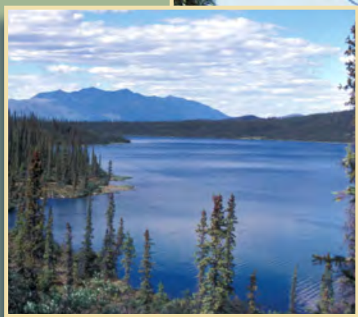

# Identifying and Protecting Healthy Watersheds

## Concepts, Assessments, and Management Approaches

February 2012

Healthy Watersheds

EPA

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# Identifying and Protecting Healthy Watersheds

## Concepts, Assessments, and Management Approaches

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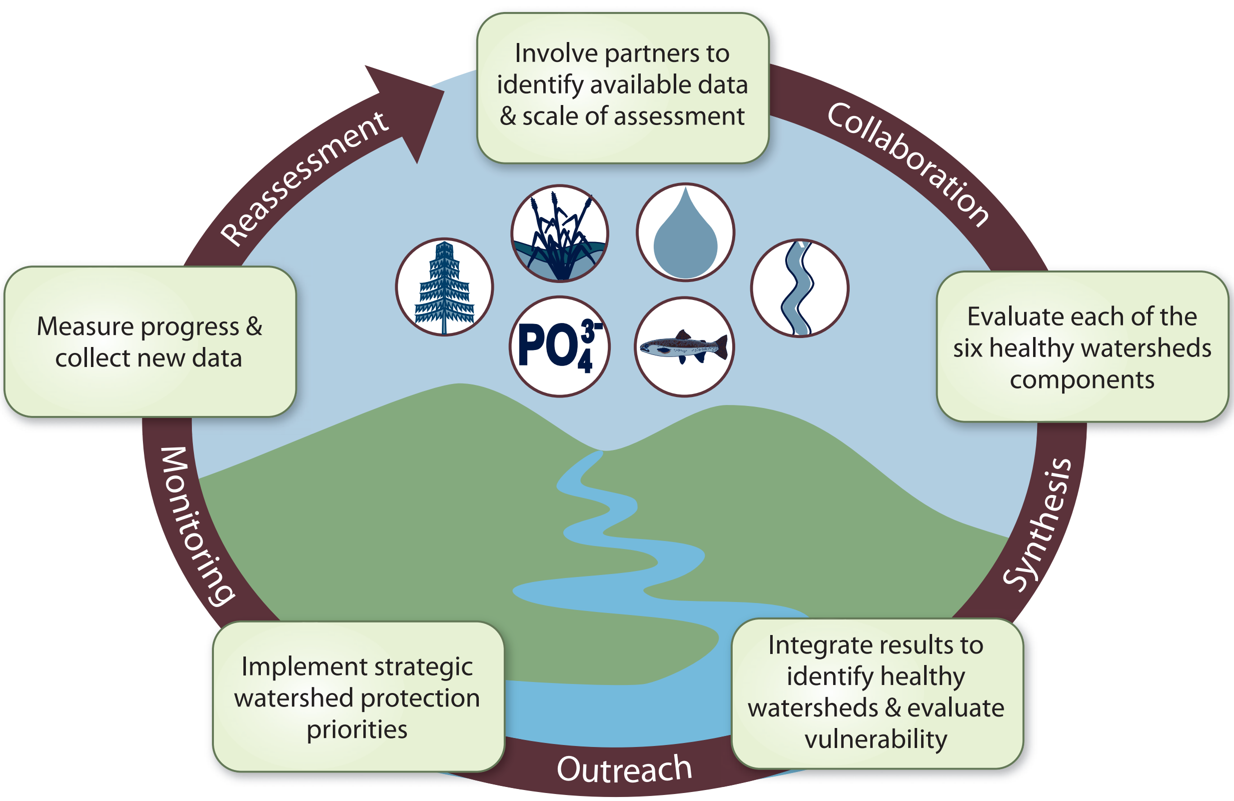
# Foreword

Forty years ago, the U.S. Environmental Protection Agency (EPA) was created and tasked with implementing programs designed to repair the damage already done to the environment and to help Americans make their environment cleaner and safer. The objective of the 1972 Clean Water Act amendments was "to restore and maintain the chemical, physical, and biological integrity of the nation's waters." Through restoration of impaired water bodies, vast environmental improvements have been seen in the last 40 years. However, the rate at which new waters are being listed for water quality impairments exceeds the pace at which waters are removed from the list. It has become clear that a broader view of aquatic ecosystems is critical if we are to truly protect the chemical, physical, and biological integrity of our waters. As we look forward to the future, EPA remains strongly committed to protecting and preserving our country's environment. On March 29, 2011, EPA released the Coming Together for Clean Water Strategy as the framework for guiding the Agency's implementation efforts and actions to meet the 2011-2015 Strategic Plan objectives for protecting and restoring our waters. One of the key areas of the Agency's strategy is to increase protection of healthy waters, including healthy watersheds. The Healthy Watersheds Initiative was launched to place a renewed emphasis on the protection of our nation's healthy waters and to leverage these natural resources to accelerate our restoration successes. Through the Healthy Watersheds Initiative, EPA is working with state, tribal, and other partners to take proactive measures to identify and protect healthy watersheds based on integrated assessments of habitat, biotic communities, water chemistry, and watershed processes such as hydrology, fluvial geomorphology, and natural disturbance regimes.

The integrity of aquatic ecosystems is directly affected by their landscape context and the processes that occur in their watershed. Natural land cover maintains hydrologic and sediment regimes within a natural range of variation that shape the aquatic habitat upon which biological communities have evolved and can't live without. Conversion from natural to anthropogenic land cover typically results in altered flow regimes, changes in sediment supply and transport, increased loading of nutrients and other pollutants, and ultimately leads to degradation of the biological community. Recognizing these connections and the role of watershed processes and functions on water quality, the Healthy Watersheds Initiative augments EPA's traditional focus on regulating specific pollutants and pollutant sources, emphasizing protection of critical watershed processes that support chemical, physical, and biological integrity. Healthy, functioning watersheds provide the building blocks that anchor water quality restoration efforts. Without this ecological support system, we will have more limited success in restoring impaired waters and will lose the many socio-economic benefits of healthy ecological systems.

This document is a technical resource that provides information for assessing, identifying, and protecting healthy watersheds. It is not program implementation guidance. EPA, state, territory, and authorized tribal decision makers retain the discretion to adopt approaches to identify and protect healthy watersheds that differ from those described in this document. This document can assist in those efforts by providing a wealth of information and examples that we hope will inspire and motivate aquatic resource scientists and managers to conduct integrated healthy watersheds assessments and initiate protection programs that are cognizant of the systems context. Chapter 1 introduces the Healthy Watersheds Initiative, discusses the characteristics of a healthy watershed, and reviews the benefits of protecting healthy watersheds. Chapter 2 describes the healthy watersheds conceptual framework and 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. Chapter 3 summarizes a range of assessment approaches currently being used to assess the health of watersheds, and are provided as examples of different assessment methods that can be used as part of a healthy watersheds integrated assessment. Chapter 4 presents an example screening level method for conducting a healthy watersheds integrated assessment and identifying healthy watersheds, and includes examples of state assessments that approximate integrated assessments. Chapter 5 summarizes a variety of management approaches for protecting healthy watersheds. Lastly, the appendices contain a summary of assessment tools, sources of data, and a compilation of assessment and management examples cited in the document. Readers can navigate between the chapters depending on their needs and priorities.

The term integrated assessment is used in this document to describe 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. The healthy watersheds integrated assessment and management framework, shown below, requires collaboration with multiple partners throughout the entire process. Critical first steps include framing the scale and context of the assessment and ensuring that all relevant data and expertise have been identified and obtained. The 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. From here, strategic watershed protection priorities can be identified by evaluating vulnerability alongside the identified healthy watersheds. As watershed protection measures are implemented, it will be important to collect new data and information that help to demonstrate the effectiveness of watershed protection activities and that can be used to refine future assessments. The healthy watersheds integrated assessment and management framework is not a linear effort with a defined endpoint. Assessment and management of healthy watersheds is an adaptive and iterative process, with new data and improved methodologies providing refined assessment results and more effective protection strategies over time.



# 1. Introduction


## 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.

## 1.1 Background

The stated objective of the Clean Water Act (CWA) is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (33 U.S.C. Section 1251(a); CWA Section 101(a)). Since the 1972 amendments to the CWA (known then as the Federal Water Pollution Control Act), federal water quality regulations have led to significant reductions in pollutant levels in many impaired lakes, rivers, and streams. Further, significant efforts have been undertaken to restore aquatic ecosystems in our nation's impaired watersheds. Despite these efforts, our aquatic ecosystems are declining nationwide (Figure 1-1). This trend has been documented by many, including the Heinz Center (2008) and the American Fisheries Society (Jelks et al., 2008). Further, the rate at which new waters are being listed for water quality impairments exceeds the pace at which restored waters are removed from the list (Figure 1-2), and restoring impaired waters is costly (Table 1-1). In addition to pollution, threats such as loss of habitat and its connectivity, hydrologic alteration, invasive species, and climate change continue to increase. A better strategy is needed if we are to achieve the objective of the Clean Water Act.

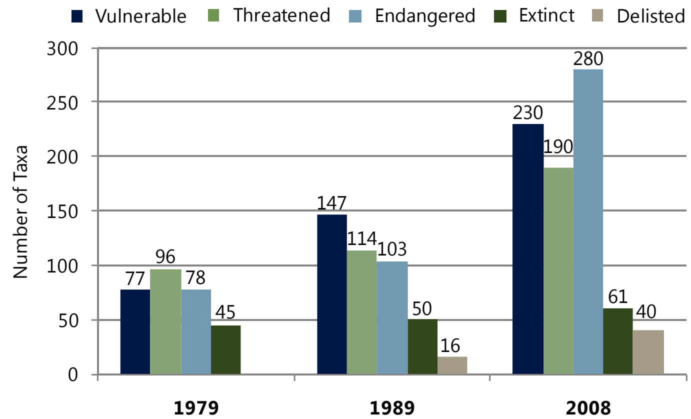



**Figure 1-1** Numbers of imperiled North American freshwater and diadromous fish taxa (modified from Jelks et al., 2008).

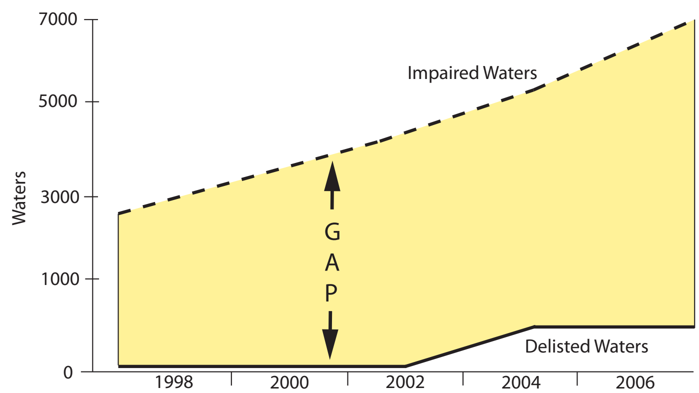



**Figure 1-2** Gap between impaired and delisted waters in EPA Region 3.

**Table 1-1** Estimated cost of pollutant cleanup in the Chesapeake Bay Watershed (EPA Region 3).

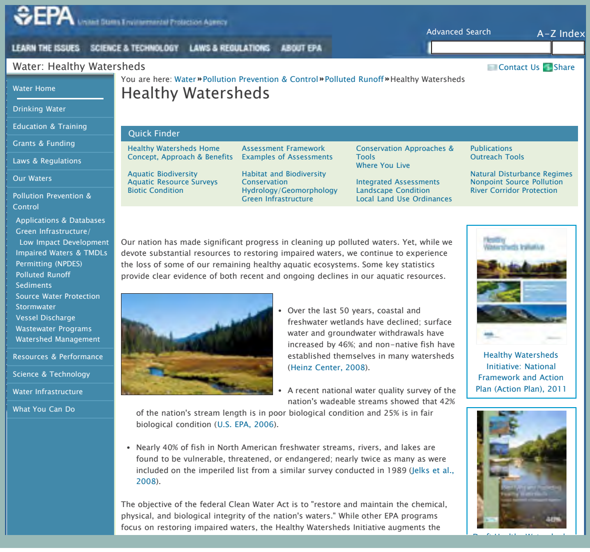
| Water Body | Impairment | Miles | Cost | Average Cost/Mile |
|---|---|---|---|---|
| Corsica River, MD | Nutrients | 7.6 | $17,500,000 | $2,302,632 |
| Little Laurel Run, PA | Metals | 3 | $1,048,013 | $349,338 |
| Conewago Creek, PA | Nutrients | 17 | $4,300,000 | $252,941 |
| Bear Creek, PA | Metals | 5 | $964,000 | $192,800 |
| Catawissa Creek, PA | Metals | 57.9 | $3,500,000 | $60,449 |
| Thumb Run, VA | Bacteria | 17 | $2,450,000 | $144,118 |
| Willis River, VA | Bacteria | 30 | $2,794,160 | $93,139 |
| Muddy Creek, VA | Bacteria | 9 | $2,612,000 | $290,222 |

## 1.2 Healthy Watersheds Initiative

The Section 101(a) objective of the CWA is "…to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The Committee Report written in support of the 1972 Federal Water Pollution Control Act amendments clarified that the term *integrity* "…refers to a condition in which the natural structure and function of ecosystems is [sic] maintained," rather than simply improving water quality in a narrow sense (U.S. Government Printing Office, 1972; Doppelt, Scurlock, Frissell, & Karr, 1993). The U.S. Environmental Protection Agency (EPA), in partnership with others, launched the Healthy Watersheds Initiative to protect and maintain remaining healthy watersheds having natural, intact aquatic ecosystems; prevent them from becoming impaired; and accelerate restoration successes. This initiative is being implemented by promoting a strategic, systems approach to identify and protect healthy watersheds based on integrated assessments of habitat, biotic communities, water chemistry, and watershed processes such as hydrology, fluvial geomorphology, and natural disturbance regimes. Once healthy watersheds or healthy components of watersheds are identified, priorities can be set for protection and restoration, with the best chances of recovery likely to be in waters near existing healthy aquatic ecosystems (Roni et al., 2002; Norton et al., 2009; Sundermann, Stoll, & Haase, 2011).

**EPA's Healthy Watersheds Website**

www.epa.gov/healthywatersheds




The key components of the Healthy Watersheds Initiative are as follows:

1. Partnerships are established to identify and protect healthy watersheds.
2. Healthy watersheds are identified state-wide using scientifically-sound integrated assessment techniques.
3. Healthy watersheds are listed, tracked, maintained, and increased in number over time.
4. Healthy watersheds are protected and enhanced using both regulatory and non-regulatory tools.
5. Progress on protecting healthy watersheds is measured and tied to achieving the overall goals of EPA's Water Program and Strategic Plan.

While the Healthy Watersheds Initiative is intended to be implemented to support strategic statewide and tribal decisions, the assessment data and other information generated as part of a healthy watersheds assessment can also be used to inform management decisions at the basin or local watershed levels, including implementing water quality and other programs. The anticipated outcomes of the Healthy Watersheds Initiative are integrated aquatic ecosystem protection programs that maintain and increase the number of healthy watersheds in our nation.

## 1.3 Characteristics of a Healthy Watershed

A healthy watershed is one in which natural land cover supports dynamic hydrologic and geomorphic processes within their natural range of variation; habitat of sufficient size and connectivity supports native aquatic and riparian species; and water quality supports healthy biological communities. An interconnected network of natural land cover throughout a watershed, and especially in the riparian zone, provides critical habitat and supports maintenance of the natural flow regime and fluctuations in water levels. It also helps to maintain natural geomorphic processes, such as sediment storage and deposition, which form the basis of aquatic habitats. Connectivity of aquatic and riparian habitats, in the longitudinal, lateral, vertical, and temporal dimensions helps to ensure that biotic refugia are available during floods, droughts, and other extreme events. In addition to connectivity, redundancy of ecosystem types helps to ensure that the characteristics of a healthy watershed will persist into the future. Processes that are maintained within their natural range of variation, connectivity, and redundancy are thus critical characteristics of healthy watersheds.

## 1.4 Benefits of Protecting Healthy Watersheds

Motivation to protect ecosystems comes from a variety of sources, including intrinsic value, the services ecosystems provide to humans, and legal mandates. There is growing recognition that functionally intact and biologically complex freshwater ecosystems provide valuable commodities and services to society (Baron et al., 2002). In 2000, the United Nations Secretary General Kofi Annan called for a global assessment of ecosystems and implications for human health and well-being. The resulting Millennium Ecosystem Assessment documents worldwide trends in ecosystem integrity and the services they provide (Millennium Ecosystem Assessment, 2005). Ecosystems provide raw products, including food, fuel, fiber, fresh water, and genetic resources. They regulate processes affecting air quality, climate, soil erosion, disease, and water purification. Non-material cultural benefits derived from ecosystems include spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences (Millennium Ecosystem Assessment, 2005). Research indicates that the short-term economic benefits from exploiting natural resources pale in comparison to the long-term loss of ecosystem services (Daily et al., 1997).

### New York City Watershed: Economic Benefits and Cost Savings of Protecting the Clean Water Supply

A case study in the Natural Resources Forum Journal (Postel & Thompson, 2005) captured how New York City was able to protect their drinking water source through a unique agreement that links ecosystem service providers and beneficiaries. The New York City case study demonstrates that watershed protection can be a highly cost-effective alternative to technological treatment in meeting water quality standards that can work for both upstream and downstream parties.

New York City was faced with building an estimated $6 billion filtration plant with an annual operating cost of $300 million to ensure compliance with the Safe Drinking Water Act. However, the City had the option of requesting a waiver if they could demonstrate that they can meet water quality standards through protection of their source watersheds. The City went through a long agreement-building process with the private landowners and communities within the Catskill-Delaware watersheds, which supply the City with 90% of its drinking water.

Terms of the agreement included that the City would not condemn any land through the state's health eminent domain process. The City would also purchase properties for their actual face value from willing sellers and pay taxes on the properties so that it would not erode the local tax revenues. The total amount of land purchased was estimated at $94 million, which doubled the area of the protected buffer. The overall investment was estimated to be $1 billion. The City also initiated other programs and a trust fund within the area to promote best management practices. These practices, along with the protected lands, increased property values, provided additional income, created healthier streams and habitats, and provided additional recreational opportunities. Future protection of this area will be dependent on population and development growth and any future regulations.

Watersheds are coupled social-ecological systems, meaning that the health and well-being of human societies are dependent on the health and well-being of the watersheds they live within, and vice versa (Bunch, Morrison, Parkes, & Venema, 2011). Key to maintaining this relationship is a diverse ecological and social structure, as well as the ability to adapt to the change and uncertainty characteristic of natural processes (Berkes, 2007). A systems approach for understanding social-ecological systems forms the backbone of sustainability science and modern-day adaptive management (Berkes & Folke, 2000). The healthy watersheds approach draws from and builds on this work to protect the ecological infrastructure that society depends on.

### The Economic Impact of Recreational Trout Angling in the Driftless Area

The Driftless Area is a 24,000 square-mile area that stretches across the boundaries of Minnesota, Iowa, Wisconsin, and Illinois. According to a study by Trout Unlimited and Northstar Economics (2008), direct spending of $647 million per year on recreational angling, plus a "ripple effect" of nearly $3,000 per angler, in the Driftless Area generates a $1.1 billion annual economic benefit to the local economy. The ripple effect is a result of the money spent by anglers flowing through the local economy, stimulating additional spending by local businesses. Trout Unlimited attributes these economic benefits to the natural potential of the Driftless Area streams, good land stewardship, public access, and wise investment in restoration. Trout fishing has very limited impact on natural resources. Anglers tend to treat the Driftless Area with respect, and many release the fish they catch back to the stream. It is clear that the thriving economy of the Driftless Area is at least partially supported by clean water, resilient streams, and healthy fish populations.

There are many economic benefits to protecting healthy watersheds, including the avoidance of expensive restoration activities. Healthy watersheds sustain water-related recreation opportunities, such as fishing, boating, and swimming, and provide hiking, birding, hunting, and ecotourism opportunities. Vulnerability to floods, fires, and other natural disasters is minimized, thereby reducing costs to communities. Healthy watersheds can also help to assure availability of sufficient amounts of water for human consumption and industrial uses. By protecting aquifer recharge zones and surface water sources, costs of drinking water treatment may be reduced. A survey of 27 drinking water utilities found that for every 10% increase in forest cover of the source area, chemical and treatment costs decrease by 20% (Ernst, 2004). The functions that healthy watersheds provide, and the benefits they create, are often taken for granted when they exist in natural systems, but are difficult and expensive to achieve when they must be reproduced (Table 1-2).

**Table 1-2** Estimated range of values for ecological services provided by healthy watersheds (Smith, de Groot, Perrot-Maître, & Bergkamp, 2006).

| Service Provided | Estimated Value ($/acre/year) |
|---|---|
| Drinking Water | $18 - $3,035 |
| Fisheries | $81 |
| Water quality control | $24 - $2,711 |
| Flood mitigation | $6 - $2,227 |
| Carbon sequestration | $53 - $109 |
| Recreation and tourism | $93 - $1,214 |

The recognition of climate change as a serious threat to ecosystem structure and function provides additional motivation to protect healthy watersheds. Natural vegetative cover (including forests, wetlands, and grasslands) sequesters large amounts of carbon, and the soil resources that this vegetation maintains can hold even larger amounts of carbon. Protection of these resources can help to mitigate increased carbon dioxide emissions (U.S. Environmental Protection Agency, 2011a).

Water is the primary medium through which climate change will be seen and felt. Both droughts and large storm events are expected to increase in frequency and severity in some parts of the country. Wetlands and forested areas have a profound effect on watershed hydrology, regulating flows during droughts and large storm events. This regulating function has far-reaching effects on provision of drinking water, flood reduction, and other natural hazard reductions. Protection of watershed processes can help to maintain and increase resilience to climate change (e.g., keeping ecosystems healthy can reduce management costs to sustain these benefits).

## 1.5 Purpose and Target Audience

The purpose of this document is to provide state water quality and aquatic resource scientists and managers with an overview of the key concepts behind the Healthy Watersheds Initiative, examples of approaches for assessing components of healthy watersheds, integrated assessment options for identifying healthy watersheds, examples of management approaches, and some assessment tools and sources of data. With this information, scientists and managers will be able to conduct healthy watersheds assessments and initiate protection programs. The results of healthy watersheds assessments can be used by local land use managers to inform protection priorities. This document is not a guide, nor does it provide step-by-step instructions, but it does identify example approaches and sources for scientists and managers to obtain detailed information on assessment methods and management tools. Finally, this document is not EPA program implementation guidance, but rather a resource that states and other entities may choose to use for assessing, identifying, and protecting healthy watersheds.

## 1.6 How Does the Healthy Watersheds Initiative and this Document Relate to What Others are Doing?

The book *Entering the Watershed* (Doppelt et al., 1993) outlines many of the concepts necessary for a truly holistic approach to riverine ecosystem protection. Since its publication, various aquatic ecosystem assessment approaches and protection strategies have been developed. Some of the many examples include the Ecological Limits of Hydrologic Alteration, The Nature Conservancy's Active River Area and Freshwater Ecoregional Assessments, Virginia's Conservation Lands Needs Assessment, Ohio's Primary Headwaters Habitat Assessment, and State Wildlife Action Plans (see Chapters 3 and 5). The Healthy Watersheds Initiative builds on this body of work. The integrated assessment approaches presented in Chapter 4 expand the value of other approaches by linking the assessments of biota, habitat, and functional processes together to evaluate aquatic ecosystem integrity within a watershed context. The Healthy Watersheds Initiative also includes strategic implementation of protection and restoration measures to maintain and increase the number of healthy watersheds. Many state agencies and other organizations are already implementing initiatives that are similar to the healthy watersheds approach, and this document highlights their projects as examples. Further, complementary approaches have also been adopted by other federal agencies. For example, along with the Association of Fish and Wildlife Agencies, the U.S. Fish and Wildlife Service and National Marine Fisheries Service developed and are implementing the National Fish Habitat Action Plan, which takes a holistic systems approach to protecting and restoring fish habitat (Association of Fish and Wildlife Agencies, 2006). Also, the U.S. Forest Service developed the Watershed Condition Framework, which employs an integrated, systems-based approach for classifying watershed condition based on an evaluation of the underlying ecological, hydrologic, and geomorphic functions and processes (U.S. Forest Service, 2011). The U.S. Forest Service is using the results of a national reconnaissance-level assessment of watershed condition, based on the Framework, to identify high priority watersheds on national forests and grasslands for restoration starting with the "best" watersheds first.

## 1.7 How to Use this Document

Every organization has a unique combination of strengths in aquatic ecosystem assessment and protection. Many have solid grounding in the field of water quality, while others have strengths in landscape ecology or biodiversity conservation. This document should be used as a reference for expanding capabilities beyond a specific area of expertise to include a holistic approach for identifying and protecting healthy watersheds. It is recommended that all users read Chapter 2 to familiarize or refresh themselves with the concepts underlying the Healthy Watersheds Initiative. Chapter 3 provides examples of assessment approaches in use across the country, and Chapter 4 provides examples of ways in which integrated assessments can be conducted and used to identify healthy watersheds and set protection priorities. Chapter 5 presents some of the many management approaches that can be used at the national, state, or local level to protect healthy watersheds. Appendix A contains assessment tools, Appendix B identifies sources of data, and Appendix C includes a compilation of resources and sources of information mentioned in this document for use in assessing and protecting healthy watersheds. Readers can navigate between these chapters depending on their needs and priorities.

# 2. Key Concepts and Assessment Approaches

**1**

## 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.

**2**

## 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.

**3**

## 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.

**4**

## 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.

**5**

## 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.

## 2.1 A Systems Approach to Watershed Protection

The healthy watersheds conceptual framework is based on a holistic systems approach to watershed assessment and protection that recognizes the dynamics and interconnectedness of aquatic ecosystems. Maintenance of aquatic ecological integrity requires that we understand not only the biological, chemical, and physical condition of water bodies, but also landscape condition and critical watershed attributes and functions, such as hydrology, geomorphology, and natural disturbance patterns.

Watersheds provide a useful context for managing aquatic ecosystems. Rivers, lakes, wetlands, and ground water are sinks into which water and materials from the surrounding landscape drain (U.S. EPA Science Advisory Board, 2002). Landform, hydrology, and geomorphic processes generate and maintain freshwater ecosystem characteristics, including stream channel habitat structure, organic matter inputs, riparian soils, productivity, and invertebrate community composition (Montgomery & Buffington, 1998; Vannote, Minshall, Cummins, Sedell, & Cushing, 1980). Consequently, the ecosystem protection approaches described in this document focus on assessing and managing landscape conditions, including connectivity, and key functional processes in the watershed of which the aquatic ecosystem is a part and cannot function without. These processes are hierarchically nested and occur at multiple spatiotemporal scales (Beechie et al., 2010) (Figure 2-1). Therefore, assessment and management must also occur at multiple spatial and temporal scales.

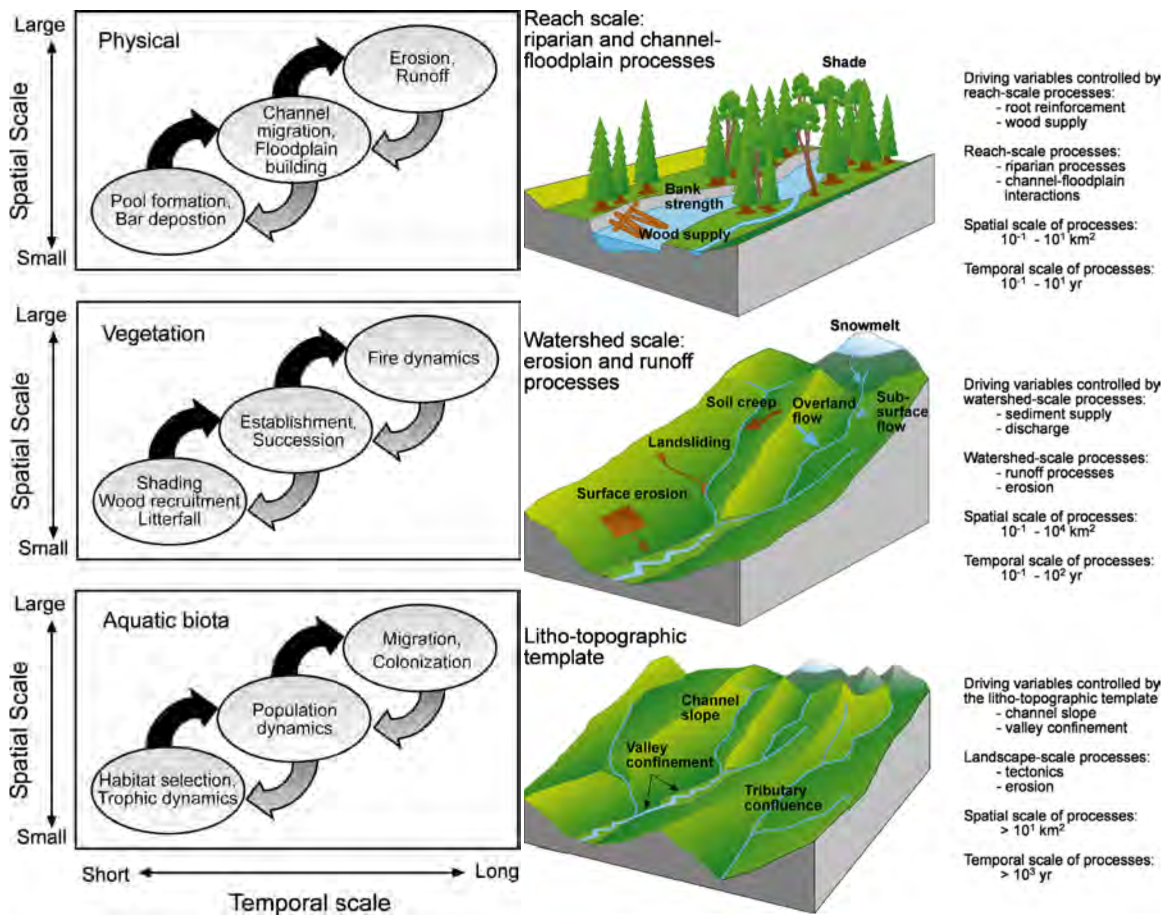



**Figure 2-1** Spatial and temporal scales of watershed processes. Watershed and ecosystem processes operate at a variety of spatial and temporal scales, with processes operating at larger spatial scales generally influencing processes operating at smaller scales. In some instances, processes operating at smaller scales may also influence processes operating at larger spatial scales. This is perhaps best illustrated in fishes, where processes such as habitat selection and competition influence survival of individuals, which influences population dynamics at the next larger space and time scale (Beechie et al., 2010). Reprinted with permission of University of California Press.

Although EPA's watershed approach has traditionally focused primarily on the management of the chemical, physical, and some biological aspects of water quality, the importance of pattern, connectivity, and process for integrated management of watershed health is emerging (e.g., California's Healthy Streams Partnership and Virginia's Healthy Waters Program). Assessments of landscape condition, hydrology, geomorphic condition, and natural disturbance regimes provide complementary information to the chemical, physical, and biological parameters commonly measured by water quality monitoring programs. Integrating the results of all of these assessment approaches can help to provide a more comprehensive understanding of aquatic ecosystem health.

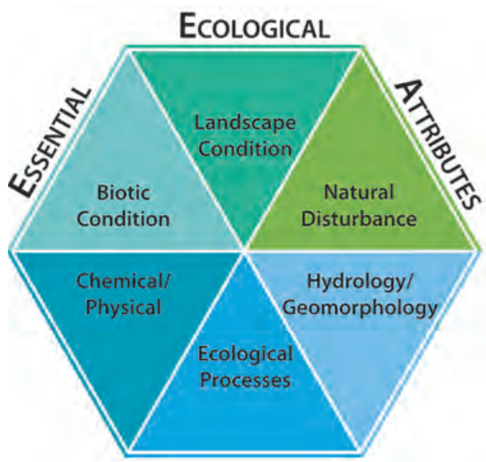



**Figure 2-3** Essential ecological attributes (U.S. EPA Science Advisory Board, 2002).

The healthy watersheds conceptual framework is consistent with recommendations by EPA's Science Advisory Board (SAB) (U.S. EPA Science Advisory Board, 2002). Building on previous work to describe aquatic resource integrity (Figure 2-2), the EPA SAB identified six essential ecological attributes (EEAs) to describe factors that support healthy ecosystems (Figure 2-3). These include landscape condition, biotic condition, chemical and physical characteristics, ecological

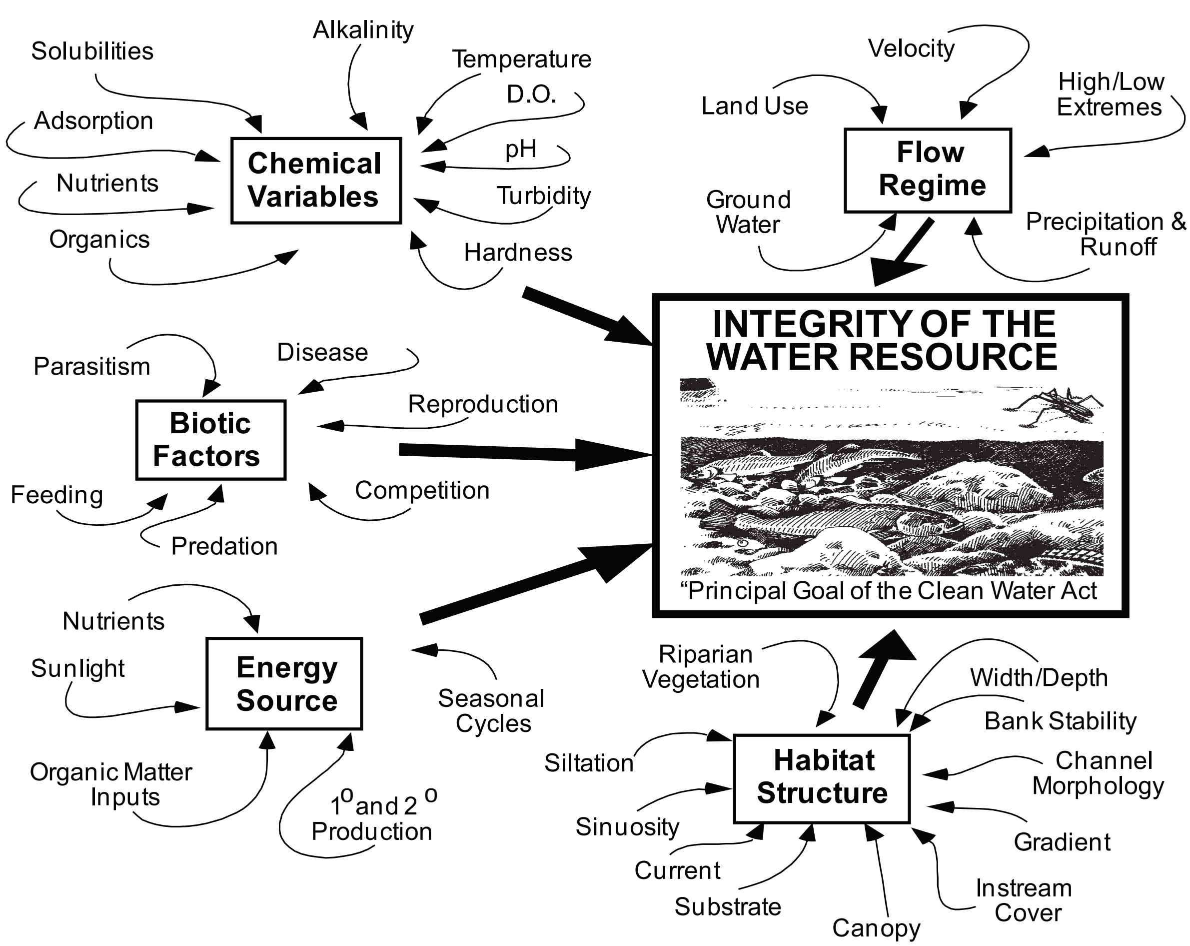



**Figure 2-2** The five major factors that determine integrity of the aquatic resource (modified from Karr, Fausch, Angermeier, Yant, & Schlosser, 1986).

elements (e.g., energy and material flow), hydrologic and geomorphic condition, and natural disturbance regimes. The healthy watersheds concept views watersheds as integral systems that can be understood through the dynamics of these essential ecological attributes.

The systems approach to healthy watersheds assessment and protection is based on an integrated evaluation of: 1) Landscape Condition, 2) Habitat, 3) Hydrology, 4) Geomorphology, 5) Water Quality, and 6) Biological Condition (Figure 2-4). Ecological processes and natural disturbance regimes are addressed in the context of these six components. Background information on each of these components is provided in the pages that follow.

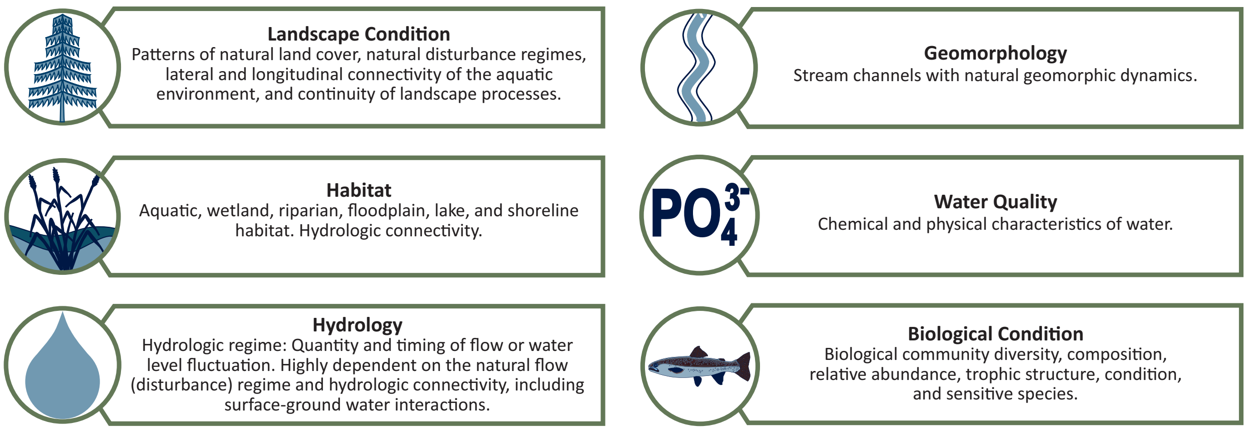



**Figure 2-4** Healthy watersheds assessment components.

## 2.2 Landscape Condition

Natural vegetative cover stabilizes soil, regulates watershed hydrology, and provides habitat to terrestrial and riparian species. The type, quantity, and structure of the natural vegetation within a watershed have important influences on aquatic habitats. Land cover is a driving factor in determining the hydrologic and chemical characteristics of a water body. Vegetated landscapes cycle nutrients, retain sediments, and regulate surface and ground water hydrology. Riparian forests regulate temperature, shading, and input of organic matter to headwater streams (Committee on Hydrologic Impacts of Forest Management, National Research Council, 2008). Conversely, agricultural and urban landscapes serve as net exporters of sediment and nutrients, while increasing surface runoff and decreasing infiltration to ground water stores.

Recognition of these landscape influences has shaped previous aquatic ecosystem management efforts. Adequate protection of a range of aquatic ecosystem types is a widely accepted conservation approach (Noss, LaRoe III, & Scott, 1995). The Center for Watershed Protection (2008c) recommends conservation of multiple landscape areas: 1) critical habitats; 2) aquatic corridors; 3) undeveloped areas, such as forests, which help maintain the pre-development hydrologic response of a watershed; 4) buffers to separate water pollution hazards from aquatic resources; and 5) cultural areas that sustain both aquatic and terrestrial ecosystems.

It is important that forest patches, wetlands, and riparian zones are of sufficient size, quantity, and quality to sustain ecological communities and processes. Interconnections among habitat patches are also important. For many species, an isolated forest patch is not a high quality habitat. However, a number of forest patches interconnected by forested corridors can provide outstanding habitat for a number of species. This is because species need to migrate, feed, reproduce, and ensure genetic diversification. Native habitat in the landscape provides a variety of benefits for aquatic ecological integrity, including maintenance of the natural watershed hydrology, soil and nutrient retention, preservation of habitat for both aquatic and terrestrial species, and the prevention of other adverse impacts associated with development. The photos in Figure 2-5 illustrate the difference between intact habitat in the landscape and fragmented habitat.


**Figure 2-5** These photos provide an example of intact landscape condition (on the left) and fragmented landscape condition (on the right).

## 2.2.1 Green Infrastructure

The concept of linked landscape elements and ecological networks has evolved into the green infrastructure movement in land conservation. Green infrastructure is "an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife" (Benedict & McMahon, 2006). The natural areas are typically referred to as "hubs," and the connections, or links, between the hubs are termed "corridors" (Figure 2-6). The green infrastructure movement is rooted in: 1) Frederick Law Olmsted's idea of linking parks for the benefit of people (e.g., Boston's famous Emerald Necklace) and 2) the recognition by wildlife biologists and ecologists that interconnected habitat patches are essential for maintaining viable ecological communities (Benedict & McMahon, 2002). The evolution of the green infrastructure movement has coincided with the development of geographic information system (GIS) technology and conceptual developments in landscape ecology and conservation biology.

The green infrastructure approach considers open and green space as a system to be managed to meet the needs of both ecosystems and humans. It can provide information to assist community planning, and to identify and prioritize conservation opportunities. It can be mapped as a network of key ecological areas, or hubs, and corridors connecting them. For example, the Green Infrastructure Vision of Chicago Wilderness identifies 1.8 million acres of potential areas for protection and restoration throughout the region (Figure 2-7; Chicago Wilderness, 2009).

The greenways movement, an evolution of Olmsted's idea, has influenced green infrastructure considerably, linking people with their landscape through recreational activities. Greenways are recreational and alternative transportation corridors surrounded by vegetation. An example of a popular greenway approach is the Rails-to-Trails Conservancy's acquisition of abandoned railways to create bike paths for local transportation and recreation. Green infrastructure is different from greenways in that green infrastructure emphasizes ecology over recreation. Further, green infrastructure focuses on large, ecologically important hubs and planning for growth around the green infrastructure, as opposed to "fitting"

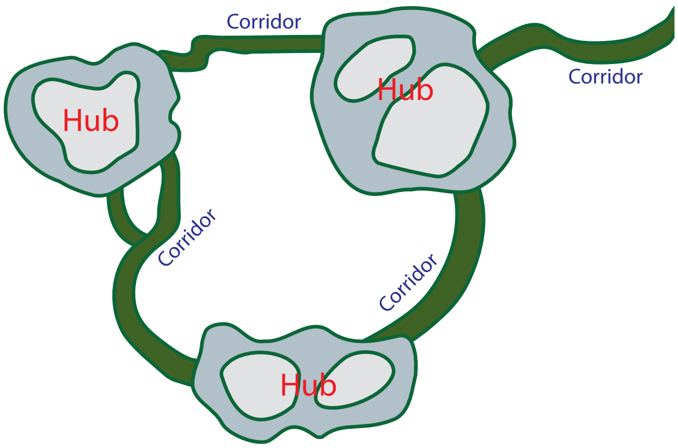



**Figure 2-6** Green infrastructure network design (modified from Maryland Department of Natural Resources, 2011).


**Figure 2-7** Map of the Chicagoland area showing land cover and currently protected areas (Chicago Wilderness, 2009).

conservation areas into developed landscapes (Benedict & McMahon, 2002). Identification of hubs in a green infrastructure program typically involves a land cover and human infrastructure assessment to identify interior habitat patches, which are areas of forest or wetland that have not been fragmented by roads or other development. These hubs often serve as core habitat for a number of species. The links, or corridors, between these hubs provide opportunities for movement of fauna and flora between the habitat patches, thus allowing for dispersal and genetic diversity, which are essential for ecological integrity.

The 1990s saw the development of a number of green infrastructure programs, the most notable of which were in Florida and Maryland (Benedict & McMahon, 2006). Ecologists Larry Harris and Reed Noss at the University of Florida conceptualized an integrated habitat conservation system to address the fragmentation of natural areas that they saw as the primary cause of biodiversity decline across the state (Benedict & McMahon, 2006). This vision led to the development of Florida's Ecological Network Project and, later, the Southeastern Ecological Framework Project, the first regionally-based green infrastructure study (John Richardson, EPA Region 4, Personal Communication). Maryland's green infrastructure assessment built off of the success of these pioneering programs (John Richardson, EPA Region 4, Personal Communication). These programs also drew upon work by The Nature Conservancy on an ecoregional approach to selecting wildlife reserves (Benedict & McMahon, 2006). The original green infrastructure approaches contain five basic steps, as outlined by Benedict and McMahon (2006):

1. Develop network design goals and identify desired features.
2. Gather and process data on landscape types.
3. Identify and connect network elements.
4. Set priorities for conservation action.
5. Seek review and input.

