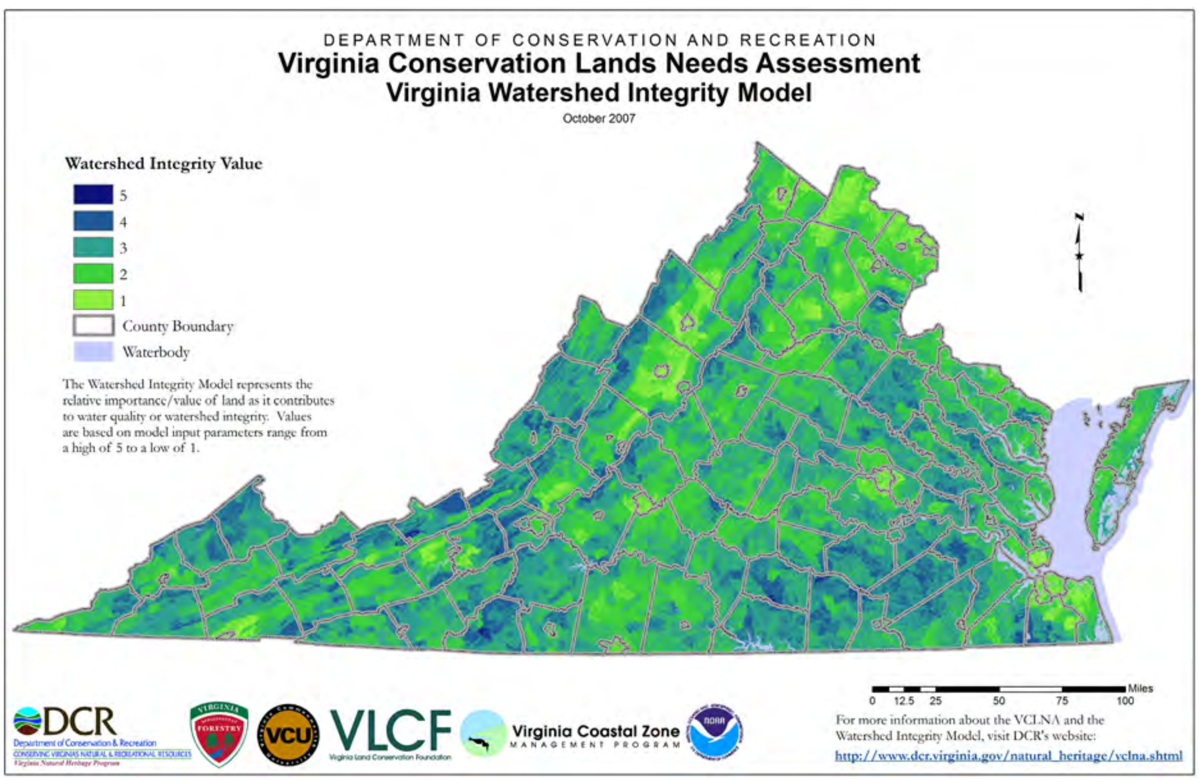

Figure 4-17 Virginia Conservation Lands Needs Assessment Watershed Integrity Model final output (Virginia Department of Conservation and Recreation, 2008).

Minnesota Watershed Assessment Tool

Author or Lead Agency: Minnesota Department of Natural Resources

More Information: http://www.dnr.state.mn.us/watershed_tool/index.html

Minnesota's Watershed Assessment Tool (WAT) is an online mapping program with pre-loaded data layers displaying information relevant to the health of the state's watersheds. Important concepts are explained in detail throughout the web site, and connections among the components of watershed health are emphasized. The program is based around five components that Minnesota considers essential to an understanding of watershed health:

1. Hydrology
2. Connectivity
3. Geomorphology
4. Biology
5. Water quality

Resource managers and other users can explore the myriad issues affecting natural resources at the watershed scale by viewing these components and the connections between them. Table 4-6 lists the data layers available for viewing with this tool. In addition to viewing the various data layers, the user has the option of downloading most layers for use in a GIS to perform original analyses at a variety of scales and for a variety of purposes.

Table 4-6 Data layers in Minnesota's Watershed Assessment Tool.

Hydrology Component		Water Quality Component	
Well index	Lakes	Water quality stations	Lake TMDL
USGS gages	Wetlands	Stream assessments	Potential contaminant sites
Water use permits	Major river centerline	Lake assessments	Superfund sites
Precipitation	Border watersheds	Stream TMDL	Waste water plants
Minor watersheds	Streams		
Biology Component		**Connectivity Component**	
Mussel survey	Designated trout streams	Municipal boundaries	Public lands
Biodiversity significance	Ecological Classification System subsections	National Inventory of Dams	Bridges/culverts
Native plant communities		FEMA floodway	Road/stream intersections
Geomorphology Component		**Base Layers**	
Soils	Ground water recharge	Counties in Minnesota	Land use land cover 1990s
% change in population	Karst features	Roads	2001 national land cover
Depth to bedrock		2003 air photos	USGS topo map 250K
		Shaded relief	

The WAT has also been used to calculate watershed health assessment scores for Minnesota's major watersheds based on index values that compare the relative health of the five components. The steps taken to create the watershed health index include:

1. Review scientific literature to inform the selection of significant and well-supported ecological relationships.
2. Review availability of statewide GIS data that support the selected relationship.
3. Discuss index development approaches with subject matter experts.
4. Compute results by applying an appropriate GIS method.
5. Rank and score results.

The indicators used to develop the statewide index are listed in Figure 4-18. Scores for each indicator must first be normalized to a 0-100 scale by dividing threshold values and/or the maximum value in the range. The average of indicator scores for each of the five components is then calculated to arrive at a component score. The five component scores are then averaged to arrive at a watershed health score. Figure 4-19 displays the results for each of Minnesota's major watersheds and Figure 4-20 displays the detailed component scores for two example watersheds. By viewing and comparing the health scores for each of the components, an understanding of the relative condition of the assessment components can be used to direct resources to protection and restoration. Minnesota plans to recalculate all index scores every five years, incorporating enhanced methods and data as available. This will allow for refinements in the watershed health assessment as well as tracking of trends in watershed health over time.

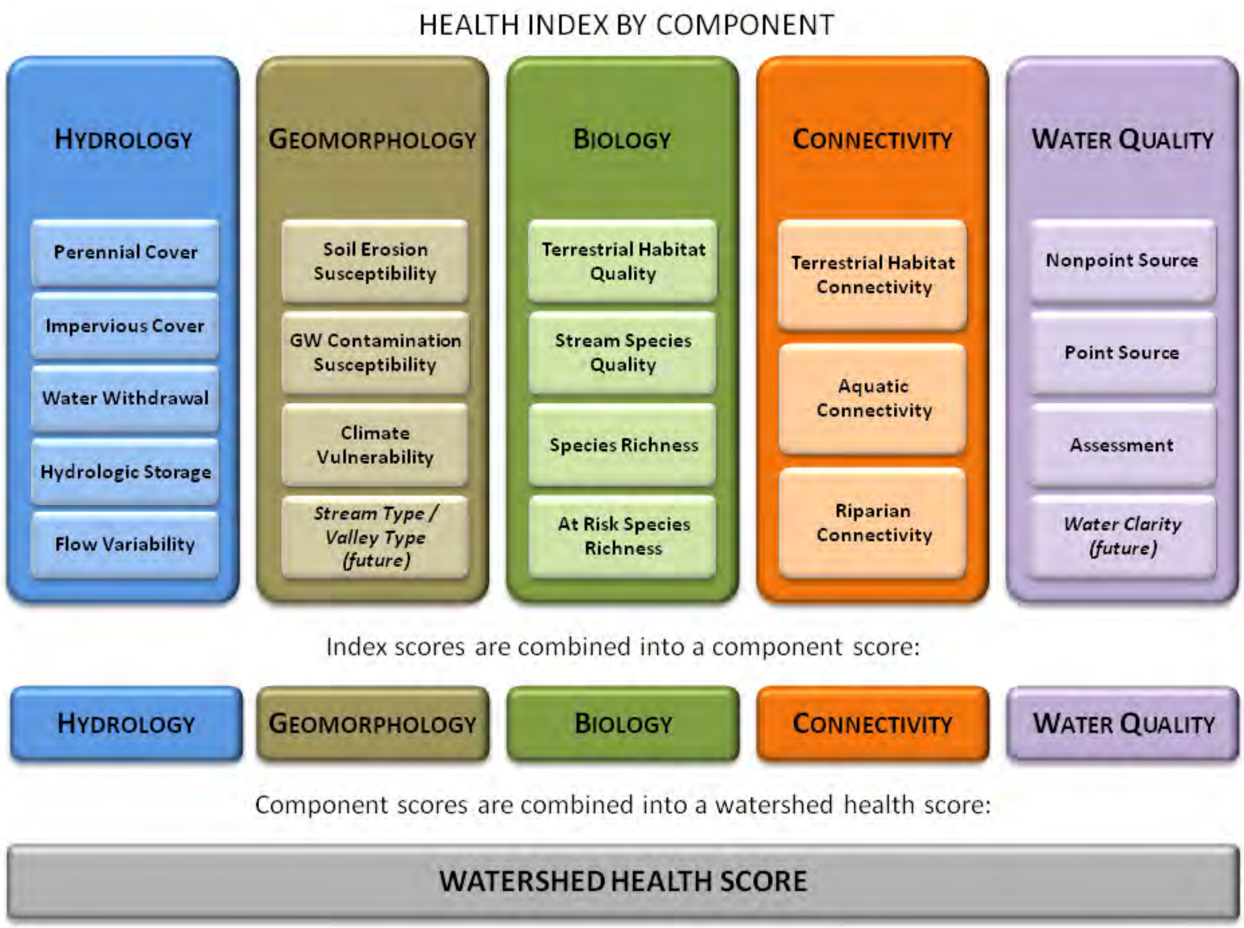

Figure 4-18 Indicators used by the Watershed Assessment Tool for calculating watershed health scores (Minnesota Department of Natural Resources, 2011).