Green infrastructure assessments utilize a weighted overlay technique in GIS that identifies the most ecologically valuable lands based on co-occurrence of multiple ecological attributes. For example, creating a map that overlays the state's road network with land cover data allows one to identify those areas with remaining natural land cover that contain the fewest road crossings. Additional data layers can be added to this analysis, with each layer weighted according to the importance of its features for ecological integrity. The final result is a map that shows the areas with the highest priority for conservation. This approach has been replicated and modified for use in a number of states, local communities, and regions throughout the United States.

### 2.2.2 Rivers as Landscape Elements

Although the term landscape implies a focus on terrestrial features, aquatic systems are just as much landscape elements as forested patches and corridors (Wiens, 2002). Rivers interact with other landscape elements over time through their natural floodplains, migrating meander belts, and riparian wetlands (Smith, Schiff, Olivero, & MacBroom, 2008). Natural hydrology provides connectivity among aquatic habitats and between terrestrial and aquatic elements. Many aquatic organisms depend on being able to move through connected systems to habitats in response to variable environmental conditions. Forested riparian zones are often some of the best remaining green infrastructure links, or corridors, for connecting hubs on the landscape. Furthermore, maintenance of natural land cover protects aquatic ecosystems from nonpoint sources of pollution, including urban and agricultural runoff.

Recognizing the importance of connectivity, The Nature Conservancy advocates a systems approach to river protection, exemplified by the Active River Area (Figure 2-8), which includes not only the river channel but also floodplains, riparian wetlands, and other parts of the river corridor where key habitats and processes occur (Smith et al., 2008). The Active River Area concept can be applied at different scales, from basin to catchment or reach. For example, identification of intact riparian areas and headwaters in the Connecticut River Basin was accomplished using standard GIS techniques, available models, and national datasets (Smith et al., 2008). A more detailed analysis, using techniques such as Vermont's Stream Geomorphic Assessment protocols (see Chapter 3), can then be used to identify specific conservation priorities on a subwatershed scale.

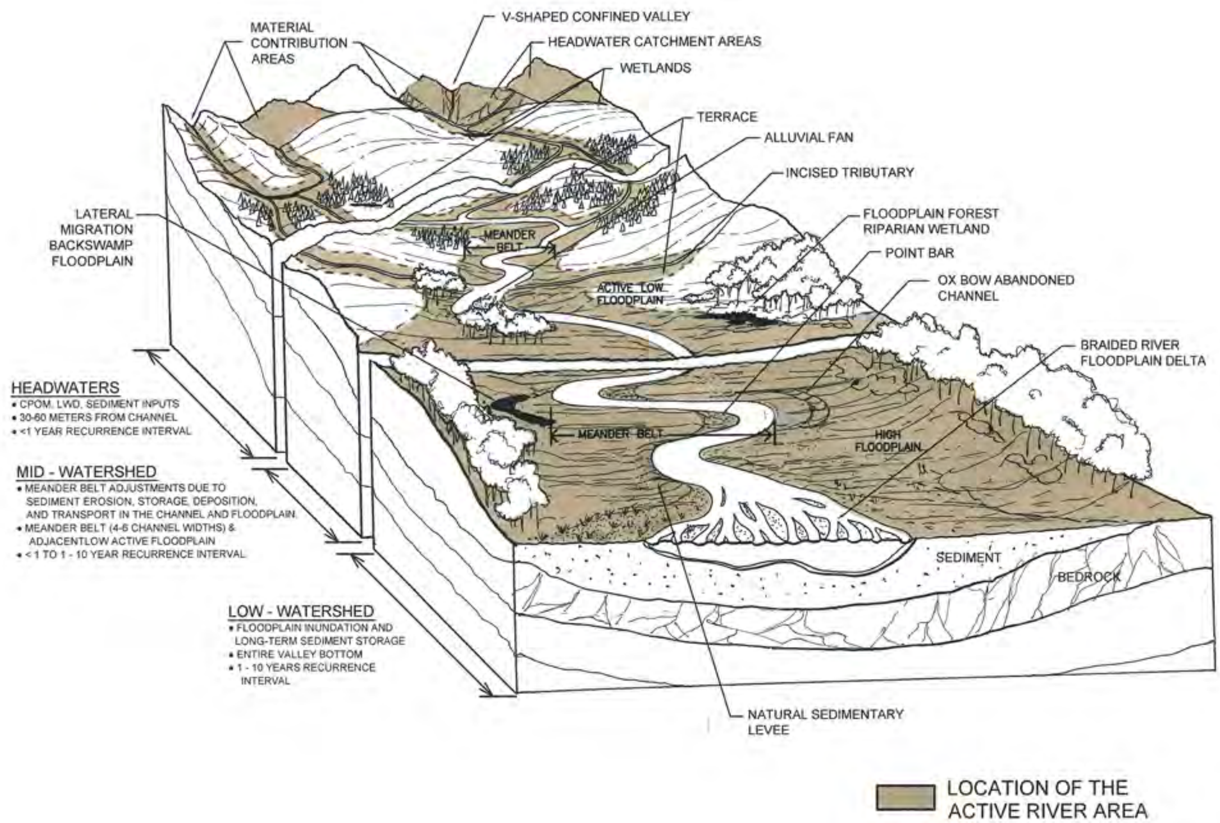



**Figure 2-8** Components and dominant processes of the Active River Area (Smith et al., 2008).

Active River Areas, in their natural state, maintain the ecological integrity of rivers, streams, and riparian areas and the connection of those areas to the local ground water system. They also provide a variety of ecosystem services, such as flood prevention and hazard avoidance, recreation and open space, and other habitat values. The Active River Area is essential to healthy and productive fish populations. Preserving riparian wetlands and a river channel's connection with its floodplain provides surface and subsurface floodwater storage and reduces stream power during flood events. This is especially important in temperate regions, where increases in average annual precipitation and frequency of extreme storm events have been observed and are expected to continue as a result of climate change (IPCC, 2007). Also, warming temperatures will increase the importance of these undeveloped areas as zones of ground water discharge provide refugia for coldwater aquatic species. Maintaining natural vegetation in the entire Active River Area and in the wider watershed provides water quality improvements through reduced surface runoff and increased opportunity for ground water infiltration and storage.

## 2.2.3 Natural Disturbance

The natural disturbance regime is an important consideration in assessment and management of landscape condition. Ecosystems are naturally dynamic and depend on recurrent disturbances to maintain their health. Natural disturbance events that affect watershed ecosystems include fires, floods, droughts, landslides, and debris flows. The frequency, intensity, extent, and duration of the events are collectively referred to as the disturbance regime (U.S. EPA Science Advisory Board, 2002). The natural fire regime, particularly in some regions of the United States (e.g., longleaf pine/flatwoods ecosystems of the southeast), helps to maintain healthy landscape condition through a process of ecological renewal that creates opportunities for some species while scaling back the prevalence of others. Fire dependant ecosystems require this periodic disturbance to maintain their natural state and composition. Suppression of the natural fire regime may cause an excessive build-up of nutrients on the forest floor due to decomposition of organic matter (Miller et al., 2006). These nutrients can then be transported to aquatic ecosystems during rainfall/runoff events, causing eutrophic conditions. Fire disturbances of natural frequency and intensity remove the excess organic matter causing the nutrient build-up and may actually improve long-term water quality, although water quality will be temporarily worsened immediately following a fire (Miller et al., 2006). The Fire Regime Condition Class methodology is an example of a landscape condition assessment that focuses on the natural disturbance regime (see Chapter 3). This approach assesses a landscape's degree of departure from the natural fire regime and suggests management approaches for emulating that regime.

### 2.2.4 Connectivity and Redundancy

Connectivity of landscape elements, including aquatic ecosystems, provides organisms with access to the habitats and resources necessary for the different stages of their life cycle (e.g., breeding, feeding, nesting). It also helps to ensure that ecosystems and species have the ability to recover and recolonize following disturbance (Poiani, Richter, Anderson, & Richter, 2000). Lateral (floodplain access), vertical (hyporheic exchange), and longitudinal (stream flow) connectivity are equally important for supporting these processes. Physical barriers, such as dams and levees, isolate aquatic populations and prevent dispersal of organisms (Frissel, Poff, & Jensen, 2001). Further, these barriers prevent the flow of water, sediment, nutrients, and heat loads that support ecosystem processes (Frissel, Poff, & Jensen, 2001). As a result, non-native species are often better able to compete with native species (Frissel, Poff, & Jensen, 2001). Connectivity is therefore critical to ensuring the persistence of native species by providing habitat refugia and recolonization access. Redundancy refers to the presence of multiple examples of functionally similar habitat and ecosystem types that help to "spread the risk" of species loss following major ecological disturbances. This can allow populations of the same species to persist in the presence of disturbance or environmental change.

## 2.3 Habitat

Habitat extent is directly related to hydrologic and geomorphic processes. The number and distribution of different habitat types, or patches, and their connectivity influence species population health (Committee on Hydrologic Impacts of Forest Management, National Research Council, 2008). Habitat quality is also affected by the physical and chemical characteristics of water (e.g., water temperature). Water quality and geomorphic and hydrologic processes are all affected by landscape condition, which also shapes riparian and terrestrial habitat. Thus, habitat condition serves as an integrating indicator of other watershed variables, upon which biological condition is highly dependent.

Protection efforts must consider a variety of habitat types that serve different needs of an ecosystem, such as cool water rivers for trout foraging (Figure 2-9), riffles in cold headwater streams for breeding, and springs for thermal refuge during low water conditions (Montgomery & Buffington, 1998). In addition, natural variability within a habitat patch provides opportunities for species with different requirements and tolerances (Aber et al., 2000).


**Figure 2-9** Cool water rivers provide important trout foraging habitat.

### 2.3.1 Fluvial Habitat

Hydrologic and geomorphic processes create the physical habitat template that supports aquatic communities in fluvial systems. As described by the River Continuum Concept (RCC), physical habitat variables can change predictably along the longitudinal gradient of the riverine system (Figure 2-10) (Vannote et al., 1980). Changes in biological communities generally correspond with this physical gradient. For example, a characteristic community of macroinvertebrates (dominated by shredders and collectors) is typically found in headwater

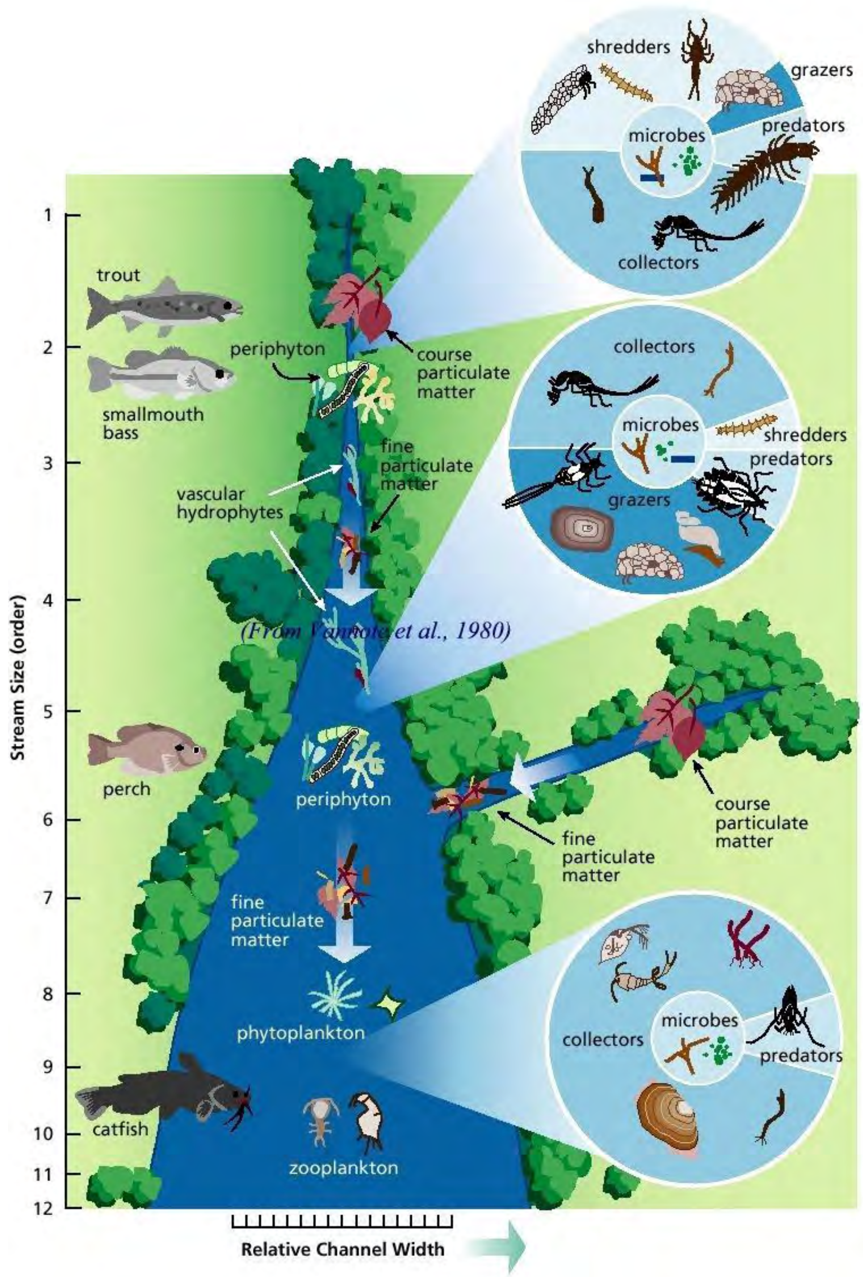



**Figure 2-10** The River Continuum Concept (Vannote et al., 1980). © 2008 NRC Canada.

streams. These species are dependent on sufficient shade and inputs of terrestrial vegetation (e.g., large woody debris) from riparian areas. As a stream channel widens, allowing more sunlight to penetrate into the open water, algae and rooted vascular plants become the primary sources of energy input, and the macroinvertebrate community reflects this transition (dominated by collectors and grazers). As a river becomes larger and wider, fine particulate matter from upstream becomes more important as an energy source for the macroinvertebrate community (dominated by collectors).

This predictable change in community structure has been shown to be generally true at broad scales. However, the influence of tributary confluences and watershed disturbances on aquatic habitat must be understood to explain the many deviations from the habitat type and expected biological community predicted by the River Continuum Concept. Inputs of sediment and large woody debris at river confluences create habitat heterogeneity, allowing for the existence of communities that would not otherwise be expected to occur in a given stream order. Additionally, flood pulses and other aspects of the natural flow regime create a lateral and temporal gradient of habitat from the stream channel and out on to the floodplain. Ground water input in the hyporheic zone also creates unique habitats that cannot be explained from a purely longitudinal perspective of riverine habitat. This inherent complexity of riverine ecosystems is responsible for the diversity of aquatic habitats and resultant biological communities found within them.

Understanding riverine ecosystems in a landscape context can help to elucidate the complex relationships that define aquatic habitat. The RCC conceptual model has been improved upon in recent years to include not only the longitudinal dimension of river systems, but also the lateral (floodplain and riparian zone), vertical (hyporheic zone), and temporal (flow regime) dimensions (Thorp, Thoms, & DeLong, 2006). The Riverine Ecosystem Synthesis (RES) (Thorp, Thoms, & Delong, 2008) builds on the RCC and other leading concepts in river ecology to explain the spatial and temporal distribution of species, communities, and ecosystem processes as a function of hydrogeomorphic differences in the riverine landscape. Heterogeneous patches of habitat result from unique combinations of hydrologic and geomorphic processes, including the dynamics of watershed disturbance and the structure of the river network within a watershed. The geomorphic, hydrologic, and ecological processes that form these patches operate at a variety of scales. Thus, hydrogeomorphic patches exist at multiple spatial and temporal scales, such as drainage basins or watersheds, functional process zones (FPZ), reaches, functional units, and individual habitats (Thorp, Thoms, & DeLong, 2006) (Figure 2-11). Hierarchically-organized units, such as watersheds, are most affected by the scale immediately below that of interest and the scale immediately above it (Thorp, Thoms, & Delong, 2008). As FPZs are the level immediately below watersheds or basins, they are an appropriate scale for integrated watershed assessments and receive special attention in the RES. These FPZs are not necessarily distributed in a manner predictable by longitudinal theories of river ecology, such as the RCC (Figure 2-12). Rather, all four dimensions of the riverine system influence their distribution.

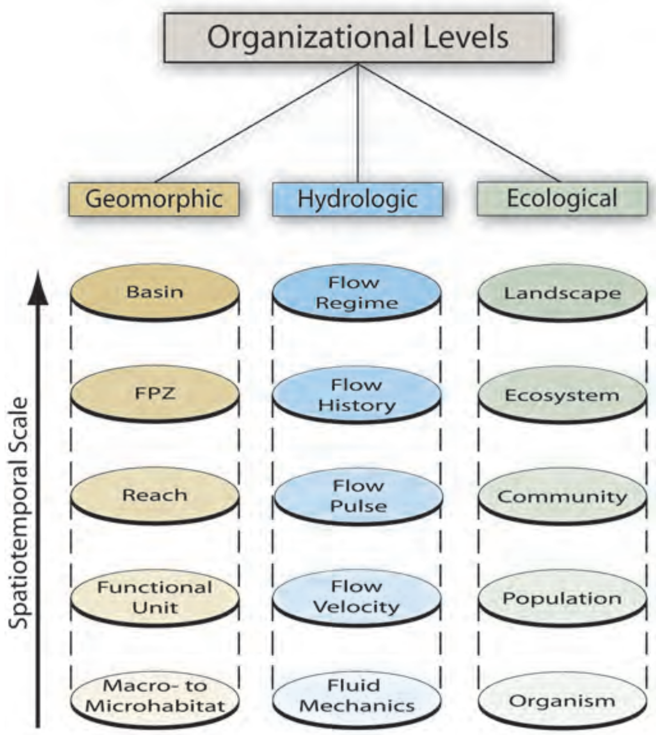



**Figure 2-11** Hierarchy defining spatiotemporal scales of hydrogeomorphic patches (Thorp, Thoms, & Delong, 2008). Reprinted with permission of Elsevier.

Through a collaborative effort, EPA and the University of Kansas developed a computer program that statistically delineates FPZs using precipitation, geology, elevation, and remote sensing data. The program extracts 14 hydrogeomorphic variables from these datasets and uses multivariate cluster analysis to identify the distinct FPZ types. This approach minimizes human bias in the classification. See Figure 2-13 for an example of the various FPZs delineated in the Kanawha River Basin of West Virginia.

Stratifying a field sampling program based on FPZs can be a useful method for ensuring that scale is adequately considered in the data collection process. Data can be collected at reaches within each FPZ and averaged to get a condition score for the FPZ. FPZs can then be compared across the watershed to understand watershed condition. Important habitat variables at the reach scale (and smaller) include substrate composition and riparian vegetation, both of which are dependent on processes operating at larger scales.

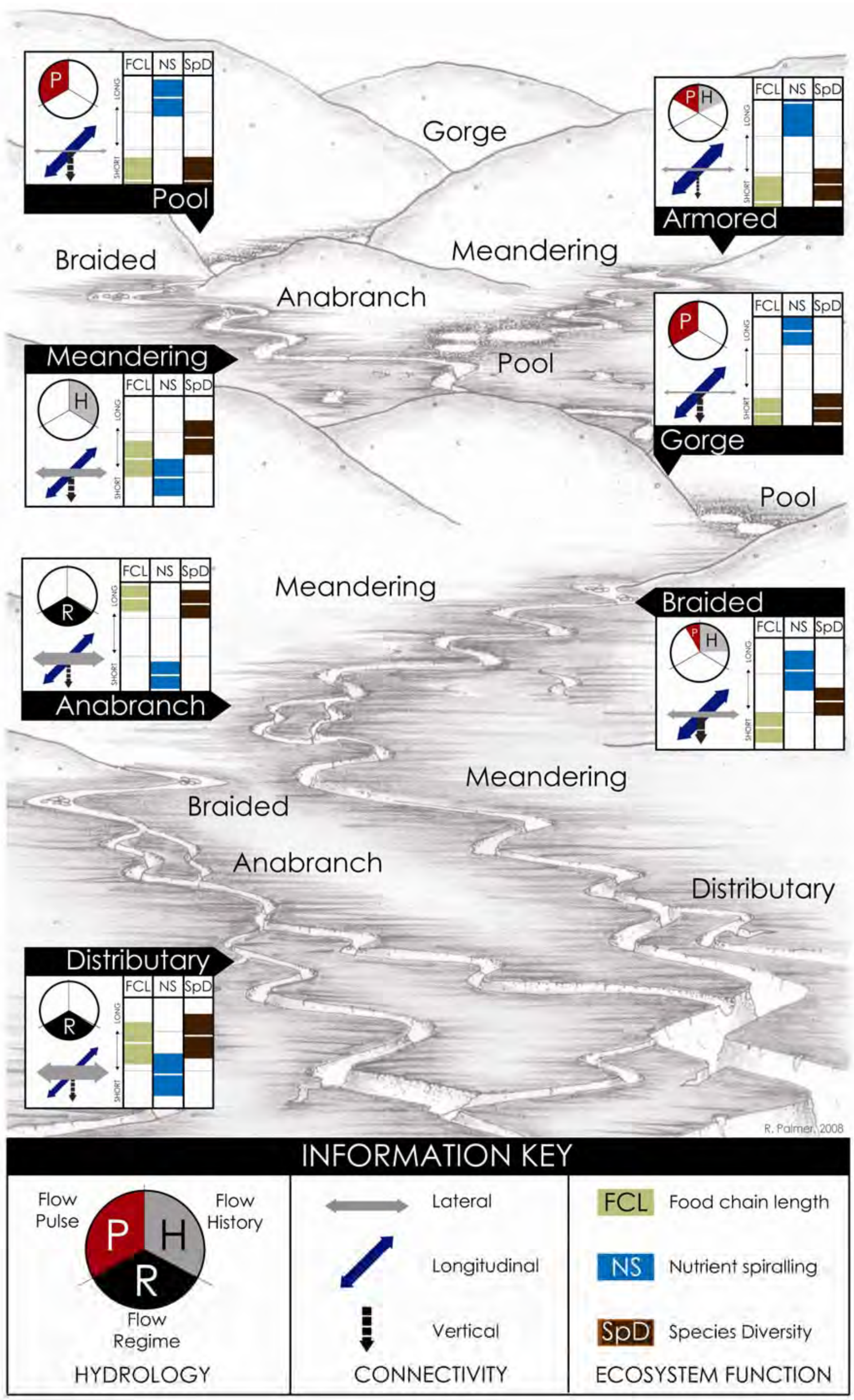



**Figure 2-12** A conceptual riverine landscape is shown depicting various functional process zones (FPZ) and their possible arrangement in the longitudinal dimension. Note that FPZs are repeatable and only partially predictable in location (corrected copy from Thorp, Thoms, & Delong, 2008). Reprinted with permission of Elsevier.

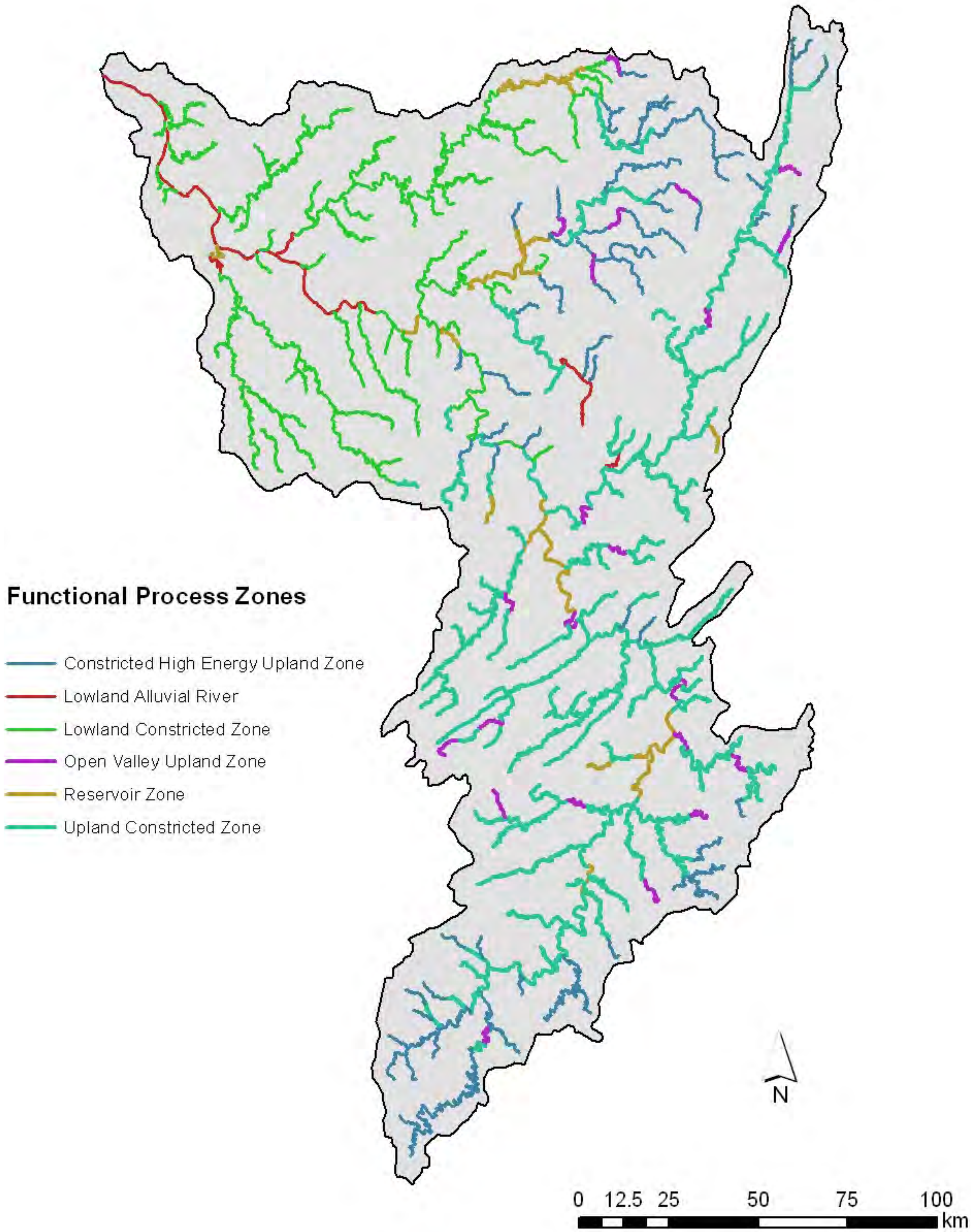



**Figure 2-13** Distribution of the various Functional Process Zones in the Kanawha River, West Virginia (from in-review manuscript by J.H. Thorp, J.E. Flotemersch, B.S. Williams, and L.A. Gabanski entitled "Critical role for hierarchical geospatial analyses in the design of fluvial research, assessment, and management").

Headwater streams represent more than half of the nation's stream miles and are fundamental to a healthy watershed. Properly functioning headwater streams are one of the primary determinants of downstream flow, water quality, and biological communities (Cohen, 1997). Headwater streams provide sediment, nutrient, and flood control and help to maintain base flow in larger rivers downstream. They support macroinvertebrate, amphibian, and plant populations that contribute to regional and local biodiversity.

Riparian zones are strongly influenced by the flow regime of a river, as well as the geomorphology of the river network, including the river banks and floodplain elevations. Riparian zones provide organic material as input to the riverine system, providing both energy and habitat to stream dwelling organisms. Riparian vegetation stabilizes the banks of the river channel and provides important nutrient and mineral cycling functions (Mitsch & Gosselink, 2007). Riparian habitats support diverse plant and animal species that provide important ecological functions and also regulate inputs to the aquatic system. These unique habitats require hydrologic connectivity with the river channel to be maintained.

Substrate composition is a physical habitat variable that is highly dependent on flow, geomorphic stability, and sediment inputs from the watershed. Many macroinvertebrates and aquatic plants require specific substrates for attachment and anchoring, while fish use cobble and boulders for shelter from currents and predators. Some fish species lay their eggs, which require unrestricted flow of well-oxygenated water, in gravel substrates. When these gravel substrates become embedded in finer sediment, the eggs do not have access to sufficient oxygen and die.

### 2.3.2 Lake Habitat

Lakeshores also have riparian zones that serve as a source of organic material to the lake's aquatic habitat and stabilize the lake's perimeter. Lakeshore vegetation creates stable habitat conditions in the peripheral waters of a lake by buffering it from exposure to environmental elements such as wind and sunlight. EPA's National Lakes Assessment (NLA) indentified poor lakeshore habitat as the most prominent stressor to the biological health of lakes (U.S. Environmental Protection Agency, 2009a).

Lakes are typically thought of as having three habitat zones: the littoral zone, the limnetic zone, and the benthic zone (Figure 2-14). The littoral zone is the nearshore area where sufficient sunlight reaches the substrate, allowing aquatic plants to grow. This zone provides habitat for fish, invertebrates, and other aquatic organisms. The limnetic zone is the open water area where light does not penetrate to the substrate. Although rooted aquatic plants cannot live in this zone, plankton and nekton are found here and serve as sources of food for many fish species. Habitat in the benthic zone (the lake bottom) consists of mostly mud and sand, which can support diverse invertebrate and algal communities, which in turn serve as primary food sources for many fish and other vertebrates.

The three lake habitat zones are tightly coupled, with organic matter from the limnetic zone serving as an important food source for animals in the benthic zone and many organisms spending different parts of their life cycles in different zones. Many fish species, for example, spend their time in the limnetic zone as juveniles, taking advantage of the abundant plankton found there. As they grow, they shift to feeding in the benthic zone and may spend their nights in the littoral zone, while other species may spend the day in the near shore zone and the night in the limnetic zone.

Lakes with greater, and more varied, shallow water habitat are able to more effectively support aquatic life (U.S. Environmental Protection Agency, 2009). Lakeshore habitat is strongly influenced by natural fluctuations in lake levels, with characteristic plant communities existing in the transition zone where the water rises and recedes. The natural fluctuation helps to prevent establishment of invasive species that are not adapted to such fluctuations and provides seasonal cues for reproduction of native species. Lake level fluctuation is influenced by ground water inputs, precipitation, evaporation, and runoff from storm events or snowmelt. Like riverine habitats, the physical and chemical characteristics of the water also contribute to the quality of a lake's aquatic habitat.

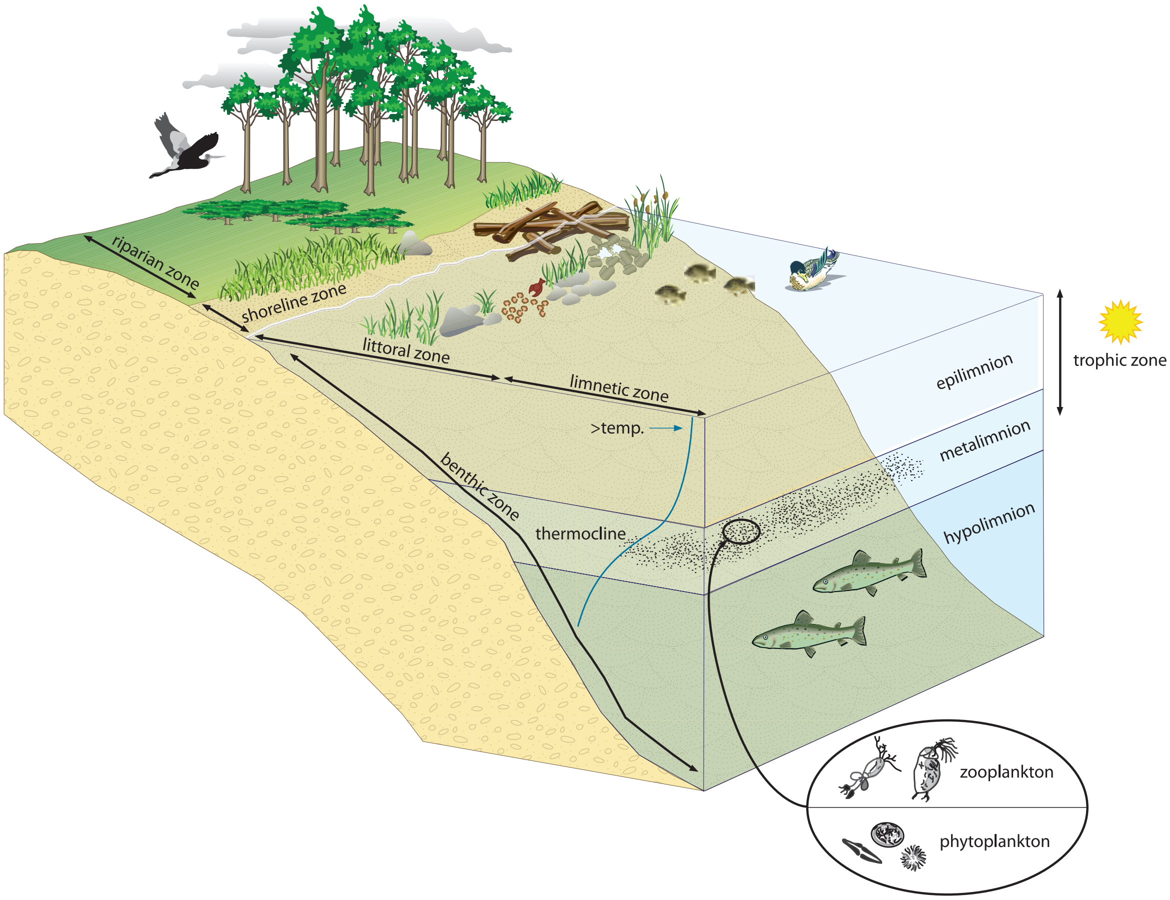



**Figure 2-14** Schematic of a lakeshore and the three habitat zones of a typical lake (U.S. Environmental Protection Agency, 2009a).

## 2.3.3 Wetland Habitat

Wetland habitat characteristics are largely affected by their hydrologic connectivity to surrounding landscape features. The hydrogeomorphic wetland classification and assessment approach defines seven types of wetlands based on their geomorphic setting and dominant water sources: *riverine* wetlands primarily receive overbank flow from the stream channel, *depressional* wetlands receive return inflow from ground water and interflow, *slope* wetlands receive return inflow from ground water, *mineral soil flats* and *organic soil flats* primarily receive inputs from precipitation, *estuarine fringe* wetlands receive their water from overbank flows from the estuary, and *lacustrine fringe* wetlands receive their water primarily from overbank flows from lakes (Smith, Ammann, Bartoldus, and Brinson, 1995).

The biological communities that occur in wetlands are uniquely adapted to their environmental conditions because wetland habitats offer essential resources in limited forms and quantities. Soil saturation reduces the availability of oxygen to plants, and nutrient availability is low in some wetland types because decomposition rates are slowed in these low-oxygen conditions. Bogs, in particular, are characterized by their low nutrient concentrations. In other wetlands, the combination of shallow water, high levels of nutrients, and primary productivity is ideal for the development of organisms that form the base of the food web and feed many species of fish, amphibians, shellfish, and insects. Many species of birds and mammals also rely on wetlands for food, water, and shelter, especially during migration and breeding. Variations in the biological communities of different wetland types provide unique habitat structures. For example, swamp communities are dominated by woody vegetation, whereas marshes are dominated by herbaceous vegetation. More than one third of the United States' threatened and endangered species live only in wetlands, and nearly half use wetlands at some point in their lives (U.S. Environmental Protection Agency, 1995).

# 2.4 Hydrology

Watershed hydrology is driven by climatic processes; surface and subsurface characteristics, such as topography, vegetation, and geology; and human processes, such as water and land use. A watershed can be thought of as a surface catchment (drainage basin) plus a subsurface catchment. A drainage basin can be defined as the surface area that, on the basis of topography, contributes all the runoff that passes through a given cross section of a stream (Dingham, 2002). Drainage that occurs via subsurface flow, controlled by hydrogeology, is called the subsurface catchment (Kraemer et al., 2000). Precipitation that falls within the watershed can be stored on the land surface (e.g., lakes or wetlands), infiltrate to the subsurface, move as overland flow to stream channels, or be lost to evapotranspiration. Ground water can also enter and exit a watershed via inflow and outflow through aquifers that extend beyond the surface catchment. Rain and snowmelt produce runoff that moves through a variety of surface and subsurface pathways as it flows through the drainage network, eventually exiting the watershed via stream or ground water flow.

An important conceptual framework for understanding and evaluating watershed structure and function is the water budget (see Appendix A). A water budget can be developed for any hydrologic feature and accounts for all water inputs and outputs. A watershed scale water budget includes the following components:

$$P + Gin - (Q + ET + Gout) = \Delta S,$$

where P is precipitation, $G_{in}$ is ground water inflow to the watershed, Q is stream outflow, ET is evapotranspiration, $G_{out}$ is ground water outflow from the watershed and $\Delta S$ is change in storage over time.

Spatial and temporal variation in evapotranspiration, infiltration, and overland flow is determined by the size of the watershed, the surface topography and vegetation, the underlying geology, climatic conditions, and water and land uses. Small watersheds are more dynamic than large watersheds, responding more rapidly to inputs from precipitation. Hydrographs for streams dominated by snowmelt and base flow follow a more predictable pattern than those for streams dominated by surface runoff (Healy, Winter, LaBaugh, & Franke, 2007). Surface and ground water interact in a variety of ways. Overland flow to surface waters results from both saturation-excess and infiltration-excess runoff processes. Water that infiltrates to the subsurface can discharge to a nearby stream as interflow or move vertically to the water table providing aquifer recharge. Water that recharges aquifers flows through the subsurface to discharge areas, such as springs, seeps, wetlands, fens, streams, and lakes.

Stream flow can be affected by surface runoff, interflow discharge, and base flow discharge. The contribution of ground water to stream flow varies significantly, but is estimated to be 40% to 50% in small- to medium-sized streams (Alley, Reilly, & Franke, 1999). A given reach of stream can be perennial, intermittent, or ephemeral (Figure 2-15) and the ground water contribution can vary over an annual hydrograph.

## 2.4.1 Hydroecology

Hydroecology is a new discipline that examines the relationship of hydrology and ecology. Although hydroecology as a distinct discipline is new, this interdisciplinary field has, at its roots, the applied science of instream flows. With increasingly large withdrawals from surface and ground water, protection of sufficient instream flow became a major concern during the middle of the last century. The difficulty in determining ecologically relevant instream flow requirements initially led to the development of "rule of thumb" hydrologic statistics serving as the basis of minimum flows requirements (Annear, et al., 2004). The 7Q10 rule is an example of this kind of thinking. 7Q10 refers to the lowest 7-day average flow that occurs on average once every 10 years. It is calculated based on historic flows and does not necessarily "protect" because it is unrelated to any explicit biological needs or thresholds. Increased knowledge of aquatic ecosystems and access to computers led to more sophisticated techniques for assessing instream flow requirements in the 1970s and 1980s (Annear, et al., 2004). The National Biological Service published its Instream Flow Incremental Methodology (IFIM) in 1995. The IFIM uses a suite of models to evaluate physical habitat availability in riverine systems based on recent historical stream flows (Stalnaker, Lamb, Henriksen, Bovee, & Bartholow, 1995). It was developed in response to the National Environmental Policy Act's mandate that all federal water

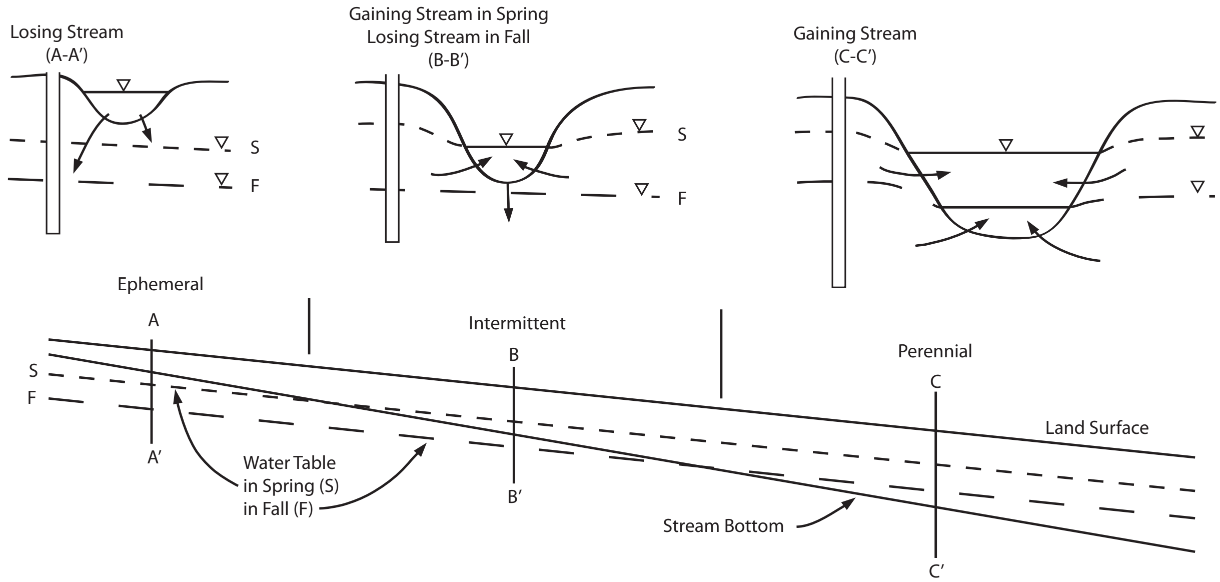



**Figure 2-15** Relation between water table and stream type (U.S. Environmental Protection Agency, 1987).

resource management agencies consider alternative water development and management schemes (Stalnaker et al., 1995). IFIM was designed to predict the flow/habitat relationships for different species and lifestages, evaluate flow management alternatives, and reach agreement on preferred flow regime(s). This method is data intensive, requiring substantial fieldwork and multidisciplinary expertise.

Ecosystems are naturally dynamic and depend on recurrent natural disturbances to maintain their health. The publication of *The Natural Flow Regime* (Poff, et al., 1997) contributed greatly to the understanding that a dynamic river is a healthy river. Natural flow regimes are composed of seasonally varying environmental flow components (Matthews & Richter, 2007), including high flows, base flows, pulses, and floods. Each flow component serves critical ecological functions such as creating habitat and providing cues for spawning and migration during discrete times of the year (Figure 2-16 and Figure 2-17). Environmental flow components can be characterized in terms of their magnitude, frequency, duration, timing, and rate of change. The Indicators of Hydrologic Alteration (IHA) (Richter et al., 1996) quantifies these characteristics of environmental flow components, as well as other ecologically relevant stream flow statistics, based on daily stream flow data. IHA can also calculate the degree to which flow components have been altered from a reference condition. The Hydroecological Integrity Assessment Process (Henriksen, Heasley, Kennen, & Nieswand, 2006) also calculates stream flow statistics, and uses them to classify streams into regional hydrologic types. The Ecological Limits of Hydrologic Alteration (Poff, et al., 2010) is a framework that relates hydrologic alteration to ecological response to support the

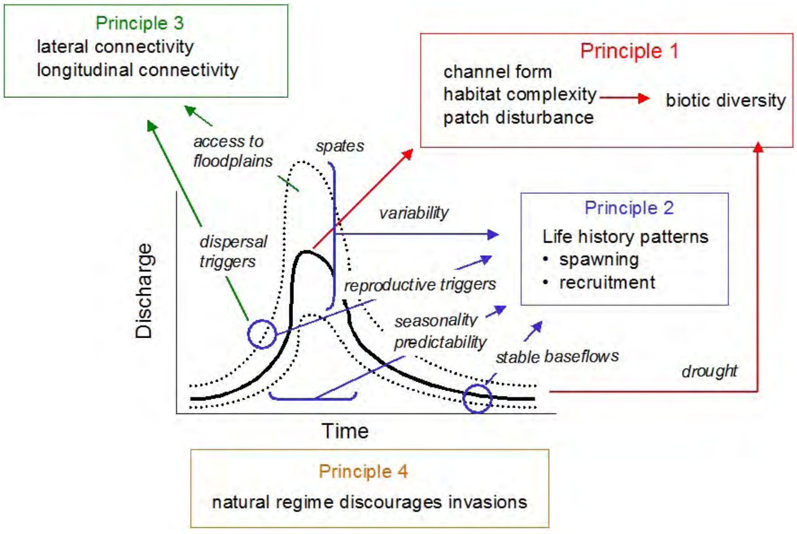



**Figure 2-16** Different components of the natural flow regime support different ecological processes and functions (Bunn & Arthington, 2002). Reprinted with permission of Springer Science and Business Media B.V.

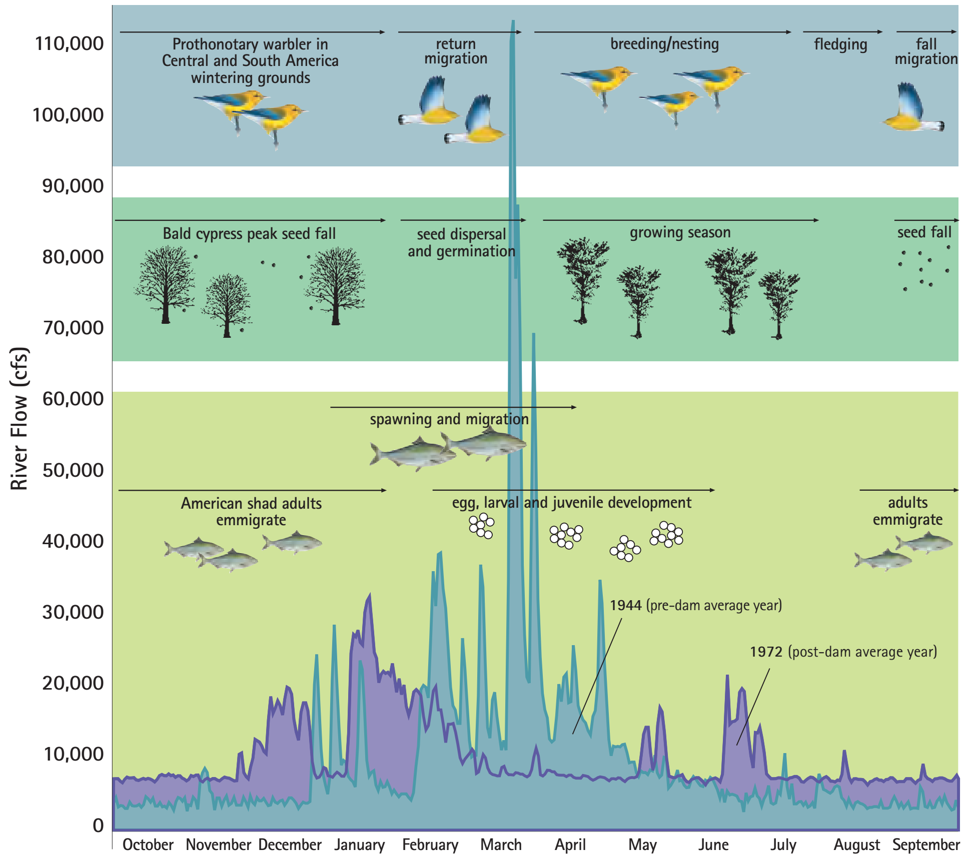



**Figure 2-17** Ecological model of the Savannah River, Georgia illustrating the ecological importance of the natural flow regime. Note the loss of high and low flows during critical bioperiods for the post-dam hydrograph (The Nature Conservancy). Illustrations from the National Audubon Society: Sibley Guide to Birds, by David Allen Sibley, published by Alfred A. Knopf, Inc. Copyright © 2000 by Andrew Stewart Publishing, Inc. All rights reserved. Reproduced with permission of the copyright holder.

determination of environmental flow standards or targets. Recognition of the role that flow variability and disturbance play on the health of aquatic and riparian species initially led to flow prescriptions focused on one or a few species (Richter, Baumgartner, Powell, & Braun, 1996). More recent, holistic assessment methods (Tharme, 2003) focus on maintaining the natural flow regime, or the flow variation that existed prior to human modification, by relating flow statistics to a variety of biological community metrics (Richter et al., 1996).

The natural disturbance regime is a vital component of instream flow assessments. Holistic assessments determine the flow variability and magnitude necessary to maintain aquatic and riparian communities over time (Figure 2-18). In the higher order reaches of large river/floodplain systems, aquatic biota have adapted their life history strategies to cope with, and even take advantage of, the predictable flood regime. For example, a gradient of plant species exists along the aquatic/terrestrial transition zone as a result of seasonal degrees of inundation, nutrients, and light (Bayley, 1995). The littoral zone in rivers is a moving zone of alternating flooding and drying as the water level rises and falls. This zone provides excellent nursing grounds for many fish species, which have adapted their life histories to spawn just before or during the rising, flooding phase. During the drawdown phase, nutrient runoff from the littoral zone increases primary production of algae, which in turn increases production of aquatic invertebrates that feed on these algae. Not only does periodic flooding affect biological communities directly, but it also affects the distribution of habitat patches through sediment deposition and scouring. In order for this natural regime of flood disturbance to effectively influence riparian biodiversity, it is essential that the river channel maintain lateral connectivity with its floodplain (Junk & Wantzen, 2004).

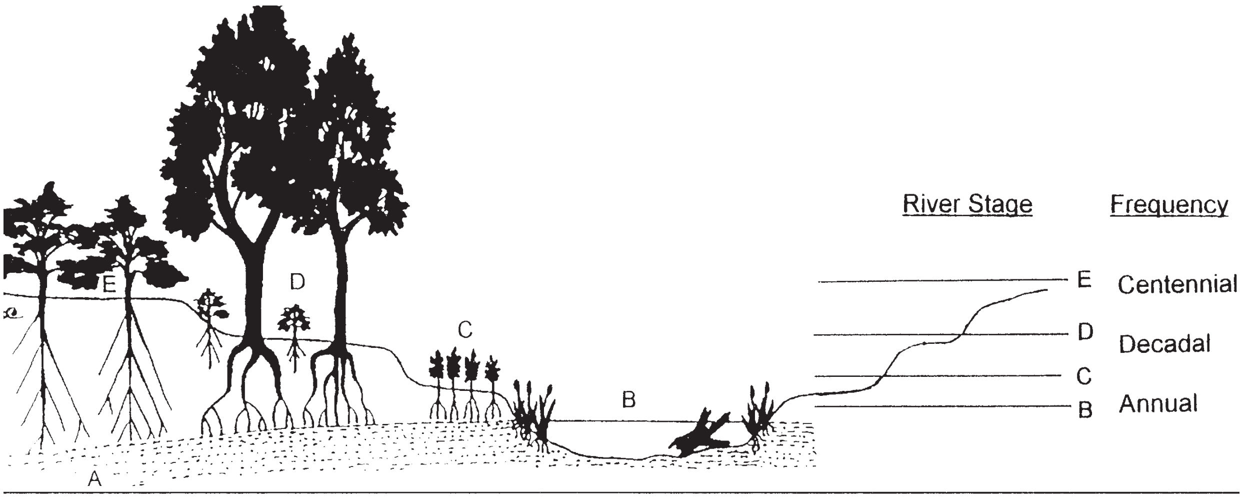



**Figure 2-18** Geomorphic and ecological functions provided by different levels of flow. Water tables that sustain riparian vegetation and that delineate in-channel baseflow habitat are maintained by ground water inflow and flood recharge (A). Floods of varying size and timing are needed to maintain a diversity of riparian plant species and aquatic habitat. Small floods occur frequently and transport fine sediments, maintaining high benthic productivity and creating spawning habitat for fishes (B). Intermediate-sized floods inundate low-lying floodplains and deposit entrained sediment, allowing for the establishment of pioneer species (C). These floods also import accumulated organic material into the channel and help to maintain the characteristic form of the active stream channel. Larger floods that recur on the order of decades inundate the aggregated floodplain terraces, where later successional species establish (D). Rare, large floods can uproot mature riparian trees and deposit them in the channel, creating high-quality habitat for many aquatic species (E) (Poff et al., 1997). Reprinted with permission of University of California Press.

## 2.4.2 Ground Water Hydrology

It is estimated that ground water represents about 97% of all the liquid freshwater on earth (Dunne & Leopold, 1978). Water stored in rivers, lakes, and as soil moisture accounts for less than 1% of the planet's freshwater. Ground water is an important source of water for meeting human needs, including drinking water, irrigation, and industrial use. In the United States, approximately 50% of the drinking water supply comes from ground water; in rural areas, 99% of the population relies on ground water to meet their drinking water needs (Kenny et al., 2009). Ground water is equally important to conservation of aquatic and terrestrial ecosystems and species. Many aquatic, riparian, and wetland ecosystems rely on ground water to meet their water needs. Ground water is also important for maintaining the water temperature and chemical conditions required by these ecosystems and the plants and animals they support. Describing the link between ground water and ecosystems, understanding and documenting the key processes and functions that ground water provides, and identifying the critical threats are key components of a healthy watersheds assessment.

Spatial and temporal distribution of ground water recharge is influenced significantly by geomorphic landforms, soil conditions, vegetation patterns, and land use. Direct recharge occurs when precipitation infiltrates to the water table at or near the point of impact and does not run off. Direct recharge, more common in humid areas, is controlled by soil moisture, plant communities, and landform type. Indirect recharge occurs when precipitation flows as surface runoff and infiltrates to the water table at some distance from its original point of impact. More common in semi-arid regions, indirect recharge can occur in two ways: 1) infiltration of overland flow into fractures, joints, faults, and macropores; and 2) seepage through the beds and banks of recognizable streams, lakes, or wetlands (Younger, 2006). This happens in beds of ephemeral streams during flood flow and through multiple channel beds in alluvial fans along mountain fronts. Recharge to regional aquifers underlying a watershed may also occur by ground water inflow from aquifers outside the boundaries of the surface catchment. Adequate recharge is fundamental to ensuring that sufficient ground water is available to support ecosystems.

Ground water flows from areas of recharge to locations of discharge. Depending on the size and geology of a watershed, multiple aquifers may be found within the boundaries of a surface catchment. Conversely, a single aquifer may underlie multiple watersheds. Watersheds of moderate to large size and significant relief typically contain multiple ground water flow systems of different scales (Figure 2-19). Flow system boundaries are controlled by topography, type, and distribution of geomorphic land forms within the watershed, and the underlying geology. Ground water discharge is dynamic and occurs at a variety of locations within a watershed, including springs and seeps, streams, wetlands, and lakes. Discharge from local and intermediate ground water flow systems is likely to fluctuate over an annual hydrograph while discharge from deeper, regional aquifers is likely to be more stable. Travel times from ground water recharge areas to ground water discharge areas can vary greatly, from days to millennia.

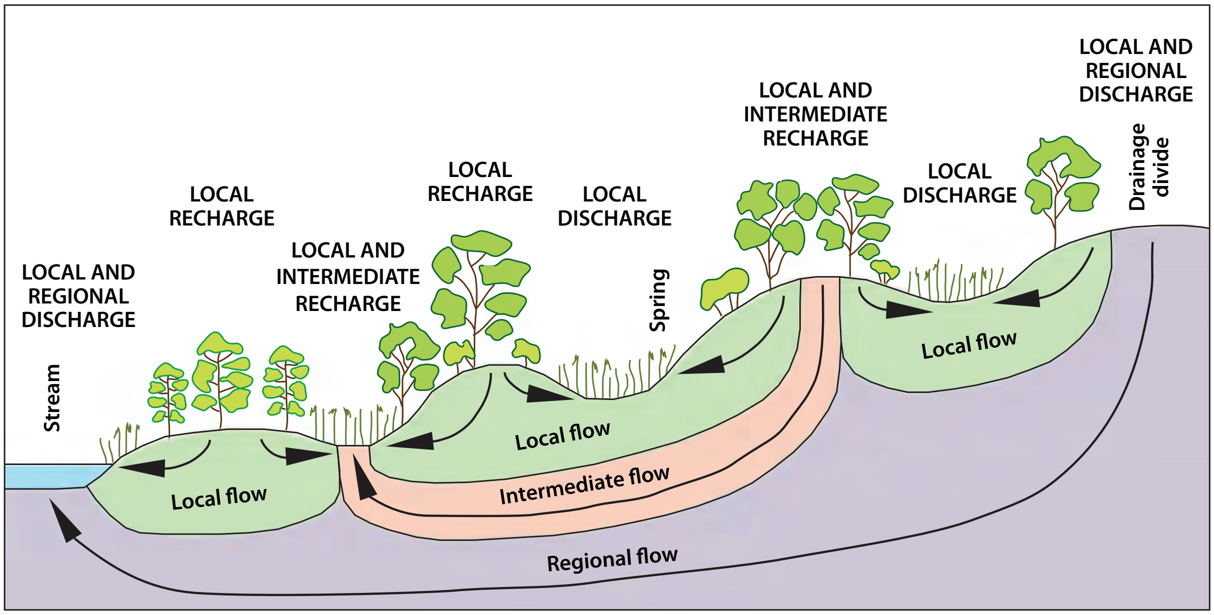



**Figure 2-19** Different scales of ground water flow systems (modified from U.S. Geological Survey, 1999).

## Discharge to Springs

Springs are focused points of ground water discharge. The locations of springs within a watershed are controlled primarily by topography and geology. Springs are the principal type of natural discharge for confined aquifers and are also important discharge features in unconfined aquifers. Springs can be divided into four types: 1) *depression springs* occur where the water table intersects the land surface; 2) *contact springs* occur along the geologic contact between an aquifer and a confining layer, usually at the lowest point where the confining layer intersects the land surface; 3) *fault springs* occur where faulting has brought an aquifer in contact with a confining layer; and 4) *sinkhole springs* occur in karst terrains where natural vertical shafts connect the land surface to underlying, confined karst aquifers. In watersheds underlain by consolidated bedrock, springs often occur where preferential flow paths composed of fractures and joints intersect the land surface. In semi-arid regions underlain by extensive bedrock formations, regional springs are critical for sustaining important ecological resources.

## Discharge to Streams

Ground water discharges to streams via seepage faces above the channel and by direct inflow through the streambed. Streams can also lose water to underlying aquifers. Temporal and spatial distribution of ground water discharge can vary over the annual hydrograph. Perennial flow in most streams is due to base flow provided by ground water discharge. In arid areas or areas where aquifer water levels have been significantly lowered due to pumping, streams can be disconnected from the underlying aquifer.

An important hydrologic process affecting the chemical and biological conditions within a stream system is hyporheic flow (Figure 2-20). In streams with coarse bed sediments, there is strong mixing between ground water and stream water within the bed sediment in response to local head conditions. Within the hyporheic zone: 1) water in the channel can flow into the coarse bed sediment and back into the channel a short distance later; 2) ground water discharge can flow upwards through the bed sediment and into the channel; and 3) water from the open channel can flow downward though the bed sediment and infiltrate into the underlying aquifer.

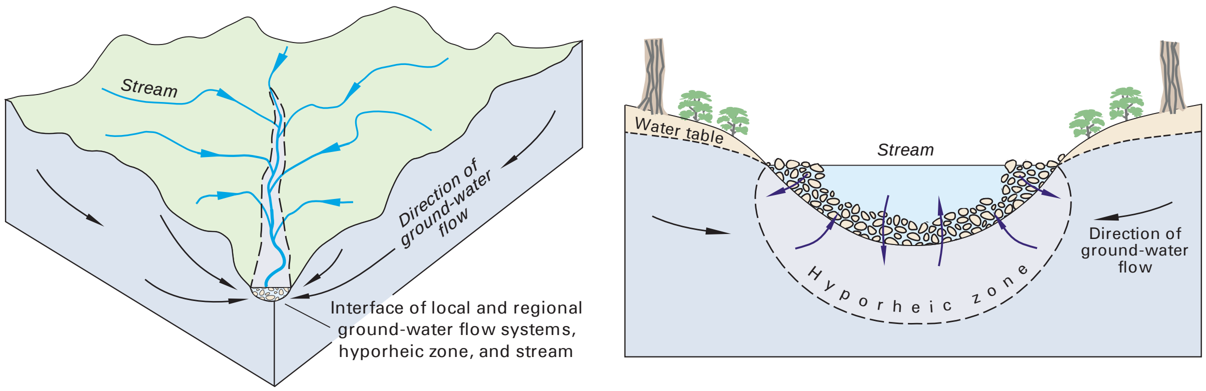



**Figure 2-20** Streambeds and banks are unique environments because they are found where ground water that drains much of the subsurface of landscapes interacts with surface water that drains much of the surface of landscapes (Winter, Harvey, Franke, & Alley, 1998).

### Discharge to Wetlands

Wetlands generally occur where hydrologic and geologic/topographic settings facilitate the retention of soil water and/or surface water. Wetlands commonly occur in topographic depressions and flat lying lowlands. However, wetlands can also occur on slopes and topographic high points. Sources of water to wetlands include rainfall, surface water inflow, and ground water discharge. Many wetlands occur where there is a perennial ground water discharge. Ground water supports wetlands by either focused discharge at the ground's surface or discharge from an underlying aquifer.

### Discharge to Lakes and Ponds

Ground water discharge to lakes and ponds occurs primarily by preferential or diffuse inflow through the lakebed sediments in the littoral zone, and less commonly from seepage faces or springs above or below the water line. In humid, temperate areas there are typically four types of lake-ground water relationships (Younger, 2006): 1) lakes that receive most inflow from ground water and all outflow is to surface water, 2) lakes that receive most inflow from surface water and most outflow is to ground water, 3) lakes that receive most inflow from ground water and all outflow goes back to ground water (through-flow lakes), and 4) lakes that receive inflow from ground water and surface water and outflow is to ground water.

### Ground Water Dependent Ecosystems

Ecosystems and species that depend on ground water to sustain their ecological structure and function are termed Ground Water Dependent Ecosystems, or GDEs (Murray, Hose, Eamus, & Licari, 2006). GDEs often harbor high species richness for their overall size, contributing significantly to the ecological diversity of a region. GDEs often contain endangered, threatened, or rare plants and animals. In addition, GDEs can act as natural reservoirs, storing water during wet periods and releasing it during dry periods, and can function as refugia during periods of environmental stress. In some circumstances, the flora and fauna of GDEs can help clean up contaminants and sediments.

Eamus and Froend (2006) identified six ecosystems that depend on ground water: springs, wetlands, rivers, lakes, phreatophytes, and subterranean systems. These ecosystems can be classified as either obligately ground water dependent or facultatively ground water dependent. Obligately ground water dependent ecosystems are found only in association with ground water. Facultatively ground water dependent ecosystems may receive some or all of their water supply from ground water, depending on the hydrogeologic setting.

Springs, including seeps, are ecosystems where ground water discharges at the surface. Thus, they are obligately ground water dependent by definition. The water supply of springs comes solely from ground water, and often this water has chemical or temperature characteristics that support uncommon communities or species (Sada et al., 2001; Williams & Williams, 1998). With some exceptions (e.g., arid regions), wetlands are generally facultative GDEs that, depending on their setting, may rely on ground water to create specific hydroperiods or chemical conditions, which govern wetland structure and function (Wheeler, Gowing, Shaw, Mountford, & Money, 2004; Mitsch & Gosselink, 2007). Some types of wetlands are obligately ground water dependent, such as fens, which receive their water supply almost exclusively from ground water (Bedford & Godwin, 2003). In some ecosystems, such as calcareous fens, the influx of ground water creates unusual water chemistry (Almendinger & Leete, 1998).

In general, rivers, lakes, and areas of phreatophytic plants are facultatively ground water dependent. However, perennial rivers and streams are often obligately dependent on ground water to maintain late-season base flow, maintain moderate temperature regimes, create certain water chemistry conditions, or produce thermal refugia for fish and other species during temperature extremes (Power, Brown, & Imhof, 1999). Lakes can receive significant inputs of ground water during certain times of the year under specific hydrologic, geologic, and topographic conditions (Grimm et al., 2003; Riera, Magnuson, Kratz, & Webster, 2000; Winter, 1978; Winter, 1995). Phreatophytic plants have deep roots that can access water in the capillary fringe, immediately above the water table; if these plants use this deep water at some point during the year or the plant life cycle, they are considered to be ground water dependent (Zencich & Froend, 2001). These species have been identified in arid climates, and recent work in more humid climates suggests this phenomenon may be more widespread than is generally acknowledged (Brooks, Meinzer, Coulombe, & Gregg, 2002).

Subterranean GDEs consist of aquatic ecosystems that are found in the free water of caves and karst systems, and within aquifers themselves (Gilbert, Danielopol, & Stanford, 1998). Aquifer ecosystems represent the most extended array of freshwater ecosystems across the entire planet (Gilbert, 1996). Their fauna largely consists of invertebrates and microbes (Humphreys, 2006). The ecological importance of subterranean ecosystems has only recently emerged in the scientific literature (Tomlinson & Boulton, 2008; Goldscheider et al., 2007; Hancock, Boulton, & Humphreys, 2005).

The type and location of GDEs depends on the hydrogeologic setting of the ecosystem in the watershed and its climate context. The hydrogeologic setting is defined by factors that control the flow of surface water and ground water to ecosystems. These factors include: elevation and slope of the land surface; composition, stratigraphy, and structure of subsurface geological materials in the watershed and underlying the GDE; and position of the GDE in the landscape (Winter, Labaugh, & Rosenberry, 1988; Komor, 1994; Bedford, 1999). Some common locations for GDEs to occur are landscape depressions, breaks in slope, and areas of stratigraphic change (Figure 2-21).

In general, there are three ecological attributes related to ground water that can be important to GDEs:

1. Water quantity: This includes timing, location, and duration of ground water discharge. In rivers and streams, ground water provides the base flow component of the hydrograph. In wetlands, ground water may partly or fully control the hydroperiod, or water table fluctuation. Shallow ground water can support terrestrial and riparian vegetation, either permanently or seasonally. Healthy watershed assessments and actions need to consider the relationship of ground water quantity to aquatic ecosystems.

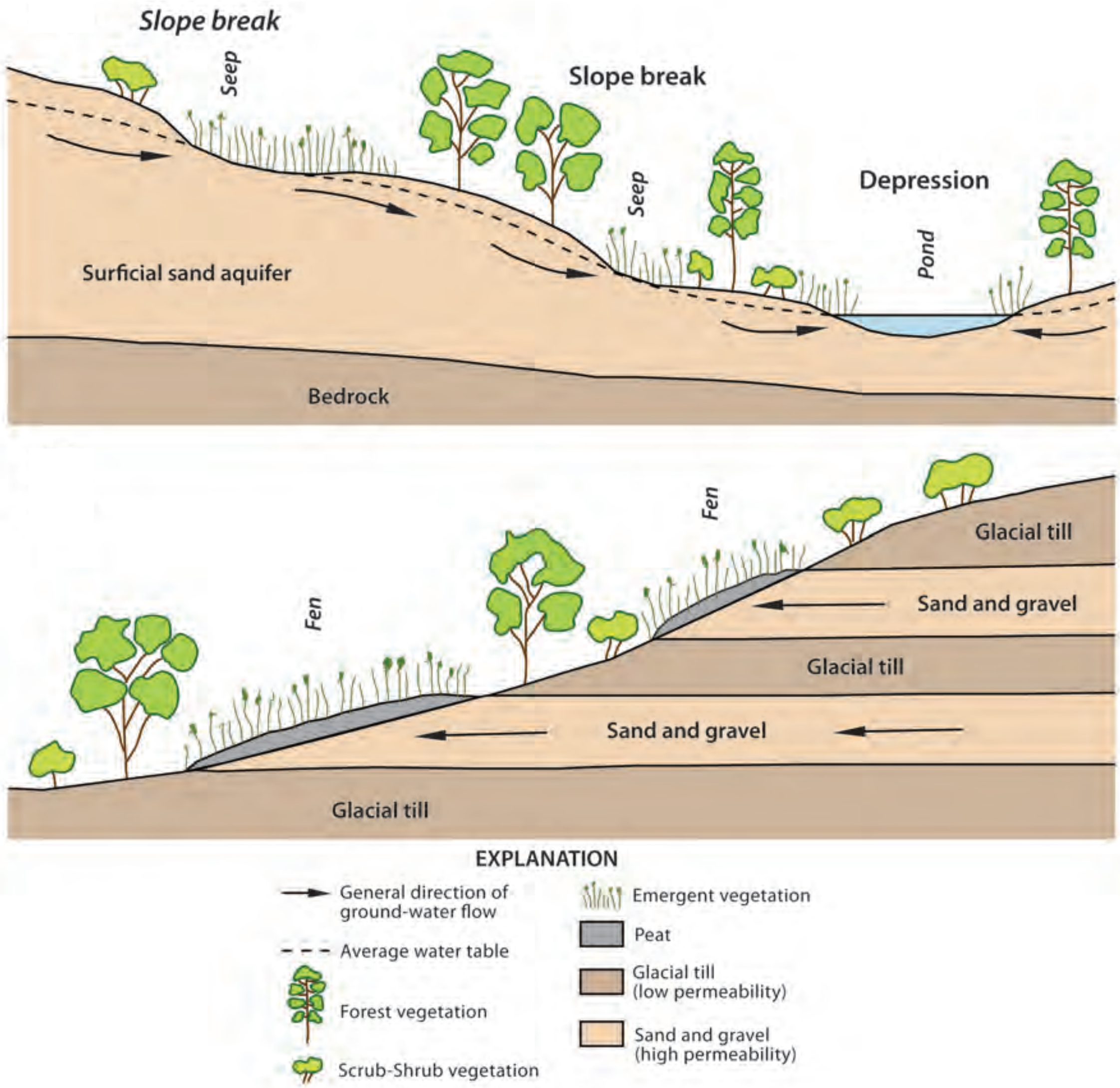



**Figure 2-21** Common locations for ground water dependent ecosystems to occur include landscape depressions, breaks in slope, and areas of stratigraphic change (modified from U.S. Geological Survey, 1999).

2. Water chemistry: When ground water discharges at the surface, its chemical composition represents a mixture affected by the quality of the recharge water and the interaction of ground water with the geologic materials through which it flows. Many ground water fed wetlands (e.g., calcareous fens) have chemical compositions that support a unique suite of flora and fauna. In some settings, ground water can be the principal source of dissolved chemicals to a lake, even in cases where ground water is a small component of the lake's water budget (Striegl & Michmerhuizen, 1998).
3. Water temperature: Ground water emerging at the surface often maintains a fairly constant temperature year round. This low variability can be important as ground water dependent species can be adapted to these stable conditions. Localized areas of ground water discharge often provide areas of thermal refugia for fish in both winter and summer (Hayashi & Rosenberry, 2002). This is particularly important for species such as salmonids, including bull trout, which have specific temperature requirements for spawning and egg incubation (U.S. Fish & Wildlife Service, 2002; King County Department of Natural Resources, 2000). In some settings, ground water emerges at the surface as hot springs, which support a unique set of flora and fauna (Springer, Stevens, Anderson, Parnell, Kreamer, & Flora, 2008).

## 2.5 Geomorphology

Fluvial geomorphology seeks to explain river forms and processes through an understanding of landscape characteristics, water movement, and sediment transport (Leopold, Wolman, & Miller, 1964). Watershed inputs (water, sediment, and organic matter) and valley characteristics (valley slope and width, bedrock and surficial geology, soils, and vegetation) determine a river channel's form (pattern, profile, and dimension) (Vermont Department of Environmental Conservation, 2007). Although watershed inputs and channel form vary over time, they are often considered to be balanced in natural systems. This natural balance is termed "dynamic equilibrium" and is illustrated by Lane's Balance (Figure 2-22), where sediment size and volume are in balance with stream slope and discharge. Any time one of these variables changes, the other variables will respond to bring the stream back to a dynamic equilibrium. Disturbances such as floods or forest fires are natural, episodic events that cause a stream to become unbalanced. After such disturbances, the stream will "seek" equilibrium conditions through adjustment of the components of Lane's Balance until the stream is once again in a form that allows it to efficiently perform its functions of water and sediment discharge. This form may or may not be the same as the pre-disturbance form. There are instances where a threshold is crossed, pushing the stream into a new, metastable state (Hugget, 2011). Periodic disturbances, of natural intensity and frequency, can increase aquatic biodiversity by creating opportunities for some species and scaling back the prevalence of others.

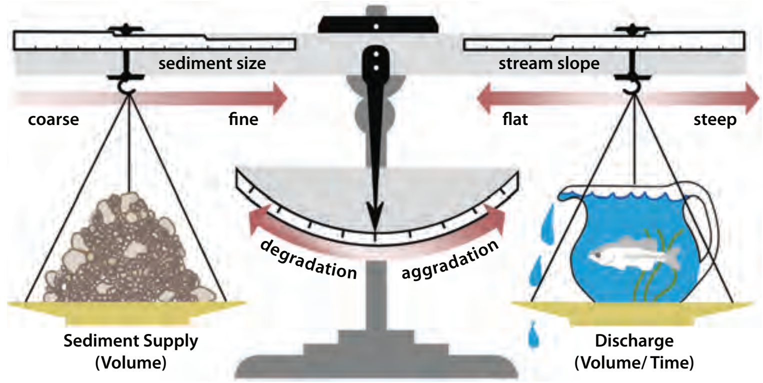



**Figure 2-22** Lane's Balance (1955). Modified from Rosgen (1996). Reprinted with permission of American Society of Civil Engineers.

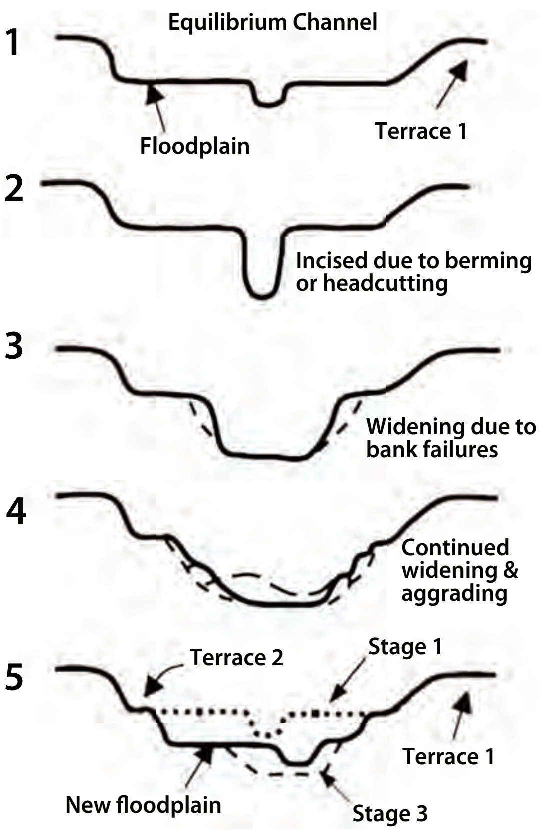


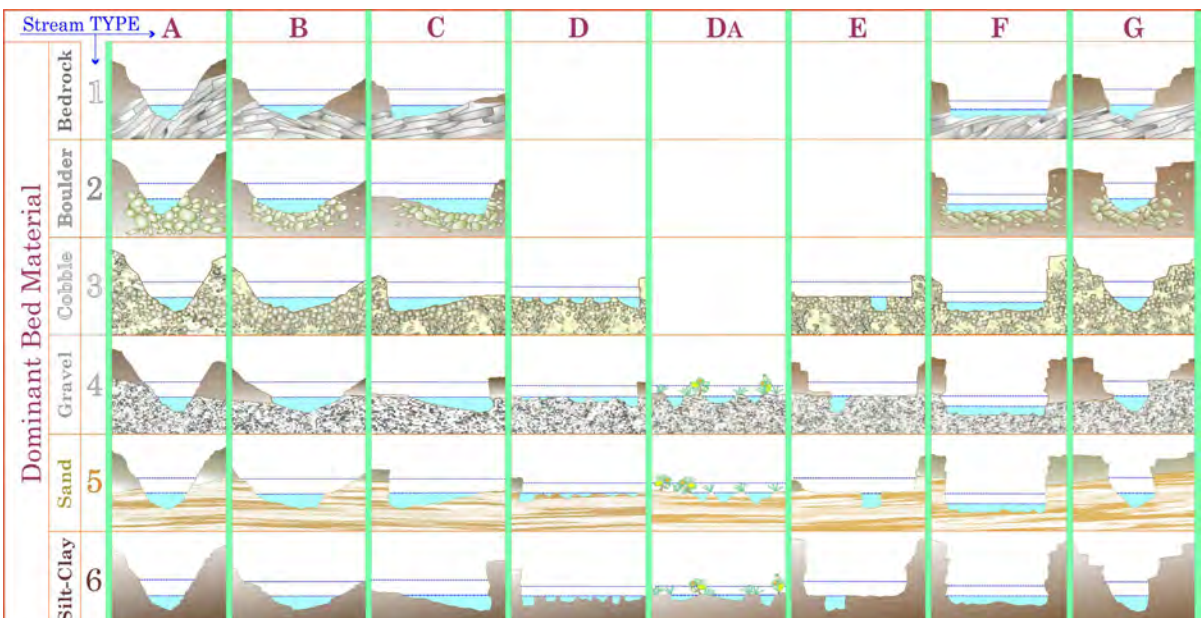

**Figure 2-23** This channel evolution model shows the stages of channel adjustment due to a disturbance (modified from Schumm, 1977).

As a result of its watershed inputs and valley characteristics, a stream will typically have a predictable and characteristic form. When watershed inputs or valley characteristics change, or when disturbances are of extreme intensity or frequency, as many human disturbances are, a stream channel will undergo adjustment to a new form. Assessing a stream's watershed inputs and valley characteristics allows the resource manager to determine the predicted form of the stream channel. If the existing channel does not match the predicted form, it is likely undergoing adjustment to a new form, which will be evidenced by head cuts or channel incision (bed degradation), sedimentation or deposition (bed aggradation), or channel widening (Figure 2-23). The channel may also have already undergone adjustment and be in a stable new form. Factors that may initiate channel adjustment include changes in land use/cover (e.g., urbanization or agriculture), channel and floodplain encroachment (e.g., bank armoring and riverside development), and flow alteration (e.g., dam construction or large municipal withdrawals) (Vermont Department of Environmental Conservation, 2007).

Before the publication of *Fluvial Processes in Geomorphology* (Leopold, Wolman, & Miller, 1964), the field was primarily descriptive. The new quantitative focus drew the interest of engineers, which resulted in the development of engineered approaches to river restoration over the next few decades. David Rosgen's 1996 publication *Applied River Morphology* is one of the most influential in modern river restoration practice. His ideas built off of Luna Leopold's classification and Stanley Schumm's concept of channel evolution. Rosgen developed a classification system for describing channel form and sequences of adjustment in disturbed channels. The underlying principles in Rosgen's *Applied River Morphology* have been used by a number of states in their own river protection programs. The following are the objectives of the Rosgen stream classification system:

- Predict a river's behavior from its appearance.
- Develop specific hydraulic and sediment relationships for a given stream type and its state.
- Provide a mechanism to extrapolate site-specific data to stream reaches having similar characteristics.
- Provide a consistent frame of reference for communicating stream morphology and condition among a variety of disciplines.

This four-level, descriptive classification system is analogous to the Linnaean classification system in biology, in which each species receives one Latin name for its genus and one for its species. Level I of the Rosgen system classifies a channel as one of seven letters (A through G) based on channel slope, entrenchment, width/depth ratio, and sinuosity. The width/depth ratio and entrenchment refer to the amount of erosion that has shaped the stream channel and relate to the stream's power. There are then six numerical categories based on the dominant bed material (Rosgen, D., 1994) (Figure 2-24). An A3 stream, for example, is one in which the dominant substrate is cobble, the slope is steep, does not have much sinuosity (the channel is relatively straight), has a low width/depth ratio, and is well entrenched. These streams are typically found in mountainous headwater areas. Level II classifies stream types to a finer level of detail based on slope ranges. Levels III and IV then assess




| Stream TYPE | A | B | C | D | DA | E | F | G |
|---|---|---|---|---|---|---|---|---|
| Entrenchment Ratio ($W_{fpa}$ / $W_{bkf}$) | <1.4 | 1.4 - 2.2 | >2.2 | n/a | > 4.0 | >2.2 | < 1.4 | <1.4 |
| W / D Ratio | < 12 | >12 | > 12 | > 40 | < 40 | < 12 | > 12 | < 12 |
| Sinuosity | 1 - 1.2 | >1.2 | > 1.2 | n/a | variable | >1.5 | > 1.2 | >1.2 |
| $H_2O$ Slope | .04-.099 | .02-.039 | <.02 | <.04 | <.005 | <.02 | < .02 | .02-.039 |

**Figure 2-24** Rosgen stream types (Rosgen, D., 1996).

the stream's condition and validate the predictions based on field measurements. The Rosgen classification system is a valuable tool for communicating stream characteristics to others. However, it has been criticized for focusing too heavily on form without sufficient regard to variation in the processes affecting streams, such as flow hydraulics, sediment transport, and bank stability (Simon et al., 2007).

The mechanisms by which streams adjust to altered inputs of energy (stream slope and discharge) and materials (sediment size and volume) are just as important as the form of the channel. Quantitative linkages between sediment transport (the combination of energy and materials) and the driving and resisting forces (flow hydraulics and bank stability) acting on the stream channel can enhance the understanding of processes controlling channel form (Simon et al., 2007). For example, three streams with the same original morphology and similar altered sediment transport scenarios may adjust to different morphologies because of differences in bank materials (e.g., clay vs. silt vs. sand) (Simon et al., 2007).

## 2.6 Water Quality

Aquatic ecosystems are substantially affected by the quality of their water, but also by the chemical and physical characteristics of the air, surrounding watershed soils, and sediment transported through the aquatic system. EPA and states have established water quality criteria for freshwater ecosystems that address important ecological constituents. Chemical and physical constituents include: (1) concentrations of organic and inorganic constituents, such as nutrients, trace metals, and dissolved organic matter; (2) additional chemical parameters indicative of habitat suitability, such as pH and dissolved oxygen; and (3) physical parameters, including water temperature and turbidity. Many of these constituents are dynamic and related to natural watershed hydrology. For example, dissolved oxygen fluctuations in streams are related to watershed nutrient loading, biotic activity, stream flow, and temperature. Monitoring methods for many of these parameters are well established and should be part of an ecosystem assessment and management approach (MacDonald, Smart, & Wissmar, 1991).

Physical and chemical water quality is strongly influenced by hydrology, geomorphology, and landscape condition. Forested landscapes cycle nutrients and retain sediments, while riparian forests regulate temperature, shading, and input of organic matter to headwater streams (Committee on Hydrologic Impacts of Forest Management, National Research Council, 2008). Natural quantities of suspended and bedded sediments (SABS) transport nutrients, detritus, and other organic matter, which are critical to the health of a water body. Natural quantities of SABS also replenish sediment bed loads and create valuable microhabitats, such as pools and sand bars.

Material flows, such as the cycling of organic matter and nutrients, are very important ecosystem functions. As described in *The River Continuum Concept* (Vannote et al., 1980), the flow of energy and materials is closely linked by downstream transport of biomass created by primary productivity in headwater streams. These areas contain unique assemblages of organisms that begin the processing of coarse particulate organic matter, providing the nutrients required by other assemblages of organisms downstream.

Chemical and physical water quality parameters are common in water quality monitoring programs. The ecological information derived from chemical/physical monitoring will become more valuable as more sophisticated monitoring designs, sampling instruments, modeling tools, and analytical procedures are developed. Chemical and physical assessment information has been well integrated into assessments of biological condition, hydrology, geomorphology, and the importance of vegetative cover.

## 2.7 Biological Condition

Ecosystem protection efforts are often driven by concerns over biodiversity. Though originally defined simply as the number of species in a given region, the term biodiversity is now commonly used to refer to the diversity of life at all levels (from genes to ecosystems). Biological condition is defined here as the ability to support and maintain a balanced, integrated, and adaptive community with a biological diversity, composition, and functional organization comparable to those of natural aquatic ecosystems in the region (Frey, 1977; Karr & Dudley, 1981; Karr, Fausch, Angermeier, Yant, & Schlosser, 1986). Thus, biodiversity is one aspect of biological condition.

Large river basins that contain a distinct assemblage of aquatic communities and species are referred to as freshwater ecoregions. Freshwater ecoregions are a useful organizational unit for conducting biodiversity assessments, as a given ecoregion contains similar species, ecosystem processes, and environmental conditions. Freshwater ecoregional assessments identify the suite of places that collectively best represent the biodiversity and environmental processes of a large river basin. Efforts to protect "enough of everything" (The Nature Conservancy, 2011a) should consider ecoregional patterns and processes when assessing and prioritizing areas for ecosystem protection actions.

Biological condition can refer to individual organisms, species, or entire communities. The health of individuals may provide an indication of future trends affecting an entire population or supporting ecological process (e.g., the spread of a virus in fish populations). Species are a common focus because they may be endangered or game species, or because they exert an important influence on an ecosystem (e.g., indicator species or keystone species). Measures of species health include population size and genetic diversity. The condition of an entire ecological community depends upon species composition, trophic structure, and habitat extent and pattern. A balanced ecological community, as naturally occurs, reflects good water quality and a naturally expected hydrologic regime. Habitat variables such as substrate and vegetative cover also impact the biological health of aquatic ecosystems. Moreover, landscape conditions in the watershed will affect aquatic habitat through the dynamic linkage of terrestrial and aquatic elements that defines a watershed. Biology and habitat are intricately entwined, with habitat structural elements often composed of biotic components themselves. For example, certain invertebrate communities live out their lives on the leaves of wetland vegetation. If it were not for the existence of the wetland vegetation, which has its own habitat requirements, these invertebrate communities would likely not exist.

Biological assessments typically rely on bioindicators (U.S. Environmental Protection Agency, 2011b). Bioindicators are groups of organisms used to assess environmental condition. Fish, invertebrates, periphyton, and macrophytes can all be used as bioindicators. Species within these groups are used to calculate metrics, such as percent Ephemeroptera, Plecoptera, Trichoptera (EPT) or an Index of Biotic Integrity (IBI), which convey important information on the state of a water body. Bioindicators are useful measurements of environmental condition because they integrate multiple effects over time. An assessment of biotic organisms can often detect ecosystem degradation from unmeasured stressors and unknown sources of stressors. Many biological assessments rely on the concept of reference conditions to determine the relative biological health of a given water body. Reference conditions are the expected conditions of aquatic biological communities in the absence of human disturbance and pollution. Reference conditions may be modeled or determined through an assessment of minimally-impacted sites that represent characteristic stream types in a given ecoregion. Identifying reference conditions provides some of the information for the biological condition assessment component of a healthy watersheds assessment.


USDA NRCS

The Biological Condition Gradient (BCG) is a conceptual, scientific model for interpreting biological response to increasing levels of stressors. It has been shown to assist with more accurate assessments of aquatic resource condition, a primary objective of the CWA (Davies & Jackson, 2006). The BCG (Figure 2-25) describes six different levels of biological condition along a generalized stressor gradient ranging from biological conditions found at no or low stress (level 1) to those found at high levels of stress (level 6). This generalized stressor gradient consists of the sum of all aquatic resource stressors, including chemical, hydrologic, and geomorphic alterations. Biological condition can be evaluated through the use of new or existing biological assessment methods that have been calibrated to the BCG, such as an IBI, the River Invertebrate Prediction and Classification System (RIVPACS), or Threshold Indicator Taxa Analysis (TITAN).

The BCG is characterized by a description of how 10 attributes of aquatic ecosystems change in response to increasing levels of anthropogenic stress. The attributes include several aspects of community structure, organism condition, ecosystem function, spatial and temporal attributes of stream size, and connectivity (Davies & Jackson, 2006). A BCG can be used in conjunction with biological assessments to more precisely define designated aquatic life uses, establish biological criteria, and measure the effectiveness of controls and management actions aimed at protecting the aquatic biota (U.S. Environmental Protection Agency, 2011b). This approach, often called tiered aquatic life uses, when applied to water quality standards (WQS), consists of bioassessment-based statements of expected biological condition in specific water bodies and is based on the following concepts:

- Surface waters and the biological communities they support are predictably and consistently different in different parts of the country (classification along a natural gradient, ecological region concept);
- Within the same ecological regions, different types of water bodies (e.g., headwaters, streams, rivers, wetlands) support predictably different biological communities (water body classification);
- Within a given class of water bodies, observed biological condition in a specific water body is a function of the level of stress (natural and anthropogenic) that the water body has experienced (the biological condition gradient);
- Similar stressors at similar intensities produce predictable and consistent biological responses in waters within a class, and those responses can be detected and quantified in terms of deviation from an expected condition (reference condition); and
- Water bodies exposed to higher levels of stress will have lower biological performance compared to the reference condition than those waters experiencing lower levels of stress (the biological condition and stressor gradients).

The results of biological assessments based on the BCG approach can be used in state healthy watersheds assessments to identify high quality biological condition (e.g., BCG levels I and II) (Figure 2-26).