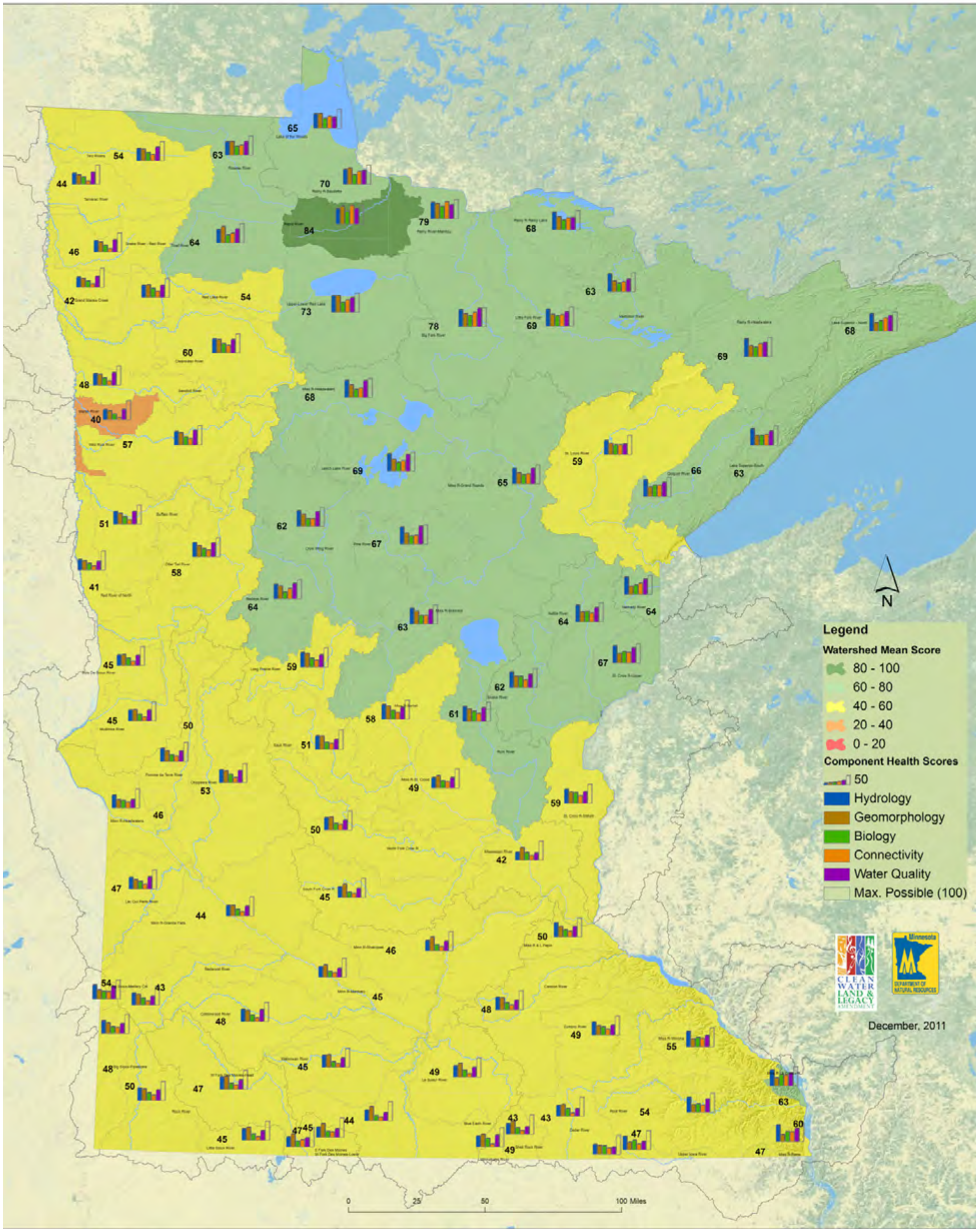

Figure 4-19 Results of the statewide watershed health assessment conducted with the Watershed Assessment Tool (Beth Knudsen, Minnesota Department of Natural Resources, Personal Communication).

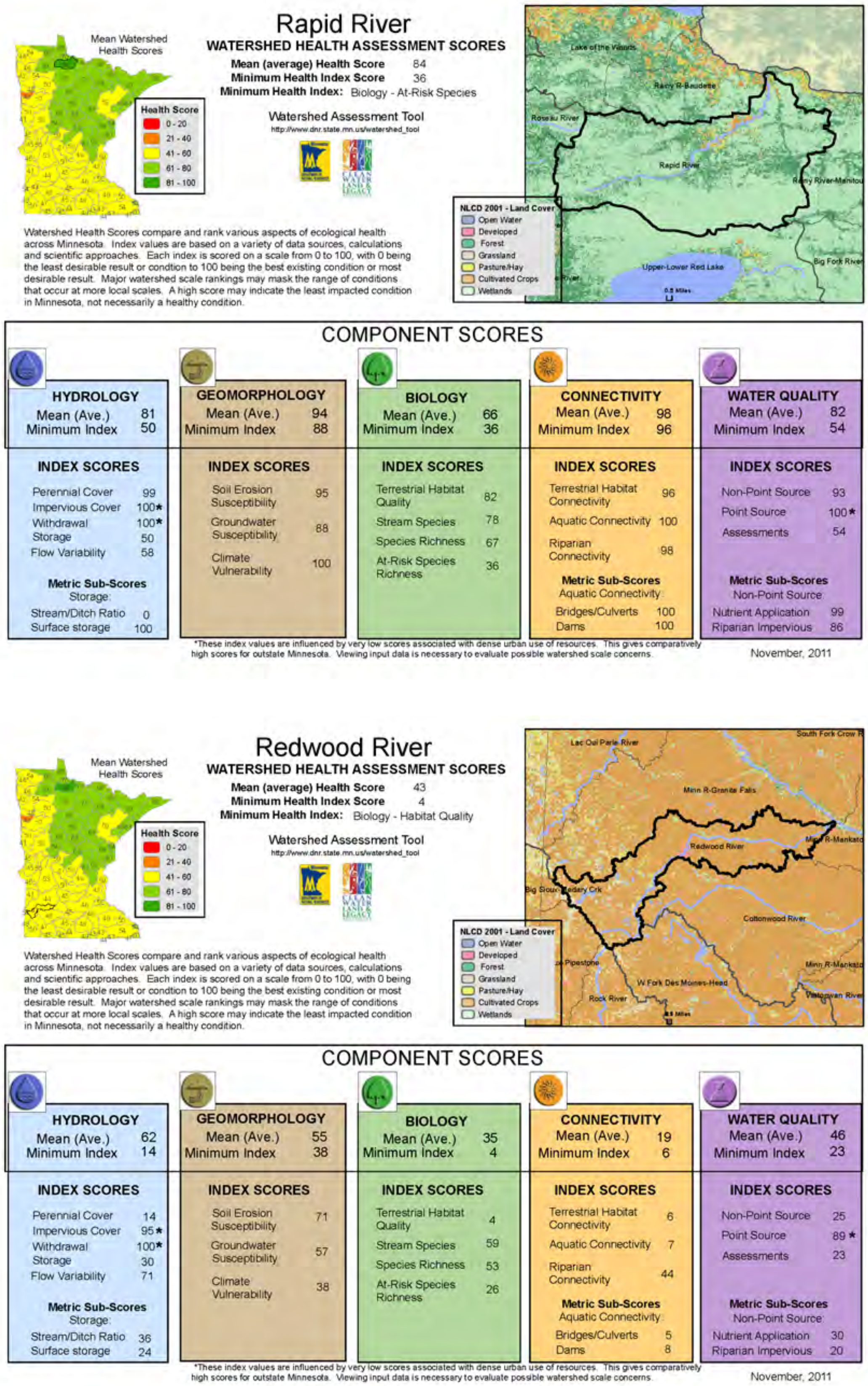

Figure 4-20 Minnesota's watershed health assessment results for the Rapid River (top) and Redwood River (bottom) watersheds.

Oregon Watershed Assessment Manual

Author or Lead Agency: Oregon Watershed Enhancement Board

More Information: http://www.oregon.gov/OWEB/docs/pubs/OR_wsassess_manuals.shtml#OR_Watershed_Assessment_Manual

The *Oregon Watershed Assessment Manual* was created in 1999 to help the state's watershed councils and other local groups to conduct holistic, screening-level watershed assessments. The assessment manual addresses hydrology, geomorphology, biological condition, chemical and physical water quality, land use, and natural disturbances. The assessment results in a watershed condition evaluation that prioritizes sites for protection or restoration actions and provides direction for additional monitoring and assessment activities.

The assessment process contains a number of steps, many of which can be completed concurrently (Figure 4-21). The initial project startup involves the identification of stakeholders, creation of an assessment team, and gathering of data. Following the initial project startup, an evaluation of historical conditions in the watershed is completed. This evaluation provides clues as to the condition of the watershed before European settlement, the history of development and resource use, and natural and human disturbances. A channel habitat type (CHT) classification is also completed at this stage of the assessment. Drawing on several established stream classification systems, these CHTs were developed by Oregon to describe stream channels in the context of their expected biota and the surrounding land uses. This step of the assessment results in a channel habitat map with different CHTs identified based on their landscape position, channel slope, confinement, and size.

Following the historical condition evaluation and CHT classification, watershed hydrology and water use are evaluated. This component examines the precipitation type that causes peak flows in the watershed (rain, rain on snow, or spring snowmelt), the types and quantities of different land uses, and water uses in the watershed. These analyses result in an assessment of flow alteration. The analysis provides guidance on prioritization of potential flow restoration activities. Riparian conditions are also evaluated based on the CHT and ecoregion maps to determine the expected vegetation of a riparian area, resulting in a map of riparian condition units and areas of large woody debris recruitment potential. A wetland characterization and optional functional assessment is also conducted to identify the locations of wetlands in the watershed and potential opportunities for restoration based on field and aerial photo observations.

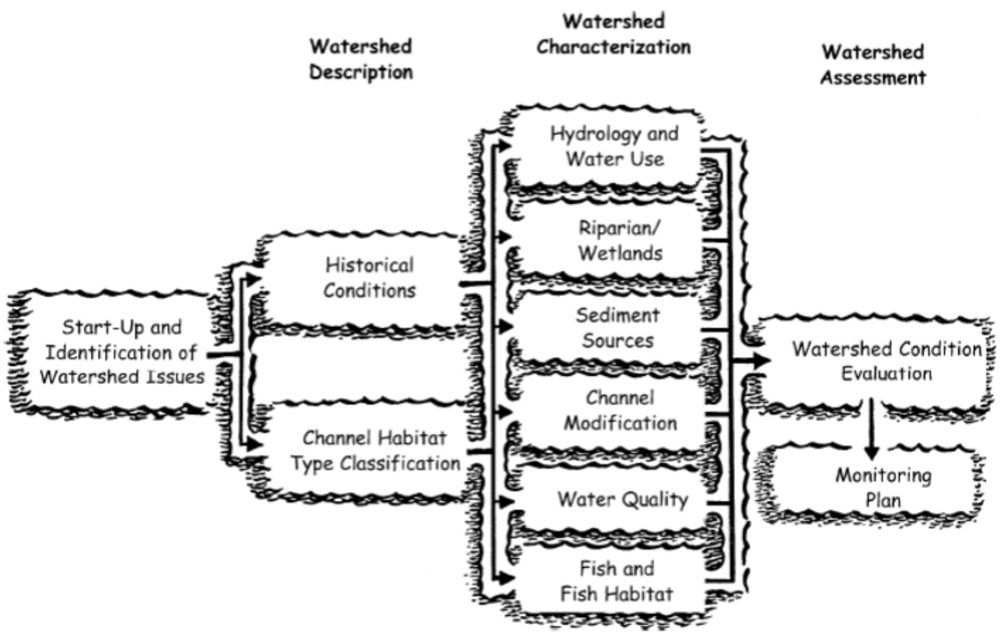

Figure 4-21 The Watershed Assessment Manual methodology framework (Watershed Professionals Network, 1999).