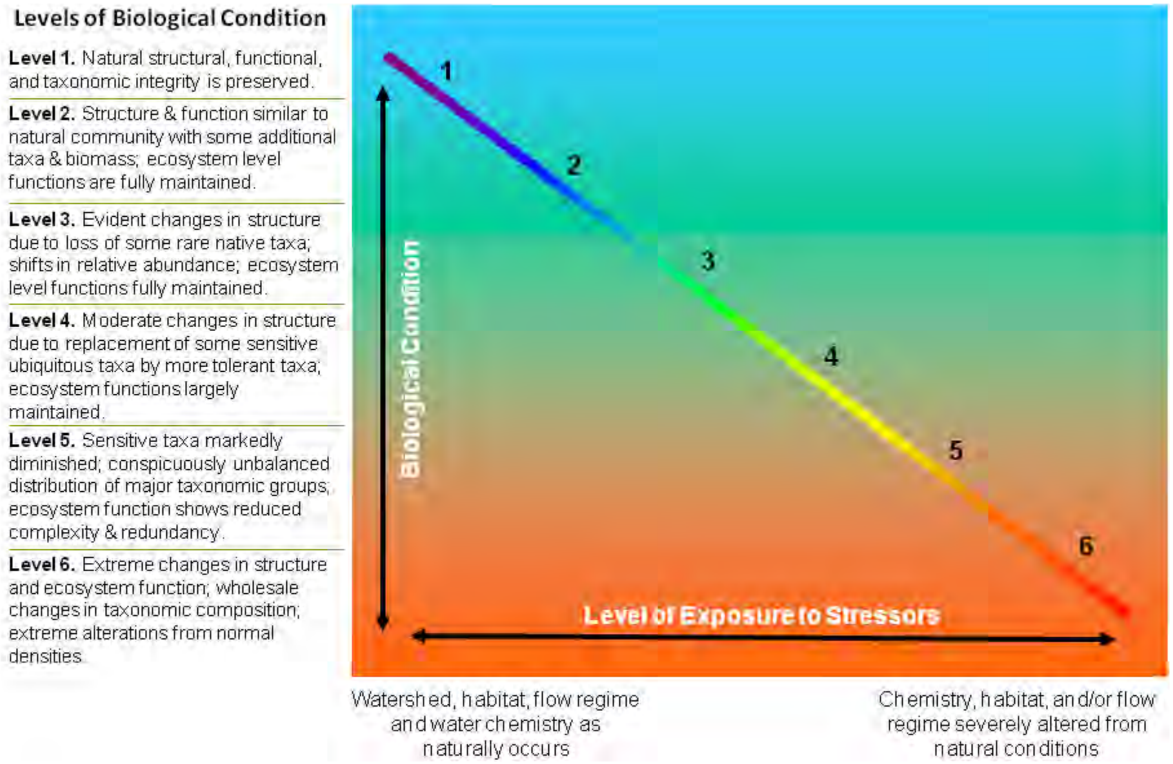



**Figure 2-25** Conceptual model of the Biological Condition Gradient (U.S. Environmental Protection Agency, 2011c).

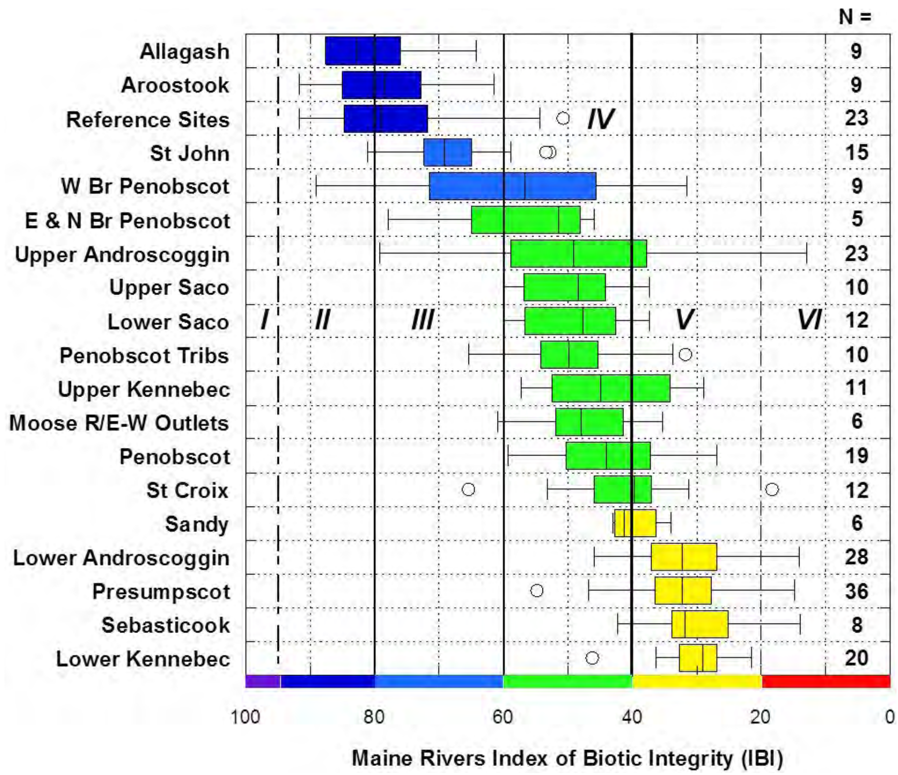



**Figure 2-26** Box-and-whisker plots of Maine Index of Biotic Integrity (IBI) scores arranged, and color coded, according to the six Biological Condition Gradient (BCG) tiers (Chris Yoder, Midwest Biodiversity Institute, Personal Communication). The dark blue watersheds can be considered the healthy watersheds.

## 2.8 Watershed Resilience

A key component of watershed health is the ability to withstand, recover from, or adapt to disturbances, such as fires, floods, and droughts. Healthy ecosystems are naturally dynamic and often depend on recurrent natural disturbances to maintain their health. However, natural disturbance regimes have been severely altered in many watersheds due to dam construction, fire suppression, surface and ground water withdrawals, and land use change (Figure 2-27). This can increase a watershed's vulnerability to future disturbance events, whether natural or anthropogenic. Anthropogenic disturbances may take years to be recognized and can persist for decades or centuries (Committee on Hydrologic Impacts of Forest Management, National Research Council, 2008).


**Figure 2-27** Sprawling development results in significant land use change, which can alter natural disturbance regimes.

Broadly speaking, stressors from human activity can be classified into two categories: 1) changes in the natural variability of ecological attributes; and 2) introduction of pollutants or species that interfere with ecological processes (Center for Watershed Protection, 2008c). The former can include urbanization impacts on the magnitude and frequency of stormwater runoff events, habitat conversion and fragmentation, climate change, and over-harvesting. If perturbations are large enough to reach a threshold, ecosystems can change rapidly to a new state (e.g., fishery collapse), and these changes are typically difficult to reverse (Noss, LaRoe III, & Scott, 1995). Pollutants that disrupt ecosystem function can be physical (e.g., sediment from construction sites) or chemical (e.g., pesticides). Salt Cedar, an example of a biological stressor, is an invasive tree that has spread throughout the western United States and uses long taproots to take advantage of deep water tables. Its invasion not only disrupts the native vegetative community, but also disrupts the natural hydrology of the area, affecting aquatic habitat as well.

The impact of climate change and other stressors on different ecosystems and regions of the United States depends on the vulnerability of those systems and their ability to adapt to the changes imposed on them. As temperature and precipitation regimes change, so too will the ecological processes that are driven by these regimes. These processes are assumed to have a natural range of variability that may be exceeded when disturbances, changes, and shocks occur to a system. In such cases, the system may still recover because its adaptive capacity has not been exceeded, or it could pass a threshold and change into another ecosystem state. Although some ecosystems can rely on their size for *resistance* to climate change, other ecosystems will need to rely on *resilient processes*. Resistance is distinguished from resilience in that resistant systems persist and remain relatively stable when faced with stresses, whereas resilient systems are affected by stresses, but are able to recover from the impacts of stress and adapt to new conditions. Increasing a system's resilience to pressures includes ensuring that watersheds have adaptive attributes such as meander belts, riparian wetlands, floodplains, terraces, and material contribution areas. For example, a disturbance may lead to changes in the timing, volume, or duration of flow that are outside the natural range of variability. In a healthy, resilient watershed, these perturbations would not cause a permanent change because riparian areas and floodplains would help to absorb some of the disturbance. Managing to optimize resilience includes both minimizing threats and protecting the most essential or sensitive areas.

An example of managing for resilience is the Massachusetts Division of Fisheries and Wildlife's process for identifying and prioritizing land protection and stewardship actions needed for long-term conservation of the state's biodiversity, and for climate adaptation (Massachusetts Department of Fish & Game and The Nature Conservancy, 2010):

1. **Prioritize habitats, natural communities, and ecosystems of sufficient size.** Larger ecosystems are more likely to provide the tracts of intact habitat and functioning ecosystem processes needed to support larger numbers of organisms and a broader diversity of native species. Climate refugia, which organisms can use to endure extreme conditions, are likely to be more prevalent in larger ecosystems than they are in smaller ecosystems as well.
2. **Select habitats, natural communities, and ecosystems that support ecological processes.** Healthy functioning of ecological processes allows an ecosystem to persist through conditions of environmental stress or adapt to the stresses imposed on it. Natural flow regime is an ecological process that is particularly important to healthy watersheds. Ecosystems that have the least potential to be disturbed by anthropogenic influences often have the greatest potential to maintain functioning processes in the long term and are thus most likely to have the resilience needed to recover from climate change impacts.
3. **Build connectivity into habitats and ecosystems.** Connectivity is a conservation priority for the same reason that large ecosystems are a conservation priority: it maximizes the accessibility of resources populations can use to survive periods of environmental stress. Many species representing diverse classes of organisms, including amphibians, aquatic insects, and anadramous and catadramous fish require multiple habitat types to carry out their life cycles. In addition to connectivity to other habitat sources, wildlife populations need connectivity to other populations of their own species in order to maintain levels of genetic diversity sufficient to sustain viable populations.
4. **Represent a diversity of species, natural communities, ecosystems, and ecological settings.** Conserving a representative set of species and habitats creates a diversified "savings bank" of physical and genetic resources that provides the greatest chances for successful ecosystem adaptation and recovery. In addition, protecting a variety of habitat conditions provides a coarse filter for protecting the diversity of biota these conditions support.

# 3. Examples of Assessment Approaches


## 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.

**Table 3-1** List of assessment approach summaries and case studies included in Chapter 3.

## 3.1 Landscape Condition

This section provides summaries for some examples of approaches currently being used to assess landscape conditions. See Chapter 2 for background information on landscape condition.

**Landscape Condition**
Patterns of natural land cover, natural disturbance regimes, lateral and longitudinal connectivity of the aquatic environment, and continuity of landscape processes.

**Geomorphology**
Stream channels with natural geomorphic dynamics.

**Habitat**
Aquatic, wetland, riparian, floodplain, lake, and shoreline habitat. Hydrologic connectivity.

$PO_4^{3-}$ **Water Quality**
Chemical and physical characteristics of water.

**Hydrology**
Hydrologic regime: Quantity and timing of flow or water level fluctuation. Highly dependent on the natural flow (disturbance) regime and hydrologic connectivity, including surface-ground water interactions.

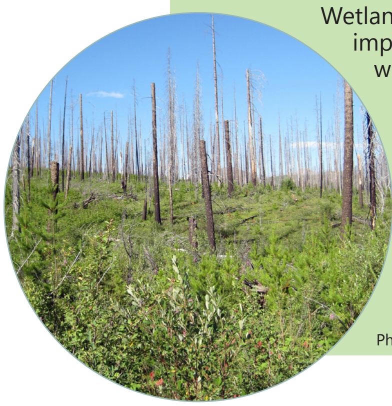
**Biological Condition**
Biological community diversity, composition, relative abundance, trophic structure, condition, and sensitive species.

Large patches of natural vegetative land cover stabilize soil, regulate watershed hydrology, and provide habitat for terrestrial and aquatic species.

Photo: BLM.

Ecosystems in some parts of the country require a natural fire regime to help maintain habitat, biodiversity, and nutrient cycling properties.

Photo: BLM.



Wetlands provide important fish and wildlife habitat, improve water quality, and help regulate water levels within watersheds.

Photo: Jane Hawkey, IAN.

Natural land cover within the Active River Area maintains connectivity between terrestrial and aquatic elements of the landscape.

Photo: USFWS.

### Maryland Green Infrastructure Assessment

**Author or Lead Agency:** Maryland Department of Natural Resources (DNR)

**More Information:** http://www.greenprint.maryland.gov/

The Maryland Green Infrastructure Assessment is a proactive approach to addressing the state's growing forest fragmentation, habitat degradation, and water quality problems. By determining those areas that are most critical to protecting the ecological integrity of Maryland's natural resources, the conservation programs operating through the Maryland Department of Natural Resources (Program Open Space and the Rural Legacy Program) can strategically and defensibly pursue the acquisition and easement of lands that are among the most ecologically valuable in the state. In addition, this assessment, joined with other natural resource assessments, now forms the foundation for the Governor's GreenPrint initiative in Maryland. As part of the GreenPrint initiative, an interactive mapping tool was developed to identify high priority conservation lands, provide performance measures to track the success of state land conservation programs, and facilitate united and integrated land conservation strategies among all conservation partners in Maryland. As part of its Coastal Atlas program, Maryland DNR is also mapping the state's "blue infrastructure." The state's blue infrastructure is defined as the critical near-shore habitat that serves as a link between the aquatic and terrestrial environments of Maryland's coast. By combining the green infrastructure assessment with the blue infrastructure assessment, a "complete ecological network" is being identified to prioritize lands for acquisition that protect both terrestrial and aquatic resources.

Conservation of habitats and multiple species is a more cost-effective and less reactive approach than single species management and engineering-based solutions to ecosystem degradation (Jennings, 2000). This proactive approach has shown significant success in Maryland in recent years. In addition, surveys have shown that the majority of Maryland's citizens support public land conservation programs. Preservation of open space is considered a worthwhile expenditure of public funds by most residents. Several land conservation programs exist in Maryland; however, only 26% of the state's green infrastructure was protected in 2000. Many of the larger tracts of land are becoming more fragmented over time. By protecting the remaining tracts of contiguous land, or hubs, and connecting them with natural corridors, many of the same benefits of larger conservation areas can be realized, including maintenance of natural watershed hydrology and thermal regimes.

Based on the principles of landscape ecology and conservation biology, Maryland's Green Infrastructure Assessment tool uses GIS to identify the ecologically important hubs and connecting corridors in the state. Hubs are defined by Maryland DNR as:

- Large blocks of contiguous interior forest containing at least 250 acres, plus a transition zone of 300 feet.
- Large wetland complexes, with at least 250 acres of unmodified wetlands.
- Important animal and plant habitats of at least 100 acres, including rare, threatened, and endangered species locations; unique ecological communities; and migratory bird habitats.
- Relatively pristine stream and river segments (which, when considered with adjacent forests and wetlands, are at least 100 acres in size) that support trout, mussels, and other sensitive aquatic organisms.
- Existing protected natural resource lands that contain one or more of the above; for example, state parks and forests, National Wildlife Refuges, locally owned reservoir properties, major stream valley parks, and Nature Conservancy preserves.

The corridors connecting these hubs are typically streams with wide riparian forest buffers, ridge lines, or forested valleys. They are at least 1,100 feet wide, which allows for the dispersal of organisms that require interior cover. These areas were identified in Maryland using a GIS technique called "least cost path." With this technique, each landscape element is assigned different values ("costs") based on its ability to provide for movement of wildlife. For example, a road is assigned a value reflective of a "high cost" for wildlife movement, while a forested area is assigned a "low cost" value. The algorithm then determines the least cost path from one hub to another.

Hubs and corridors in Maryland were given ecological scores based on their relative importance in the overall green infrastructure network (Table 3-2). Each hub or corridor's ecological score was evaluated alongside an assessment of development risk to rank and prioritize lands for protection actions. The lands outside of the network (developed, agricultural, mined, or cleared lands) were also evaluated for their restoration potential by considering watershed condition, landscape position, local features, ownership, and programmatic considerations.

**Table 3-2** Parameters and weights used to rank overall ecological significance of each hub within its physiographic region (Weber, 2003).

| Parameter | Weight |
|---|---|
| Heritage and Maryland's Biological Stream Survey element occurrence (occurrences of rare, threatened and endangered plants and animals; rated according to their global or range-wide rarity status; state-specific rarity status; and population size, quality, or viability) | 12 |
| Area of Delmarva fox squirrel habitat | 3 |
| Fraction in mature and natural vegetation communities | 6 |
| Area of Natural Heritage Areas | 6 |
| Mean fish IBI score | 1 |
| Mean benthic invertebrate IBI score | 1 |
| Presence of brook trout | 2 |
| Anadromous fish index | 1 |
| Proportion of interior natural area in hub | 6 |
| Area of upland interior forest | 3 |
| Area of wetland interior forest | 3 |
| Area of other unmodified wetlands | 2 |
| Length of streams within interior forest | 4 |
| Number of stream sources and junctions | 1 |
| Number of GAP vegetation types | 3 |
| Topographic relief (standard deviation of elevation) | 1 |
| Number of wetland types | 2 |
| Number of soil types | 1 |
| Number of physiographic regions in hub | 1 |
| Area of highly erodible soils | 2 |
| Remoteness from major roads | 2 |
| Area of proximity zone outside hub | 2 |
| Nearest neighboring hub distance | 2 |
| Patch shape | 1 |
| Surrounding buffer suitability | 1 |
| Interior forest within 10 km of hub periphery | 1 |
| Marsh within 10 km of hub periphery | 1 |

Maryland's Program Open Space, operating since 1969, funds land conservation through the real estate transfer tax. Since the completion of the green infrastructure assessment, Program Open Space and other land conservation efforts have continued to refine targeting and acquisition/easement approaches for conserving and protecting the most ecologically significant lands in the state. In addition to mapping out the highest priorities, a GIS-based parcel evaluation scores the potential project based on the property's importance in the green infrastructure network and on other natural resource values. These assessments are validated through field visits before additional decisions are made. As the project is prepared for approval, a conservation scorecard, documenting conservation values, is presented to the Board of Public Works (consisting of the Governor, the Treasurer, and the Comptroller) to justify the expenditure of state funds on protection efforts. In addition to Program Open Space and the Rural Legacy Program, the Maryland Environmental Trust and the Maryland Agricultural Land Preservation Foundation form an "implementation quilt" of state land conservation programs that bring together different resources to implement the protection strategies identified by the green infrastructure assessment. The GreenPrint initiative provides transparency and accountability through performance measures, and clearly identifies and maps land conservation goals that bolster the integration and effectiveness of Maryland's conservation programs. The results of the green infrastructure assessment (Figure 3-1) are being used by other counties and municipalities in their local land use planning efforts as well. Private land trusts are using the results to help prioritize their land acquisition strategies. Private citizens can also use the online mapping tool to see the ecological value of the land they own and make wise decisions for future use of their land. Since 1999, 88,000 acres have been protected in Maryland through the use of green infrastructure assessment information.

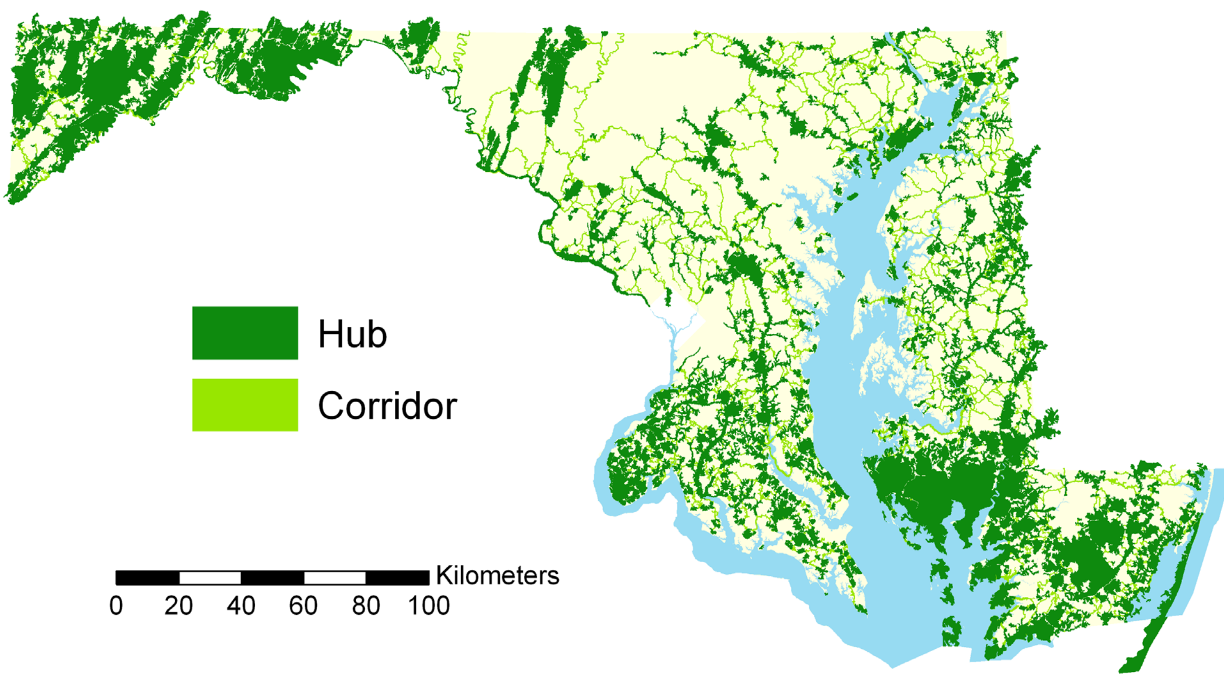



**Figure 3-1** Green infrastructure in Maryland (Maryland Department of Natural Resources, 2011).

# Case Study

## Anne Arundel County Greenways Master Plan

**More Information:** Anne Arundel County, 2002 (http://www.aacounty.org/PlanZone/MasterPlans/Greenways/Index.cfm)

Anne Arundel County was the first county in the State of Maryland to base its Greenways Plan on the results of the Maryland green infrastructure assessment. The Plan won an award from the Maryland chapter of the American Planning Association in 2003. Greenways are typically focused on recreational and scenic opportunities as priorities. Anne Arundel County, in its Greenways Plan, takes an ecological approach to identifying its potential greenways, using the following criteria:

1. Habitat value.
2. Size.
3. Connections to other land with ecological value.
4. Future potential.
5. National and countywide trails.

The county used habitat requirements of indicator species (downy woodpecker, bobcat, and red-spotted newt) to identify the "best" lands for inclusion in the greenways system. These species were chosen because their habitat requirements are general enough to provide protection to most other species as well. Using the five criteria for identifying potential greenways, a network of hubs and corridors was designed. This network closely reflects the green infrastructure assessment network (Figure 3-2). One of the advantages of the Anne Arundel County Greenways Plan is that it makes explicit the added benefit of low impact recreational and scenic use to the general public, which can greatly increase public support of the plan. In addition, it protects and improves water quality and wildlife habitat.

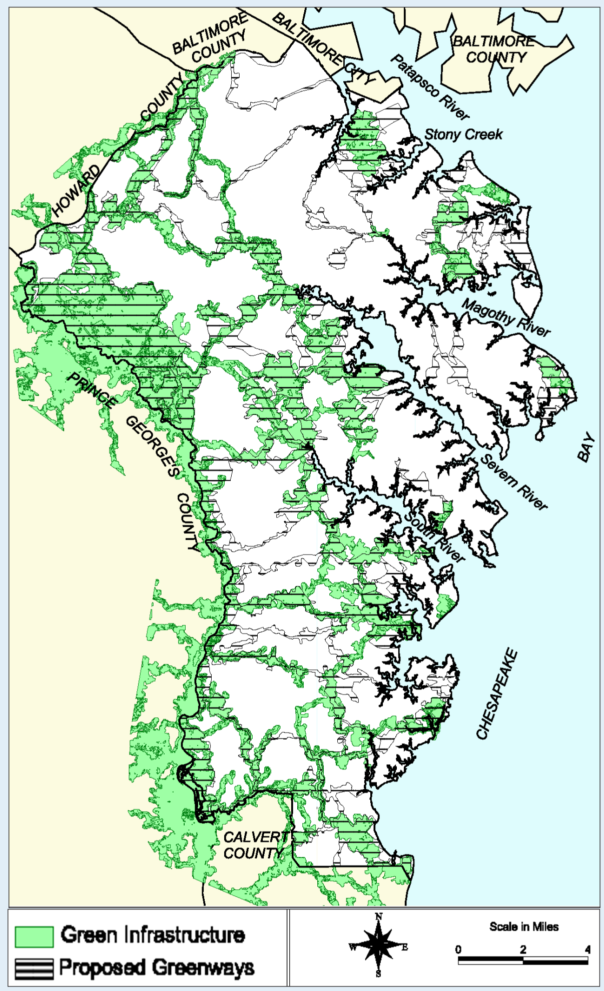



**Figure 3-2** Comparison of proposed greenways and green infrastructure in Anne Arundel County, MD (modified from Anne Arundel County, 2002).

### Virginia Natural Landscape Assessment

**Author or Lead Agency:** Virginia Department of Conservation and Recreation (DCR) – Division of Natural Heritage

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

The Virginia Conservation Lands Needs Assessment (VCLNA) is a flexible 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 Assessment 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. The Natural Landscape Assessment Model is described here. The Watershed Integrity Model is described in Chapter 4. All VCLNA models, along with Virginia's Conservation Lands and a variety of reference layers, can be viewed on an interactive mapping site called the Virginia Land Conservation Data Explorer at www.vaconservedlands.org.

The VCLNA Natural Landscape Assessment Model is a geospatial inventory of the remaining patches of natural land and the links between those patches throughout Virginia. Large patches are those with interior cover of at least 100 acres, while small patches are identified as areas containing between 10 and 99 acres of interior cover. Interior cover, also known as the core area, is defined as the natural land cover beginning 100 meters inside of a habitat patch. As large patches of core area tend to have a greater variety of habitats and increased protection from adjacent disturbances, biodiversity in these areas typically doubles for every 10-fold increase in habitat size. In addition, certain species require large areas deep within interior habitat patches to carry out their life histories. Large patches of natural land cover also prevent erosion, filter nutrients and other pollutants in runoff, provide pollinators for crops, and sequester carbon in their biomass. Fewer and fewer large patches of natural vegetation remain in Virginia, as fragmentation resulting from roads and suburban development continues to spread at an advancing rate. As more habitat is fragmented, the interior area to edge perimeter ratio decreases to such an extent that, while there continue to be patches of vegetation scattered across the landscape, there will be virtually no interior cover remaining for species that require this core area to survive and reproduce.

Although conservation of larger natural areas is typically an effective strategy for preserving biodiversity and ecological integrity, patchwork patterns of human development make it necessary to conserve many modestly-sized natural areas. By connecting these smaller areas with corridors of natural vegetation, the levels of biodiversity maintained in large conservation areas can be approached. However, these corridors should also contain nodes, or smaller habitat patches interspersed along these links that facilitate dispersal of organisms between ecological cores. Through the evaluation of ecologically significant attributes (such as species diversity, presence of rare habitats, and water quality benefits), a prioritization scheme was developed by Natural Heritage biologists for use in selecting those lands most critical for maintaining ecological integrity across the landscape of the Commonwealth of Virginia. One of five scores was given to each ecological core area, and corridors between patches receiving the two highest rankings were designated using a GIS technique called "least cost path." This technique employs a variety of user defined attributes for determining the easiest routes for wildlife to migrate between the ecological core areas. Wherever possible, lower-ranked ecological core areas were used as nodes in the corridors connecting the larger ecological cores.

The landscape assessment results are provided in GIS data, hardcopy, and digital maps (Figure 3-3), which can be explored with an online interactive tool called Land Conservation Data Explorer (Virginia Department of Conservation and Recreation, 2009).

The results of the Natural Landscape Assessment provide guidance on lands to prioritize for conservation actions in Virginia. A number of municipalities, counties, land trusts, and other organizations are using the methods and results from the Virginia Natural Landscape Assessment. Ranked cores and corridors are used by the Virginia Land Conservation Foundation and various conservation organizations (e.g., land trusts) throughout the commonwealth to help assure that conservation efforts are concentrated on the areas with high ecological integrity. Furthermore, the cores are an essential component of the State Wildlife Action Plan. The Virginia Natural Landscape Assessment identifies and ranks ecological integrity statewide, while also providing a tool that can be used to better inform local conservation planning efforts.

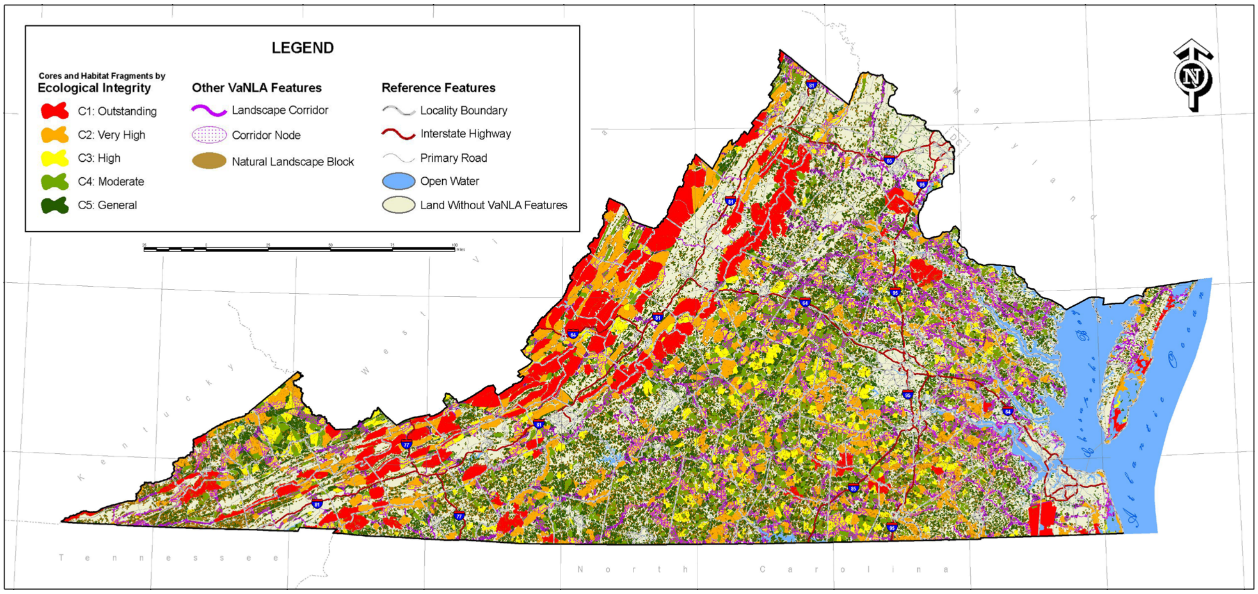



**Figure 3-3** Map of results from the Virginia Natural Landscape Assessment Model (Virginia Department of Conservation and Recreation, 2008).

# Case Study

## Green Infrastructure in Hampton Roads

**More Information**: Kidd, McFarlane, & Walberg, 2010 (http://www.hrpdc.org/PEP/PEP_Green_InfraPlan2010.asp)

The Hampton Roads Green Infrastructure Plan was undertaken to expand upon the Southern Watershed Area Management Program Conservation Corridor System previously developed as a collaborative state, federal, and local effort. The corridor system identified in that study was contained to southern Chesapeake and Virginia Beach, Virginia. The Hampton Roads Green Infrastructure Plan identifies green infrastructure throughout the entire Hampton Roads region (Figure 3-4). With conservation and restoration of water quality as a primary goal, the technical development and stakeholder involvement process focused on riparian areas as they provide multiple benefits including water quality protection, wildlife habitat, and flood storage.

The Hampton Roads green infrastructure model uses the output layer from the VCLNA project to identify ecological cores. It also uses wetlands, land cover, and a riparian corridor layer developed specifically for the project. Each of these four layers was ranked and prioritized by stakeholders for use in a weighted overlay analysis in GIS. Given the riparian focus, the links between ecological cores were mostly found along streams and rivers.

The green infrastructure network is being implemented through several parallel efforts including provision of GIS data to Hampton Roads localities for use in comprehensive plan updates and other planning efforts, working with the Department of Defense to include the regional network in efforts to buffer military facilities from encroachment, and use of the network as a basis for obtaining grant funding to purchase lands based on habitat value. Efforts are also underway to improve the integration of the green infrastructure network with the implementation of wetlands mitigation and stormwater and water quality regulatory programs.

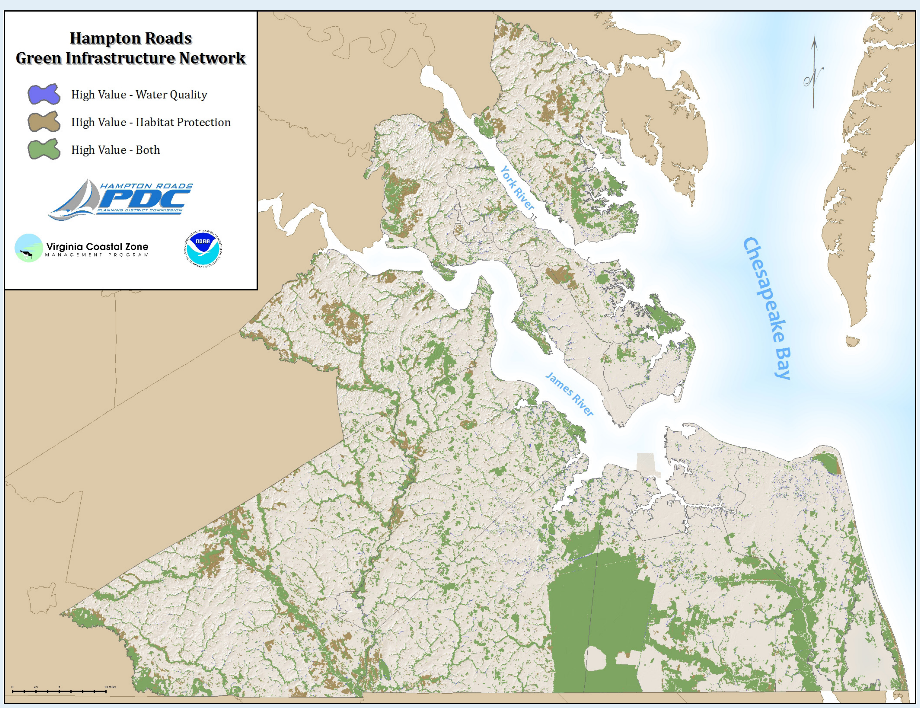



**Figure 3-4** Green infrastructure in the Hampton Roads region (Kidd, McFarlane, & Walberg, 2010).

## Beaver Creek Green Infrastructure Plan

**Author or Lead Agency:** Tracy Moir-McClean and Mark DeKay of University of Tennessee's College of Architecture and Design

**More Information:** http://ww2.tdot.state.tn.us/sr475/library/bcgitdot.pdf

The Beaver Creek Green Infrastructure Plan was created in 2006 to protect and restore naturally functioning ecosystems in the Beaver Creek watershed along the northern border of Knox County, TN for the purposes of improving water quality, mitigating floods, protecting wildlife habitat, and connecting communities and neighborhoods. The underlying perspective of the plan is "the idea that the form of settlement grows out of an understanding of landscape context, both ecological and social." The three primary elements of the plan are the water network, open space network, and settlement network. Analyzing these networks and basing land use decisions around them can help to create a sustainable and livable community.

A Land Stewardship Network was identified based on a composite of four assessments identifying: 1) stream protection corridors, 2) ground water protection corridors, 3) ridge protection corridors, and 4) heritage protection corridors. This network represents the most ecologically and culturally valuable conservation land in the watershed, forming a framework around which to base development and protection strategies. Three-zone buffers were created around each of the four corridor types. The innermost zone is a protection zone, followed by a conservation zone, and a stewardship zone at the interface with surrounding developed land uses (Figure 3-5).

As a result of development patterns in the Beaver Creek watershed, water quality has degraded and flooding has become severe. The full length of Beaver Creek is included on Tennessee's list of impaired waters and the floodplain has expanded as a result of the increased runoff from growing impervious areas in the watershed. The stream and ground water protection corridors in the Green Infrastructure Plan address these issues by protecting and restoring vegetated riparian areas, which slow runoff and filter pollutants, and by protecting wetlands and sinkholes that help to maintain the watershed's natural hydrology. Stream and ground water protection corridors were created by buffering first and second order streams, wetlands, and sinkholes with 100 foot protection zones. Third order streams were buffered with a 125 foot protection zone and springs were given a 500 foot radius protection zone. In order to create a continuous network of protected waters, features adjacent to streams and chains of related features were all linked to the zone 1 protected stream network. The boundaries of the zone 2 conservation network were extended 75 feet for streams with defined Federal Emergency Management Agency (FEMA) floodways and 50 feet for smaller streams. This distance is in addition to the first zone buffer distances and is extended to the edges of the FEMA floodplain when present. A 50 foot conservation buffer was added to sinkholes and wetlands and 450 feet was added to the uphill sides of springs. The final zone 3 buffer adds an additional 25 feet to the network.

Ridge protection corridors were created by identifying all land with slopes greater than 25% plus adjacent forested areas with slopes greater than 15%. Heritage protection corridors were identified as areas with prime or good farmland, remaining forests, prime grassland habitat, and riparian habitat areas. Ground water and stream protection corridors were identified and linked with the ridge and heritage protection corridors. The composite of the ground water, stream, ridge, and heritage protection corridors provides the final land stewardship network.

Parcels that intersect the land stewardship network were identified for consideration in conservation and development decisions such as conservation easements and proposed town, village, and neighborhood centers. A proposed future settlement pattern was created to guide land use planning decisions in the coming years. This involves a density gradient of neighborhood types that allows for the most ecologically important areas to be protected while allowing other areas to be developed at reasonable and desirable densities.

Green infrastructure plans, such as the one developed for Beaver Creek, can help communities to plan for smart growth and sustainable development that preserves the socially and ecologically valuable lands that will provide recreational, aesthetic, and ecosystem services to future generations. This kind of planning is necessary for maintaining healthy watersheds while allowing for the economic growth that is necessary to support growing populations.

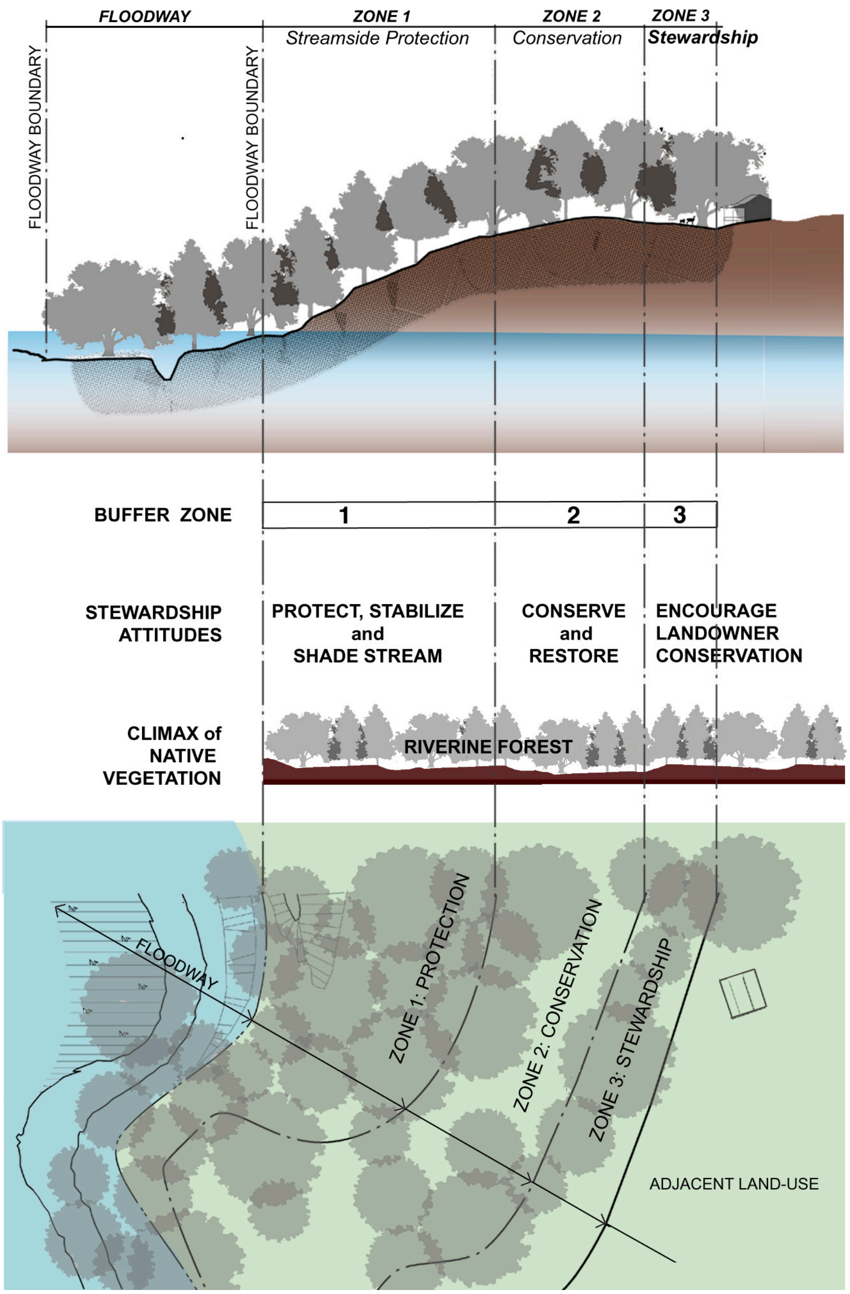



**Figure 3-5** Three-zone buffer showing the protection, conservation, and stewardship zones (Moir-McClean & DeKay, 2006).

### The Active River Area

**Author or Lead Agency:** The Nature Conservancy

**More Information:** http://conserveonline.org/workspaces/freshwaterbooks/documents/active-river-area-a-conservation-framework-for/view.html

The Nature Conservancy's Active River Area approach is a framework for protecting rivers and streams. The health of a stream or river depends on a variety of physical and ecological processes that operate within the dynamic environment of the water/land interface. This environment has been termed the "Active River Area" and is formed and maintained by disturbance events and regular variations in flow. The Active River Area includes the river channel itself, as well as the riparian lands necessary for the physical and ecological functioning of the river system. The approach complements other programs that seek to protect natural hydrologic regimes, maintain connectivity, improve water quality, eradicate invasive species, and maintain riparian lands in natural cover.

The proper functioning of rivers and riparian areas depends on the dynamic ecological interactions and disturbance events that characterize natural flowing water systems. The Active River Area focuses on five key processes: hydrology and fluvial action, sediment transport, energy flows, debris flows, and biotic actions and interactions. The approach identifies the places where these processes occur based on valley setting, watershed position, and geomorphic stream type. The five primary components of the Active River Area are:

1. Material contribution areas.
2. Meander belts.
3. Floodplains.
4. Terraces.
5. Riparian wetlands.

*Material contribution areas* are small headwater catchments in the uppermost reaches of the watershed, as well as upland areas immediately adjacent to streams and rivers that are not floodplain, terrace, or riparian wetlands. Material contribution areas provide food and energy (e.g., falling leaves) to aquatic organisms that is then transported downstream through ecological processes. *Meander belts* are the most active part of the Active River Area and are defined as the area within which the river channel will migrate, or meander, over time. The meander belt width is the cross-channel distance that spans the outside-most edges of existing or potential meanders and can be easily measured and mapped for both healthy and altered rivers, providing a basis for management decisions (e.g., implementation of no-build zones). *Floodplains* are expansive, low-slope areas with deep sediment deposits. Low floodplains are immediately adjacent to the stream channel and are typically flooded annually, while high floodplains are at somewhat higher elevations and flooded every one to 10 years on average. *Terraces* are former floodplains that may be flooded and provide storage capacity during very large events (e.g., the 100-year flood). *Riparian wetlands* are areas with hydric soils that support wetland plant species. Riparian wetland soils are flooded by the adjacent river water and/or high ground water levels. These areas support a high biodiversity with a variety of aquatic and terrestrial habitat types.

The physical and ecological processes occurring in each of these five areas differ depending on watershed position (Figure 3-6). The Active River Area framework uses Schumm's (1977) system of classifying watershed position to organize the five Active River Area components into upper-watershed, mid-watershed, and low-watershed zones. This system of organization helps to understand the Active River Area in the context of the landscape of which it is a part. The mosaic of habitat patches formed by the dynamic interactions in the Active River Area could be considered landscape elements, with the river corridor itself serving as a link between the elements.