A sediment source assessment is conducted, in which eight potential sources of sediment are evaluated using maps of roads, peak flow, debris flow, landslides, forest road hazards, soils, stormwater, and fire locations. The purpose of this step is to identify areas of human-caused erosion with a priority for restoration or protection measures. A channel modification assessment is also completed, which identifies dams, artificial impoundments, stream bank protection (riprap), roads next to streams, sand or gravel mining near channels, etc. The affected CHTs are then identified and an evaluation of low, moderate, or high impact is assigned to the modified areas. A water quality assessment, using chemical and biological data available from relevant agencies, is conducted to determine areas of impairment or at risk of impairment. Maps of fish distribution and habitat condition are created using available data from relevant fish and wildlife agencies. These maps are also used to identify areas of impairment or at risk of impairment. A survey of stream crossings and migration barriers also contributes to the habitat condition maps.

The final product of all of the individual assessment components is the watershed condition evaluation. This is the stage where all of the information is compiled to create a channel habitat – fish use map that also identifies threats to water quality and aquatic life. A summary of historical and current watershed conditions will also help in the creation of a list and map of watershed protection and restoration opportunities. One of three action opportunities is assigned to each item on the list and map:

1. Protect stream reaches that are in relatively good condition.
2. Restore stream reaches with habitat or fish populations that are currently in degraded condition but have the potential to support high-quality habitat and fish populations.
3. Survey stream reaches where there are insufficient data to assess stream habitat quality or fish population status.

A number of watershed councils and soil and water conservation districts throughout Oregon have used the Watershed Assessment Manual to conduct their own analyses. Sometimes these analyses enlist the assistance of technical specialists, but typically they are conducted by the local organization and its volunteers.

California Watershed Assessment Manual

Author or Lead Agency: University of California, Davis

More Information: http://cwam.ucdavis.edu/

The *California Watershed Assessment Manual* (CWAM) was written for local watershed groups, local and state agencies, and others to use in performing assessments of rural California watersheds between 10,000 – 1,000,000 acres in size. Building on ideas and techniques outlined in other manuals, including the *Oregon Watershed Assessment Manua*l, the CWAM was designed to meet the specific needs of California's extraordinary hydrological, geological, and biological diversity. The CWAM was developed by an interdisciplinary team of scientists from the University of California Davis and the Office of Environmental Health Hazard Assessment (within the California Environmental Protection Agency) with assistance from the California Department of Forestry and Fire Protection.

The CWAM contains two volumes, with the first focusing on the overall process of watershed assessment, reporting, and planning. The second volume focuses on specific assessment techniques and methodologies that can be used in an integrative watershed assessment. Key steps covered in the first volume include:

- Planning of the assessment (team building, defining purpose, etc.).
- Basic watershed concepts.
- Collection and organization of existing data.
- Data analysis and presentation.
- Information integration.
- Development of the assessment report.
- Decision making.

Beginning with the identification of environmental indicators and conceptual modeling, the second volume of the CWAM provides a framework and covers the technical aspects of conducting an integrative watershed assessment. Without prescribing specific techniques, approaches for assessing water quality, hydrology and geomorphology, biotic condition, fire ecology (natural disturbance), and cumulative effects are discussed. In its discussion of environmental indicators, the manual discusses the importance of basing indicators around a framework such as the EPA SAB's Essential Ecological Attributes. The indicators chosen should inform environmental decision making.

Indicators for the different system components can be aggregated into an index that represents the overall condition of the watershed. This is accomplished by rescaling each indicator to a unitless scoring system (e.g., 1-100) and combining the scores to create an index of overall watershed condition. This process requires some knowledge of statistics and should include a validation phase to determine if the index is accurately conveying the intended information.

The CWAM promotes the use of conceptual modeling in the watershed assessment and adaptive management process. Conceptual models can help in the process of selecting indicators, as shown in Figure 4-22. An appendix on the construction and use of conceptual models is provided in the CWAM.

The CWAM is an example of a statewide effort to provide a framework and explanation of tools and methods for conducting holistic watershed assessments to local watershed groups, local and state agencies, and others. Rather than focus solely on chemical/physical water quality or aquatic biology, the manual outlines approaches for all of the components of an integrated watershed assessment. The second volume of the CWAM remains to be completed, although most of the chapters are available for download from the web site. As resources become available, the remaining chapters will be completed.

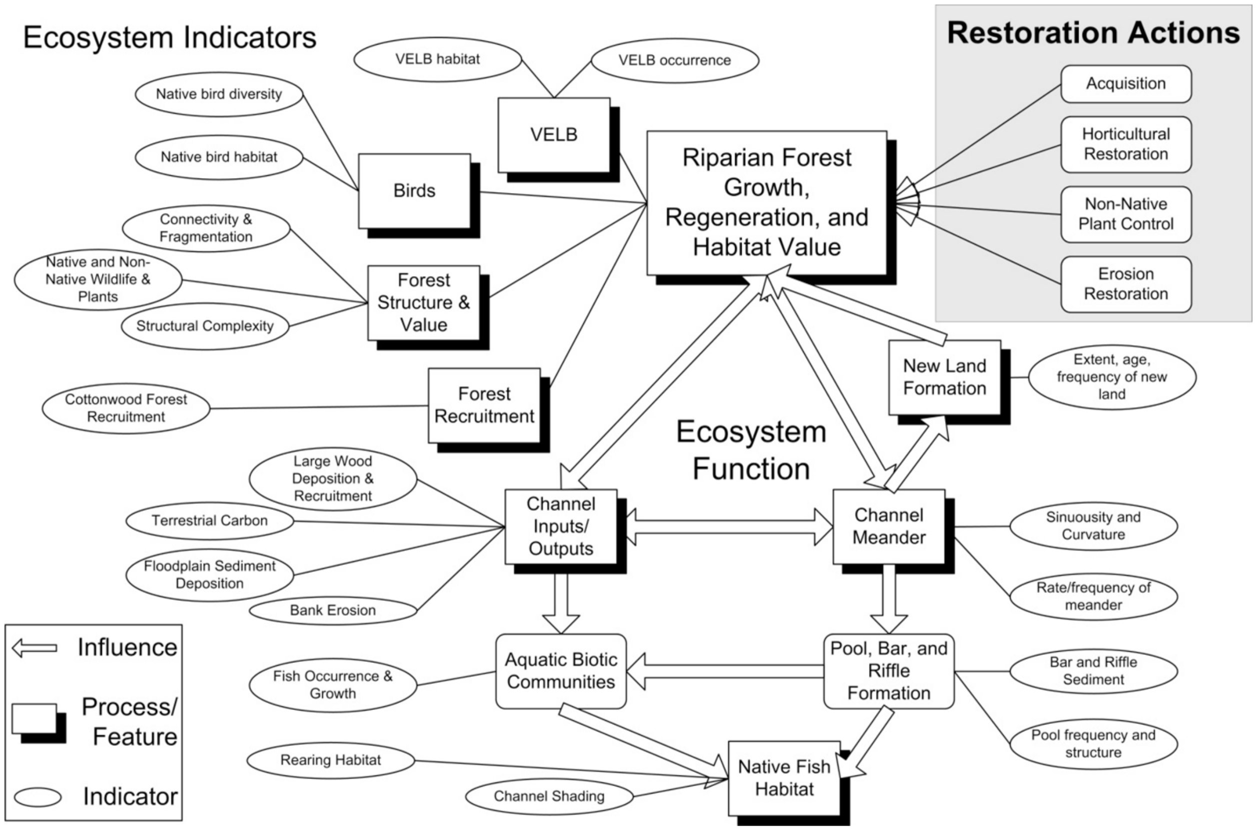

Figure 4-22 Example conceptual model for riparian forest indicator selection (Shilling, 2007).

Pennsylvania Aquatic Community Classification and Watershed Conservation Prioritization

Author or Lead Agency: Pennsylvania Natural Heritage Program

More Information: http://www.naturalheritage.state.pa.us/aquaticsIntro.aspx

The Pennsylvania Aquatic Community Classification was conducted for the State of Pennsylvania to identify stream community types and habitat types for freshwater mussels, macroinvertebrates, and fish. A condition assessment was then conducted to identify the least disturbed streams and set watershed conservation, restoration, and enhancement priorities. Various conservation planning and watershed management projects are already applying this classification system throughout Pennsylvania.

One of the objectives identified in Pennsylvania's Comprehensive Wildlife Conservation Strategy (Wildlife Habitat Action Plan) is the development of a standardized community/habitat classification system (The Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission, 2005). In addition, the Pennsylvania Department of Conservation and Natural Resource's Biodiversity Workgroup Report and State Forest Resource Management Plan also identify a standardized classification system as a priority. In response to this need, the Pennsylvania Natural Heritage Program created the Aquatic Community Classification. Classification of aquatic community types and the physical habitat upon which they depend is important for assessing the condition of freshwater ecosystems. Through a common classification system, reference conditions can be determined for similar community types. The degree of a disturbance can then be assessed through an evaluation of disturbance indicators. In addition to Pennsylvania's Wildlife Habitat Action Plan, The Nature Conservancy's Lower New England Ecoregional Plan was a key resource in the development of the project, as the classification procedure is very similar to TNC's macrohabitat classification approach. The National Fish Habitat Assessment also uses a similar approach, and Pennsylvania plans on incorporating their results into such national and regional scale classifications.

The primary steps in the analysis are as follows:

- Develop a study approach.
- Mine and manage data.
- Create biological classifications.
- Associate environmental data with communities and develop a physical stream classification.
- Evaluate and refine biological classifications.
- Model community habitats.
- Identify high quality streams and watersheds.
- Select poor quality watersheds for restoration prioritization.

Multivariate ordination and cluster analysis were used to classify biological communities. This classification was then refined through an expert review and indicator species analysis. The classification resulted in 13 mussel communities, 11 fish communities, 12 macroinvertebrate communities at the genus level, and eight macroinvertebrate communities at the family level. Watershed, stream channel, and water chemistry data were then used to describe community habitats, and a model of physical stream types was developed to predict community occurrence based on these channel and watershed attributes. Watershed and riparian land cover, mines and point sources, stream crossings, and dams were used to assess the condition of each stream reach. Least disturbed streams were identified and prioritized for watershed conservation actions (Figure 4-23), and the results are being used in a variety of conservation and watershed management projects in Pennsylvania.

The results of the least disturbed streams analysis were combined with fish, mussel, and macroinvertebrate data to prioritize streams based on their ecological integrity. Tier 1 streams are of the highest quality (≥90th percentile, or the best 10%) and are the highest priority for conservation, Tier 2 streams are still high quality (80th–90th percentile) and considered for conservation, and streams that do not contain high quality biological communities (<80th percentile) are considered a non-priority for conservation. The analysis was completed region-wide and for specific unique areas including large rivers, watersheds with calcareous geology, and specific physiographic provinces. Figure 4-24 shows the watershed conservation priorities in Pennsylvania.

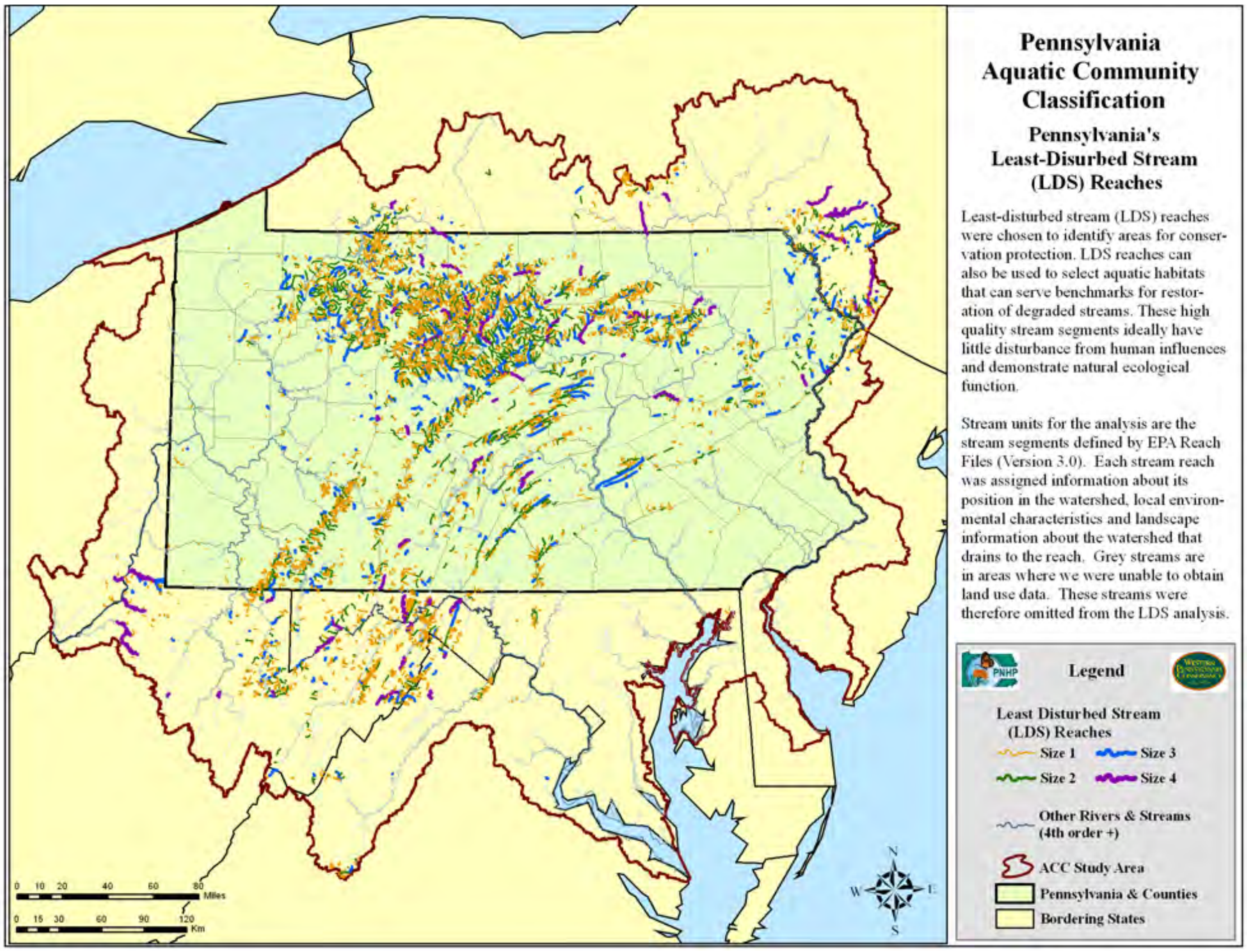

Figure 4-23 Map of Pennsylvania's least disturbed streams (Walsh, Deeds, & Nightingale, 2007).

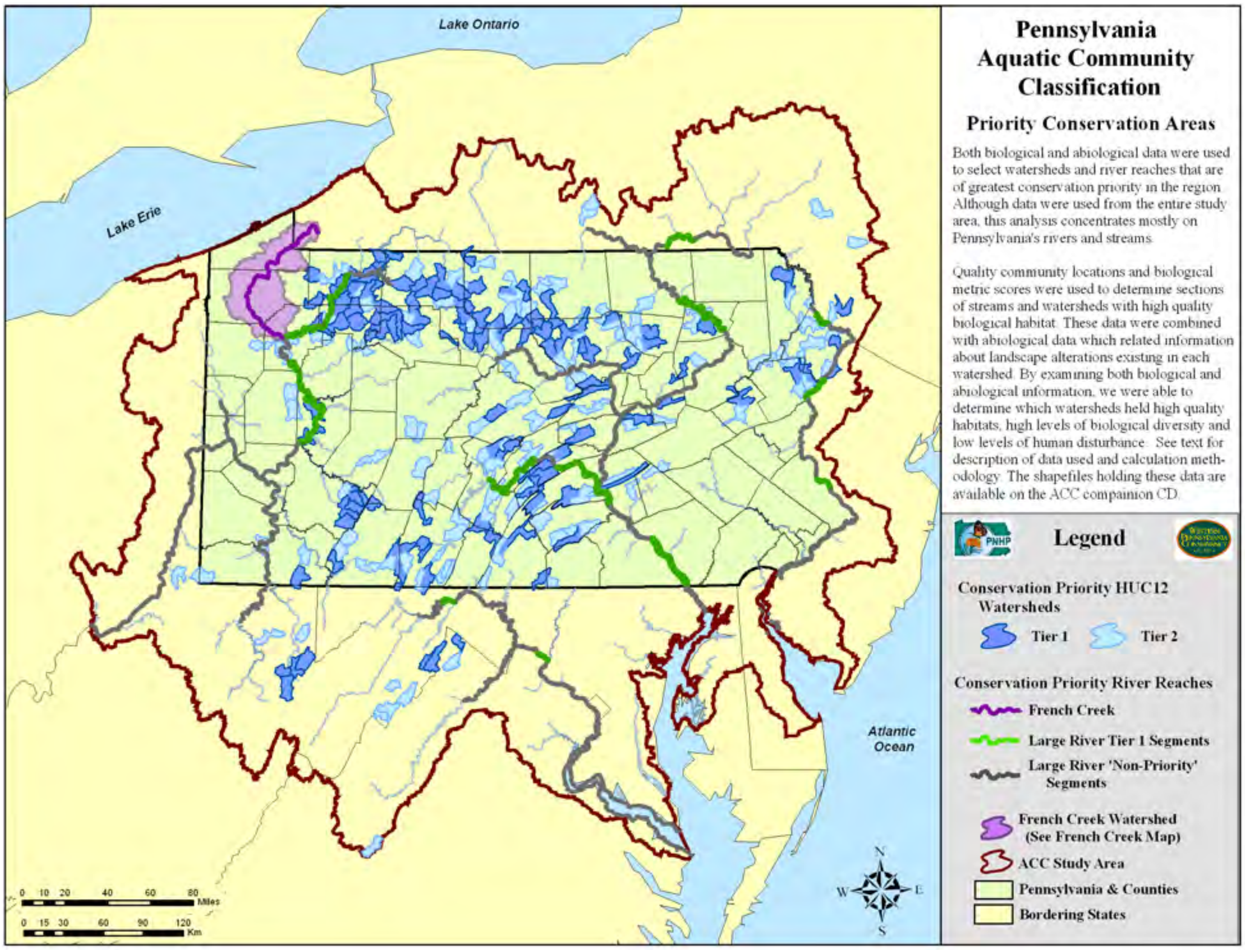

Figure 4-24 Watershed conservation priorities in Pennsylvania (Walsh, Deeds, & Nightingale, 2007).

Connecticut Least Disturbed Watersheds

Author or Lead Agency: Connecticut Department of Environmental Protection

More Information: http://www.ct.gov/dep/lib/dep/water/water_quality_management/ic_studies/least_disturbed_rpt.pdf

Using GIS to evaluate watershed characteristics for the State of Connecticut, the Department of Environmental Protection identified the 30 watersheds considered least disturbed based on Stoddard's (2006) definition of "best available physical, chemical, and biological habitat conditions given today's state of the landscape." This analysis expands upon the Connecticut Impervious Cover (IC) Model that was developed for use in the TMDL program (Figure 4-25). Macroinvertebrates and fish were sampled in the 30 least disturbed watersheds, as identified by the IC model and other watershed stressors.

The negative effects of IC on aquatic biota are numerous (Schueler, 1994) and include altered hydrology, increased erosion, and degraded water quality, all of which impact the biological communities present in these urban watersheds. Connecticut has modeled the aggregate effects of IC on macroinvertebrate communities in the state and uses this IC Model in its TMDL program. The low end of the IC gradient in this model (<4%) was used to identify small watersheds with streams that fall into the "best" stream class. Locations of dams, diversions, and salmonid fry stocking were used to further refine the selection of these least disturbed watersheds. Table 4-7 describes these parameters and the thresholds used.

Table 4-7 Parameters and criteria used to identify least disturbed watersheds in Connecticut.

Parameter	Criterion
Impervious cover	< 4%
Natural land cover	> 80%
Developed land	< 10%
Diversions	None
Reservoirs/large Class C dams	None
Sample site distance below a dam	> 0.5 mile downstream from dam
Streams stocked with salmonid fry	No known stocking
Watershed size	> 1 square mile

Macroinvertebrates and fish were then sampled at the identified least disturbed sites to determine the health of the biological community. An IBI approach, borrowed from Vermont, was used to evaluate the fish community at all sites. A macroinvertebrate multimetric index (MMI) score was also calculated for each site based on the following seven metrics:

- Ephemeroptera taxa.
- Plecoptera taxa.
- Percent Sensitive EPT.
- Trichoptera taxa.
- Scraper Taxa.
- BCG Taxa Biotic Index.
- Percent Dominant Genus.

Temperature, water chemistry, and nutrient samples were also collected at each site. Results from the biological and water quality sampling confirmed minimally impacted conditions in all but one of the 30 watersheds identified through the GIS-based screening process. This suggests that the IC Model is able to predict the locations of the "best" stream classes that should be prioritized for "preservation" strategies. Figure 4-26 shows the results of the statewide assessment of least disturbed watersheds.