The methods used to delineate the Active River Area involve GIS techniques and analyses of elevation, land cover, and wetlands data. The meander belt/floodplain/riparian wetland/terrace area can be identified using a Digital Elevation Model (DEM) and a technique that calculates the area within which the river is expected to interact dynamically with the land surface. It is based on both the lateral and vertical distance (elevation) from

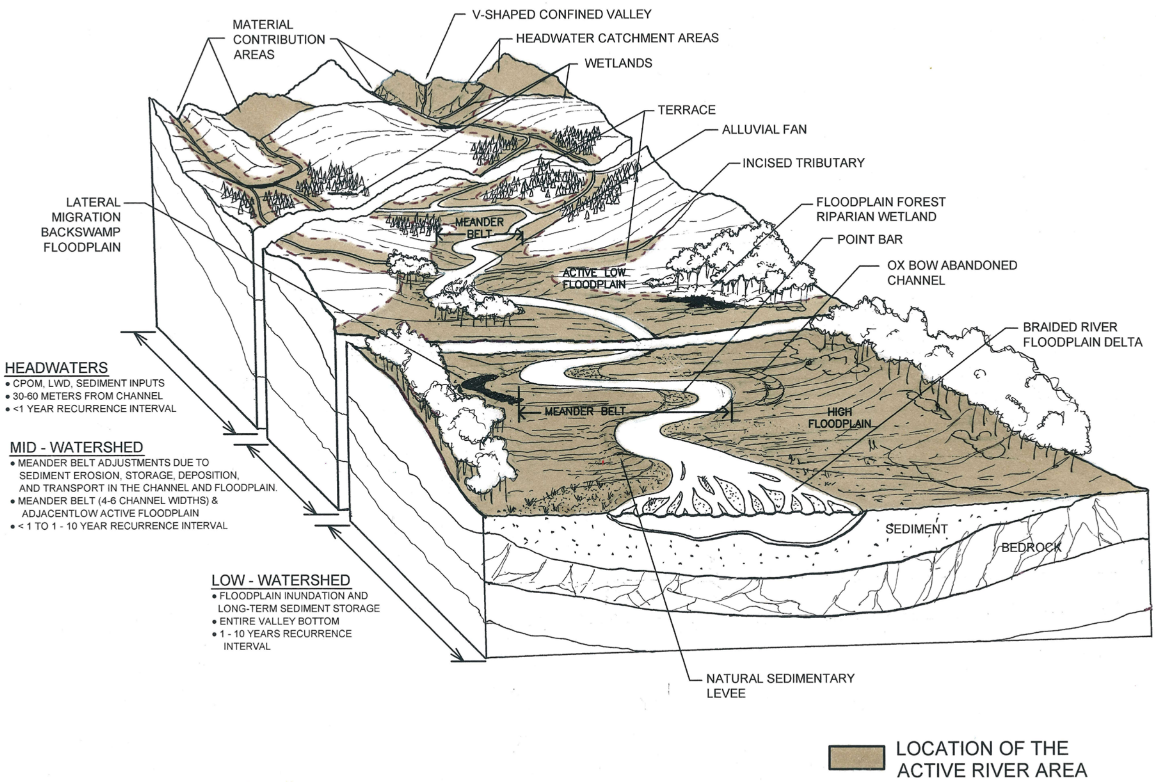



**Figure 3-6** Components and dominant processes of the Active River Area (Smith et al., 2008).

the stream and user-supplied cutoff distances that are determined based on stream size (Strager, Yuill, & Wood, 2000). By considering stream size, the dominant physical processes occurring in each zone of the watershed are accounted for. Since the extent of riparian wetlands is dependent not only on overbank flows, but also on ground water and runoff from adjacent uplands, a second technique is used to determine those areas expected to be wet based on slope and a flow moisture index. Combining these identified areas with the known occurrence of wetlands from the National Land Cover Database (NLCD) and National Wetlands Inventory (NWI) data and a distance cutoff based on stream size, riparian-associated wetlands can be identified.

Material contribution areas can also be identified using GIS techniques. The DEM data layer for a watershed is divided into 10 equal elevation groups. Headwater catchments can be defined based on size relative to the watershed and inclusion in the appropriate elevation group. The appropriate elevation group and headwater catchment size depends on area-specific conditions and is determined by the user. For example, a headwater catchment area of <10 $m^2$ falling mostly within the top 40% of elevation bands could be used as the criteria for identifying headwater material contribution areas. For the streamside areas not yet included in either of the above methods, an area with a width of 30-50 meters can be used as a cutoff for identifying streamside material contribution areas.

These GIS techniques identify the material contribution areas, riparian wetlands, and the combined area consisting of the meander belt/floodplains/terraces. Distinguishing between the meander belt, floodplains, and terraces requires more detailed field assessments such as the Vermont Stream Geomorphic Assessment Protocols (Kline, Alexander, Pytlik, Jaquith, & Pomeroy, 2009). However, these simple GIS techniques alone are enough to delineate the Active River Area and begin to prioritize lands for conservation.

The Nature Conservancy has demonstrated the technique in the Connecticut River Basin to highlight the utility of the methodology for identifying and prioritizing lands within the Active River Area for conservation actions (Figure 3-7). The Active River Area was delineated using the GIS techniques described above. A condition analysis using land cover data was then performed to identify the largest intact areas with minimal developed or agricultural lands. For example, riparian areas with less than 25% agricultural land use could be considered most intact and prioritized for conservation. Similarly, headwater areas with less than 1% impervious surfaces and less than 5% agricultural land use could be considered very good, while those headwater areas with less than 3% impervious surfaces and less than 25% agricultural land use could be considered good. This is a simple method for identifying priority conservation lands within the Active River Area. Other prioritization methodologies are available to address more specific objectives. Prioritization methodologies should be based on local knowledge and data whenever possible.

Combining the Active River Area approach with other approaches such as a green infrastructure assessment or GAP analysis can provide a comprehensive framework for identifying those areas critical for maintaining watershed and river ecological integrity. Water quality, habitat, and biomonitoring data can further refine the analysis of healthy components of the watershed. Identifying those areas within the Active River Area that are not currently protected, but that are comprised of land uses compatible for conservation, as well as the corridors connecting the Active River Area with other hubs, or habitat patches, on the landscape creates the outline of a strategy to protect aquatic ecosystems. The Active River Area components can be used to design freshwater protected areas that support natural disturbance regimes, natural hydrologic and geomorphic variability, and a connected network of healthy areas.

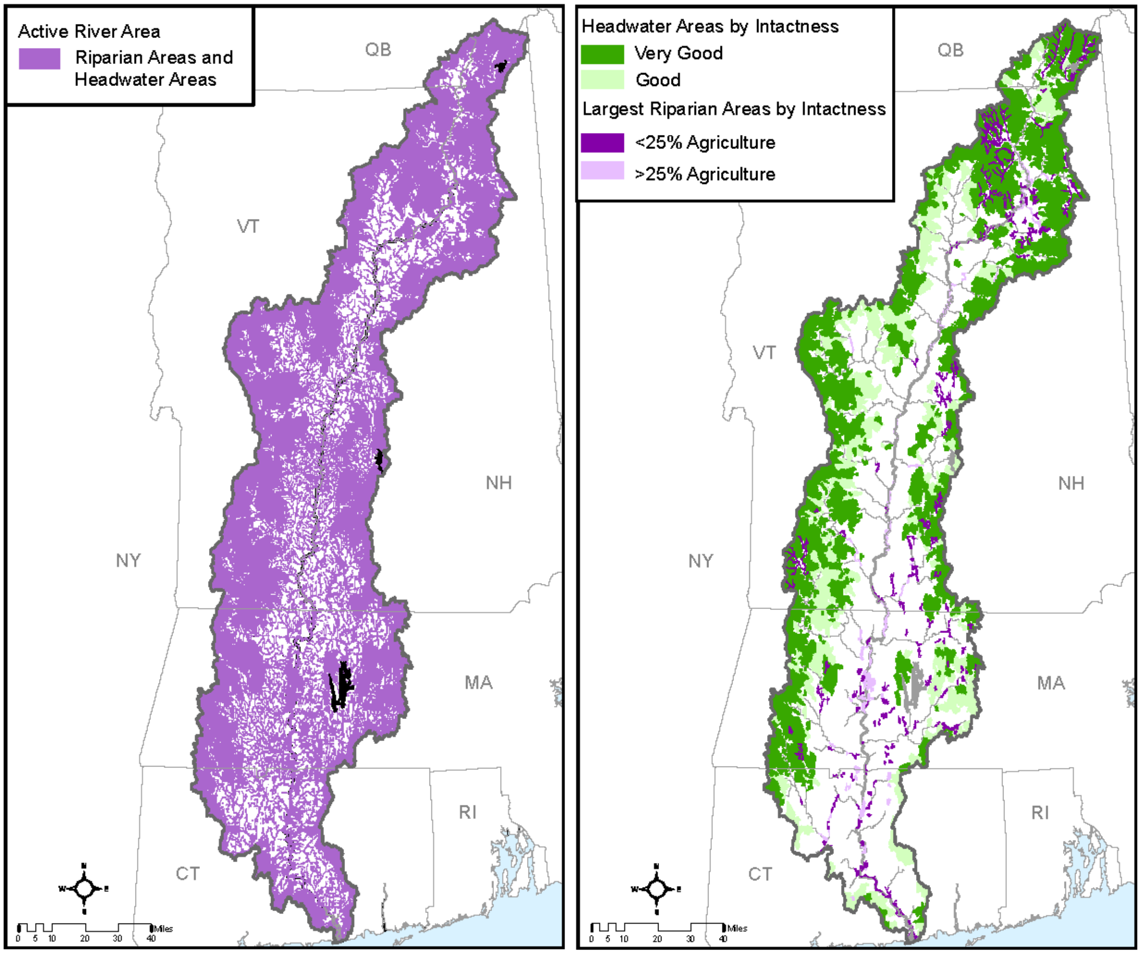



**Figure 3-7** The Active River Area in the Connecticut River Basin (Smith et al., 2008).

### Interagency Fire Regime Condition Class

**Author or Lead Agency:** Hann et al., 2008. U.S. Forest Service, U.S. Department of the Interior, The Nature Conservancy, and Systems for Environmental Management

**More Information:** http://frames.nbii.gov/documents/frcc/documents/FRCC+Guidebook_2008.10.30.pdf

The Fire Regime Condition Class (FRCC) methodology relies upon concepts that define the natural fire regime as "the role fire would play across a landscape in the absence of modern human mechanical intervention but including the possible influence of aboriginal fire use." The FRCC field and mapping assessment methods describe the departure of fire disturbance regime from reference periods or the natural range of variability (as determined through modeling). These results allow land managers to focus management strategies on maintaining or restoring the natural disturbance regime of the forest or rangeland ecosystem. These methods were developed by an interagency working group and The Nature Conservancy, and managed by the National Interagency Fuels Coordination Group.

The FRCC methodology allows for the assessment of the fire disturbance regime and resultant vegetation at the stand and landscape scales. Two procedures exist for determining the FRCC. The FRCC Standard Landscape Worksheet Method provides the background understanding necessary to use the other tools in the FRCC Guidebook, as well as allows for assessment at both the landscape and stand scales. The FRCC Standard Landscape Mapping Method determines FRCC based on vegetation departure alone, while the Worksheet Method assesses both vegetation departure and fire regimes directly. However, methods are under development for assessing the fire regime through the Mapping Method. Outputs from the Mapping Method are consistent, objective, and spatially explicit at multiple scales. The Mapping Method can also be employed for larger geographic scales with much less staff time. Maintenance or restoration of the natural fire regime is important for preventing severe fires that can destroy entire forest ecosystems, contribute vast quantities of sediment to streams from surface erosion, and damage public and private infrastructure. Areas that have departed from their natural fire regime have also been shown to cause excessive build-up of nutrients on the forest floor due to decomposition of organic matter (Miller et al., 2006). These nutrients can then be transported to aquatic ecosystems during rainfall/runoff events, causing eutrophic conditions. The continual build-up of nutrients on the forest floor provides a constant source of pollution to streams and lakes in the watershed. Fire disturbances, of natural frequency and intensity, remove the excess organic matter causing the nutrient build-up and may actually improve long-term water quality, although it will be temporarily worsened immediately following a fire (Miller et al., 2006). These are important considerations for watershed managers seeking to maintain overall watershed health.

Five natural fire regimes are classified based on frequency and severity, which reflect the replacement of overstory vegetation (Table 3-3). The natural fire regime for a landscape unit is determined based on its biophysical setting. A biophysical setting, in the FRCC methodology, is described based on the vegetation composition and structure associated with particular fire regimes.

**Table 3-3** Fire regime groups and descriptions (Hann et al., 2008).

| Group | Frequency | Severity | Severity Description |
|---|---|---|---|
| I | 0-35 Years | Low/Mixed | Generally low-severity fires replacing less than 25% of the dominant overstory vegetation; can include mixed-severity fires that replace up to 75% of the overstory. |
| II | 0-35 Years | Replacement | High-severity fires replacing greater than 75% of the dominant overstory vegetation. |
| III | 35-200 Years | Mixed/Low | Generally mixed-severity; can also include low-severity fires. |
| IV | 35-200 Years | Replacement | High-severity fires replacing greater than 75% of the dominant overstory vegetation. |
| V | 200+ Years | Replacement/Any Severity | Generally replacement-severity; can include any severity type in this frequency range. |

The LANDFIRE Program (U.S. Department of Agriculture; U.S. Department of the Interior, 2009) models reference conditions for biophysical settings for the entire United States based on five characteristic succession classes of forest and rangeland ecosystems:

1. S-Class A: Early seral, post-replacement.
2. S-Class B: Mid seral, closed canopy.
3. S-Class C: Mid seral, open canopy.
4. S-Class D: Late seral, open canopy.
5. S-Class E: Late seral, closed canopy.

Evaluating the vegetation across the project landscape allows for the delineation of biophysical settings, which can be compared to the relative amounts of each succession class for reference conditions in that biophysical setting. For example, Table 3-4 shows the percent coverage of each succession stage (columns A-E) within the biophysical setting. The last column displays the "fire regime group" for each biophysical setting's reference conditions, which has a frequency range of 35-200 years and an average severity of mixed to low.

**Table 3-4** Example reference condition table (Hann et al., 2008).

| Biophysical Setting | A | B | C | D | E | Fire Regime Group |
|---|---|---|---|---|---|---|
| Rocky Mountain Aspen Forest & Woodland | 34% | 20% | 8% | 26% | 12% | 3 |
| Rocky Mountain Lodgepole Pine Forest | 29% | 47% | 26% | 0% | 0% | 4 |
| Rocky Mountain Alpine Dwarf Shrubland | 14% | 86% | 0% | 0% | 0% | 5 |

Weighted averages for percent coverage of succession classes in all biophysical settings within the project landscape and weighted averages of the fire frequency and severity for all biophysical settings in the project landscape are used to determine the degree of departure from reference conditions. The FRCC is then determined based on this degree of departure:

1. FRCC 1: ≤ 33% (within reference condition range of variability).
2. FRCC 2: > 33% to ≤ 66% (moderate departure).
3. FRCC 3: > 66% (high departure).

Management implications are then defined based on the FRCC and relative amount of succession class (Table 3-5). For example, an FRCC of 3 and an abundant amount of the succession class would suggest that thinning of the forest stand would improve the condition. Conversely, an FRCC of 1 with only trace amounts of the succession class does not require any action.

**Table 3-5** Management implications for the stand-level fire regime condition class based on the S-Class relative amount (Hann et al., 2008).

| S-Class Relative Amount | Stand FRCC | Improving Condition if Stand is: |
|---|---|---|
| Trace | 1 | Maintained |
| Under-represented | 1 | Maintained |
| Similar | 1 | Maintained |
| Over-represented | 2 | Reduced |
| Abundant | 3 | Reduced |

The relative amount of each S-Class (A, B, C, D, and E) is determined for the stand and evaluated against the reference conditions for its biophysical setting (e.g., Table 3-4). Five natural fire regimes are classified based on frequency and severity, which reflect the replacement of overstory vegetation (Table 3-3). The natural fire regime for a landscape unit is determined based on its biophysical setting. A biophysical setting, in the FRCC methodology, is described based on the vegetation composition and structure associated with particular fire regimes (Table 3-4). The FRCC for the stand is then determined based on the departure from reference conditions (e.g., under-represented or over-represented).

The entire process involves a significant amount of data gathering and input that can be greatly facilitated through the use of the GIS-based FRCC Mapping Tool. Outputs of the FRCC Mapping Tool include:

1. Succession class relative amount.
2. Succession class relative departure.
3. Stand FRCC.
4. Biophysical setting departure.
5. Biophysical setting FRCC.
6. Landscape departure.
7. Landscape FRCC.

The FRCC Mapping Method provides condition class outputs at three scales (stand, biophysical setting, and landscape). Figure 3-8 displays an example of the landscape scale output.

The results of the FRCC assessment are used to prioritize fire suppression activities across the United States. They can also be used to help manage invasive species through the use of controlled burns without destroying natural ecosystem components. The methodology also provides a foundation on which other disturbance regime assessments can be built.

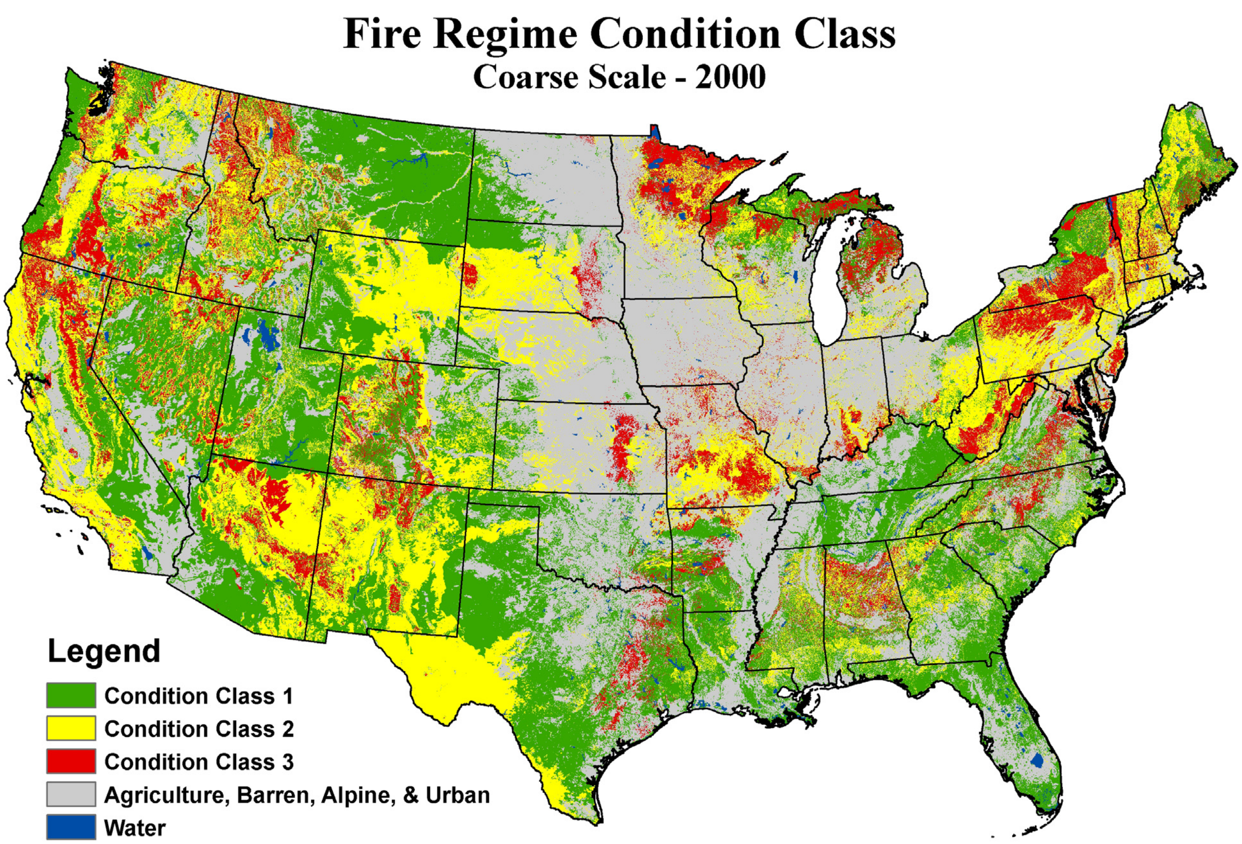



**Figure 3-8** National landscape-scale output of the Fire Regime Condition Class Mapping Method. (Hann et al., 2008).

## 3.2 Habitat

This section provides summaries for some examples of approaches currently being used to assess habitat. See Chapter 2 for background information on habitat.

**Landscape Condition**
Patterns of natural land cover, natural disturbance regimes, lateral and longitudinal connectivity of the aquatic environment, and continuity of landscape processes.

**Geomorphology**
Stream channels with natural geomorphic dynamics.

**Habitat**
Aquatic, wetland, riparian, floodplain, lake, and shoreline habitat. Hydrologic connectivity.

**Water Quality**
Chemical and physical characteristics of water.

**Hydrology**
Hydrologic regime: Quantity and timing of flow or water level fluctuation. Highly dependent on the natural flow (disturbance) regime and hydrologic connectivity, including surface-ground water interactions.

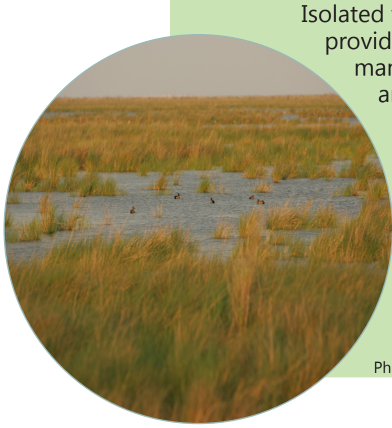
**Biological Condition**
Biological community diversity, composition, relative abundance, trophic structure, condition, and sensitive species.

Headwater streams maintain water quality, attenuate flooding, maintain water supplies, trap and retain sediments, process organic matter, and maintain aquatic biodiversity.

Photo: Adrian Jones, IAN.

Large woody debris increases stream habitat diversity, helps control the grade of a stream channel, and protects streambanks from erosion.

Photo: USFS.



Isolated wetlands provide habitat for many threatened and endangered species, including plants, amphibians, and birds.

Photo: USFWS.

Vegetated riparian areas provide habitat for turtles, birds, and a variety of fish species; they also can trap sediment and reduce nutrients and other pollutants from runoff.

Photo: USFWS.

### Ohio's Primary Headwaters Habitat Assessment

**Author or Lead Agency:** Ohio Environmental Protection Agency

**More Information:** http://www.epa.state.oh.us/dsw/wqs/headwaters/index.aspx

Ohio EPA's Primary Headwater Habitat (PHWH) Assessment procedure uses a rapid Headwater Habitat Evaluation Index (HHEI) along with two optional levels of biological assessment (order-family level or genus-species level) to assign a headwater stream to one of three classes. Primary headwater streams comprise over 80% of all stream miles in Ohio and provide a variety of ecosystem services and benefits (Meyer, Wallace, Eggert, Helfman, & Leonard, 2007). Most primary headwater streams in Ohio have not been assigned a designated beneficial use. Additionally, due to habitat differences, biological criteria and methods of sampling used in larger streams are not applicable to many primary headwater streams. In response to these limitations, Ohio EPA conducted a statewide evaluation of PHWH and developed the HHEI. The HHEI uses a combination of three habitat variables to predict the presence or absence of an assemblage of cold-cool water adapted vertebrates and benthic macroinvertebrates. Using the results of the HHEI, a *potential* existing aquatic life use can be assigned to the stream reach. When biological assessment data are available, these data will be used to determine the *actual* existing aquatic life use designation.

Primary headwater streams are defined by Ohio EPA as streams having a watershed area of less than one square mile, with a defined stream bed and bank, and a natural pool depth of less than 40 cm. Streams with a larger watershed area or natural pool depths greater than 40 cm should be evaluated using the Qualitative Habitat Evaluation Index, as opposed to the HHEI. For the purposes of the HHEI, stream reaches of up to 200 ft. should be delineated for assessment. Tributaries of the PHWH stream should be evaluated separately from the main stem. The evaluation should be conducted at a time when base flow conditions are present. Once the watershed drainage area has been calculated and the stream reaches delineated, physical habitat conditions including bank full width, maximum pool depth, and substrate composition are recorded on the PHWH form. Additional habitat parameters may be measured and recorded if desired. These include gradient, flood prone width, and pebble counts. Water chemistry, salamander, fish, and macroinvertebrate survey data can also be collected if desired or deemed appropriate. The data from the HHEI and/or the biological survey data (if available) should be used to determine the appropriate Class I, II, or III existing aquatic life use designation (Class III being of the highest quality). The HHEI is calculated based on a scoring system using the bank full width, maximum pool depth, and substrate composition.

Biological survey data can be collected for a more detailed evaluation of primary headwater streams. A Headwater Macroinvertebrate Field Evaluation Index can be calculated to refine a PHWH stream classification. Based on the taxa present, a scoring system places the stream reach into one of the three classes of PHWH. The presence of cold water fish indicator species automatically places the stream in the Class III PHWH category. In the absence of fish, aquatic and semi-aquatic salamanders are the primary vertebrate predator functional group in Ohio's headwater streams. Therefore, a salamander survey is used to evaluate the biological health of headwater habitats. Three different assemblages of salamander species have been identified by Ohio EPA as corresponding to the three PHWH Classes. The goal of the salamander survey is simply to document the presence or absence of the species representing the three assemblages.

The output of the Primary Headwaters Habitat Assessment is a classification of:

- Class I PHWH - ephemeral stream, normally dry channel.
- Class II PHWH - warm water adapted native fauna.
- Class III PHWH - cool-cold water adapted native fauna.

These classifications help to protect Ohio's primary headwater streams through the state's water quality standards, which are chemically and biologically based.

## A Physical Habitat Index for Freshwater Wadeable Streams in Maryland

**Author or Lead Agency:** Maryland Department of Natural Resources

**More Information:** http://www.dnr.md.gov/streams/pubs/ea03-4phi.pdf

The Maryland Biological Stream Survey developed a multimetric index to describe stream physical habitat. The effort resulted in a Physical Habitat Index (PHI) that relates metrics of geomorphology, visual habitat quality, and riparian condition to classify streams compared to reference conditions in the state. The PHI is significantly correlated with the benthic IBI and fish IBI. This correlation can help to elucidate the effects of physical habitat attributes and chemical stressors on biological condition.

Based on the understanding that physical habitat degradation is one of the leading causes of stream impairment, the Maryland Biological Stream Survey began collecting a variety of physical habitat variables as part of its routine biomonitoring program in 1994. Based on a statistical evaluation of these data, the Coastal Plain, Piedmont, and Highland regions were chosen to represent three biologically distinct stream classes. Reference and degradation criteria were determined based on the amount of forested, agricultural, and urban land use. Different reference criteria were developed for each of the three stream classes. The metrics selected for each stream class are shown in Table 3-6. The final PHI for a stream is calculated by averaging the individual metric scores.

**Table 3-6** Metrics for the Physical Habitat Index in each of the three stream classes in Maryland (Maryland Department of Natural Resources, 2003).

| Coastal Plain | Piedmont | Highland |
|---|---|---|
| Bank stability | Riffle quality | Bank stability |
| Instream wood | Bank stability | Epibenthic substrate |
| Instream habitat quality | Instream wood | Shading |
| Epibenthic substrate | Instream habitat quality | Riparian width |
| Shading | Epibenthic substrate | Remoteness |
| Remoteness | Shading | |
| | Remoteness | |
| | Embeddedness | |

The relationship between the PHI, fish IBI, and benthic IBI were examined by ecoregion and river basin. These relationships were found to be significantly correlated. However, the degree to which the PHI predicts fish or benthic IBI depends on the presence and levels of other stressors, such as low dissolved oxygen or high temperatures. Given that the PHI was found to be significantly correlated with biological condition, the analysis was completed statewide (Figure 3-9). The PHI is used in Maryland's statewide monitoring and assessment program and, along with biological and chemical assessments, is used to communicate the condition of Maryland's streams to the public and decision makers.

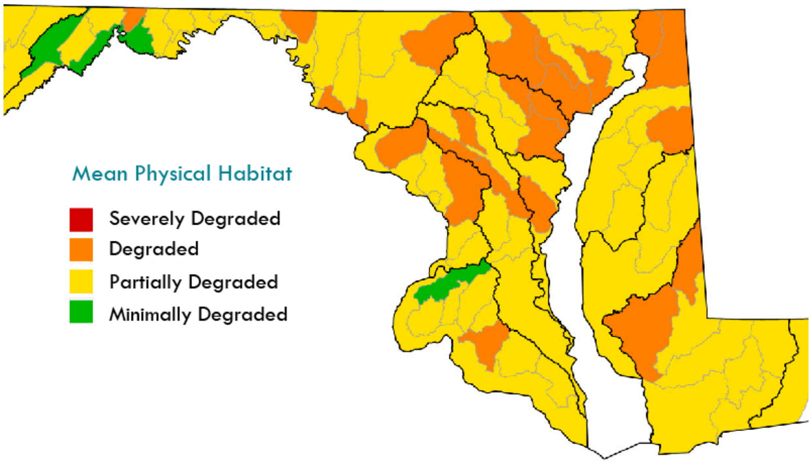



**Figure 3-9** Map of stream habitat condition in Maryland, as determined with the Physical Habitat Index (Maryland Biological Stream Survey, 2005).

### Proper Functioning Condition

**Author or Lead Agency:** U.S. Bureau of Land Management, U.S. Fish and Wildlife Service, and Natural Resources Conservation Service

**More Information:** ftp://ftp.blm.gov/pub/nstc/techrefs/Final%20TR%201737-9.pdf

The Proper Functioning Condition (PFC) assessment method is a checklist-based evaluation of riparian wetland functional status that was developed by the Bureau of Land Management, U.S. Fish and Wildlife Service, and the Natural Resources Conservation Service (NRCS). It is a qualitative, field-based methodology developed by an interdisciplinary team around the principles of the quantitative Ecological Site Inventory (Habich, 2001) method. The method was developed with the purpose of restoring and managing riparian wetlands in 11 western states.

The PFC process requires an interdisciplinary team of soil, vegetation, hydrology, and biology specialists and follows three overall steps: 1) review existing documents, 2) analyze the PFC definition, and 3) assess functionality using the checklist. The PFC method defines a riparian wetland area as being in proper functioning condition when adequate vegetation, landform, or large woody debris is present to:

- Dissipate stream energy associated with high water flow, thereby reducing erosion and improving water quality.
- Filter sediment, capture bedload, and aid floodplain development.
- Improve flood-water retention and ground water recharge.
- Develop root masses that stabilize stream banks against cutting action.
- Develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses.
- Support greater biodiversity.

The PFC method evaluates a specific riparian wetland area against its capability and potential. Capability is defined as "the highest ecological status an area can attain given political, social, or economical constraints, which are often referred to as limiting factors." Potential is defined as "the highest ecological status a riparian-wetland area can attain given no political, social, or economical constraints, and is often referred to as the potential natural community." Restoration goals resulting from the assessment emphasize achievement of the highest level of functioning given the political, social, or economic constraints that are present. Therefore, PFC does not necessarily equate to "natural" conditions. Assessing a specific area's capability and potential involves examination of soils for evidence of previous saturation, frequency and duration of flooding, historic record of plant and animal species present, relic areas, and historic photos. Table 3-7 contains the 17 components of the PFC checklist.

Using the checklist and the definition of PFC, an assessment of a riparian wetland results in one of four ratings:

- Proper functioning condition.
- Functional - at risk.
- Nonfunctional.
- Unknown.

A rating of proper functioning condition means that the riparian area is stable and resilient at high flow events, while ratings of functional – at risk or nonfunctional mean that the area is susceptible to damage at medium to high flow events. Rehabilitation strategies should be developed for areas rated as nonfunctional (e.g., riparian revegetation). Areas placed in the functional - at risk category should be evaluated for their trend toward or away from proper functioning condition and the appropriate protection or monitoring strategies put in place. The results of a PFC analysis can be combined with other types of watershed assessments for a better understanding of how the riparian and upland areas interact. A PFC analysis is also often used as a screening level assessment to determine whether or not more intensive, quantitative analyses are necessary.

**Table 3-7** Proper Functioning Condition checklist worksheet (Bureau of Land Management, 1998).

| Yes | No | N/A | HYDROLOGY |
|---|---|---|---|
| | | | 1) Floodplain above bankfull is inundated in "relatively frequent" events |
| | | | 2) Where beaver dams are present they are active and stable |
| | | | 3) Sinuosity, width/depth ratio, and gradient are in balance with the landscape setting (i.e., landform, geology, and bioclimatic region) |
| | | | 4) Riparian-wetland area is widening or has achieved potential extent |
| | | | 5) Upland watershed is not contributing to riparian-wetland degradation |

| Yes | No | N/A | VEGETATION |
|---|---|---|---|
| | | | 6) There is diverse age-class distribution of riparian-wetland vegetation (recruitment for maintenance/recovery) |
| | | | 7) There is diverse composition of riparian-wetland vegetation (for maintenance/recovery) |
| | | | 8) Species present indicate maintenance of riparian-wetland soil moisture characteristics |
| | | | 9) Streambank vegetation is comprised of those plants or plant communities that have root masses capable of withstanding high stream flow events |
| | | | 10) Riparian-wetland plants exhibit high vigor |
| | | | 11) Adequate riparian-wetland vegetative cover is present to protect banks and dissipate energy during high flows |
| | | | 12) Plant communities are an adequate source of coarse and/or large woody material (for maintenance/recovery) |

| Yes | No | N/A | EROSION/DEPOSITION |
|---|---|---|---|
| | | | 13) Floodplain and channel characteristics (i.e., rocks, overflow channels, coarse and/or large woody material) are adequate to dissipate energy |
| | | | 14) Point bars are revegetating with riparian-wetland vegetation |
| | | | 15) Lateral stream movement is associated with natural sinuosity |
| | | | 16) System is vertically stable |
| | | | 17) Stream is in balance with the water and sediment being supplied by the watershed (i.e., no excessive erosion or deposition) |

### Rapid Stream-Riparian Assessment

**Author or Lead Agency:** Wild Utah Project

**More Information:** http://wildutahproject.org/files/images/rsra-ug2010v2_wcover.pdf

The Rapid Stream-Riparian Assessment (RSRA) protocol (Stevens et al., 2005 and Stacey et al., 2007) was developed to provide a mechanism to objectively determine the functional condition of both the aquatic and riparian components of small and medium sized streams and rivers in the American Southwest and in other arid and semi-arid regions. It provides a standardized method to evaluate the existing conditions along a particular reach of river to determine which components of the stream-riparian ecosystem differ from what would be expected within the reach under geomorphically similar but unimpacted reference conditions. It also creates a yardstick by which to objectively monitor any future changes within the system that result either from active restoration programs or from allowing the system to follow its current trajectory under existing management programs. Because the protocol can be completed in a relatively short time and does not require specialized and expensive equipment, it is possible to efficiently survey a number of different reaches within a particular watershed. This can then provide an understanding of both the variation in conditions within a particular watershed, as well as any potential trends that might indicate cumulative impacts of various activities upon the stream-riparian ecosystem.

The RSRA utilizes a primarily qualitative assessment based on quantitative measurements made in the field. It focuses upon five functional components of the stream-riparian ecosystem that provide important benefits to humans and wildlife and which, on public lands, are often the subject of government regulation and standards. These components are:

1. Non-chemical water quality and pollution;
2. Stream channel and floodplain morphology and the ability of the system to limit erosion and withstand flooding without damage;
3. The presence of habitat for native fish and other aquatic species;
4. Riparian vegetation structure and productivity; including the occurrence and relative dominance of exotic or nonnative species; and
5. Suitability of habitat for terrestrial wildlife, including threatened or endangered species.

Within each of these areas, the RSRA evaluates between two and seven variables that reflect the overall function and health of the stream-riparian ecosystem. Variables are measured either along the entire study reach (usually around 1 kilometer in length, depending on local conditions) or along 200 meter sample transects. Each variable is assigned a score from 1 to 5, using pre-defined scoring levels that can be scaled to the individual geomorphic and ecological conditions of that particular reach. A score of 1 indicates that the ecosystem is highly impacted and non-functional for that variable, while a score of 5 indicates that the system is healthy and is functioning in a way that would be found in a local and geomorphically similar reference stream that has not been impacted by human activities. A complete description of the variables and the methods used to collect and score them can be found in Stacey et al. (2007).

#### Examples of RSRA Variables

- Large woody debris
- Overbank cover and terrestrial invertebrate habitat
- Plant community cover and structural diversity
- Dominant shrub and tree demography
- Non-native herbaceous and woody plant cover
- Mammalian herbivory impacts on ground cover
- Mammalian herbivory impacts on shrubs and small trees
- Riparian shrub and tree canopy cover and connectivity
- Fluvial habitat diversity

The RSRA provides information that will be of value to land managers in making policy decisions and to help provide guidance for potential restoration programs. The protocol considers features or variables that not only indicate the ability of the system to provide specific functions, but ones that also reflect important ecological processes within the stream-riparian system. For example, the fish habitat section includes a measure of the relative amount of undercut banks along the reach. Undercut banks not only provide important habitat and hiding cover for fish and other aquatic species, but their presence along a reach indicates that the banks themselves are well vegetated and that there is sufficient root mass from vegetation to allow the development of the hour-glass shape channel cross-section that is typical of most healthy stream systems. The presence of this channel shape, in turn, indicates that the fluvial processes of erosion and deposition along that reach are in relative equilibrium. Thus, when interpreting RSRA surveys, the results of all indicators should be considered in concert. This will facilitate deciding which parts of the ecosystem within the study reach may be most out of balance with natural processes and, therefore, which of those parts may be the most important or the most suitable for future restoration efforts.

In order to increase the number of survey sites that can be sampled, the protocol uses variables that can be measured rapidly in the field and that do not require specialized equipment. More detailed and extensive methods have been developed for several of the individual indicators included in this protocol. Many of these analyses may take one or more days to complete, just for that single variable. However, should any of the individual indicators be found to be particularly problematic or non-functional in a specific reach using the RSRA protocol, more specialized methods can be used during subsequent visits to the site in order to collect additional quantitative information on that particular indicator.

The RSRA protocol measures only the current condition of the ecosystem. It does not base its scores upon some hypothesized future state or successional trend within the reach, as is done with several other riparian assessment methods (e.g., the BLM's Proper Functioning Condition assessment). The RSRA method addresses the ability of the ecosystem to provide some important function at the present time, not whether it would be likely to do so at some point in the future, if current trends or management practices on the reach continue. This approach is used because stream-riparian systems are highly dynamic, and they are often subject to disturbances (e.g., large floods) that can alter successional trends and make predictions of future conditions on an individual reach highly problematic. Also, by evaluating only current conditions, this protocol can serve as a powerful tool for monitoring and measuring future changes in the functional status of the system. For example, if a particular set of indicators suggest that a reach is in poor condition, re-evaluating the system with the same protocol in subsequent years gives one the ability to measure the effectiveness of any management change or active restoration program and to undertake corrective action if the restoration efforts are not found to be producing the desired changes. This type of adaptive management approach can be extremely challenging if the evaluation and monitoring measures are based primarily upon the expectations of some future, rather than current, condition.


Peter Stacey

### Ohio Rapid Assessment Method

**Author or Lead Agency:** Ohio EPA Division of Surface Water

**More Information:** http://www.epa.ohio.gov/dsw/wetlands/WetlandEcologySection.aspx#ORAM

Having worked through five previous versions of a wetlands assessment methodology based on the Washington State Wetlands Rating System, Ohio EPA decided to impart a new format and structure on the assessment process when the Ohio Rapid Assessment Method (ORAM) for Wetlands Version 5.0 was developed. ORAM is designed to measure the intactness of the hydrologic regime and habitat of a wetland relative to the type of wetland in question. The basis for ORAM is a ten-page wetland categorization form. The form includes worksheets that direct the assessor through the process of identifying background information, a scoring boundary, and a narrative rating for the wetland. The first part of the assessment is to use the wetland's hydrologic regime to define the boundary of the area to be assessed. Following the six-step process outlined on the form, the assessor:

1. Identifies the area of interest;
2. Locates physical evidence of rapid changes in hydrology;
3. Delineates a boundary around all areas within and contiguous with the area of interest that have the same hydrologic regime as the area of interest;
4. Verifies that none of the boundaries of the delineation have been defined using artificial boundaries;
5. Adjusts the delineation as needed to encompass multiple wetlands for scoring if appropriate; and
6. Consults the current version of the ORAM manual to ensure that any complex situations (i.e., patchworks, wetlands bounded by water bodies, wetlands transected by artificial boundaries, or wetlands that may fit into multiple categories) have been handled properly.

Once the boundary to be used in the assessment has been defined, the assessor proceeds to awarding the wetland a narrative rating. Additional information is gathered through site visits, literature searches, and data requests from relevant agencies. Site visits should be carefully scheduled paying close attention to the possibility that seasonal changes may affect the assessor's ability to make unbiased observations. The narrative rating uses the presence or absence of threatened or endangered species to determine whether or not the wetland should be considered for superior function/integrity status (Category 3). Wetlands that are not candidates for Category 3 are divided between wetlands having moderate function/integrity (Category 2) and wetlands with minimal function/integrity (Category 1) in the quantitative rating process. As in a dichotomous key, the "Yes" or "No" questions used in the narrative rating process form a decision tree that solicits responses from the assessor that set him or her up to be able to answer questions appropriately in the quantitative rating process.

Metrics assessed in the quantitative rating process include:

- Wetland size (6 points);
- Buffer size and intensity of pressure from surrounding land use (14 points);
- Hydrology (30 points);
- Habitat alteration and development (20 points);
- Special wetlands (i.e. bogs, fens, old growth forest) (10 points); and
- Plant communities, interspersion, and microtopography (20 points).

In the hydrology and habitat alteration and development sections of the assessment, there are also tables that prompt the assessor to identify any disturbances observed during the site visit. After rating the wetland for all six metrics, the assessor compares the total number of points awarded to the wetland to the set of breakpoints between categories to place the wetland into one of the same set of three categories used in the narrative rating process. The categories break according to the following point values for emergent wetland vegetation communities: 0-11 points (Category 1), 12-16 points (Category 1 or 2), 17-29 points (Category 2), 30-34 points (Category 2 or 3), and 35 or more points (Category 3). In the case of forested and shrub-scrub wetlands, the categorical breakpoints are as follows: 0-16.9 points (Category 1), 17.0-19.9 points (Category 1 or 2), 20.0-25.9 points (Category 2), 26.0-28.9 points (Category 2 or 3), and 29.0 or more points (Category 3). In either categorization scheme, a wetland can earn up to a maximum of 100 points. The assessment questions and point values are based on significant differences in vegetation index of biotic integrity scores, as developed by Mack et al., (2000). For wetlands that score in point ranges assigned to multiple categories (i.e., “gray zones”), the wetland is assigned to the higher (lower quality) of the two categories, unless detailed assessments and narrative criteria justify assigning the wetland to the lower (higher quality) category. Even with this protocol in place, it remains a possibility that a wetland could be under- or over-categorized because it in some way defies one of ORAM’s underlying assumptions, such as the assumption that human disturbance degrades biotic integrity and function.

Although the numeric output and wetland categorization drawn from ORAM are neither absolute values nor comprehensive ratings of ecological and human value, but rather are most useful when interpreted in the context of all available, relevant information, the results of ORAM assessments nonetheless are useful for comparing different types of wetlands because scores are derived using standardized procedures. In the State of Ohio, the ORAM categories are used to divide wetlands into regulatory groups. Different antidegradation procedures are applicable for Category 1 wetlands, which are held to lower avoidance, minimization, and mitigation standards because they have been so severely degraded. Many of the wetlands that fall into Category 2 have also been degraded, but have a reasonable potential for successful restoration. Ohio’s stormwater runoff control also only applies to wetlands in Categories 2 and 3, and demonstration of public need for disturbing a wetland only applies to wetlands in Category 3. In cases where impact cannot be avoided, compensatory mitigation is required; however, ORAM is not recommended for use beyond the wetland classification process (i.e., analyzing the success of a mitigation project).

### California Rapid Assessment Method

**Author or Lead Agency**: California Wetland Monitoring Group

**More Information:** http://www.cramwetlands.org/

Like other rapid assessment methods, the California Rapid Assessment Method (CRAM) uses field indicators to evaluate the ecological condition of wetlands and associated aquatic resources. CRAM was initially designed for use in assessing the ambient condition of wetlands of seven main types: depressional, estuarine (separated into saline and non-saline), lacustrine, playa, riverine and riparian, vernal pool, or wet meadow. More recent work has focused on the use of CRAM assessment to inform regulatory decisions involving dredge and fill projects and associated mitigation. The results generated by CRAM for these uses have been found to correspond well with other biological and landscape disturbance assessments (Stein et al., 2009). The assessment can be conducted at one of four scales: an individual project, watershed, geographic region, or state. Eight key steps are involved in implementing CRAM (Collins et al., 2008):

1. Assemble background information about the management history of the wetland.
2. Classify the type of wetland with the assistance of the CRAM user's manual.
3. Determine the appropriate season and other timing aspects of the assessment.
4. Estimate the boundary of the area of assessment.
5. Conduct an office assessment of stressors and on-site conditions of the area of assessment.
6. Conduct a field assessment of stressors and on-site conditions of the area of assessment.
7. Complete CRAM scores and perform quality assurance and control procedures.
8. Upload CRAM results to state and regional information systems.

The user's manual (Collins et al., 2008) provides guidance, derived from the Ohio Rapid Assessment Method (Mack, 2001) on determining what portions of the wetland should be included in the area of assessment(s). The CRAM software package makes assessments standardized and cost-effective, requiring a team of two trained professionals to invest half of a day conducting preparations and analyses in the office and half of a day collecting data in the field. Real-time data collection can be conducted using the PC-based data-entry and imagery-delivery system eCRAM, which interfaces with the CRAM website and eliminates the need to produce hard-copy data in the field.

CRAM evaluates wetland condition through an analysis of the size and structural complexity of a wetland determined through assessments of buffer and landscape context, hydrology, physical structure, and biotic structure. Several metrics are used to assess each of these four wetland attributes. For each metric, the assessor matches field observations to one of the condition descriptions (A, B, C, or D) for that metric. Landscape and buffer context is used to estimate the capacity of area surrounding a wetland to shield it from the impacts of pollution and pollutants. Hydrology metrics strive to characterize the magnitude, intensity, and duration of water movement because these hydrologic characteristics affect the wetland's structure as well as the movement of both nutrients and pollutants through the wetland. The physical structure and biotic structure of wetlands are assessed for their ability to support ecosystem functioning as indicated by the complexity of wetland site morphology and plant community composition respectively. The letter grades associated with each of the descriptions given to the wetland are then converted into ordinal scores that can be added across metrics to obtain a score for each attribute; the attribute scores are then summed to obtain the wetland's overall CRAM score. Since the scoring characteristics are consistent regardless of the scale at which the assessment is conducted, wetland scores are comparable across scales.

The spectrum of output scores from CRAM encompasses ecologically-intact aquatic systems, severely degraded aquatic systems, and various conditions between these extremes. In the State of California, CRAM scores are being used to describe trends in wetland condition over time. When comparing the CRAM scores of different wetlands, it is important to consider that the context of a wetland can degrade its condition. The stressor checklist developed as part of CRAM provides assessors with a means of identifying possible factors that may be causing a wetland to score poorly. Similarly, in a regulatory context the stressor checklist can be used to evaluate the ecological suitability of sites proposed for compensatory mitigation.

### Wyoming Wetland Complex Inventory and Assessment

**Author or Lead Agency:** The Nature Conservancy

**More Information:** Copeland et al., 2010

Wetlands are a key component to assess when evaluating watershed health, as they lay at the intersection of terrestrial and aquatic ecosystems. Because wetlands support a hybrid of terrestrial and aquatic features, a disproportionately large number of wildlife species depend on wetlands at some point in their life histories. This point has been particularly noted in Wyoming, where 90% of the state's wildlife species use wetlands, but most of the state is arid and lacks the surface hydrology needed to support wetland complexes and riparian habitat (Hubert, 2004; Nicholoff, 2003). Furthermore, these wetlands face a number of potential threats, including impacts from surrounding lands that are irrigated, fertilized, or treated with pesticides; urban runoff; dams and water withdrawals; climate change; permitted mines and underground injection wells; and fragmentation due to development of oil and gas reserves or residential subdivisions. The need to protect the health of Wyoming's wetlands is clear; however, with limited resources available to support conservation and management, it is critical that resources are strategically allocated to the wetlands where protection and restoration will have the greatest impact.

The Nature Conservancy developed a GIS-based assessment tool to aggregate all the layers of geospatial data for Wyoming, including current and future conditions that decision makers need to consider when developing wetland conservation priorities. Evaluating all data in the same manner at a consistent level for each wetland allows decision makers to compare and rank wetlands for conservation. The assessment is done at the wetland complex level, which requires that wetlands be mapped and then grouped into complexes. To map Wyoming's wetlands, National Wetlands Inventory data were merged with National Hydrography Data via a crosswalk table. The protection status of the assessed wetlands was determined using merged and intersected datasets from the 1994 Wyoming GAP Analysis, the Bureau of Land Management's Areas of Critical Environmental Concern, and conservation easement data from Wyoming Land Trusts and the Wyoming Game and Fish Department. Wetlands were grouped by hydroperiod, and palustrine systems were selected for study in this assessment. Areas in which the wetland density exceeded one per $km^2$ were designated as wetland complexes.

Several refinements were made to the resulting set of wetland complexes to reach the final set of complexes shown in Figure 3-10. Wetland complexes less than 200 hectares in size were excluded from the assessment because the datasets used were poorly suited for such a small scale. On the other hand, the three largest complexes were partitioned into smaller complexes by ecoregion because they encompassed too much environmental variability to be assessed as single units. Furthermore, watersheds larger than 40,500 hectares were split into their sixth level hydrologic unit codes (HUC), although Yellowstone National Park was maintained as a single unit because it is uniformly managed by the National Park Service.

Each complex was divided into hexagons 259 hectares in size. Distribution data for the 49 species identified in Wyoming's 2005 Comprehensive Wildlife Conservation Strategy were generated using geospatial data such as ecological systems, watersheds, water features, and elevation to predict the presence of each species in each hexagon. Shannon's Diversity Index and rare species richness were calculated for each hexagon. The mean values for these indicators were calculated for each complex, and mean indicator scores were normalized to a 0-100 scale (Figure 3-11).

The most current publicly available geospatial data depicting locations and values of factors known to affect the functional integrity of wetlands were compiled. This included irrigated lands, urban areas, golf courses, roads, dams, permitted mines and underground injection permits, potential sources of contamination (e.g., oil and gas wells, wastewater discharge, hazardous waste sites), pipelines, surface water use, toxic contaminants, and county-wide pesticide use. Overall landscape condition was assessed for each wetland complex by summing the scores for individual landscape condition factors and scaling those sums from 1 to 100. Individual condition factor scores were based on the mean distance between the wetland complex and the landscape condition factor, and normalizing the distances on a zero to one scale. Area-weighted means were used for county-based factors.

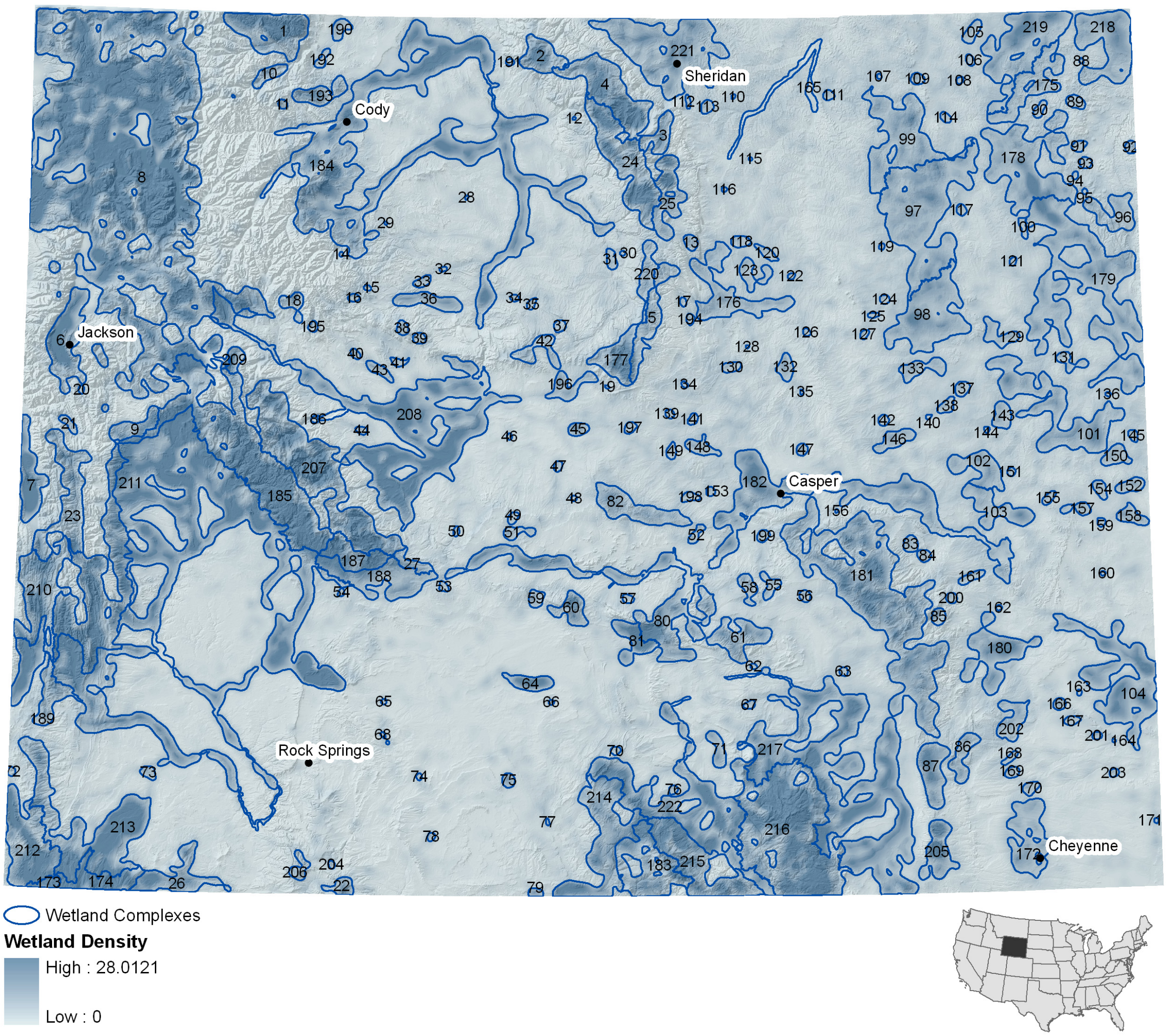



**Figure 3-10** Map of focal wetland complexes shown by wetland density. Density is defined as the unit area of wetlands divided by the area of the wetland focal complex. The labels are unique wetland IDs (Copeland et al., 2010). Reprinted with permission of Elsevier.

The assessment also examined the vulnerability of each wetland complex to three key potential environmental changes: oil and gas development, rural residential subdivision, and climate change. A spatial model of oil and gas development potential based on geophysical and topographic predictor variables was used to determine vulnerability to oil and gas development. Each wetland complex was given an area-weighted score based on the percent of its area that has high (exceeding 75%) potential for oil and gas development. A model forecasting exurban subdivision development potential in the United States for 2030 was used to identify cells of land vulnerable to subdivision development. The percent cover of exurban development cells was calculated for each wetland complex. Lastly, climate change vulnerability was assessed using water balance deficit trends. Water balance deficit was calculated by subtracting total monthly precipitation (mm) from potential evapotranspiration for wetland complexes already experiencing drying trends.

Water balance deficit values for all months were summed for each year. The ClimateWizard climate change analysis tool was used to calculate linear trends in water balance deficit; complexes with a positive trend (increasing water balance deficit) were treated as vulnerable to climate change. The vulnerability of wetland complexes to all three land use changes was documented in maps.

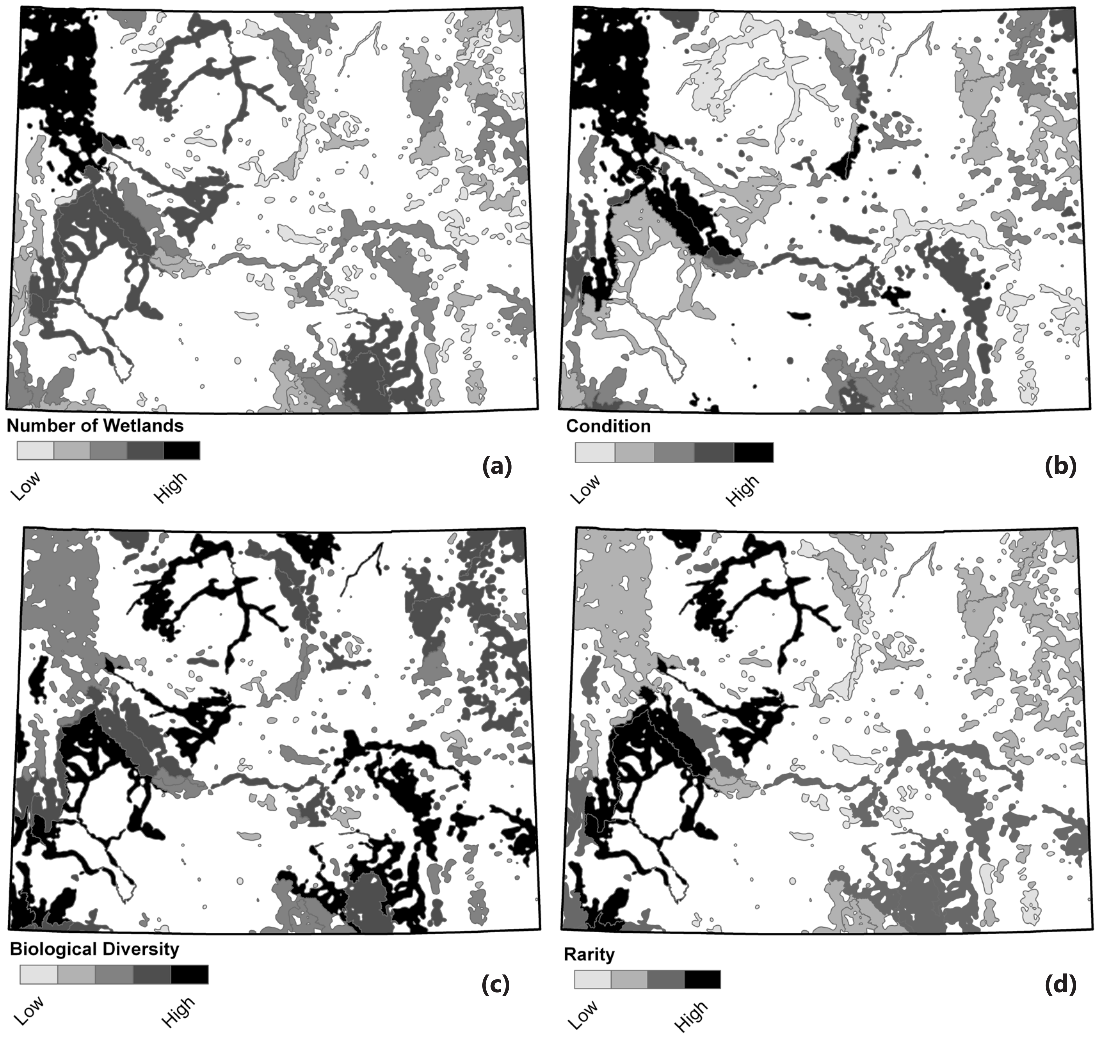



**Figure 3-11** Wyoming's wetlands ranked by number (a), condition (b), Shannon diversity (c), and rarity (d). All rankings are presented using the Jenks natural breaks method (Copeland et al., 2010). Reprinted with permission of Elsevier.

Two other key land uses that impact wetland condition are agriculture and hunting. To quantify agricultural influence, the area and percent of irrigated lands was calculated for each wetland complex. Hunting potential was quantified using duck breeding data and duck harvesting data. Where "average indicated breeding pair density" data were available for duck species, survey areas were given a 10 kilometer buffer and data were extrapolated to wetland complexes by calculating the maximum buffered survey value per wetland complex. In addition, the mean annual duck harvest from 2002 to 2005 was calculated within each waterfowl management area using data provided by the Wyoming Game and Fish Department. The influence of agriculture and hunting potential were also documented in maps.

The final step of the assessment is to integrate the appropriate individual assessments of biological diversity, protection status, proximity to sources of impairment, and susceptibility to land use changes to make conservation decisions. The results highlight wetlands that are supporting high biodiversity, as well as those that are most vulnerable to degradation. Some wetlands, especially at lower elevations, fall into both of these categories and would thus make good candidates for protection. It is intended that this assessment will be used in Wyoming not only by the Department of Environmental Quality (DEQ) in the development of its wetland assessment protocol, but also to inform the State Wildlife Action Plan and nonpoint source pollution control program. At the national level, assessments such as this one may help establish a trend emphasizing landscape-scale wetlands mitigation.

## 3.3 Hydrology

This section provides summaries for some examples of approaches currently being used to assess hydrology. See Chapter 2 for background information on hydrology.

**Landscape Condition**
Patterns of natural land cover, natural disturbance regimes, lateral and longitudinal connectivity of the aquatic environment, and continuity of landscape processes.

**Geomorphology**
Stream channels with natural geomorphic dynamics.

**Habitat**
Aquatic, wetland, riparian, floodplain, lake, and shoreline habitat. Hydrologic connectivity.

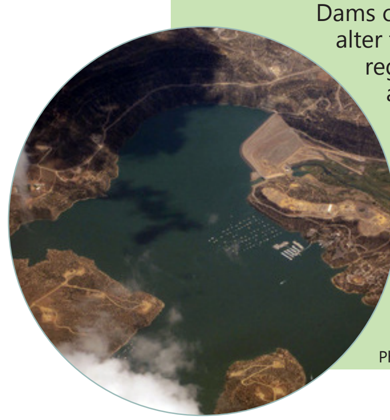
**Water Quality**
Chemical and physical characteristics of water.

**Hydrology**
Hydrologic regime: Quantity and timing of flow or water level fluctuation. Highly dependent on the natural flow (disturbance) regime and hydrologic connectivity, including surface-ground water interactions.

**Biological Condition**
Biological community diversity, composition, relative abundance, trophic structure, condition, and sensitive species.

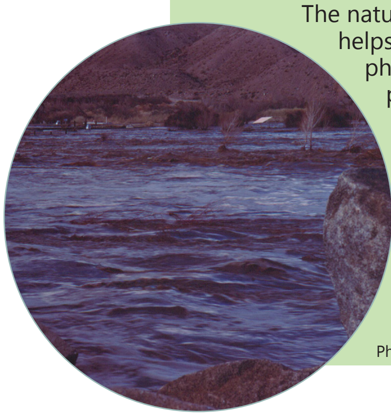
Springs are a type of ground water dependent ecosystem that are characterized by relatively stable ground water discharge, temperature, and chemistry.

Photo: USFWS.



Dams can dramatically alter the natural flow regime of a river and disconnect many aquatic species from upstream habitats.

Photo: Jane Hawkey, IAN.



The natural flow regime helps to shape physical habitat, provides cues for spawning and migration, and maintains ecosystem processes.

Photo: BLM.

Lake levels fluctuate naturally, resulting in variations in lake shore vegetation, including some plant species whose succession is dependent upon lake level cycles.

Photo: Melissa Andreycheck, IAN.

## Ecological Limits of Hydrologic Alteration

**Author or Lead Agency:** International Workgroup comprised of Colorado State University, The Nature Conservancy, U.S. Forest Service, U.S. Geological Survey, and seven other U.S. and international organizations

**More Information:** http://www.conserveonline.org/workspaces/eloha

The Ecological Limits of Hydrologic Alteration (ELOHA) is a framework for assessing instream flow needs at the regional level where in-depth, site-specific studies are not feasible. The approach involves a scientific and social process for classifying river segments, determining flow-ecology relationships, and identifying environmental flow targets based on socially acceptable ecological conditions (Figure 3-12). The process is flexible, allowing the user to choose between a number of tools and strategies for each step of the process.

The concepts put forth in *The Natural Flow Regime* (Poff et al., 1997) have rapidly gained acceptance in the scientific and resource management community (see Chapter 2). However, due to the difficulty in determining the specific flow requirements of a river and its biota, simple "rules of thumb" are still being used in place of scientifically sound environmental flow requirements for the management of riverine resources (Arthington, Bunn, Poff, & Naiman, 2006). This poses a great threat to the nation's freshwater biodiversity. Many aquatic and riparian organisms depend on the natural variability in the flow magnitude, duration, timing, frequency, and rate of change that characterize the natural flow regime. ELOHA addresses the threats to freshwater biodiversity through an assessment of flow alteration-ecological response relationships for different types of rivers. Classifying rivers based on their unaltered hydrology allows for limited ecological information to be applied to unstudied rivers in the same hydroecological class. This involves the assumption that ecosystems with similar stream flow and geomorphic characteristics respond similarly to flow alterations.

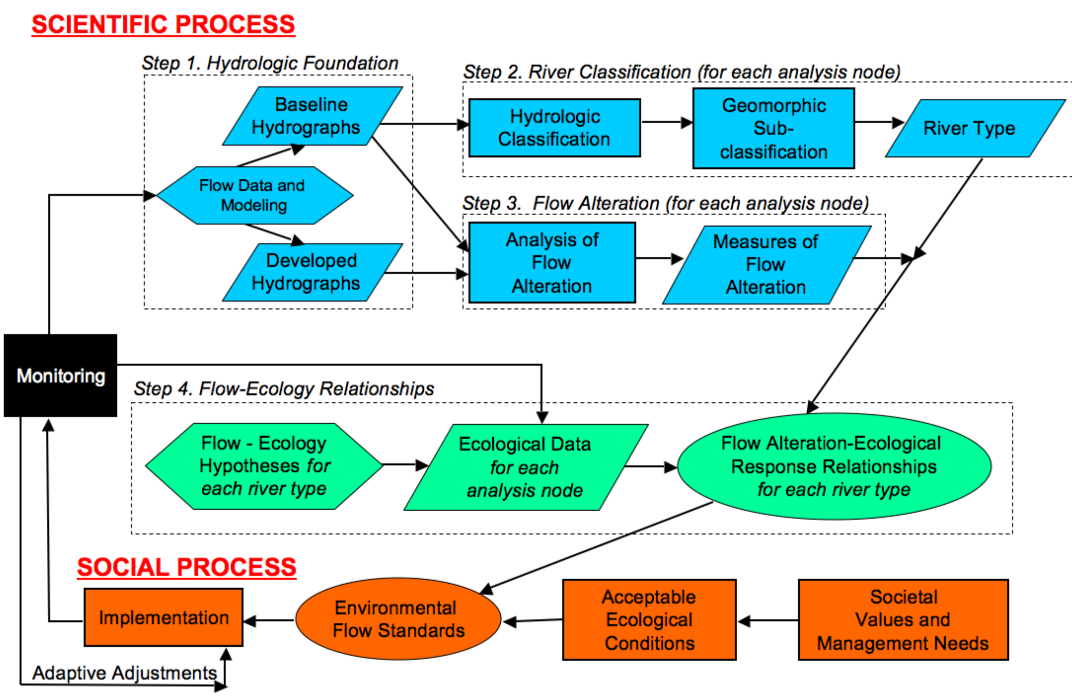



**Figure 3-12** Framework for the Ecological Limits of Hydrologic Alteration Process (Poff et al., 2010). Reprinted with permission of John Wiley and Sons.

The scientific and social components of the ELOHA framework may be conducted concurrently. The scientific component involves four steps:

1. **Building a hydrologic foundation** involves the development of a regional database that includes daily or monthly stream flow hydrographs from both baseline (i.e., natural) conditions and developed conditions. The time period of stream flow data should be long enough to represent climatic variability (typically about 20 years). Sites where biological data have also been collected should be included in order to facilitate development of flow alteration-ecological response relationships in step 4. Hydrologic modeling can be used to extend stream flow records beyond their dates of data collection or to estimate stream flow records at ungaged sites.
2. **Classifying river segments** involves grouping rivers according to similar flow regimes and geomorphic characteristics. A nationwide classification of stream flow regimes (Poff N. L., 1996) identifies rivers as: 1) harsh intermittent, 2) intermittent flashy or runoff, 3) snowmelt, 4) snow and rain, 5) superstable or stable ground water, or 6) perennial flashy or runoff. Other, region-specific, classifications have used temperature (as a surrogate for flow) and catchment geomorphic characteristics to classify stream types (Zorn, Seelbach, Rutherford, Willis, Cheng, & Wiley, 2008).
3. **Compute hydrologic alteration** as the percentage deviation of developed flows from baseline flows for each river segment. Use a small set of flow statistics that are strongly correlated with ecological conditions (e.g., frequency of low flow conditions, etc.).
4. **Develop flow alteration-ecological response relationships** by associating the degree of hydrologic alteration with changes in ecological condition for each river type. Ecological data can come from aquatic invertebrate or fish biomonitoring, riparian vegetation assessments, or other sources, but should be sensitive to flow alteration and able to be validated with monitoring data. Expert knowledge and a literature review should supplement ecological data.

The social component of ELOHA involves three steps:

1. **Determining acceptable ecological conditions** involves a stakeholder process for identifying the goals for each river segment or river type. ELOHA does not attempt to protect or restore pristine conditions in all rivers. It recognizes society's needs for water as well. Therefore, some amount of degradation may be acceptable to stakeholders in some rivers, while other rivers will receive the highest degree of protection.
2. **Development of the environmental flow targets** is based on the ecological condition goals determined in the stakeholder process. The flow alteration-ecological response curves translate acceptable ecological condition into allowable degree of flow alteration.
3. **Implementation of environmental flow management** incorporates the environmental flow targets into existing or proposed water policies and planning.

There are many instances where stream flow data are not available for computing the flow statistics required to implement the methodology. A number of tools have been developed to address this, including rainfall-runoff models such as the Soil and Water Assessment Tool and Hydrologic Simulation Program Fortran; water budget models such as the Colorado River Decision Support System (CRDSS); and regression models such as the Massachusetts Sustainable Yield Estimator (SYE) (The Nature Conservancy, 2011b). The Massachusetts Sustainable Yield Estimator was developed as a USGS/Massachusetts Department of Environmental Protection collaboration to estimate the unimpacted daily hydrograph for any stream in southern New England, gaged or ungaged. Basin characteristics were related to the flow duration curves in gaged streams in order to estimate the flow duration curve in ungaged streams. The tool can be used to evaluate the impacts of proposed and existing withdrawals to determine the baseline stream flow conditions needed for aquatic habitat integrity and to estimate inflows to drinking water supply reservoirs for safe yield analyses at ungaged locations (Archfield, 2009).

A variety of tools are available for assessing the degree of flow alteration including USGS' Hydroecological Integrity Assessment Process (HIP) and The Nature Conservancy's Indicators of Hydrologic Alteration (IHA). The IHA examines 67 biologically relevant flow statistics, quantified in terms of their magnitude, duration, timing, frequency, and/or rate of change. All 67 flow statistics may be evaluated for pre- and post-development timeframes and are compared to calculate the degree of hydrologic alteration. IHA is available as a free download from TNC.

USGS' HIP uses a Hydrologic Index Tool (HIT) to calculate 171 biologically relevant stream flow statistics, stream classification, and a Hydrologic Assessment Tool (HAT) to determine the degree of departure from baseline conditions. The two tools are available for download from USGS (U.S. Geological Survey, 2009b) and allow the user to calculate all 171 hydroecological indices using daily and peak stream flow data imported directly from the National Water Information System (U.S. Geological Survey, 2009b). 10 statistically significant, non-redundant, hydroecologically relevant indices are then chosen out of these 171. These 10 indices may include:

1. Magnitude of:
   - Average flow conditions.
   - Low flow conditions.
   - High flow conditions.
2. Frequency of:
   - Low flow conditions.
   - High flow conditions.
3. Duration of:
   - Low flow conditions.
   - High flow conditions.
4. Timing of:
   - Low flow conditions.
   - High flow conditions.
5. Rate of change in flow events.

Stream classification in the HIP is conducted according to Poff (1996) and requires user expertise in hydrology. USGS will work with state agencies and other organizations to develop their own stream classification tool to facilitate the classification process. Such a tool was created in New Jersey. Similarly, a state-specific HAT was created in New Jersey and can also be created for any other state wishing to do so (Henriksen et al., 2006). However, in the absence of a state-specific HAT, the National HAT can be used. This tool helps to determine the degree of departure in stream flow from baseline conditions if they have been determined, for example, via rainfall-runoff modeling

The HAT can be used to evaluate alternative flow management scenarios. This evaluation can be as simple as modifying the flow data in a spreadsheet and re-importing the data into the tool or can involve the use of a sophisticated watershed model for simulating future stream flow under different land use, climate, or withdrawal conditions.

ELOHA advances the state of the science by relating ecologically relevant flow statistics from IHA or HIP to biological responses in the riverine or riparian system. The outcome of the ELOHA process is a set of ecological-flow standards for different river types and ecological condition goals determined from the flow alteration-ecological response relationships and the acceptable ecological conditions determined through the social process. Environmental flow standards are then implemented through protection or restoration strategies as part of an overall water policy.

The case study from Michigan (see next page) provides an example of the practical application of an ELOHA-like framework. The Michigan case study is the closest example to date of carrying the science process through to policy implementation, but it differs significantly from ELOHA in: 1) only fish, not entire biological communities were assessed; 2) only minimum flows were examined, and; 3) current condition is considered "baseline" so flow restoration is not a goal.

# Case Study

## A Regional Scale Habitat Suitability Model to Assess the Effects of Flow Reduction on Fish Assemblages in Michigan Streams

**More Information:** Zorn et al., 2008 (http://www.michigan.gov/documents/dnr/RR2089_268570_7.pdf)

In response to the 2001 Annex to the Great Lakes Charter of 1985, the State of Michigan enacted Public Act 33 of 2006. This Act required the creation of an assessment model to determine the potential effects of water withdrawals on the aquatic natural resources of the state. Fish were chosen as the indicator of stream health because they are widely recognized as indicators of stream health by scientists and are known and appreciated by the general public. The state's Ground Water Conservation Advisory Council was charged with the development of this assessment model.

Many of the same steps outlined by the ELOHA process were followed to build a hydrologic foundation, classify river segments based on similar ecological characteristics, and develop flow alteration-ecological response curves for each river type. River segments were delineated and classified based on relationships between fish species and water temperature in Michigan according to the following four categories:

- Cold = July mean water temperature ≤63.5°F (17.5°C). The fish community is nearly all coldwater fishes; small changes in temperature do not affect species composition.
- Cold-transitional = July mean water temperature >63.5°F (17.5°C) and ≤67°F (19.5°C). The fish community is mostly coldwater fishes, but some warm water fishes are present; small changes in temperature cause significant changes in species composition.
- Cool (or warm-transitional) = July mean water temperature >67°F (19.5°C) and ≤70°F (21.0°C). The fish community is mostly warm water fishes, but some coldwater fishes are present; small changes in temperature cause significant changes in species composition.
- Warm = July mean water temperature >70°F (21.0°C). The fish community is nearly all warm water fishes and is not affected by small changes in temperature.

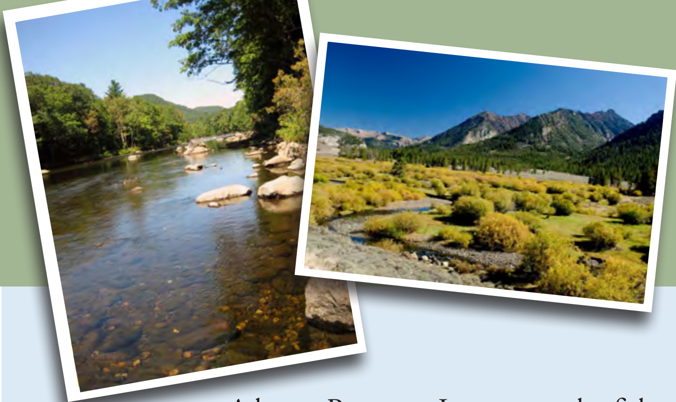
Each of the approximately 9,000 river segments was also given a size classification as follows:

- Stream = Segment catchment area ≤80 $mi^2$ (207 $km^2$).
- Small river = Segment catchment area >80 $mi^2$ (207 $km^2$) and ≤300 $mi^2$ (777 $km^2$).
- Large river = Segment catchment area >300 $mi^2$ (777 $km^2$).

The resulting 11 temperature-size categories are the classification upon which the flow alteration-ecological response modeling was then performed (Figure 3-13).

Using catchment size, baseflow yield, July mean temperature, and fish survey data, impacts to fish species and assemblages were predicted for 10% incremental reductions in base flow for each river type. The flow alteration-ecological response curves (Figure 3-14) developed from this modeling analysis were used as a basis for determining, for each river type, the level of flow reduction that would cause

*Continued on page 3-38*



an Adverse Resource Impact on the fish community. The river-type specific, flow reduction limits were linked to a database with flow predictions for rivers statewide and a model that predicts effects of ground water pumping on stream flow (the hydrologic foundation) to develop a water withdrawal assessment tool. This water withdrawal assessment tool is available as an online decision support system for use by proposed water users to determine whether the impacts of proposed withdrawals combined with all existing withdrawals will cause degradation of fish communities beyond the allowable amount.

Using the water withdrawal assessment tool, Michigan policy makers are able to use sound science to determine maximum allowable withdrawal amounts that will maintain fish communities well into the future.

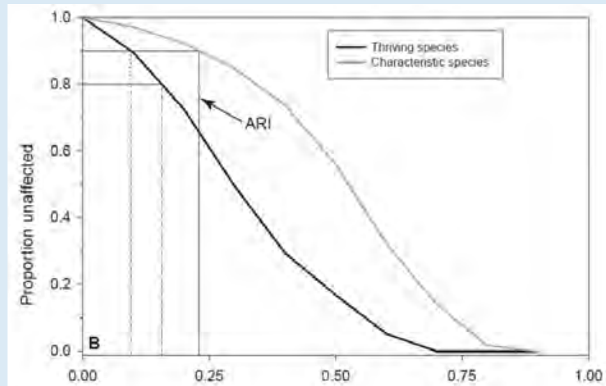



**Figure 3-14** Example flow alteration-ecological response curves from Michigan (Zorn et al., 2008). For this river type, an Adverse Resource Impact (10% decline in the fish community metric) occurs when the index flow declines by about 23%.

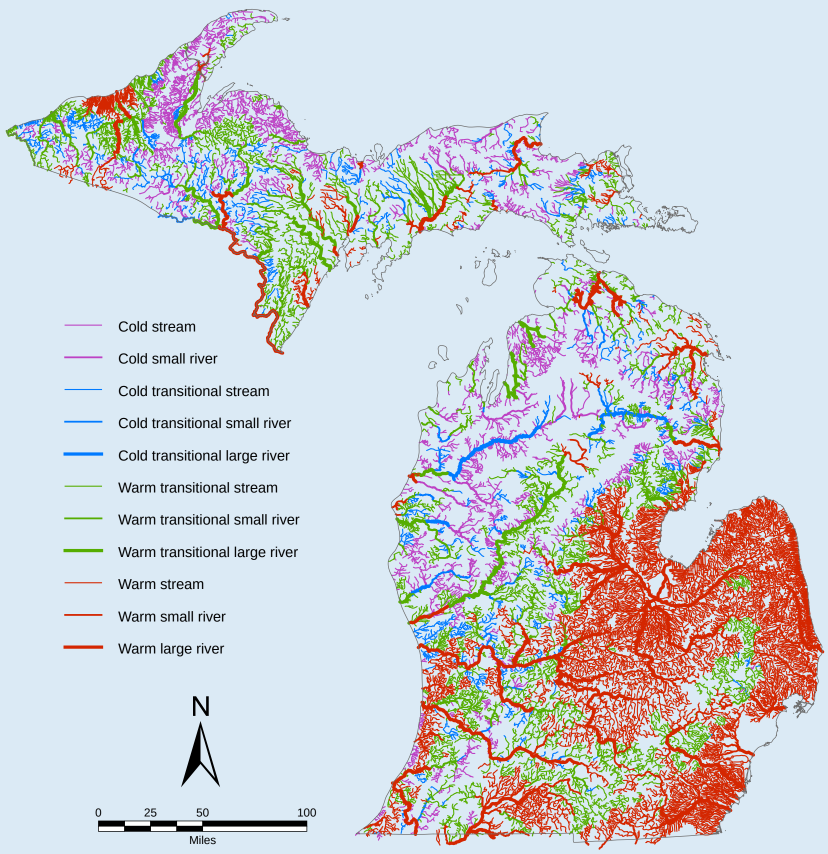



**Figure 3-13** Thermal and fish assemblage based classification of streams, small rivers, and large rivers in Michigan (Zorn et al., 2008).

## Texas Instream Flow Program

**Author or Lead Agency:** Texas Water Development Board

**More Information:** http://www.tceq.state.tx.us/permitting/water_supply/water_rights/eflows/resources.html

Recognizing the substantial risk imposed on the State of Texas by rapid population growth and resultant water shortages, the Texas Legislature enacted Senate Bill 2 to establish the Texas Instream Flow Program (TIFP) in 2001. The Texas Commission on Environmental Quality (TCEQ), Texas Parks and Wildlife Department, and Texas Water Development Board are primarily responsible for the development and implementation of the Instream Flow Program, which relies on “multidisciplinary studies, considering a range of spatial and temporal scales, focusing on essential ecosystem processes, and recommending a flow regime to meet study goals and objectives.” These studies are conducted on individual sub-basins, recognizing that assessment methods must be consistent across the state, but adaptable to accommodate the diversity of aquatic ecosystems in Texas.

Due to the relatively long time frame required to conduct the sub-basin studies under the TIFP, Senate Bill 3 was enacted in 2007 to provide for an aggressive, adaptive management process for generating regulatory environmental flow standards based on the best science currently available. In accordance with this statute, each of the state’s basins has a Basin and Bay Area Stakeholder Committee (BBASC), which appoints a Basin and Bay Expert Science Team (BBEST) to conduct environmental flow analyses and recommend flow regimes based solely on the best available science. The BBESTs are not permitted to consider other water needs, such as drinking water, irrigation, recreation, etc. Once the BBEST makes their recommendations, the BBASC then considers these other water needs along with the science-based environmental flow recommendations to make balanced flow management recommendations to the TCEQ. TCEQ then adopts environmental flow standards for each river basin and bay through a public rule-making process. Since the statute requires that the BBEST complete its work within one year and the BBASC complete its work six months later, environmental flow standards can be set before a TIFP sub-basin study has been completed.

The sub-basin studies conducted under the TIFP, which are carried out separately from, but strongly influence, the BBEST studies, focus on hydrology, geomorphology, biology, water quality, and four environmental flow components (Table 3-8). Connectivity and scale (spatial and temporal) are also considered. There are

**Table 3-8** The four primary environmental flow components considered in the Texas Instream Flows Program and their hydrologic, geomorphic, biological, and water quality characteristics (Texas Commission on Environmental Quality; Texas Parks and Wildlife Department; Texas Water Development Board, 2008).

| Component | Hydrology | Geomorphology | Biology | Water Quality |
|---|---|---|---|---|
| Subsistence flows | Infrequent, low flows | Increase deposition of fine and organic particles | Provide restricted aquatic habitat; Limit connectivity | Elevate temperature and constituent concentrations; Maintain adequate levels of dissolved oxygen |
| Base flows | Average flow conditions, including variability | Maintain soil moisture and ground water table; Maintain a diversity of habitats | Provide suitable aquatic habitat; Provide connectivity along channel corridor | Provide suitable in-channel water quality |
| High flow pulses | In-channel, short duration, high flows | Maintain channel and substrate characteristics; Prevent encroachment of riparian vegetation | Serve as recruitment events for organisms; Provide connectivity to near-channel water bodies | Restore in-channel water quality after prolonged low flow periods |
| Overbank flows | Infrequent, high flows that exceed the channel | Provide lateral channel movement and floodplain maintenance; Recharge floodplain water table; Form new habitats; Flush organic material into channel; Deposit nutrients in floodplain | Provide new life phase cues for organisms; Maintain diversity of riparian vegetation; Provide conditions for seedling development; Provide connectivity to floodplain | Restore water quality in floodplain water bodies |

essentially four steps in the process of conducting a sub-basin study (blue boxes in Figure 3-15) and hydrology, geomorphology, biology, and water quality are all considered at each step. In addition, stakeholder involvement and peer review are incorporated throughout the process (yellow and pink boxes in Figure 3-15). The end result is a flow regime prescription that includes targets for each of the four environmental flow components: subsistence flows, base flows, high flow pulses, and overbank flows.

The primary objective of the subsistence flow component is to maintain water quality. Hydrologic and water quality models are used to relate biologically-relevant water quality constituents to low flow conditions so that flow management guidelines that maintain these constituents within their natural range can be identified. The primary objective of the base flow component is to ensure adequate habitat conditions, including their natural variability. GIS-based physical habitat models are used along with biological and geomorphic data collected in the field to determine the habitat versus flow relationships specific to each river basin. Flow management guidelines are developed (often for wet, average, and dry conditions) to ensure that base flows adequately protect the target species or guilds. The primary objective of the high flow pulse component is to maintain physical habitat and longitudinal connectivity. Hydrologic statistics that characterize the magnitude, frequency, timing, and shape of high flow pulses can then be used along with geomorphic data and sediment budgets to ensure that habitat structure and connectivity adequately support the aquatic biota. The primary objective of the overbank flows component is to maintain riparian areas and lateral connectivity with the floodplain. Geomorphic studies that characterize the active floodplain and channel processes are used with flood frequency statistics to model the extent of inundation during flood events.

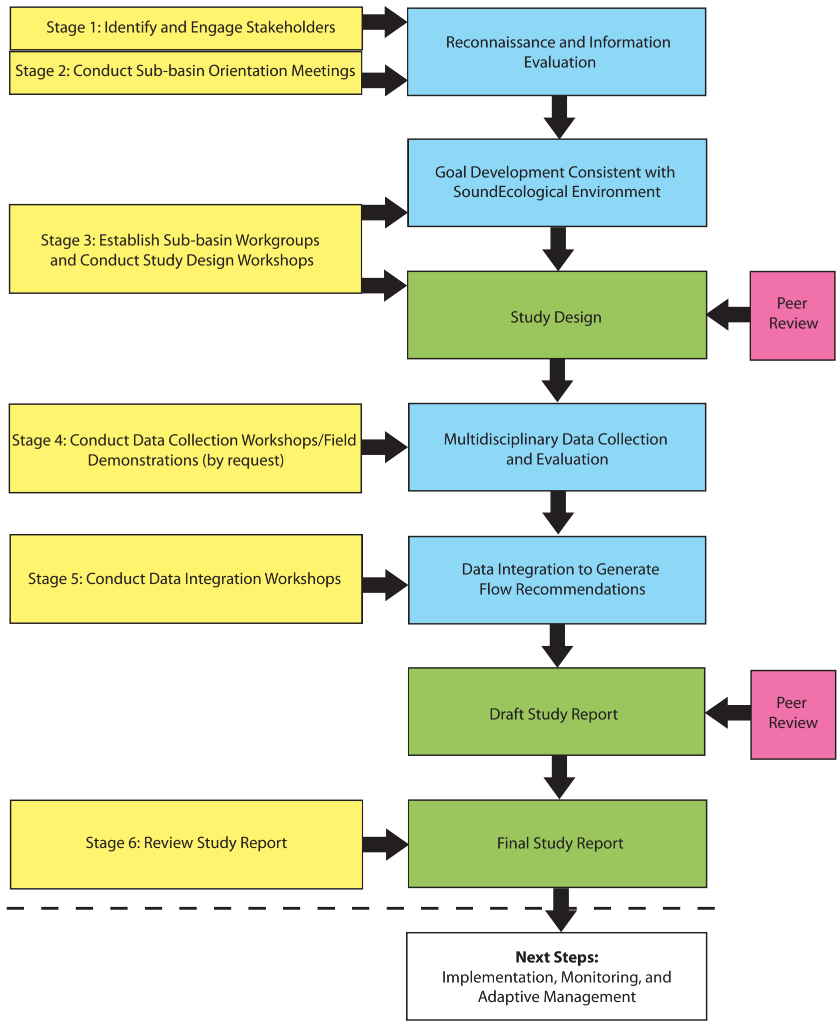



**Figure 3-15.** Diagram of the Texas Instream Flows Program process. Blue boxes represent the four primary steps, green boxes represent deliverables, yellow boxes represent public outreach components, and pink boxes represent peer review steps (Texas Commission on Environmental Quality; Texas Parks and Wildlife Department; Texas Water Development Board, 2008).

# Case Study

## San Antonio River Basin

**More information:** http://www.twdb.state.tx.us/instreamflows/sanantonioriverbasin.html

The San Antonio River Basin occupies 14 counties in south central Texas and has experienced rapid population growth and development over the past several decades. The increased use of ground water to support this rapid development, combined with increased areas of impervious surface, has led to increased base flows as a result of the dramatically increased wastewater return flows. Depending on future water management policies in the basin, this trend could continue (as population grows even further) or reverse (if water reuse policies are put in place). Based on these concerns, development of a TIFP sub-basin study design for the San Antonio River Basin began in 2006. A BBASC was named in the fall of 2009, a BBEST was named in the spring of 2010, the BBEST recommendations report was submitted on March 1, 2011, and the BBASC recommendations report was submitted on September 1, 2011.