Applications of the Connecticut Least Disturbed watersheds assessment include refinement of Tiered Aquatic Life Uses (TALUs) based on a new BCG for fish species, identification of BCG Level 1 sites, providing information to local land use planners on locations of sensitive areas, development of nutrient criteria, and development of minimum stream flow regulations.

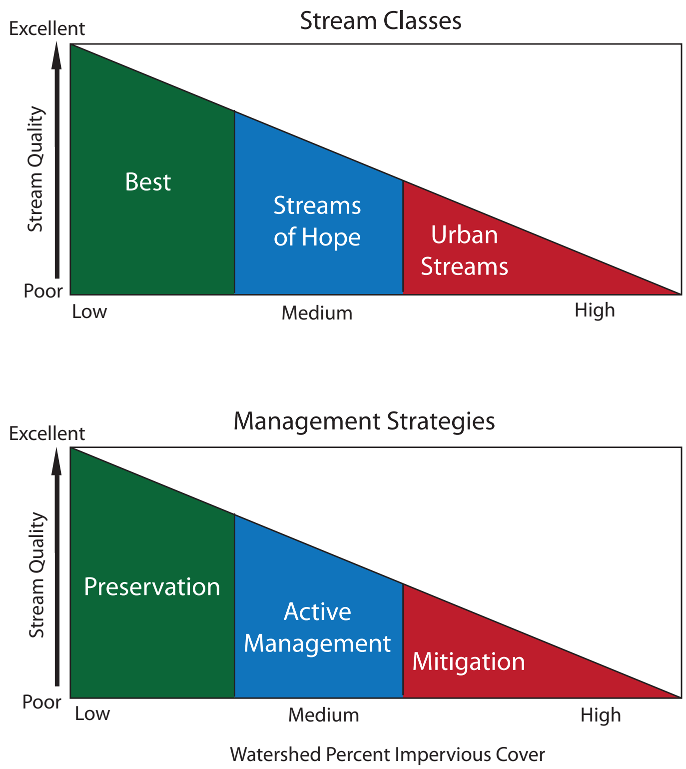

Figure 4-25 Conceptual model of the effect of impervious cover on stream quality. Watershed percent impervious cover is used to identify stream classes (top) and potential management strategies (bottom) (Bellucci, Beauchene, & Becker, 2009).

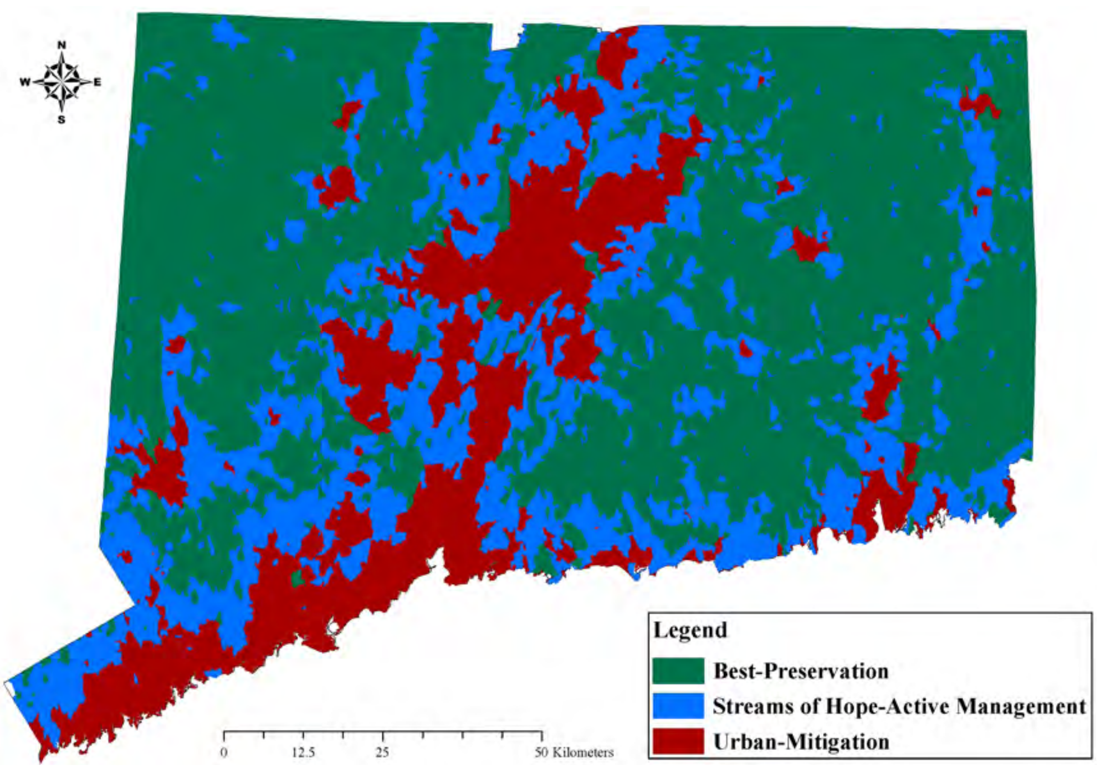

Figure 4-26 Map of Connecticut showing stream classes and management classes by watershed (Bellucci, Beauchene, & Becker, 2009).

Kansas Least Disturbed Watersheds Approach

Author or Lead Agency: Kansas Department of Health and Environment

More Information: http://www.kdheks.gov/befs/download/bibliography/Kansas_reference_stream_report.pdf

The streams selected to represent reference condition, the highest attainable quality in a given environment, are an important factor in stream water quality assessments. Reference streams are used to characterize baseline conditions, establish surface water quality criteria, identify impaired streams, interpret the findings of statewide water quality assessments, and set restoration goals. Because stream ecosystems are dynamic and the interactions between their biological, chemical, and physical components are poorly understood, reference streams provide the context needed for determining when stream ecosystem conditions are healthy or unhealthy. The types of streams chosen to represent reference conditions are often found in healthy watersheds. Recognizing the influence that the reference stream selection process has on its state water quality program, the Kansas Department of Health and Environment (KDHE) has begun to assess how a set of reference streams can be best selected and protected.

KDHE began this assessment by compiling a database of geospatial watershed data. NHDPlus data were used to delineate stream reaches, allocated and accumulated watersheds, and 90-meter riparian corridors. An allocated watershed in the NHDPlus is the immediate drainage area to a single stream reach whereas an accumulated watershed is the entire upstream drainage area for that stream reach. Watershed attributes, such as land cover composition, can be tracked as allocated or accumulated values. Annual average flow was also estimated for each reach using the unit runoff method in NHDPlus. In order to ensure that the set of candidate reference streams identified was representative of the variety of environments found in Kansas, all streams were first sorted into ecoregions. Principal components analysis (PCA) and non-hierarchical clustering analysis were used to group watersheds by ecoregion (Figure 4-27). Scores for the first three principal components, pertaining largely to elevation and climate, topographical relief, and soil water retention capacity, were converted to a color intensity scale, and average values were calculated and mapped for each ecoregion.

Once environmental variability had been analyzed, KDHE incorporated variability in human disturbance levels into the assessment. Arithmetic means were calculated and normalized to a zero to one scale for twenty variable measures of landscape alteration for all watersheds (Table 4-8). A PCA was performed on the watershed disturbance data, and principal components accounting for most of the variability in the data were retained for further analysis. Component scores were converted to absolute values and used as weighting coefficients for their respective disturbance indicators. The weighted sum of all indicators was calculated for each component and the average of these weighted sums was used as an integrated disturbance index to sort watersheds into seven equally-sized groups (septiles) of watersheds. Groups were mapped in colors corresponding to their integrated disturbance index scores, in a spectrum ranging from green (low disturbance) to red (high disturbance). A summation of the normalized means of landscape alteration variables for each watershed was used to check the watersheds' integrated disturbance classifications.

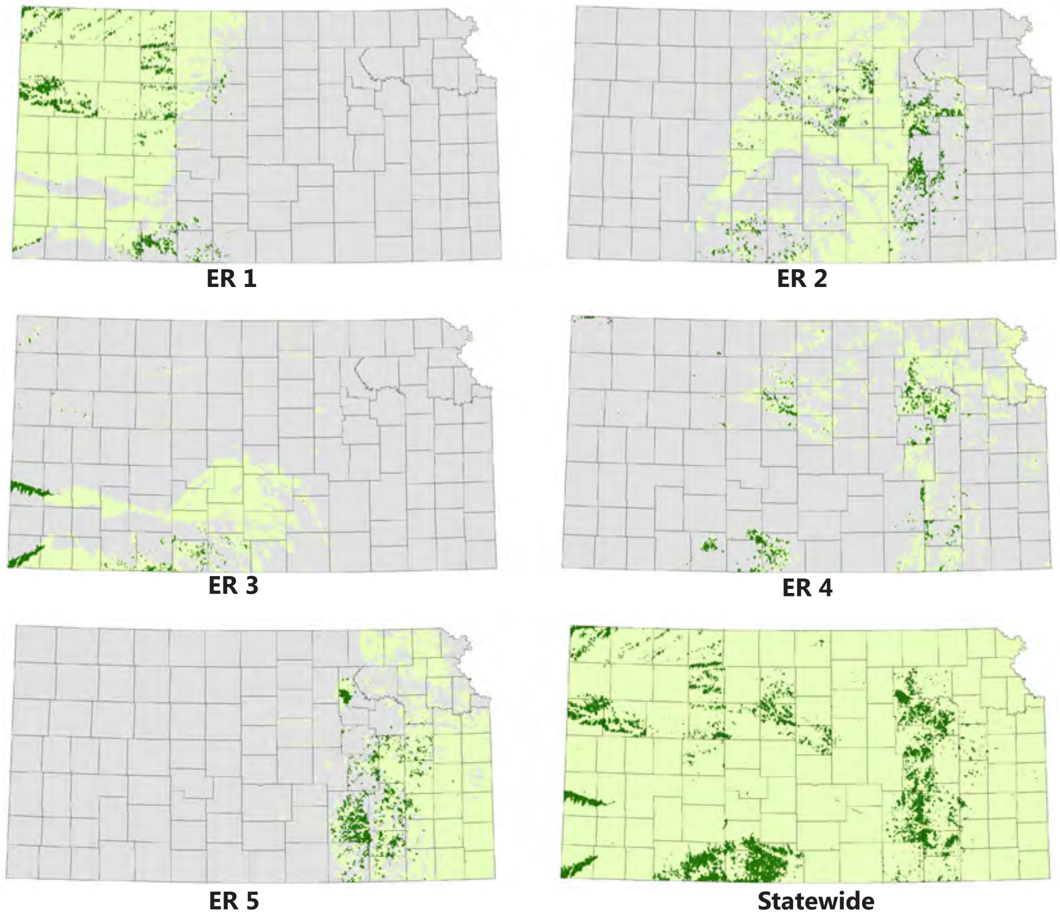

Figure 4-27 Location of least disturbed watersheds within individual quantitative ecoregions (ER) (k = 5) (Angelo, Knight, Olson, & Stiles, 2010). Rankings are based on the disturbance index derived via principal components analysis. Highlighted watersheds rank in the lowest (best) 10th percentile within their respective ecoregions. The statewide (10th percentile) map is shown for comparison.