To maintain consistency with the separate TIFP sub-basin study, the BBEST selected indicators representing hydrology, biology, water quality, and geomorphology for the larger Guadalupe River Basin, San Antonio River Basin, San Antonio–Nueces Coastal Basin, San Antonio Bay, and the Mission, Copano, and Aransas Bays (the GSA Basins). The first step in the assessment was to select flow gages for which environmental flow recommendations would be developed. Sixteen USGS gages in the GSA Basins were selected, ensuring that a range of hydrologic, water quality, geomorphic, and biological conditions were represented. Using the Hydrology-based Environmental Flow Regimes (HEFR) methodology, initial recommendations were developed based on the long-term hydrologic data collected from the USGS gages. The HEFR methodology involves hydrograph separation to parse the hydrograph into components that provide the ecological functions described in Table 3-8. This facilitates characterization of the four flow regime components: subsistence flows, base flows, high flow pulses, and overbank flows. Additional steps in the HEFR methodology include selection of an appropriate period of record and selection of the appropriate length and number of seasons for development of environmental flow recommendations. Once the initial flow recommendations were developed through the HEFR process, a number of ecological "overlays" were developed and used to refine the flow recommendations as necessary.

A Biology Overlay was developed based on habitat suitability curves. Habitat suitability curves are created by identifying habitat guilds, or groups of species using similar habitats, and relating habitat characteristics to different hydrologic conditions. For example, the Texas Logperch and Burrhead Chub both rely on shallow riffle habitat for critical stages of their life. Fish abundance and associated depth, velocity, and substrate data are compiled from multiple studies to determine the relationship between fish use and habitat characteristics. A focal species is then selected for each habitat guild and the species-specific habitat suitability curves are used as the basis for defining overall habitat guild habitat suitability curves. Habitat-discharge relationships are then determined through physical habitat modeling and, finally, results of the HEFR analysis are used to estimate habitat availability for various discharges at the sixteen flow recommendation sites.

A Water Quality Overlay was also developed by the BBEST. This involved regression analyses between water quality variables of concern and flow. Dissolved oxygen, pH, conductivity, temperature, ammonia-nitrogen, total phosphorus, and total kjeldahl nitrogen were all evaluated. Results of these analyses showed no significant relationships and thus do not impact the environmental flow recommendations.

For the BBEST Geomorphology Overlay, sediment transport was evaluated with sediment rating curves. Sediment rating curves allow for an examination of relationships between flow and transport of sediments of various sizes. Combined with a flow duration curve, sediment rating curves can be used to estimate effective discharge – "the (relatively narrow) range of flows from the entire range of flows associated with some hydrologic condition that transports the most sediment over time." This can be thought of as the channel forming flow that must be attained in order

*Continued on page 3-42*

to maintain stream channel shape over time. Current and proposed flow regimes can then be evaluated to determine their impact on the shape of the stream channel. It was found that maintaining the effective discharge within +/- 10% of current conditions requires a flow regime that does not fall below 80% of the current average annual water yield. While this information was included in the BBEST report, there was no formal recommendation to maintain 80% of the current average annual water yield.

The results of the biological, water quality, and geomorphology overlays were compared with the initial HEFR recommendations and modifications were made to ensure protection of these attributes. In order to account for variable hydrologic conditions, high, medium, and low flow criteria were determined. These flow levels are calculated on the first day of each season and are based on the previous 12-months of flow data. High flow pulse and overbank flow recommendations are not subject to these hydrologic conditions. The final environmental flow recommendations were then developed for the 16 USGS gage sites in the Guadalupe-San Antonio system (Figure 3-16).

These matrices form the quantitative recommendations of the BBEST. Details on the implementation of these values are included in the recommendations report. Most importantly, these flow values are solely intended as pass-through conditions on new and amended water rights. They are not intended or expected to be achieved all of the time and these pass-through conditions will not be imposed on existing water rights. These matrices were subsequently modified by the BBASC and both reports are under review at TCEQ for future rule-making.

| | Winter (Jan, Feb, Mar) | Spring (Apr, May, Jun) | Summer (Jul, Aug, Sep) | Fall (Oct, Nov, Dec) |
|---|---|---|---|---|
| Overbank Flows | Qp: 23,600 cfs with Average Frequency 1 per 5 years<br>Regressed Volume is 273,000<br>Duration Bound is 69 | | | |
| Overbank Flows | Qp: 10,600 cfs with Average Frequency 1 per 2 years<br>Regressed Volume is 107,000<br>Duration Bound is 45 | | | |
| Overbank Flows | Qp: 7,680 cfs with Average Frequency 1 per year<br>Regressed Volume is 73,500<br>Duration Bound is 38 | | | |
| High Flow Pulses | Qp: 1,520 cfs with Average Frequency 1 per season<br>Regressed Volume is 12,800<br>Duration Bound is 19 | Qp: 3,540 cfs with Average Frequency 1 per season<br>Regressed Volume is 30,000<br>Duration Bound is 24 | Qp: 1,640 cfs with Average Frequency 1 per season<br>Regressed Volume is 11,200<br>Duration Bound is 16 | Qp: 2,320 cfs with Average Frequency 1 per season<br>Regressed Volume is 17,600<br>Duration Bound is 19 |
| High Flow Pulses | Qp: 550 cfs with Average Frequency 2 per season<br>Regressed Volume is 3,940<br>Duration Bound is 11 | Qp: 1,570 cfs with Average Frequency 2 per season<br>Regressed Volume is 11,300<br>Duration Bound is 16 | Qp: 750 cfs with Average Frequency 2 per season<br>Regressed Volume is 4,450<br>Duration Bound is 10 | Qp: 780 cfs with Average Frequency 2 per season<br>Regressed Volume is 5,070<br>Duration Bound is 11 |
| Base Flows (cfs) – High | 290 | 280 | 220 | 270 |
| Base Flows (cfs) – Medium | 200 | 180 | 150 | 200 |
| Base Flows (cfs) – Low | 140 | 130 | 120 | 130 |
| Subsistence Flows (cfs) | 76 | 60 | 54 | 66 |

| Flow Levels |
|---|
| High (75th %ile) |
| Medium (50th %ile) |
| Low (25th %ile) |
| Subsistence |

Notes:
1. Period of Record used: 1/1/1940 to 12/31/1969.
2. Volumes are in acre-feet and durations are in days.

**Figure 3-16.** Environmental flow regime recommendations for the San Antonio River at Goliad (GSA BBEST, 2011).

### Hydrogeomorphic Classification of Washington State Rivers

**Author or Lead Agency:** University of Washington, National Oceanic and Atmospheric Administration, Australian Rivers Institute, Skidmore Restoration Consulting, United States Geologic Survey, and The Nature Conservancy

**More Information:** Reidy Liermann et al., 2011

Hydrologic classification is a necessary prerequisite to the development of regional environmental flow rules. By determining the stream flow characteristics common amongst rivers across a state or region, limited ecological response data can be extrapolated to other streams and rivers with similar flow regimes. In addition to the stream flow characteristics common amongst rivers, aquatic habitat is also strongly influenced by geomorphic characteristics. Thus, classification systems based on both hydrologic and geomorphic characteristics result in improved resolution of flow alteration – ecological response relationships used in the development of regional environmental flow standards.

Scientists from the University of Washington, National Oceanic and Atmospheric Administration, Australian Rivers Institute, Skidmore Restoration Consulting, United States Geologic Survey, and The Nature Conservancy developed a statewide hydrogeomorphic classification for streams and rivers in Washington State. In addition to predicting the unregulated hydrologic and geomorphic characteristics of ungaged streams, the classification incorporates climate change projections and potential reassignment of streams to different flow classes in the future. The classification fills data gaps across the state at the resolution of practical management units that will support the development of regional environmental flow protection programs that are flexible and responsive to the expected ecological responses that will result from climate change.

Sixty-four reference gages were first selected out of a total of 372 stream gages with long-term (≥15 years) flow records. The upstream catchment areas were delineated for all gages and those with no more than one dam regulating ≤5% mean annual discharge, ≤10% urban or agricultural land use, and ≤20% water rights or permits allocation were identified as reference gages. With a goal of maximizing the spatial coverage of reference stream gages, these criteria were then relaxed somewhat to ensure that a sufficient number of gages encompassed all ecological drainage units in the state.

Hydrologic classification was performed using Bayesian mixture modeling and a classification tree based on recursive partitioning (Figure 3-17), while the geomorphic classification was based on whether a channel is able to migrate and create a floodplain or not. This was determined based on estimates of the confinement ratio using a digital elevation model, precipitation, and field measured geomorphic data. The hydrologic and geomorphic classifications were then combined into a 14-tier hydrogeomorphic classification. Other than elevation, drainage basin characteristics did not prove to be as strong predictors of hydrogeomorphic class as the climatic variables. This is in contrast to hydrogeomorphic classifications conducted in other states. The interactive effects of elevation and precipitation variables in the classification are a result of snowpack typically melting later in the season at higher elevations. The timing and magnitude of this snowmelt runoff are the most influential hydrologic metrics in the classification. This suggests that climate change may result in significant changes to the hydrologic regimes of Washington streams and rivers if high elevation snowmelt occurs earlier in the season.

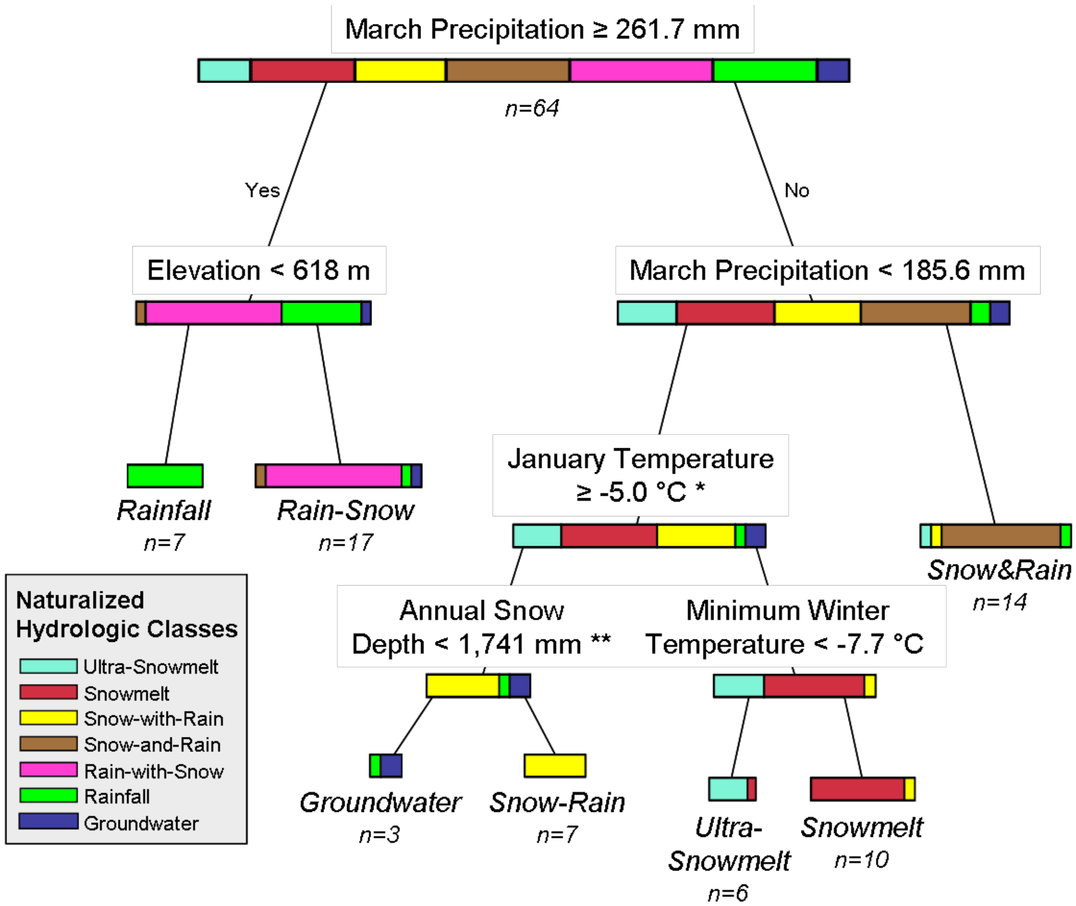



**Figure 3-17** Classification tree showing the seven naturalized hydrologic classes. Combined with the geomorphic classification distinguishing between migrating and non-migrating channels, the number of stream classes doubles (Reidy Liermann et al., 2011).

Shifts in hydrologic class as a result of climate change were predicted using both high and low emissions scenarios produced from the Intergovernmental Panel on Climate Change's ensemble of global circulation models. The projected changes in precipitation, temperature, and snowfall were input into the random forest classifier (i.e., collection of classification trees) to produce the projected future hydrologic classification. Results from both climate change scenarios indicated large-scale shifts from streams dominated by snowmelt runoff to streams dominated by rainfall runoff. The number of streams that are currently classified as 'ultra-snowmelt', for example, decreased by 86% while streams currently classified as 'rainfall' increased by over 125%. Ground water-dominated streams were relatively insensitive to climate changes.

The results of the climate change analysis are generally consistent with other findings for the region and allow for management planning at the reach scale. The affected stream reaches represent one third of the state's total river miles and alteration of their flow regimes will have large effects on the timing of water availability. This will have far-reaching effects on both humans and aquatic ecosystems, as earlier snowmelt will result in less runoff to water supply reservoirs during the summer months and loss of biological refugia during summer low flows. For example, five Pacific Northwest salmon and steelhead species are currently listed as threatened or endangered under the Endangered Species Act. With flow alteration cited as the primary cause of their decline, the ability to target specific management actions to specific stream classes that these species depend on will be critical.

### Ground Water Dependent Ecosystems Assessment

**Author or Lead Agency:** The Nature Conservancy

**More Information:** http://tinyurl.com/GDE-Workspace

Ground water is a vital source of water that sustains ecosystems, aquatic species, and human communities worldwide. Wetlands, rivers, and lakes often receive inflow from ground water; it provides late-summer flow for many rivers, and creates cool water upwelling critical for aquatic species during the summer heat. These species and ecosystems that rely on ground water discharge for water quantity or quality are collectively called ground water dependent ecosystems, or GDEs.

The Nature Conservancy has developed tools to map and understand GDEs at two scales. At the landscape scale (i.e., multiple adjacent watersheds), a GIS-based assessment tool is available to identify and map all types of GDEs and the land uses and human activities that threaten their ecological integrity. At the scale of individual watersheds, tools are available to assist in understanding ground water processes and characterizing the ground water requirements of individual GDEs. These tools were developed and tested in the Pacific Northwest; detailed analyses are available for Oregon and similar assessments were developed in Washington and California. The assessment tools should be transferable to most watersheds, providing technical expertise is available to ensure that the local hydrogeologic context is adequately incorporated.

**Landscape scale assessment**. *The Oregon Groundwater Dependent Biodiversity Spatial Assessment* (Brown J., Wyers, Bach, & Aldous, 2009a) is a GIS-based screening methodology that uses existing datasets to identify and locate ground water-dependent ecosystems and describe threats to their integrity and sustainability. It describes the assessment processes, and includes a detailed description of the GIS-based analysis methods. A companion document, *Atlas of Oregon Groundwater Dependent Biodiversity and Associated Threats* (Brown J., Wyers, Bach, & Aldous, 2009b; Brown, J., Bach, Aldous, Wyers, DeGagné, 2011) contains all of the maps that were produced using this assessment protocol for Oregon. The assessment is focused on the landscape scale and relies on readily available data sets. These data include physical parameters (e.g., soils, geology, topography, surface hydrology, and hydrogeology), and biological data (e.g., species distributions maps of wetlands and springs, and vegetated land cover).

The analysis is carried out in two steps. First, data are analyzed to determine the distribution of GDEs across the landscape. Obligate GDEs, such as springs, are ground water-dependent regardless of where they occur. Facultative GDEs such as certain wetlands, rivers, and lakes, may be fed by ground water, depending on their hydrogeologic setting. Thus, further analysis is required to evaluate whether these ecosystems are GDEs. The assessment includes analysis tools for determining whether a specific ecosystem is ground water-dependent. Once each freshwater ecosystem is coded as being a GDE or not, the data are aggregated at the HUC12 scale. This is done to better understand the relative importance of ground water in different areas of the landscape. A rule set was developed to classify HUC12 units that contain relatively high densities of GDEs (Table 3-9). The specific rule sets may need to be modified for other landscapes, depending on the relative distribution of GDEs. Once each HUC12 was coded as containing GDEs, the data were further aggregated by number of GDE types within the HUC (Figure 3-18). For example, a green HUC12 has three types of GDEs, and can include springs, a wetland, and a river that are all ground water-dependent.

**Table 3-9** Criteria used to identify HUC12s in Oregon where ground water is important for freshwater ecosystems (Brown et al., 2009a).

| GDE | Criteria |
|---|---|
| Springs | Contains >1 spring/2236 ha (5525 acres) |
| Wetlands | Contains a fen OR Area of ground water dependent wetlands >1% of HUC12 area |
| Rivers | Contains ground water dependent river |
| Lakes | Contains a lake |
| Species and communities | Contains an obligately ground water dependent species or community |

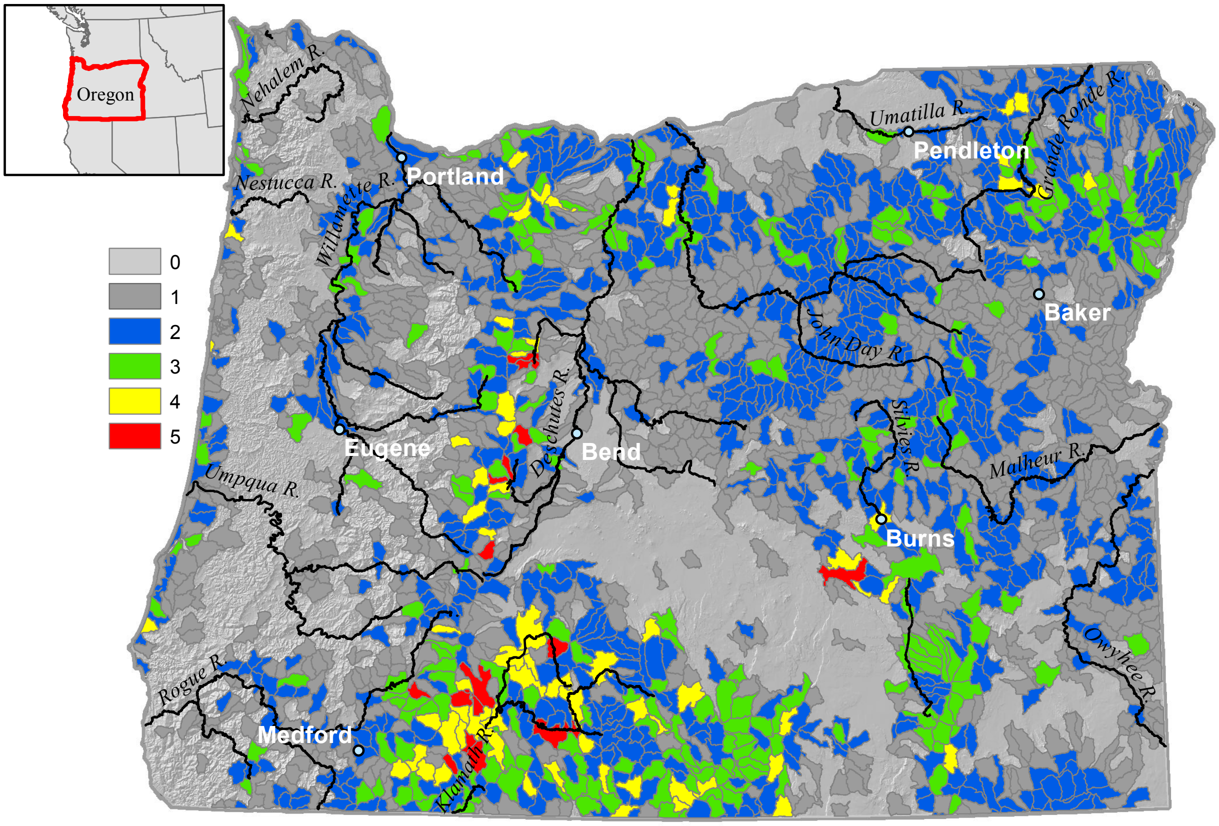



**Figure 3-18** Ground water dependent ecosystem clusters (blue through red). Number of ground water dependent ecosystems present in each HUC12, per criteria in Table 3-9 (Brown et al., 2009a).

The second step in this landscape-scale assessment is to identify and map threats to ground water and GDEs. The ecological integrity of GDEs may be impacted by activities that threaten their essential ecological attributes, specifically from alterations to water quantity, water quality (chemistry and temperature), and direct habitat destruction. Specific methods are included for evaluating current and potential future threats such as ground water extraction for irrigation and domestic use, as well as contamination from nutrients, pesticides, and toxic chemicals. This analysis uses available data of the human fingerprint on the landscape (e.g., land use; municipal, agricultural, and industrial water uses; population projections; and waste disposal types and locations).

In some cases, further analyses were required to evaluate the threat of certain activities to GDEs. One example is the effect of pesticides on GDEs. Very few data are available quantifying the presence of agricultural pesticides in ground water outside of drinking water systems. For any one of these pesticides to pose a threat to a GDE, it must be mobile in ground water, toxic to aquatic life, and have the potential to move from its source to the GDE. Therefore, the 43 pesticides registered for agricultural uses in Oregon were evaluated. Of those, 10 were mobile in ground water and toxic to aquatic life. HUC12 reporting units that have soils with low potential to retain those 10 pesticides (meaning they would be easily transported in ground water) were then identified. Finally, HUC12 reporting units meeting all three of the following criteria were identified: at least one of the 10 mobile pesticides is applied in the HUC, the soils do not retain the pesticides, and GDE clusters are present. GDEs in these HUCs are at highest risk of pesticide contamination.

**Watershed scale assessment**. *The Groundwater Dependent Ecosystem Methods Guide* (Brown J., Wyers, Aldous, & Bach, 2007) was developed to help resource managers and conservation groups identify site-specific GDEs, understand their ecological requirements, and incorporate this information into water resources and biodiversity conservation plans. The assessment is focused on the watershed or project scale, and utilizes more site-specific information than the landscape scale assessment. This protocol includes three sections: 1) determining if ecosystems within the planning area are GDEs, 2) characterizing the ground water requirements of each type of GDE, and 3) understanding and mapping the ground water flow systems that provide ground water discharge to those GDEs.

The assessment provides a set of decision trees for evaluating whether an ecosystem is dependent on ground water. This involves a series of yes/no questions in sequence, similar to a dichotomous key used in plant or animal taxonomy. Individual decision trees are provided for wetlands, rivers, lakes and species. An example decision tree is provided for rivers (Figure 3-19). As described above, springs and subterranean ecosystems are, by definition, ground water-dependent.

Once an ecosystem or species has been determined to be a GDE, characterizing its ground water requirements is an important step in protecting and/or restoring its ecological integrity, and in conducting adaptive management of that resource. This is done by identifying the essential ecological attributes, or EEAs, identifying measurable indicators that can be used to track the status of the EEAs over time, and describing a desired future condition for each of those EEAs.

While different types of GDEs will have different EEAs, two categories of EEAs are common to all GDEs: water quantity and water quality. Water quantity is a function of the hydrogeology of the contributing area and ground water discharge to the ecosystem, and water quality is generally expressed in terms of the water chemistry or water temperature. Indicators specific to a particular GDE can be developed based on these two EEAs. Table 3-10 provides an example for ground water-dependent rivers.

Finally, the ground water flow system can be characterized to understand the context of the GDE in relation to its ground water sources. This includes identifying ground water recharge and discharge areas and developing conceptual ground water flow paths. These final steps, as well as the previous two, are illustrated in the following case study from Whychus Creek, in the Deschutes Basin, Oregon.

**Table 3-10** Essential ecological attributes associated with ground water and potential indicators of the integrity of rivers: (Brown et al., 2007).

| Essential Ecological Attribute | Indicator |
|---|---|
| Temperature regime | Maximum 7-day average of daily maximum temperature |
| | Location and number of thermal refugia |
| Hydrologic regime | Number of zero-flow days |
| | Trend in annual mean low flow |
| | Location and continued presence of springs/seeps adjacent to the stream. |

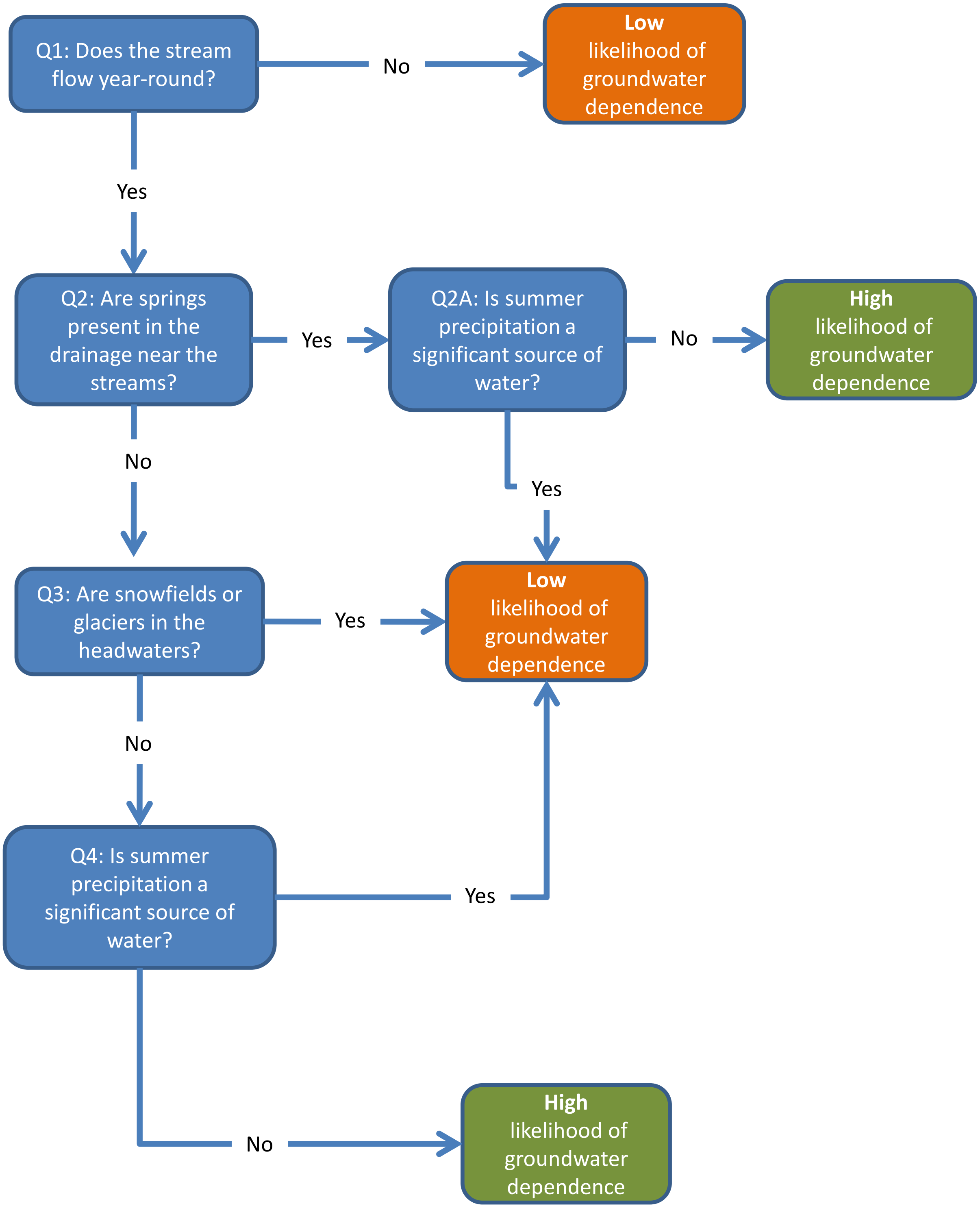



**Figure 3-19** Decision tree for identifying ground water dependent river ecosystems (Brown et al., 2009a).

# Case Study

## Identifying GDEs and Characterizing their Ground Water Resources in the Whychus Creek Watershed

**More Information:** http://tinyurl.com/GDE-Workspace

The Whychus Creek Watershed, located in Oregon's Upper Deschutes Basin, offers a good illustration of how a combination of GIS datasets and decision trees can be used to identify GDEs. Using the decision tree for river ecosystems, TNC determined that the rivers in the Whychus Creek Watershed are highly likely to be ground water dependent, because they are perennial (determined through examination of the National Hydrography Dataset (NHD)), they are associated with springs, and summer precipitation is not a significant source of water. USGS gage data further confirm the high likelihood of ground water dependence, because they show that low flow is 59% of annual mean monthly flow, and base flow is active through most of the year. Lastly, seepage-run data provided by the Oregon Water Resources Department and USGS gage data indicate that stream reaches in the Whychus Creek Watershed are gaining streams (i.e., ground water discharges into them).

To identify ground water dependent wetlands, TNC compiled datasets for known and potential wetlands from the NWI, the Northwest Habitat Institute's Interactive Biodiversity System, STATSGO, and the Deschutes Wetland Atlas developed by the Deschutes River Conservancy. Applying the wetlands ecosystem decision tree, TNC determined that both subalpine parkland and wet meadow wetlands in the Whychus Creek Watershed are highly likely to be ground water dependent, because they are present year round and they either occur in slope breaks or are associated with springs or seepage areas.

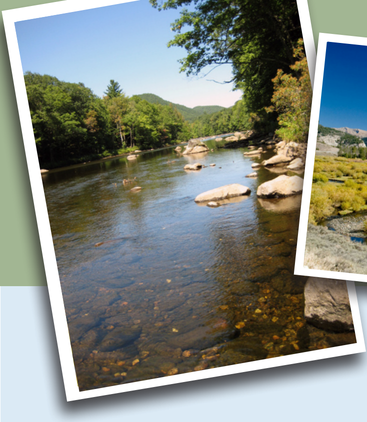
Using the decision tree for lake ecosystems, TNC determined that lakes in the watershed are likely to depend on local ground water for part of their water supply, because they are located on permeable geologic deposits, no seeps or springs are known to discharge into the lakes, and the lakes are located in the upper portion of the watershed.

Spring ecosystems, which are ground water dependent by definition, were mapped using data from the USGS Geographic Names Information System, the Pacific Northwest Hydrography data layer, the Oregon Gazetteer, and Forward Looking Infrared data. Phreatophytic ecosystems (above ground ecosystems that depend on subsurface expressions of ground water) were not included in this assessment because extensive laboratory study would be needed to confirm their dependence upon ground water. Subterranean ecosystems were also not considered in this assessment, because there are no mapped caves in the Whychus Creek Watershed.

The assessment also identified ground water dependent species in the watershed. Species that were potentially dependent upon ground water were identified from TNC's ecoregional assessment and the U.S. Forest Service's watershed analysis. This list was refined with input from local experts to consist exclusively of ground water dependent species by comparing species distributions with the distributions of ground water dependent ecosystems in the watershed.

The assessment then used geologic and topographic maps to delineate the ground water contributing area, which in this case matched the surface watershed for Whychus Creek. A layer of precipitation data was used with the geologic data layer to locate wet, permeable areas that are likely sites for ground water recharge. Recharge areas were refined using USGS' Deep Percolation Model. Horizontal flow paths were mapped, connecting ground water recharge and discharge sites. Hydrogeologic cross-sections were developed from geologic and topographic maps using ground water recharge and discharge data. Vertical ground water flow paths were mapped on the cross-sections. These recharge, discharge, flow path, and GDE distribution data are now available to inform conservation priorities for the Whychus Creek Watershed (Figure 3-20).

*Continued on page 3-50*



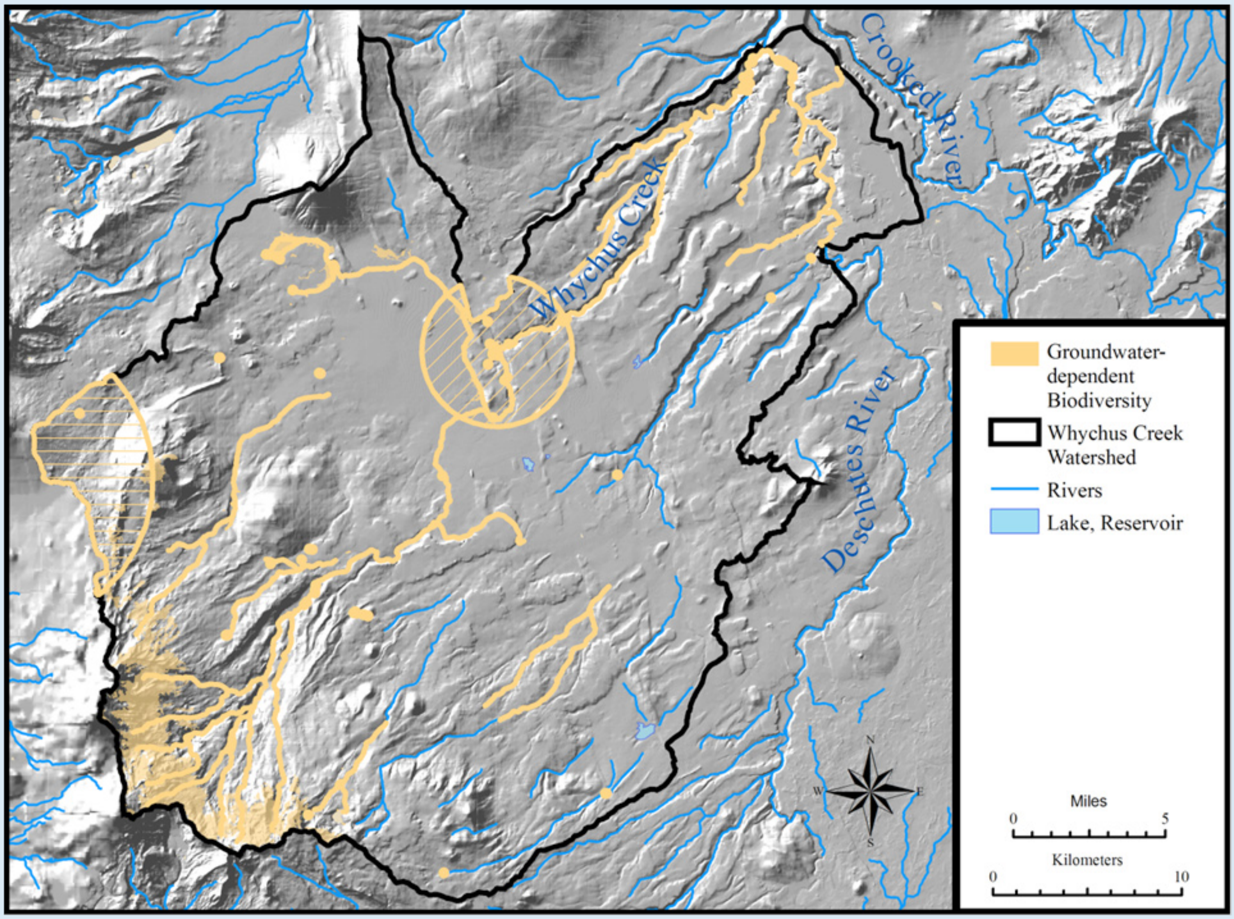
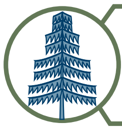



**Figure 3-20** Ground water dependent biodiversity in the Whychus Creek Watershed (Brown et al., 2007).

## 3.4 Geomorphology

This section provides summaries for some examples of approaches currently being used to assess geomorphology. See Chapter 2 for background information on geomorphology.

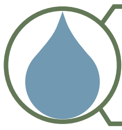


**Landscape Condition**
Patterns of natural land cover, natural disturbance regimes, lateral and longitudinal connectivity of the aquatic environment, and continuity of landscape processes.

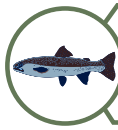
**Geomorphology**
Stream channels with natural geomorphic dynamics.

**Habitat**
Aquatic, wetland, riparian, floodplain, lake, and shoreline habitat. Hydrologic connectivity.


**Water Quality**
Chemical and physical characteristics of water.



**Hydrology**
Hydrologic regime: Quantity and timing of flow or water level fluctuation. Highly dependent on the natural flow (disturbance) regime and hydrologic connectivity, including surface-ground water interactions.



**Biological Condition**
Biological community diversity, composition, relative abundance, trophic structure, condition, and sensitive species.

High gradient mountain streams are characterized by relatively straight stream channels and larger substrate, such as cobble and boulders.

Photo: BLM.

Meandering is a common characteristic of low gradient streams and is critical to the physical stability of the channel and the health of the stream.

Photo: USFWS.

Maintenance of a river channel's lateral connectivity with its floodplain allows for the natural regime of flood disturbance to effectively influence riparian biodiversity.

Photo: NRCS.

Stream geomorphic state and processes are intricately tied to aquatic habitat condition and macro-invertebrate community composition.

Photo: USFWS.

### Vermont's Stream Geomorphic and Reach Habitat Assessment Protocols

**Author or Lead Agency:** Vermont Agency of Natural Resources

**More Information:** http://www.vtwaterquality.org/rivers/htm/rv_geoassess.htm

The Vermont Agency of Natural Resources (VT ANR) is using fluvial geomorphic-based watershed assessments to plan and manage streams toward their natural dynamic equilibrium. The state has developed a series of assessment protocols that are broken down into three phases, facilitating assessment at multiple scales. A growing statewide database of fluvial geomorphic and physical habitat data collected through the use of these protocols is allowing resource managers across Vermont to understand river systems as integral components of the landscape and to classify river segments according to reference conditions specific to Vermont. Vermont's Stream Geomorphic Assessment Protocols (Kline, Alexander, Pytlik, Jaquith, & Pomeroy, 2009) provide resource managers with a method to characterize riparian and instream habitat, stream-related erosion and depositional process, and fluvial erosion hazards for informing watershed planning and management activities that are ecologically sustainable and that avoid conflicts between human investments and river systems. Vermont has fully integrated Reach Habitat Assessment Protocols (Schiff, Kline, & Clark, 2008) with stream geomorphic protocols to evaluate habitat connectivity and the departures in natural hydrologic, sediment, and woody debris regimes that explain physical processes and alterations to the hydro-geomorphic units associated with shelter, feeding, and reproductive habitats (Table 3-11).

**Table 3-11** Parameters and variables in the Vermont Reach Habitat Assessment Protocol (Schiff, Kline, & Clark, 2008).

| Key Ecological Processes | Aquatic Life Cycle Requirements |
|---|---|
| Longitudinal connectivity | ***Cover/Shelter Habitat based on:*** |
| Riparian/floodplain connectivity | Wood debris |
| Sediment regime | Sediment substrates |
| Hydrologic regime | Riparian vegetation |
| Temperature regime | Channel morphology |
| Large wood/organics regime | Depth-velocity |
| **Habitat Types** | Side channel refuge |
| Cascade/step pool | Bank undercuts |
| Plane bed | ***Feeding Habitat*** |
| Riffle-pool/dune-ripple | Allochthonous production |
| **Habitat Complexity** | Autochthonous production |
| Disturbance regime | ***Reproductive-Seasonal Habitat*** |
| Habitat heterogeneity | Migration |
| | Substrates |

The Vermont Stream Geomorphic and Reach Habitat Assessment Protocols provide resource managers with a scientifically sound, consistent set of tools to classify, assess the condition of, and design management approaches for the state's flowing water resources. The protocols are separated into three phases. Phase 1 includes watershed-scale assessments that are based on valley land forms, geology, land use, and channel and floodplain modifications, and are typically conducted with remotely-sensed data. Stream type, condition, fluvial processes, and sensitivity are provisionally assigned and can be refined in phases 2 and 3. Although phase 1 assessments are primarily desktop analyses, a few months is typically necessary to assess a large watershed. Phase 2 assessments are rapid field assessments. Channel and floodplain cross-section, as well as stream substrate are measured. Qualitative field evaluations of erosion and depositional processes, changes in channel and floodplain geometry, and riparian land use/cover are used to identify geomorphic and physical habitat condition, adjustment processes, reach sensitivity, and stage of channel evolution. A phase 2 assessment on a one mile reach requires one to two days in the field to complete. Phase 3 assessments are survey-level field assessments. Quantitative measurements of channel dimension, pattern, profile, and sediments confirm, and provide further detail on, the stream types, hydraulic conditions, and adjustment processes identified in phases 1 and 2 (Figure 3-21). Phase 3 assessments are used to characterize reference reaches and to gather intensive data for river corridor protection or restoration projects. Phase 3 assessments require three to four days to survey a sub-reach of two meander wavelengths, as well as professional level stream survey and geomorphic assessment skills and equipment.

Interactive web-based data storage, retrieval, and mapping systems, as well as spreadsheets and GIS tools, have been developed by VT ANR to facilitate data reporting and analysis for all three phases of the assessment process. Whether the user decides to perform the phase 1 screening level assessment or the detailed phase 3 assessment, they will have a better understanding of the physical conditions of their streams and the linkages of stream channel condition with watershed inputs and floodplain and valley characteristics. Assessing the streams access to its floodplain; sediment size, quantity, and transport processes; erodibility of the stream bed and banks; and runoff characteristics of the watershed allows for a classification of stream type. The resource manager then categorizes the stream type as a *reference stream type* – the natural stream type in relation to the natural watershed inputs and valley characteristics, *existing stream type* – the stream type and processes under current conditions, or *modified reference stream type* – the stream type that may evolve as a result of the human imposed channel, floodplain, or watershed changes. The existing stream type is often the same as the reference stream type, with the exception that its geomorphic and physical habitat condition is different. Stream reach condition can be assessed as *in regime* – exhibiting dynamic equilibrium, *in adjustment* – changing in form and process outside of natural variability, or *active adjustment and stream type departure* – exhibiting adjustment to a new stream type or fluvial process as a result of a change in floodplain function and/or watershed inputs (Figure 3-22). In addition, a stream sensitivity rating is assigned to each assessed reach. A stream's inherent sensitivity is related to its setting and location within the watershed. Sensitivity ratings are assigned based on the reference stream type and the degree of departure from that reference. Certain reference stream types, as a result of their natural characteristics, are more susceptible or sensitive to certain perturbations that may initiate adjustment and channel evolution.

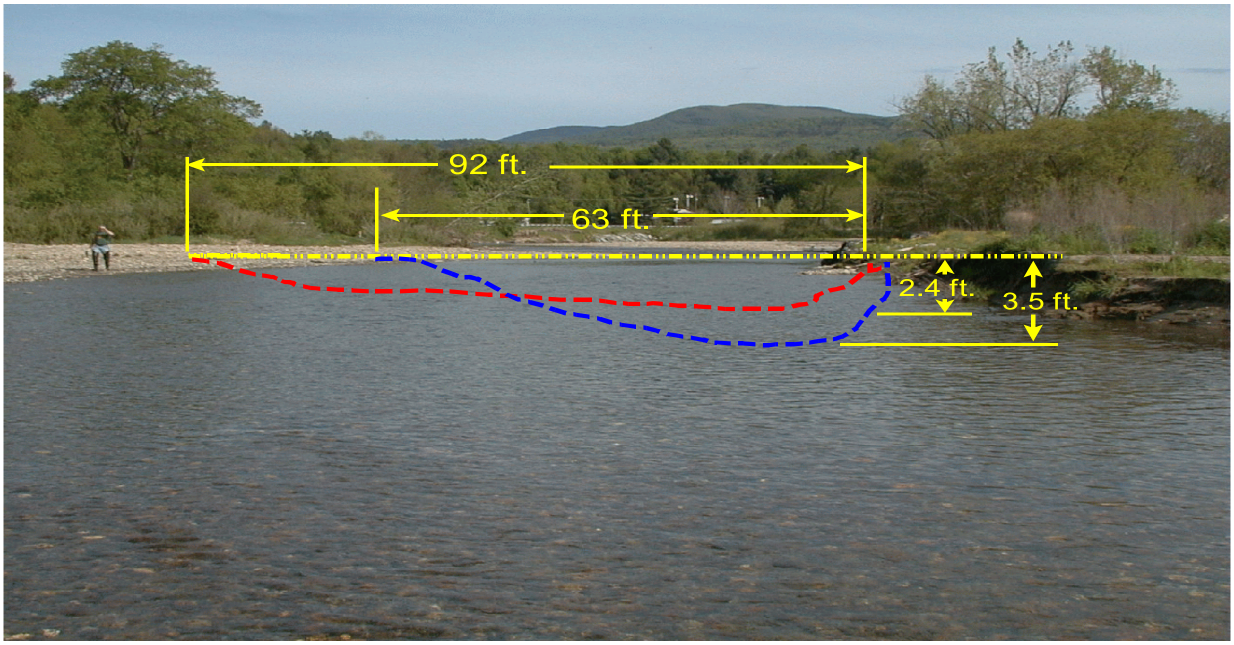



**Figure 3-21** Phase 3 data gathering (Vermont Department of Environmental Conservation, 2007).

With the resulting stream type, geomorphic and physical habitat condition, and sensitivity rating, an assessment indicates what type of stream should exist and why, what type of stream does exist and the watershed characteristics that caused it, the type of stream that will evolve if left alone, and the potential actions that can be taken to restore or accommodate the adjustment of a stream to its reference type or protect it from departing from its reference type. A stream that has departed from its reference type, due to excess watershed runoff from impervious surfaces or other causes, no longer provides its proper functions (e.g., maintenance of habitat, sediment storage and transport, etc.). This type of information is invaluable to the natural resource planner evaluating alternative management scenarios for land use, flow regulation, or channel modification.