Table 4-8 Landscape alteration variables used in KDHE's reference stream assessment (Angelo et al., 2010).

Density of:	Ratio of:
Active and inactive Superfund sites	Cropland area to total land area
Active and inactive permitted landfills	Cropland area to total land area within 90-meter riparian corridor
Active and inactive permitted mines and quarries	Inundated land area to total land area
Confined livestock (animal units)	Urban area to total land area
Grazing cattle	Urban area to total land area within 90-meter riparian corridor
Human residents	
Permitted ground water diversions	**Other:**
Permitted surface water diversions	Combined annual application rate for all pesticides
Registered active and inactive oil and natural gas wells	Total permitted wastewater output divided by catchment area
Registered and unregistered dams	
Stream/industrial pipeline intersections	
Stream/railroad intersections	
Stream/road intersections	

KDHE also evaluated the association between human disturbance level and an important indicator of watershed health: stream taxonomic richness. Richness data were drawn from state-sponsored biological surveys of native fish species, freshwater mussel species, and aquatic insects of the EPT orders conducted between 1990 and 2007. Taxonomic richness data were then merged with the integrated disturbance index dataset. Separate models were developed for each ecoregion and for the state overall, incorporating all five ecoregions. The ability to accurately predict responses to new observations, as measured by the predicted R^2 statistic, was used to select the final models.

Governmental planning documents, statistical abstracts, permit applications, unpublished databases, and various reports were reviewed to evaluate potential future threats to candidate reference streams in Kansas. Data pertaining to the following potential sources of degradation were extracted from these resources: urban and residential sprawl; transportation and utility infrastructure development; mineral resource development; development of new dams and reservoirs; growing anthropogenic water demand; conversion of grassland to other uses; industrialization of livestock production; and introduction and spread of non-native species. This literature review was used to identify the most serious threats to stream integrity and the regions of the state most vulnerable to those threats.

KDHE intends to sort watersheds in the tenth percentile by ecoregion and stream flow and assess them with computer-assisted desktop reconnaissance. Final reference stream selections will be based on four primary factors: watershed disturbance score, field assessment results, site accessibility (i.e., permission from the landowner), and perceived future disturbance risk. The physical habitat, water chemistry, and biological communities of the selected reference streams will be monitored every four to eight years. As a database of reference stream conditions is developed over time, it can be used to inform regulatory, incentive-based, and interagency efforts to protect reference streams and their watersheds from degradation.

Case Study

National Fish Habitat Assessment

More Information: Esselman et al., 2011

Similar to the way in which KDHE used NHDPlus and an integrated index of human disturbance to analyze watershed condition, scientists working on the National Fish Habitat Assessment (NFHA) have also assessed landscape disturbance for stream catchments using NHDPlus (Figure 4-28). The NFHA cumulative disturbance index uses five environmental variables and 15 human disturbance variables quantified at local and network catchment levels to assess landscape disturbance. The local and network catchments are comparable to the allocated and accumulated watersheds that KDHE used in their analysis. Means for elevation, slope, and soil permeability were calculated for each network catchment. Mean annual precipitation and air temperature were calculated for each local catchment. Human disturbance variables were calculated for both catchment types. Catchment means were calculated for water use estimates and cattle density. Catchment percentages were generated for each land use type: low, medium, and high intensity development; impervious cover; pasture; and cultivated crops. Catchment densities were calculated for point data (road crossings, dams, mines, superfund sites, toxic release inventory sites, and national pollutant discharge elimination system sites), and road densities were represented as total road length per square kilometer of catchment area.

Using principal components analysis, the human disturbance variables were combined into a few composite disturbance axes that describe most of the variation in these variables at the stream reach level. Individual disturbance axes were then weighted according to their influence on freshwater fishes using canonical correlation analysis and summed into indices of local and network catchment disturbance. Local and network disturbance indices were weighted using canonical correspondence analysis to reflect the different impacts disturbances have on communities in streams of different sizes. They were then combined to determine a cumulative landscape disturbance index score for each stream reach. The cumulative disturbance index was scaled from zero to 100 with high scores indicating greater disturbance. A national fish community dataset was used to calibrate the landscape disturbance index. The NFHA team identified vulnerability to future threats as an information gap in their landscape disturbance index, a factor that KDHE found a way to address in concert with its integrated human disturbance index.

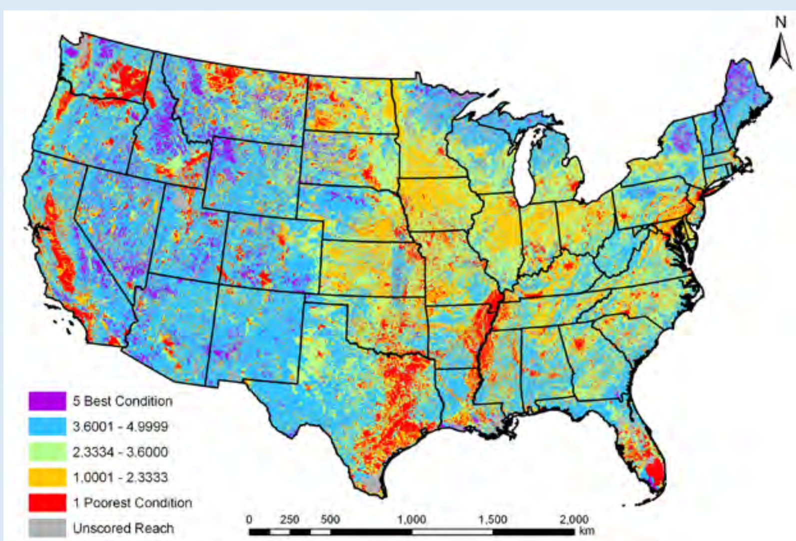

Figure 4-28 Reach cumulative landscape disturbance scores summarized by local catchments for the United States. Scores are presented in five percentile categories, each containing 20% of the reaches (Esselman et al., 2011).

Recovery Potential Screening

Author or Lead Agency: U.S. Environmental Protection Agency, Office of Water

More Information: www.epa.gov/recoverypotential/ and http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/recovery_empub-2.pdf

The Recovery Potential Screening method provides a systematic approach for comparing waters or watersheds and identifying differences in how well they may respond to restoration. Recovery potential is defined as the likelihood of an impaired water to attain water quality standards or other valued attributes given its ecological capacity to regain function, its exposure to stressors, and the social context affecting efforts to improve its condition.

Although originally developed as a tool to help states set restoration priorities among the impaired waters on their CWA Section 303(d) lists, this method can also be used to assess healthy waters or watersheds for protection (Norton, Wickham, Wade, Kunert, Thomas, & Zeph, 2009; Wickham & Norton, 2008). The screening process is based on ecological, stressor, or social indicators measured from a wide variety of landscape datasets, impaired waters attributes reported by states to EPA, and monitoring data sources. The user's control over assessment purpose and selection of relevant indicators and weights makes this flexible method adaptable to numerous uses and differences in locality. The method prioritizes watersheds for restoration through a transparent and consistent comparison process.

Examples of the 130 indicators developed for use in the recovery potential screening are provided in Table 4-9. Five to eight metrics in each of three different classes are chosen for an individual assessment. Ecological capacity, stressor exposure, and social context represent three gradients, or axes, along which watersheds are rated using the selected indicators. The user's objective is to choose indicators that collectively estimate the influence of each of the three classes on a watershed's overall recovery potential. Within each class, raw scores for each selected indicator are normalized to a maximum score of one, weighted if desired, then compiled into a summary score normalized to 100 across all the scored watersheds. Higher ecological and social scores signify better recovery potential, and higher stressor scores imply lower recovery potential.

Scoring the three classes of metrics ensures that ecological condition, stressor scenarios, and the influence of social factors are all addressed, and they can be considered together or separately. It is particularly valuable to distinguish the influence of social variables from the influence of watershed condition, as social variables are often the dominant variable determining restoration success. Although it is useful to distinguish the ecological, stressor, and social summary scores of each watershed, it is also desirable to have the scores in an integrated form. This is accomplished in two ways. If a single score per watershed is desired (e.g., for rank ordering, or developing a mapped representation of watersheds color-coded by relative recovery potential scores), the formula is as follows:

$$\frac{\text{(Ecological summary score + Social summary score)}}{\text{Stressor summary score}}$$

A second method for integrating the three summary scores uses three-dimensional "bubble-plotting" (Figure 4-29). In this approach, the X and Y axes represent the stressor and ecological summary scores, and this determines the position of each watershed bubble on the graph. The social summary score determines the size of the bubble (the larger the better). While more a visualization than quantitative method, this display method is effective at producing 'at a glance' understanding of the basic differences among a population of watersheds considering all three classes. As a starting point, the watersheds that fall in the upper left quadrant of the bubble plot have higher ecological summary scores and lower stressor summary scores, and are initially assumed to have high recovery potential. The user, however, may choose to elevate the importance of ecological score in both upper quadrants to select priorities, or may consider social score as the primary factor. This flexibility allows expert judgment to play a more interactive role. For example, a watershed with moderate ecological and stressor scores but an exceptionally strong social score could be prioritized along with watersheds that meet the initial high-ecological and low-stressor scoring criterion.

Table 4-9 Example Recovery Potential Indicators. The user selects five to eight minimally correlated metrics from each class that are most relevant to the place and purpose of the screening, selects the measurement technique for each metric given available data, and weights the indicators if desired before calculating ecological, stressor, and social summary scores. Yellow-highlighted metrics are potentially appropriate for healthy watersheds protection and priority-setting as well as restoration planning.

Ecological Capacity Metrics	Stressor Exposure Metrics	Social Context Metrics
Natural channel form	Invasive species risk	Watershed % protected land
Recolonization access	Channelization	Applicable regulation
Strahler stream order	Hydrologic alteration	Funding eligibility
Rare taxa presence	Aquatic barriers	303(d) schedule priority
Historical species occurrence	Corridor road crossings	Estimated restoration cost
Species range factor	Corridor road density	Certainty of causal linkages
Elevation	Corridor % u-index	Plan existence
Corridor % forest	Corridor % agriculture	University proximity
Corridor % woody vegetation	Corridor % urban	Certainty of restoration practices
Corridor slope	Corridor % impervious surface	Watershed organizational leadership
Bank stability/soils	Watershed % u-index	Watershed collaboration
Bank stability/woody vegetation	Watershed road density	Large watershed management potential
Watershed shape	Watershed % agriculture	Government agency involvement
Watershed size	Watershed % tile-drained cropland	Local socio-economic stress
Watershed % forest	Watershed % urban	Landownership complexity
Proximity to green infrastructure hub	Watershed % impervious surface	Jurisdictional complexity
Contiguity w/green infrastructure corridor	Severity of 303(d) listed causes	Valued ecological attribute
Biotic community integrity	Severity of loading	Human health and safety
Soil resilience properties	Land use change trajectory	Recreational resource

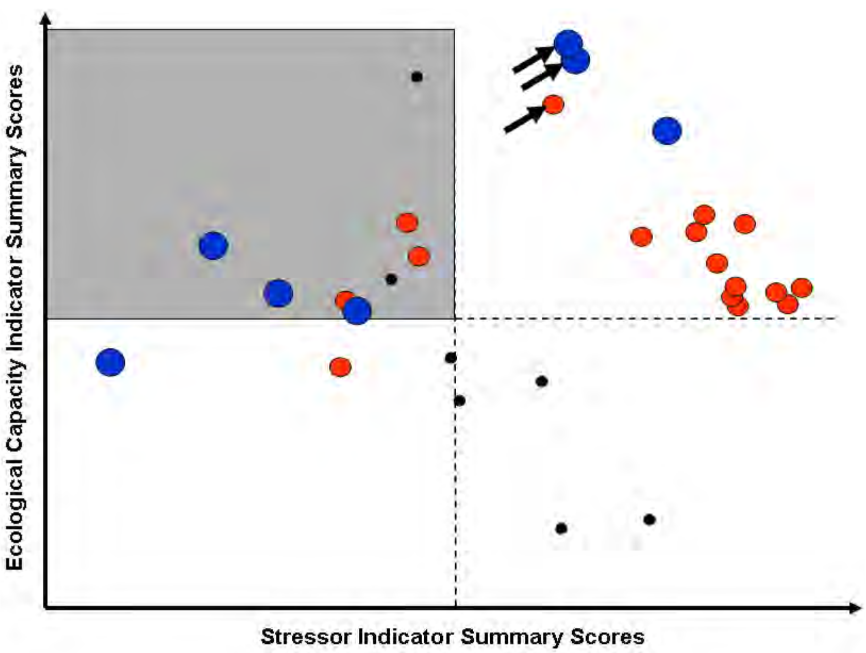

Figure 4-29 Three-dimensional bubble plot comparing recovery potential among subwatersheds. Dots represent subwatersheds plotted by summary score relative to the ecological and stressor axes. Social context scores (higher = better) are incorporated as dot size and color. Median values for ecological and stressor scores statewide (dashed lines) are added to enable a coarse sorting by quadrant that initially targets high ecological/low stressor subwatersheds (upper left, shaded), with selected subwatersheds (arrows) added where special information warrants. This example screening flagged 11 of 30 subwatersheds as more restorable (Norton et al., 2009). Reprinted with permission of Springer Science and Business Media B.V.

The recovery potential screening data formats contain flexibility for further analyses. Indicator scores are managed in spreadsheets and, once completed, alternate combinations or weights of indicators can be selected and plotted to verify consistency of high-scoring watersheds under alternate scoring approaches. Large (e.g., statewide) datasets can often be re-assessed in a matter of hours. The "R" script used for bubble plotting (Figure 4-30) also allows for varying color assignment based on any attribute in the spreadsheet.

Recovery potential screening in Maryland demonstrates how a restoration-oriented screening can easily be adapted for protection screening purposes. The goal was to identify which impaired watersheds are the strongest prospects for successful restoration, but all of the state's healthy watersheds were also screened with the same indicators (Table 4-10). Despite the main focus on impaired watersheds, the screening secondarily revealed many patterns about the healthy watersheds that may also be relevant to their management. For example, the watersheds that passed bioassessment but still show elevated stressor scores may be at risk. Further, wide differences in social score imply that some of the healthy watersheds have far better social context for continued protection than others. In addition, several of the impaired watersheds that scored as well as the healthy watersheds (see upper left quadrant, Figure 4-30) may be strong prospects for protection in time. Assessing watersheds specifically for protection purposes is feasible given the many protection-relevant metrics that can be considered (Table 4-10) or developed.

Table 4-10 Recovery potential indicators used to screen Maryland watersheds.

Ecological Metrics (5)	Stressor Metrics (5)	Social Metrics (5)
Biotic condition: benthic IBI score	Proportion of degraded sites per watershed	Protected landownership % by watershed
Biotic condition: fish IBI score	Corridor % impervious cover per watershed	Proportion of stream miles with stressor Attributed Risk
Recolonization: density of confluences	Watershed % cropland and pasture	Complexity: watershed # of local jurisdictions
Bank stability: MBSS buffer vegetation	Housing counts per corridor length in watershed	Tier 2 waters % per watershed
Natural channel form and condition	Watershed 2006 # of impairment causes	Watershed % targeted by DNR for protection

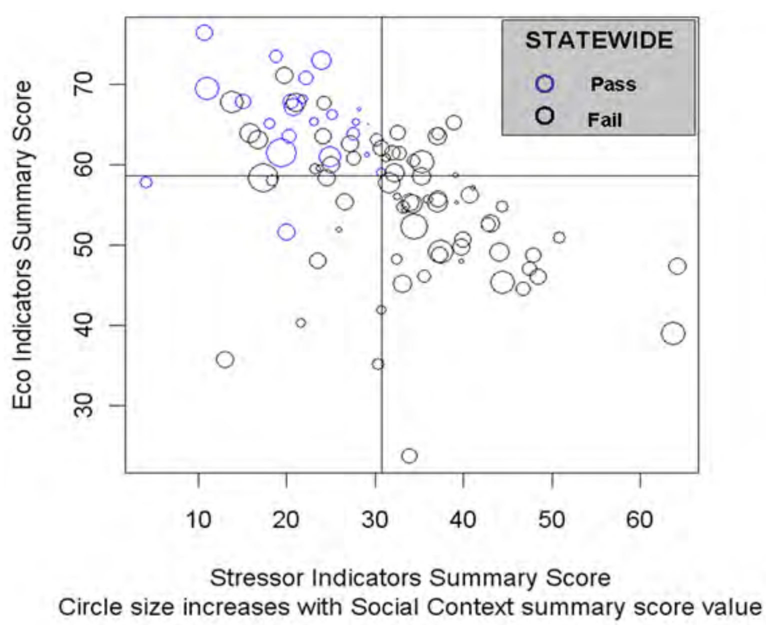

Figure 4-30 Bubble plot of recovery potential screening of 94 non-tidal watersheds in Maryland. Colors signify whether watersheds passed the state's watershed bio-assessment. Although indicators were selected to compare recovery potential of impaired waters, the output also contrasts healthy watershed differences (e.g., social context and stressor levels) that have implications for protection priority-setting.

Classification Systems and Indicators Used in Integrated Assessments

Indicator	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Hydrologic Unit Code	✔	✔			✔			✔
Ecoregions							✔	
Channel Habitat Types			✔					
Landscape Position			✔					
Channel Slope			✔					
Confinement			✔					
Size			✔					
Physical Habitat Types					✔		✔	
Geology					✔			
Stream Gradient					✔			
Mean Stream Flow							✔	
Watershed Size					✔			
>1 mi^2					✔	✔		
>2,000 mi^2					✔			
Biological Communities					✔	✔	✔	
Mussels					✔		✔	
Fish					✔	✔	✔	
Macroinvertebrates					✔	✔	✔	
Ecological Classification System Subsections		✔						
Climate		✔					✔	
Geology		✔						
Topography		✔					✔	
Soils		✔					✔	
Hydrology		✔					✔	
Vegetation		✔						

VA WIM: Virginia Watershed Integrity Model
MN WAT: Minnesota's Watershed Assessment Tool
OR WAM: Oregon Watershed Assessment Manual
CA WAM: California Watershed Assessment Manual
PA ACC: Pennsylvania Aquatic Community Classification
CT LDW: Connecticut Least Disturbed Watersheds
KS LDW: Kansas Least Disturbed Watersheds
EPA RPST: EPA Recovery Potential Screening Tool

Landscape Indicators Used in Integrated Assessments

Indicator	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Index of Terrestrial Integrity	✓							
% Watershed Natural Land Cover	✓	✓				✓		
>80% Natural Land Cover						✓		
% River Corridor Natural Land Cover	✓							
Proportion of habitat fragmentation due to roads	✓							
% Impervious Cover	✓					✓		
<4% Impervious Cover						✓		
Catchment % Forested (>75%)					✓			
Watershed % Developed Land					✓	✓		
<10% Developed						✓		
Catchment % Urbanization (<1.5%)					✓			
Ratio of urban land area to total land area							✓	
Watershed % Urban			✓					
Watershed % Forestry			✓					
Watershed % Agriculture/Rangeland			✓					
Density of Confined Livestock							✓	
Density of Grazing Cattle							✓	
Ratio of Cropland to Total Land Area							✓	
Annual Pesticide Application Rate							✓	
Catchment Non Row Crop Agriculture <17%					✓			
Catchment Row Crop Agriculture <3.5%					✓			
Corridor % Impervious Surface								✓
Corridor % Urban								✓

VA WIM: Virginia Watershed Integrity Model
MN WAT: Minnesota's Watershed Assessment Tool
OR WAM: Oregon Watershed Assessment Manual
CA WAM: California Watershed Assessment Manual
PA ACC: Pennsylvania Aquatic Community Classification
CT LDW: Connecticut Least Disturbed Watersheds
KS LDW: Kansas Least Disturbed Watersheds
EPA RPST: EPA Recovery Potential Screening Tool

Landscape Indicators Used in Integrated Assessments (cont.)

Indicator	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Stream Crossings					✓		✓	✓
<11,500 for watersheds larger than 2,000 mi^2					✓			
# Road Stream Crossings (all streams and first order streams)							✓	
Density of Stream/ Pipeline Intersections							✓	
Density of Stream/ Railroad Intersections							✓	
Corridor Road Density								✓
Corridor % Agriculture								✓
Corridor % Woody Vegetation								✓
Location of FEMA Floodplain		✓						
Locations of Headwaters	✓							
Steep Slopes	✓							
Green Infrastructure (GI)	✓							
Watershed % Forested								✓
Locations of Ecological Cores	✓							
Contiguity with GI Corridors								✓
Proximity to GI Hub								✓
Locations of Riparian Areas	✓							
Locations of Source Water Protection Zones	✓							
Remaining High Quality Native Plant Communities		✓						
Wetland Locations		✓	✓					
Wetland Attributes (size, connectivity, buffer, watershed position)			✓					
Locations of Fires			✓					
Fire Regime Condition Class				✓				

VA WIM: Virginia Watershed Integrity Model
MN WAT: Minnesota's Watershed Assessment Tool
OR WAM: Oregon Watershed Assessment Manual
CA WAM: California Watershed Assessment Manual
PA ACC: Pennsylvania Aquatic Community Classification
CT LDW: Connecticut Least Disturbed Watersheds
KS LDW: Kansas Least Disturbed Watersheds
EPA RPST: EPA Recovery Potential Screening Tool

Habitat Indicators Used in Integrated Assessments

Indicator	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Designated Trout Streams		✓						
Karst Features		✓						
Springs		✓						
Stream Sink		✓						
Sinkhole		✓						
Species Range Factor				✓				
Domestic Predators				✓				
Habitat Diversity				✓				
RTE Species Habitat				✓				
Stream Crossing Density		✓					✓	
Recolonization Access				✓				✓
Migration Barriers			✓		✓			
Culverts Passable			✓					
Water Velocity ≤2 fps			✓					
Outlet perching ≤6 in.			✓					
Flow Depth ≥12 in.			✓					
Outlet Drop less than 6 in.			✓					
Slope <0.5%			✓					
Diameter >0.5 X bankful channel width			✓					
Length <100 feet			✓					
Substrate Complexity and Embeddedness			✓					
Riffles with ≥35% Gravel			✓					
Riffles with <8% Silt, Sand, Organics			✓					
Ratio of Fine Sediment Volume In Pools To Total Pool Volume				✓				
Large Woody Debris Recruitment Potential			✓					
>20 Pieces of Large Woody Debris per 100 Meters			✓					
Expected Riparian Vegetation by Ecoregion			✓					
Stream Shading by Riparian Vegetation			✓					
Shade >70% of reach			✓					
Pool Area > 35% of stream area			✓					
Pool Frequency (every 5-8 channel widths)			✓					
>300 Conifers within 30 M of Stream per 1,000 ft			✓					
Corridor % Woody Vegetation				✓				✓

VA WIM: Virginia Watershed Integrity Model
MN WAT: Minnesota's Watershed Assessment Tool
OR WAM: Oregon Watershed Assessment Manual
CA WAM: California Watershed Assessment Manual
PA ACC: Pennsylvania Aquatic Community Classification
CT LDW: Connecticut Least Disturbed Watersheds
KS LDW: Kansas Least Disturbed Watersheds
EPA RPST: EPA Recovery Potential Screening Tool

Hydrologic Indicators Used in Integrated Assessments

Indicator	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Average Annual Precipitation		✓	✓					
Precipitation Type that Causes Peak Flows			✓					
Rain			✓					
Rain on Snow			✓					
Spring Snowmelt			✓					
Discharge				✓				
Peak Flow			✓					
Dams and Impoundments		✓	✓	✓	✓	✓	✓	
No Reservoirs						✓		
<160 for watersheds >2,000 mi^2					✓			
No large Class C Dams						✓		
<11,500 Road Crossings for Watersheds >2,000 mi^2					✓			
Water Use Permits (>10,000 GPD)		✓						
Consumptive Use			✓					
No Diversions						✓		
Number of Permitted Water Diversions							✓	
Permitted Wastewater Relative to Catchment Size							✓	
Dry Season Artificial Discharges				✓				
Average Annual Ground Water Recharge		✓						
Well Index		✓						
Floodplain Connection				✓				
Hydrologic Alteration								✓

VA WIM: Virginia Watershed Integrity Model
MN WAT: Minnesota's Watershed Assessment Tool
OR WAM: Oregon Watershed Assessment Manual
CA WAM: California Watershed Assessment Manual
PA ACC: Pennsylvania Aquatic Community Classification
CT LDW: Connecticut Least Disturbed Watersheds
KS LDW: Kansas Least Disturbed Watersheds
EPA RPST: EPA Recovery Potential Screening Tool

Geomorphology Indicators Used in Integrated Assessments

Indicator	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Roads Next to Streams			✔					
Locations of Stream Bank Protection (riprap)			✔					
Channelization								✔
Bank Erosion				✔				
Bank Stability/Soils								✔
Bank Stability/Woody Vegetation								✔
Soil Resilience Properties								✔
Locations of Debris Flows			✔					
Locations of Landslides			✔					
Sand or Gravel Mining Locations			✔					
Sinuosity				✔				
Channel Migration Rate				✔				
Floodplain Drainage Density				✔				
Natural Channel Form								✔
Dominant Catchment and Reach Geology					✔			
Sandstone					✔			
Shale					✔			
Calcareous					✔			
Crystalline Silicic					✔			
Crystalline Mafic					✔			
Unconsolidated Materials					✔			
Stream Gradient					✔			
Low (<0.5%)					✔			
Medium (0.51-2%)					✔			
High (>2%)					✔			
Watershed Size					✔			
Headwaters (0-2 mi^2)					✔			
Small (3-10 mi^2)					✔			
Mid-Reach (11-100 mi^2)					✔			
Large (>100 mi^2)					✔			

VA WIM: Virginia Watershed Integrity Model
MN WAT: Minnesota's Watershed Assessment Tool
OR WAM: Oregon Watershed Assessment Manual
CA WAM: California Watershed Assessment Manual
PA ACC: Pennsylvania Aquatic Community Classification
CT LDW: Connecticut Least Disturbed Watersheds
KS LDW: Kansas Least Disturbed Watersheds
EPA RPST: EPA Recovery Potential Screening Tool

Water Quality Indicators Used in Integrated Assessments

Indicator	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Locations of Unimpaired Streams		✓						
Potential Contaminant Sites (e.g., Superfund, landfills, mines, oil or gas wells, etc.)		✓					✓	
Point Sources		✓			✓			
<200 for watersheds >2,000 mi^2					✓			
Dissolved Organic Carbon				✓				
Dissolved Organic Carbon Export Downstream				✓				
Bromide Reactive Compounds								
Temperature			✓	✓				
Daily Maximum of 64°F			✓					
Dissolved Oxygen			✓	✓				
8.0 mg/l			✓					
>7.0 mg/l for coldwater streams				✓				
>3.5 mg/l for warmwater streams				✓				
Nitrogen						✓		
Nitrate			✓	✓				
0.30 mg/l			✓					
Total Phosphorus			✓	✓		✓		
0.05 mg/l			✓					
Suspended Solids				✓		✓		
Turbidity			✓	✓		✓		
50 ntu maximum above background			✓					
Conductivity				✓				
Between 150 and 500 µmhos/cm				✓				
pH			✓	✓				
6.5 to 8.5 units			✓	✓				
Chloride			✓			✓		
Hardness						✓		
Alkalinity						✓		

VA WIM: Virginia Watershed Integrity Model
MN WAT: Minnesota's Watershed Assessment Tool
OR WAM: Oregon Watershed Assessment Manual
CA WAM: California Watershed Assessment Manual
PA ACC: Pennsylvania Aquatic Community Classification
CT LDW: Connecticut Least Disturbed Watersheds
KS LDW: Kansas Least Disturbed Watersheds
EPA RPST: EPA Recovery Potential Screening Tool

Biological Indicators Used in Integrated Assessments

Indicator	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Observed/Expected				✔				
Modified Index of Biotic Integrity	✔							
Number of Intolerant Species	✔			✔				
Species Richness	✔							
Number of RTE Species	✔							
Number of Non-Indigenous Species	✔							
Number of Critical/Significant Species	✔							
Number of Tolerant Species	✔			✔				
Mussel Catch per Unit Effort		✔						
Areas of Biodiversity Significance		✔						
Rare Taxa Presence								✔
Biotic Community Integrity								✔
Fish State or Federally Listed as Endangered			✔					
Fish Stocking History			✔					
Streams Stocked with Salmonid Fry (No Known Stocking)						✔		
Fish Species Distribution			✔			✔		
Salmonid Species Distribution, Abundance, and Population Status			✔					
Brook Trout Density						✔		
Fluvial Specialists						✔		
Fluvial Dependants						✔		
Macrohabitat Generalists						✔		

VA WIM: Virginia Watershed Integrity Model
MN WAT: Minnesota's Watershed Assessment Tool
OR WAM: Oregon Watershed Assessment Manual
CA WAM: California Watershed Assessment Manual
PA ACC: Pennsylvania Aquatic Community Classification
CT LDW: Connecticut Least Disturbed Watersheds
KS LDW: Kansas Least Disturbed Watersheds
EPA RPST: EPA Recovery Potential Screening Tool

Biological Indicators Used in Integrated Assessments (cont.)

Indicator	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Periphyton Dry Biomass				✔				
<5 mg/cm^2				✔				
Periphyton Chl-a Mass				✔				
Between 2 and 6 µg chl-a/cm^2				✔				
Periphyton Community Succession				✔				
Periphyton % Cover				✔				
Shannon Diversity Index for Diatoms				✔				
Pollution Tolerance Index for Diatoms				✔				
Percent Sensitive Diatoms				✔				
Abundance Achnanthes minutissima (<25%)				✔				
Taxa Richness (Total # of Taxa)				✔	✔		✔	
# Intolerant Taxa					✔			
# Tolerant Taxa					✔			
Native Taxa					✔			
Non-Native Taxa					✔			
Darter + Perch					✔			
Minnow					✔			
Sucker					✔			
Sunfish					✔			
% Similarity to Reference Reach (of fish taxa metrics above)					✔			
EPT Index (Total # of Ephemeroptera, Plecoptera, Trichoptera Taxa)				✔			✔	
% Sensitive EPT						✔		
% Collector				✔				
% Filterers				✔				
% Scrapers				✔		✔		
% Predators				✔				
% Shredders				✔				
% Dominant Taxa				✔		✔		

VA WIM: Virginia Watershed Integrity Model
MN WAT: Minnesota's Watershed Assessment Tool
OR WAM: Oregon Watershed Assessment Manual
CA WAM: California Watershed Assessment Manual
PA ACC: Pennsylvania Aquatic Community Classification
CT LDW: Connecticut Least Disturbed Watersheds
KS LDW: Kansas Least Disturbed Watersheds
EPA RPST: EPA Recovery Potential Screening Tool

Vulnerability Indicators Used in Integrated Assessments

Indicator	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Population Density		✔					✔	
Change in Population		✔						
Modeled Erosion Potential				✔				
Land Use Trajectory							✔	✔
Watershed % Protected Land								✔
Location of Public Lands or Protected Areas		✔						
Expanding Transportation and Utility Infrastructure							✔	
Escalating Mineral Resource Extraction							✔	
Proliferation of Dams and Reservoirs							✔	
Industrialization of Livestock Industry							✔	
Growing Anthropogenic Demand for Water							✔	
Introduction and Spread of Nonnative Species							✔	

VA WIM: Virginia Watershed Integrity Model
MN WAT: Minnesota's Watershed Assessment Tool
OR WAM: Oregon Watershed Assessment Manual
CA WAM: California Watershed Assessment Manual
PA ACC: Pennsylvania Aquatic Community Classification
CT LDW: Connecticut Least Disturbed Watersheds
KS LDW: Kansas Least Disturbed Watersheds
EPA RPST: EPA Recovery Potential Screening Tool