Vermont's *River Corridor Planning Guide* (Kline & Cahoon, 2010) provides detailed data reduction methods and mapping tools, and helps watershed planners make management recommendations to address fluvial process-based departures and reach-specific stressors. River corridor plans include watershed-scale strategies for prioritizing river corridor protections and restorative actions aimed at helping the state and its local partners manage streams toward their dynamic equilibrium condition. Plans also include river corridor maps based on the meander beltways that provide a critical spatial context for achieving and maintaining equilibrium by limiting land use encroachments and channelization (Kline & Cahoon, 2010). The results of Vermont's stream geomorphic and reach habitat assessments can be used to identify: a) conservation reaches, b) strategic sites, c) reaches with high recovery potential, and d) moderately to highly degraded sites. Conservation reaches are the least disturbed reaches of a watershed and should be maintained in their natural state in a protected river corridor. Starting from this base of healthy ecosystem components, protection and restoration measures can be focused on less healthy reaches. Strategic sites are those vulnerable, sensitive sites where protection strategies should be prioritized to avoid impacts to adjacent conservation reaches or to accommodate fluvial processes that will lead to a more even distribution of energy and sediments within the watershed (Leopold, 1994). Reaches with high recovery potential are those where active restoration strategies should be prioritized. Moderate or highly degraded sites are those where expensive and uncertain restoration actions would be necessary. These projects should only be undertaken after impacts to watershed hydrologic and sediment regimes have been remediated and upstream sources of instability have been resolved. Working out from conservation reaches to strategic sites, reaches with high recovery potential, and finally to moderate and highly degraded sites provides the most efficient method of protecting and restoring the dynamic equilibrium of the watersheds running water resources.

**Figure 3-22.** Intact (left) and incised (right) streambeds. (Images courtesy of Ben Fertig (left) and Jane Thomas (right), IAN Image Library (ian.umces.edu/imagelibrary/)).

# Case Study

## Geomorphic Assessment and River Corridor Planning of the Batten Kill Main-Stem and Major Tributaries

**More Information:** http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassess.htm

The Batten Kill is considered Vermont's best trout fishing stream and has been rated by Trout Unlimited as one of the 10 best trout streams in the United States (Cox, 2006). However, since the early 1900s the quality of the fishery has been declining (Jaquith, Kline, Field, & Henderson, 2004). Altered land use patterns, channel straightening, floodplain encroachment, and dam construction have been prevalent in the Batten Kill watershed, as they have been in much of New England for over a century. A phase 1, watershed-scale, fluvial geomorphic assessment was conducted in the Batten Kill watershed to understand the extent to which these disturbances are affecting the geomorphic condition of the stream and the degradation of physical habitat due to channel adjustment processes.

The phase 1 assessment identified over half of the Batten Kill and its tributaries as being in some form of channel adjustment. Phase 2 assessments were conducted on 36 reaches and phase 3 assessments were conducted on eight segments in the watershed to verify the results of the phase 1 assessment. Likely causes of channel adjustment were determined through an examination of historic channel and floodplain modifications including deforestation, dam construction, agricultural practices, transportation development, and the more recent straightening, dredging, and berming of the river for flood control. As the low gradient, meandering streams of the Batten Kill were straightened due to rail and road construction and berming of the river, the channelized streams were no longer able to dissipate the energy of their flows through lateral migration. Instead, the energy was dissipated through erosion of the channel bed, causing channel incision and loss of access to the streams floodplain. Additionally, watershed runoff and sediment supply were historically altered due to changing land use patterns, deforestation, and agricultural practices. Aggradation or deposition of sediment occurred in downstream, low-gradient reaches, resulting in embedded substrates. Embeddedness refers to the deposition of finer sediments in the spaces between cobbles and boulders. These spaces are prime habitat for juvenile fish. Deep pools and other structural elements, such as large woody debris, have been scoured from the river bed, reducing habitat for adult fishes. In addition, gravel substrate critical for spawning in some tributaries of the Batten Kill has been scoured and lost.

The recommendations resulting from this geomorphic assessment include strategic river corridor protection to protect segments that are in regime (exhibiting the dynamic equilibrium characteristic of natural stream channels), and to allow for channel adjustments and the evolution of the channel and floodplains to a dynamic equilibrium condition. The river corridor plan also focuses activities (e.g., erosion control practices) on the whole system instead of individual sites, in order to restore geomorphically unbalanced streams to equilibrium conditions. An education program to increase public awareness, perception, and participation in appropriate watershed activities was also identified as critical to the long-term health of the Batten Kill.

## 3.5 Water Quality

This section provides summaries for some examples of approaches currently being used to assess water quality. See Chapter 2 for background information on water quality.

**Landscape Condition**
Patterns of natural land cover, natural disturbance regimes, lateral and longitudinal connectivity of the aquatic environment, and continuity of landscape processes.

**Habitat**
Aquatic, wetland, riparian, floodplain, lake, and shoreline habitat. Hydrologic connectivity.

**Hydrology**
Hydrologic regime: Quantity and timing of flow or water level fluctuation. Highly dependent on the natural flow (disturbance) regime and hydrologic connectivity, including surface-ground water interactions.

**Geomorphology**
Stream channels with natural geomorphic dynamics.

$PO_4^{3-}$

**Water Quality**
Chemical and physical characteristics of water.

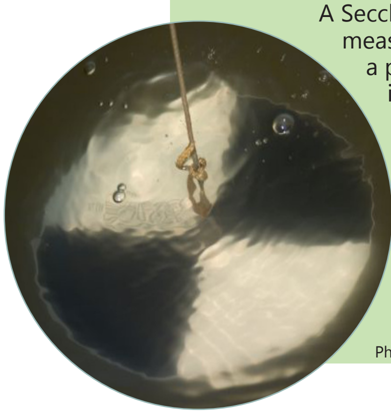
**Biological Condition**
Biological community diversity, composition, relative abundance, trophic structure, condition, and sensitive species.

Riparian buffers filter pollutants, regulate water temperature, and help to maintain hydrologic regimes that support water quality.

Photo: NRCS.

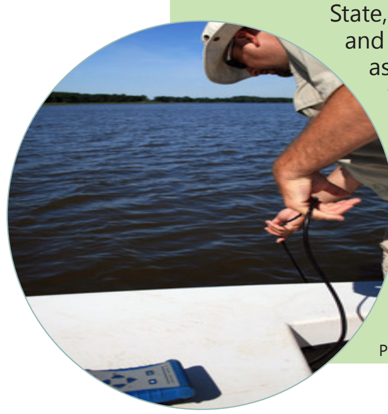
As runoff and surface water pass through, wetlands remove or transform pollutants (e.g., sediments, nutrients, etc.) through physical, chemical, and biological processes.

Photo: NRCS.



A Secchi disk is used to measure how deep a person can see into the water, and provides an approximate evaluation of the transparency of water.

Photo: Adrian Jones, IAN.



State, tribal, federal, and local agencies, as well as many watershed organizations, conduct water quality monitoring programs.

Photo: Jane Thomas, IAN.

## Oregon Water Quality Index

**Author or Lead Agency:** Oregon Department of Environmental Quality

**More Information:** http://www.deq.state.or.us/lab/wqm/wqimain.htm

The Oregon Water Quality Index (WQI) is a single number that describes water quality by integrating measurements of eight water quality variables: temperature, dissolved oxygen, biochemical oxygen demand, pH, ammonia and nitrate nitrogen, total phosphorus, total solids, and fecal coliform. The purpose of the WQI is to provide a simple and concise method for expressing the ambient water quality of Oregon's streams. The WQI is useful for answering general questions (e.g., how well does water quality in my stream rate on a scale of 0 to 100?) and for comparative purposes (e.g., comparing several streams within the same watershed; detecting trends over time, etc.). The WQI is not, however, suited for site-specific questions that should be based on the analysis of the original water quality data. The WQI can serve as a useful screening tool for general water quality conditions, as well as to help to communicate water quality status and illustrate the need for, and effectiveness of, protective practices.

The Oregon WQI is calculated in two steps. First, the raw analytical results for each parameter are transformed into unitless, subindex values. These values range from 10 (poor water quality) to 100 (excellent water quality) depending on that parameter's contribution to water quality impairment. These subindices are combined to give a single water quality index value ranging from 10 to 100. The unweighted harmonic square mean formula used to combine subindices allows the most impacted parameter to impart the greatest influence on the water quality index. This method acknowledges that the influence of each water quality parameter on overall water quality varies with time and location. The formula is sensitive to changing conditions and to significant impacts on water quality.

Water quality indices, such as the Oregon WQI, when used appropriately, can be powerful tools for comparing aquatic health conditions in different water bodies and in communicating information to the general public (Figure 3-23). A water quality index has the potential to be combined with other indices (such as an IBI or Index of Terrestrial Integrity) in order to evaluate the overall health of a watershed.

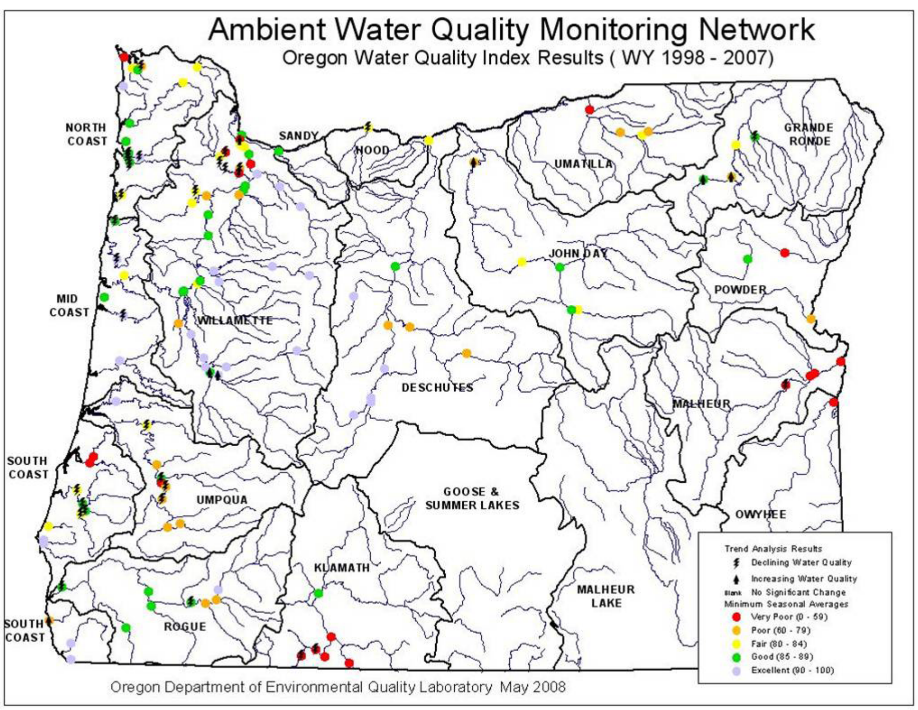
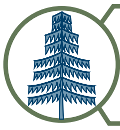



**Figure 3-23** Map of Oregon Water Quality Index (WQI) results for water years (WY) 1998-2007 (Oregon Department of Environmental Quality, 2008).

# 3.6 Biological Condition

This section provides summaries for some examples of approaches currently being used to assess biological condition. See Chapter 2 for background information on biological condition.

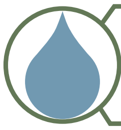


**Landscape Condition**
Patterns of natural land cover, natural disturbance regimes, lateral and longitudinal connectivity of the aquatic environment, and continuity of landscape processes.

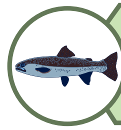
**Geomorphology**
Stream channels with natural geomorphic dynamics.

**Habitat**
Aquatic, wetland, riparian, floodplain, lake, and shoreline habitat. Hydrologic connectivity.


**Water Quality**
Chemical and physical characteristics of water.



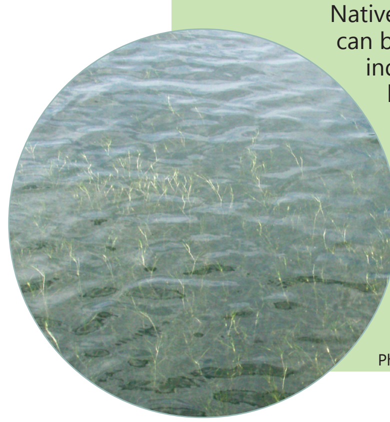
**Hydrology**
Hydrologic regime: Quantity and timing of flow or water level fluctuation. Highly dependent on the natural flow (disturbance) regime and hydrologic connectivity, including surface-ground water interactions.



**Biological Condition**
Biological community diversity, composition, relative abundance, trophic structure, condition, and sensitive species.

Macroinvertebrates are a critical element in the aquatic food chain and are frequently used as indicators of aquatic ecosystem condition.

Photo: Jane Hawkey, IAN.



Native aquatic plants can be an important indicator of biological condition, and also create habitat for other aquatic organisms.

Photo: Ben Fertig, IAN.

Amphibian species are an indicator of biological condition, especially in headwater streams that lack fish populations.

Photo: USFWS.

Presence of certain fish species, such as trout and salmon in coldwater streams, can be indicators of good biological condition.

Photo: USFWS.

### Index of Biotic Integrity

**Author or Lead Agency:** James Karr

**More Information:** http://www.epa.gov/bioiweb1/html/ibi_history.html

The Index of Biotic Integrity (IBI) is a multi-metric index of aquatic health based on ecological characteristics of biological communities. It was originally developed by James Karr in 1981 for use in warm water streams in Illinois and Indiana and has since been modified for use in other states and aquatic ecosystem types in the United States, as well as in other countries. It was developed to provide an alternative perspective to physicochemical water quality monitoring programs that were initially the typical monitoring approach for addressing the requirements of the Federal Water Pollution Control Act Amendments of 1972 (the Clean Water Act). The advantage of integrating biological assessments into physicochemical assessments is a more complete understanding of the effects of point and nonpoint source pollution in the context of aquatic life.

Biological communities are sensitive to a variety of environmental factors including chemical contamination from point and nonpoint sources, physical habitat alteration, flow modification, and disruption of ecological processes and biotic interactions. Since chemical monitoring programs are not designed to detect some of these, such as habitat alteration and flow modification impacts, biological assessments provide a mechanism for evaluating the effects of all of these factors on ecosystem health. Additionally, biological communities integrate the cumulative, and sometimes synergistic, effects of pollutants and other disturbances over time. Chemical monitoring programs, for example, might miss episodic discharges of untreated wastewater while the resident biota can often be affected by those events for an extended period of time.

The original IBI developed by James Karr assessed 12 characteristics of fish communities. These 12 metrics captured information about species richness and composition, indicator species, trophic organization, reproductive behavior, and individual condition. These metrics are directly affected by human disturbance and alteration of the aquatic system and its watershed. Choosing specific metrics within these classes allows for the development of an IBI in any region based on local ecological and biological conditions. The IBI approach requires that the fish sample used is representative of the fish community at the sample site, the sample site is representative of the stream or watershed, and that the lead biologist is very familiar with the local fish fauna and stream ecology.

A score is assigned to each of the chosen metrics, and then summed to arrive at the IBI for the site. The IBI score for the site is interpreted relative to undisturbed, reference conditions for the region. However, reference sites in many states represent least disturbed conditions so threshold selection needs to take into consideration the quality of the reference sites (Stoddard et al., 2006; U.S. Environmental Protection Agency, 2011c) Reference conditions must be defined for each stream type in an ecoregion. The final IBI score represents the health of the biological community relative to reference conditions for that stream type. Through careful selection of metrics, human alteration of the five water resource features can be determined (Figure 3-24).

Ohio is an example of a state that uses biological data and biocriteria as the principal mechanism for assessing aquatic life use attainment for its Water Resource Inventory (CWA Section 305(b) report) (see following case study). Biocriteria are also used in setting water quality standards, supporting the National Pollutant Discharge Elimination System (NPDES) permitting process, performing nonpoint source assessments, and as part of risk assessments in various states. Other states have used modified IBIs in integrative assessments of watershed condition. For example, the Virginia DCR uses a modified IBI in its Watershed Integrity Model (summarized in Chapter 4). In the Watershed Integrity Model, a spatial representation of the IBI is combined with other aquatic and terrestrial ecological indicators and a weighted overlay is created in a GIS. The weighted overlay provides guidance on watershed lands that are most valuable for maintaining aquatic ecosystem integrity.

The IBI approach to assessing the biological health of surface water resources is a valuable and widely used method that can be modified and integrated into region-specific conditions and objectives. Evaluating the biological condition of a watershed's streams, lakes, and rivers allows for the identification of the healthiest sites that should be prioritized for protection.

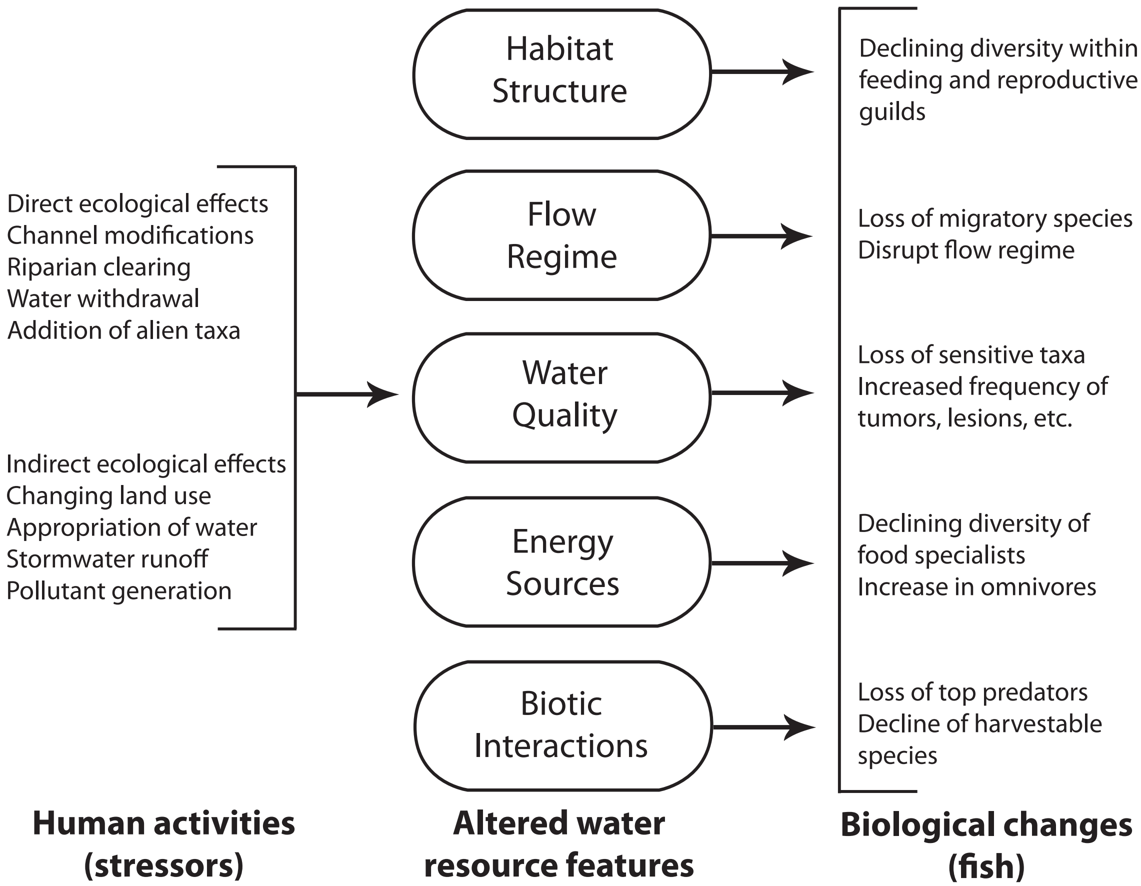



**Figure 3-24** Human activities alter five water resource features, resulting in alteration of fish communities (Modified from Karr & Yoder, 2004).

# Case Study

## Ohio Statewide Biological and Water Quality Monitoring and Assessment

**More Information:** State of Ohio Environmental Protection Agency, 2009 (http://www.epa.state.oh.us/dsw/bioassess/ohstrat.aspx)

Ohio EPA has relied on biological monitoring and assessment as a critical component of its water quality program for almost three decades. Ohio created three different modified versions of Karr's IBI for application to headwater streams (drainage area <20 mi$^2$), wadeable sites, and larger non-wadeable sites. These three different versions were necessary due to fundamental differences of the fauna at different site types and consideration of sampling methods. However, Karr's original ecological structure was maintained throughout the development of the three versions. In addition, Ohio created modified versions of an Invertebrate Community Index and a Modified Index of Wellbeing. These are conceptually similar to the IBI. The IBI and Modified Index of Wellbeing are based on assessments of stream fish assemblages while the Invertebrate Community Index is based on macroinvertebrate assemblages.

Ohio uses the IBI, Invertebrate Community Index, and Modified Index of Wellbeing biological assessments along with physicochemical assessments to assess compliance with water quality standards. Numeric biocriteria have been specified for each of the three indices, and in each of Ohio's five ecoregions, using a system of tiered aquatic life uses (limited resource water, modified warm water habitat, warm water habitat, and exceptional warm water habitat). Biocriteria for the exceptional warm water habitat are derived from biological assessments conducted in undisturbed, reference reaches for each ecoregion. Management responses are prioritized along this tiered aquatic life use gradient. For example, exceptional warm water habitats are of the highest quality and would merit protection as a management measure. Warm water habitats are somewhat degraded and would thus be ideal locations for restoration projects. Highly degraded sites would receive enhancement management measures and the most severely degraded sites are considered irretrievable. Ohio adopted numeric biocriteria into its water quality standards in 1990, which has allowed the state to assess cumulative impacts, define appropriate aquatic life use designations, assess impacts from altered habitat, and to identify high quality waters.

## The Biological Condition Gradient and Tiered Aquatic Life Uses

**Author or Lead Agency:** Susan K. Jackson (U.S. EPA)

**More Information:** http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/biocriteria/uses_index.cfm

The Biological Condition Gradient (BCG) is a conceptual, scientific model for interpreting the biological response of aquatic ecosystems to increasing levels of stressors. The BCG model was developed by a workgroup of aquatic ecologists and biologists from different regions of the United States to represent their empirical observations of biological response to ecosystem stress, regardless of the monitoring methodology employed. The model evaluates the response of 10 aquatic ecosystem attributes to locate a stream's condition on the stressor-response curve (Figure 3-25). There are six levels, or tiers, of biological condition on the stressor response curve. The BCG model is intended to assist states and tribes to more precisely define the aquatic biota expected along a gradient from undisturbed to severely disturbed conditions and assign goals for a water body that better represent its highest achievable condition. The model accounts for geographical differences in ecosystem attributes, so is applicable across the nation; however, modifications to the levels can be made by individual states and tribes to most appropriately characterize their regional conditions (e.g., use of three levels, as opposed to six). For example, New Jersey calibrated a five level BCG for their upland streams and is evaluating options for application. Maine has incorporated a three tier BCG to define their aquatic life use classification framework (U.S. Environmental Protection Agency, 2011c).

The ten attributes assessed in the BCG evaluate several aspects of community structure, organism condition, ecosystem function, and spatial and temporal attributes of stream size and connectivity. The stressor axis of the BCG model represents a composite of all of the chemical, physical, and biological factors that can disrupt ecological integrity. Placement of a monitoring site in one of the six BCG levels, as described in Figure 3-25, is determined through an examination of the ten attributes:

1. Historically documented, sensitive, long-lived or regionally endemic taxa.
2. Sensitive-rare taxa.
3. Sensitive-ubiquitous taxa.
4. Taxa of intermediate tolerance.
5. Tolerant taxa.
6. Non-native or intentionally introduced taxa.
7. Organism condition.
8. Ecosystem functions.
9. Spatial and temporal extent of detrimental effects.
10. Ecosystem connectance.

A number of states have, or are in the process of developing, their own regional or statewide BCG models. The initial step in developing a state-specific or ecoregional BCG model is to identify and define, where possible, undisturbed conditions on which the model's level 1 category will be based. Calibration of the model has sometimes resulted in combining BCG level 1 and level II categories to define the upper gradient of a local BCG because of lack of undisturbed sites. A workgroup of professional biologists with considerable field experience and knowledge of the local fauna should be assembled to calibrate the BCG model. They will define the ecological attributes by, for example, assigning taxa to attributes 1-6. This will involve the examination of a variety of bioassessment and stressor data and the classification of different sites into the different levels of biological condition along a gradient of increasing stress. It is often possible to calibrate existing indices of biotic integrity, such as the IBI, to the levels of biological condition, which will facilitate the application of the BCG model to future monitoring endeavors (e.g., Pennsylvania Case Example in U.S. Environmental Protection Agency, 2011c). If a biotic index system does not exist, an index that corresponds to the newly established levels may be developed. The stressor axis of the BCG model represents the composite stressors on the aquatic ecosystem. These stressors can originate from: 1) chemical factors, 2) the flow regime, 3) biotic factors, 4) energy sources, and 5) habitat structure (Karr, Fausch, Angermier, Yant, & Schlosser, 1986). Like the biological condition axis, the stressor axis is based upon deviation from natural (e.g., undisturbed, minimally disturbed) conditions and thus should be calibrated to the local conditions and stressors.

Once the BCG model has been calibrated to local conditions, it can be used by states and tribes to more precisely evaluate the current and potential biological conditions of their streams and more precisely define aquatic life uses. The BCG is based on 30 years of conceptual development in aquatic ecology and represents the understanding that biological communities differ in a predictable manner across ecoregions, water body types, and levels of stressors (Davies & Jackson, 2006). The use of the BCG allows states to assess the ecological condition of water bodies from a more holistic standpoint than using chemical and physical water quality data alone. The method is scientifically and statistically robust, and can be used to complement existing or develop new quantitative measures of ecosystem health.

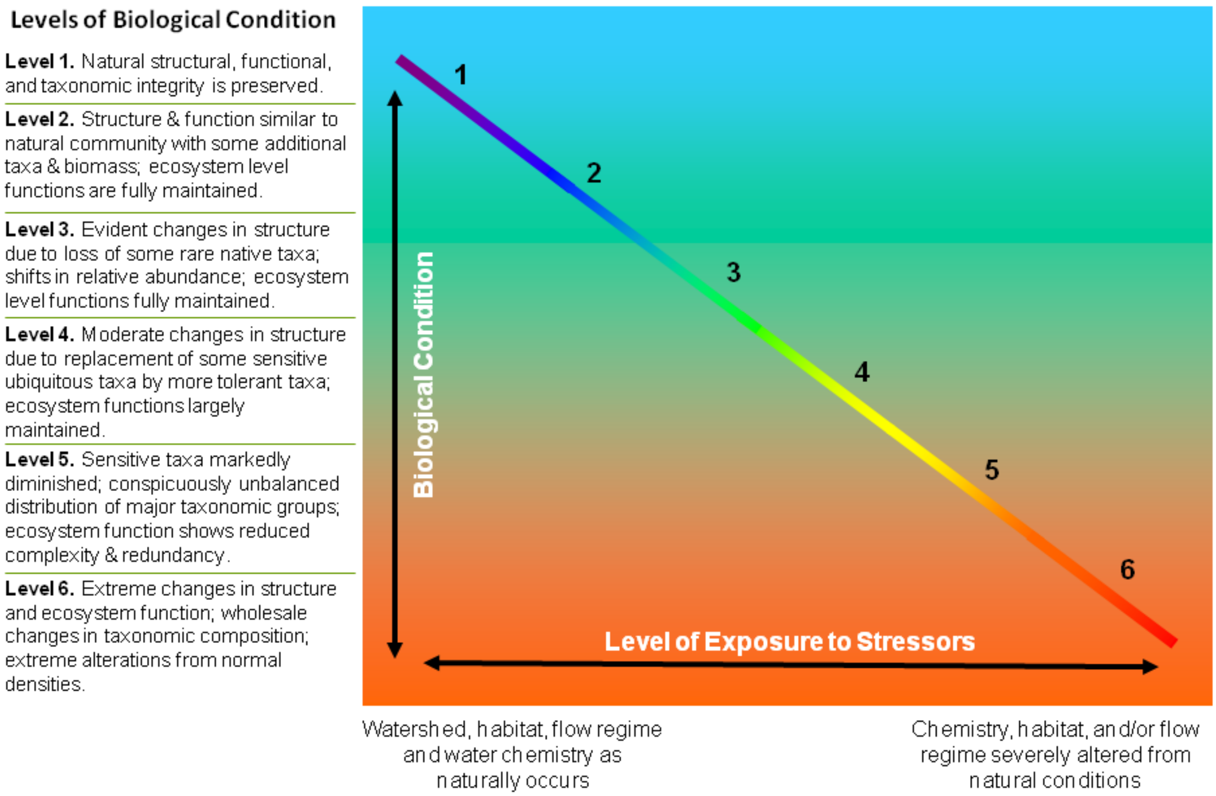



**Figure 3-25** Conceptual model of the Biological Condition Gradient (U.S. Environmental Protection Agency, 2011c).

# Case Study

## Maine Tiered Aquatic Life Use Implementation

**More Information:** http://www.maine.gov/dep/water/monitoring/biomonitoring/index.html

The Maine Department of Environmental Protection (DEP) has used a tiered approach to water quality management since the early 1970s, before adoption of the Clean Water Act. Classifications of AA, A, B, or C are given to the state's water bodies, with Class AA waters receiving the highest levels of protection. Numeric biocriteria have been developed based on benthic macroinvertebrate assessments. Over the years, Maine DEP biologists have made empirical observations of the differences in aquatic macroinvertebrate communities across gradients of stressors. At the same time, work in aquatic stress ecology, particularly by Eugene Odum, helped to reinforce these observations with a theoretical underpinning. Narrative biological criteria were designed to be consistent with these observations and ecological understanding. Maine DEP biologists aligned the narrative criteria with a slight modification of the already-established four tier classification system. Class AA and A were combined to yield a three-tier system of Class A, B, or C (Figure 3-26).

Maine DEP quantified each of their aquatic life use classes in the late 1980s using a probability-based statistical model of 31 biological variables. This model was developed based on the best professional judgment of Maine DEP biologists through an evaluation of 144 samples with 70,000 organisms. The model was recalibrated with an additional 229 samples in 1999. Using this model and current biomonitoring data, an aquatic life attainment classification of A, B, or C is given to each stream. If the stream is not attaining its aquatic life use designation, it is listed as impaired on the state's 303(d) list of impaired water bodies.

With 51% of the state's water bodies designated as Class AA or Class A, Maine maintains a strong focus on protection of aquatic life use. Any discharge to waters with these classifications must be of equal or better quality than the receiving water and any flow obstructions must not have effects greater than what would be expected from a natural flow obstruction, such as a beaver dam.

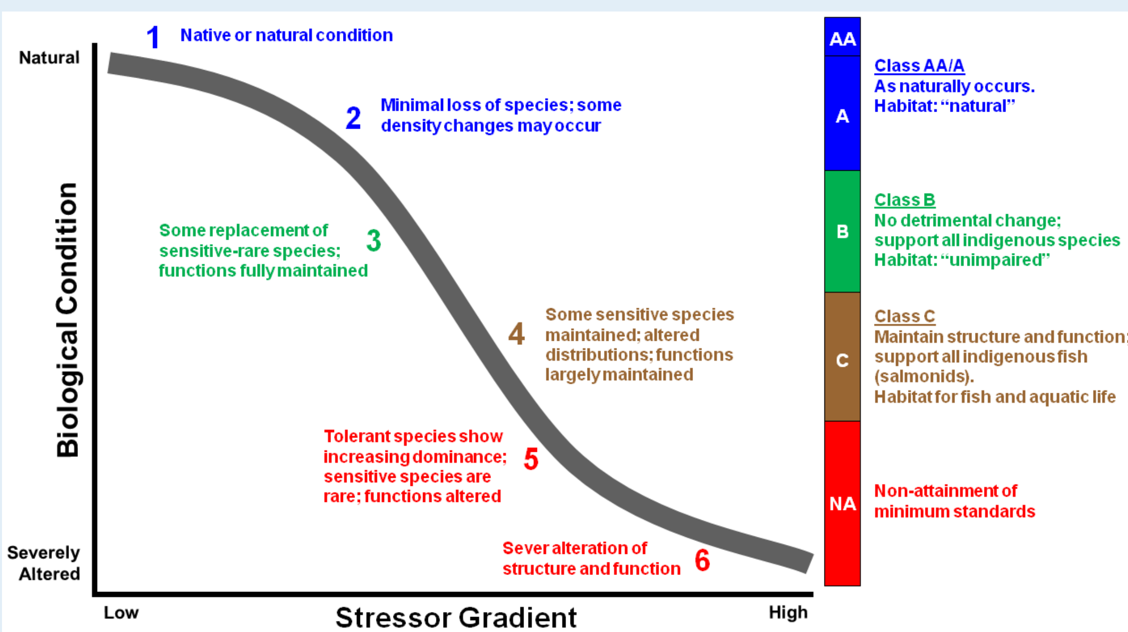



**Figure 3-26** Maine Tiered Aquatic Life Uses in relation to Biological Condition Gradient Levels (Davies and Courtemanch, 2012).

## Aquatic Gap Analysis Program

**Author or Lead Agency:** U.S. Geological Survey (USGS)

**More Information:** http://www.gap.uidaho.edu/projects/aquatic/default.htm; http://morap.missouri.edu/Projects.aspx

The USGS Gap Analysis Program (GAP) is designed to keep common species common by proactively identifying the distribution of habitats and species not currently represented in conservation networks and disseminating this information to relevant stakeholders before the organisms become threatened or endangered. A fundamental concept to the GAP program is that species distributions can be predicted based on habitat indicators. Many approaches to biodiversity conservation have focused on single-species management, typically threatened or endangered species. While these approaches have their place, a proactive approach to biodiversity conservation will include methods for identifying habitats that support a diversity of species and ensuring protection of these areas before the species become threatened. The availability of remotely sensed data and the vast improvements in computing power over the past couple of decades have facilitated the possibility of identifying these areas at multiple scales and with minimal resources. By identifying these areas and comparing them with the current network of conservation lands, the "gaps" in the network can be identified and these areas prioritized for conservation.

The terrestrial component of the USGS GAP program began in 1988 and is now operating in every state. The aquatic component of GAP has only recently begun, with nine state projects and four regional projects. Similar to the terrestrial component, Aquatic GAP seeks to identify areas of high biodiversity within watersheds and use remotely sensed data to map habitats and predict aquatic biodiversity to provide a biological basis on which to create aquatic conservation plans. While the terrestrial component relies primarily on vegetation as a habitat indicator, the Aquatic GAP uses multiple indicators to identify Aquatic GAP habitat types and develop species-habitat relationships. While each individual project may use a different subset of habitat indicators, the following are typically used:

- Stream size.
- Stream gradient.
- Watershed land use.
- Riparian forest cover.
- Bedrock and surficial geology.
- Water quality.
- Stream sinuosity.

Remote sensing data are used to determine the first four indicators. Digital Elevation Models, which are available from the USGS, can be used to determine *stream size* and *stream gradient*. *Watershed land use* and *riparian forest cover* data are readily available from sources such as the Multi-Resolution Land Characteristics Consortium, which is a group of federal agencies working together to produce and maintain comprehensive and current data on land cover. *Bedrock surficial geology* maps are available from the USGS. Ambient *water quality* data are typically available from state and national monitoring programs, as well as through some local monitoring programs. *Stream sinuosity* can be measured using available stream data layers such as the National Hydrography Dataset. These habitat indicators must be combined to establish discrete habitat types for each delineated catchment or watershed. Relationships between species presence and habitat type are then determined with statistical models using biomonitoring data for fish and macroinvertebrate taxa.

An aquatic GAP assessment for Missouri (Sowa, Annis, Morey, & Diamond, 2007), for example, used indicators such as those mentioned above, along with biological data, to generate a hierarchical classification of riverine ecosystems, with the smallest unit representing distinct habitat types. This eight-level classification was developed in collaboration with TNC's Freshwater Initiative staff (see Appendix A) and includes aquatic subregions, ecological drainage units (EDUs), aquatic ecological systems (AESs), and valley-segment types (VSTs) (Figure 3-27). Using this classification system and species-habitat relation models, maps of predicted species distribution were then generated. The conservation status (based on ownership/stewardship) of each AES was also mapped. A human threat index was created to evaluate the vulnerability of these systems using eleven different metrics (Table 3-12) and AESs and VSTs were prioritized for conservation (Table 3-13). Regional experts weighted each of the metrics in the human threat index, which was also calculated for every stream reach in the region (Annis et al., 2010). The individual metric data, as well as the index results, can be summed cumulatively at any location.

The results of an Aquatic GAP assessment, such as the one conducted for Missouri, are intended to be used by state and local decision makers for land use planning, conservation management, and public education. Partnerships between various agencies and other stakeholders are vital to coordinating collection and analysis of the data required as well as to the successful use of the assessment in actual management plans. Use of this information as part of a comprehensive watershed assessment strategy can complement other biological condition and landscape condition assessment approaches and provide a greater level of protection to healthy ecosystems and their components.

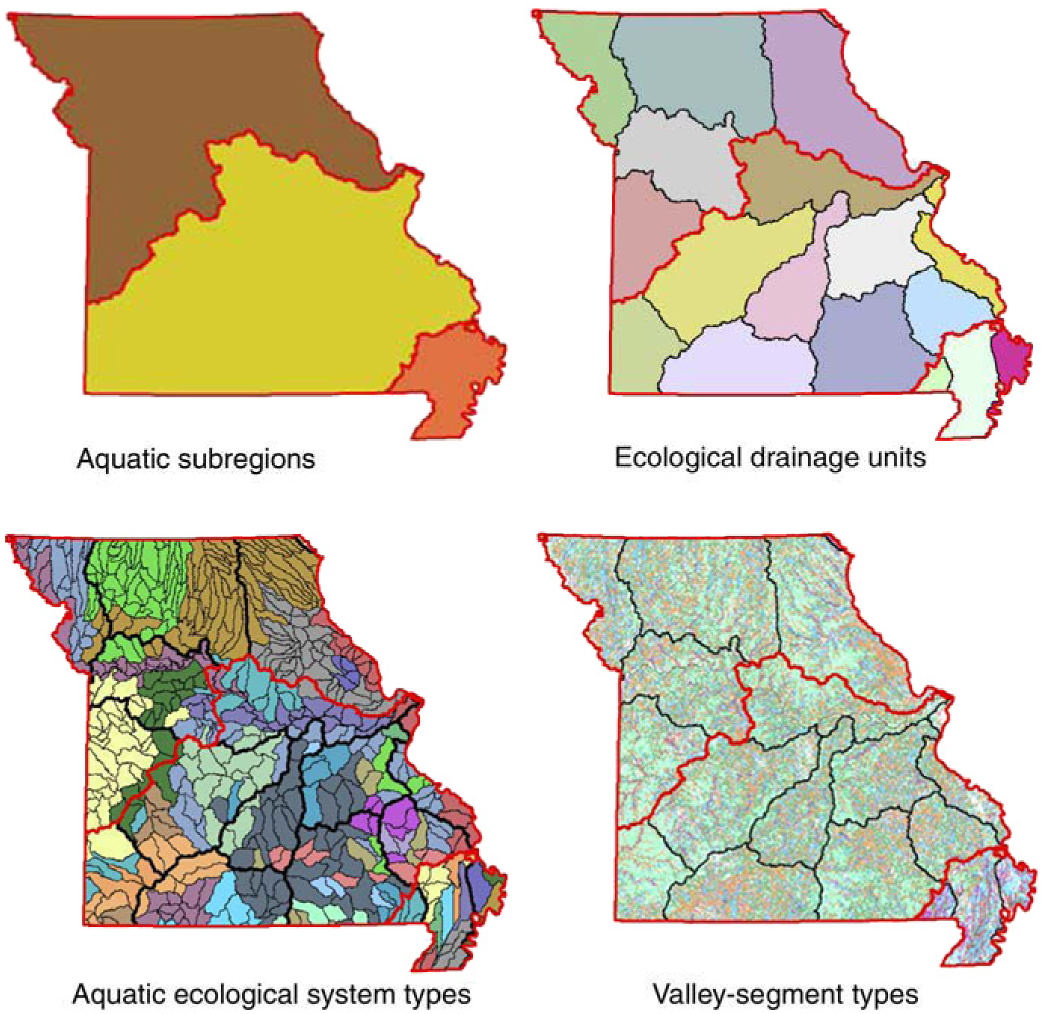



**Figure 3-27** Maps of Missouri showing levels four through seven of the aquatic ecological classification hierarchy (Sowa et al., 2007). Reprinted with permission of Ecological Society of America.

**Table 3-12** Eleven metrics included in the human-threat index and the criteria used to define the four relative ranks for each individual metric (Sowa et al., 2007).

| Metric | Relative Ranks | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Number of introduced species | 1 | 2 | 3 | 4 - 5 |
| Percentage urban | 0 - 5 | 5 - 10 | 11 - 20 | 0.20 |
| Percentage agriculture | 0 - 25 | 26 - 50 | 51 - 75 | 0.75 |
| Density of road–stream crossings (no./$km^2$) | 0 - 0.09 | 0.10 - 0.19 | 0.2 - 0.4 | 0.4 |
| Population change 1990–2000 (no./$km^2$) | -16 - 0 | 0.04 - 5 | 6 - 17 | 0.17 |
| Degree of hydrologic modification and/or fragmentation by major impoundment | 1 | 2 or 3 | 4 or 5 | 6 |
| Number of Federally licensed dams | 0 | 1 - 9 | 10 - 20 | 0.20 |
| Density of coal mines (no./$km^2$) | 0 | 0.1 - 2 | 2.1 - 8 | 0.8 |
| Density of lead mines (no./$km^2$) | 0 | 0.1 - 2 | 2.1 - 8 | 0.8 |
| Density of permitted discharges (no./$km^2$) | 0 | 0.1 - 2 | 2.1 - 8 | 0.8 |
| Density of confined animal feeding operations (no./$km^2$) | 0 | 0.1 - 2 | 2.1 - 4 | 0.4 |

**Table 3-13** Assessment criteria used for prioritizing and selecting aquatic ecological system (AES) polygons and valley-segment type (VST) complexes for inclusion in the portfolio of conservation opportunity areas (Sowa et al., 2007).

| AES-level Criteria<br>***Select the AES polygon that:*** | VST-level Criteria<br>***Select an interconnected complex of VSTs that:*** |
|---|---|
| Has the highest predicted richness of target species. | Contains known viable populations of species of special concern. |
| Has the lowest degree of human disturbance based on human-threat index value and qualitative evaluation of threats using the full breadth of available human-threats data. | Has the lowest degree of human disturbance based on a qualitative evaluation of relative local and watershed conditions using the full breadth of available human-threats data. |
| Has the highest percentage of public ownership. | Is already contained within the existing matrix of public lands. |
| Overlaps with existing conservation initiatives or high public support for conservation. | Overlaps with existing conservation initiatives or high public support for conservation. |

# Case Study

## Ohio Aquatic GAP Analysis: An Assessment of the Biodiversity and Conservation Status of Native Aquatic Animal Species

**More Information:** U.S. Geological Survey, 2006 (http://pubs.er.usgs.gov/usgspubs/ofr/ofr20061385)

The Ohio Aquatic GAP pilot project assessed all continuously flowing streams in Ohio to identify gaps in the current conservation network that could potentially pose a risk to freshwater biodiversity. A classification system was developed to characterize and map the aquatic habitats of 217 freshwater fish, crayfish, and bivalve species. The classification system used geomorphic and stream network variables, such as stream size and connectivity, sinuosity, and gradient to identify physical habitat types.

Biological data were compiled from multiple sources representative of the variety of stream types and sizes in Ohio. Species distributions were predicted using statistical models that relate the eight habitat indicators to the occurrence of individual species. The results of this analysis were overlain on a map of all conservation lands in the state. Predicted species distributions from the GAP Analysis showed that the predicted distribution of 24 species fell completely outside of these conservation lands. Nine of the 24 species are threatened or endangered. The results of this analysis were used to identify conservation priority lands based on predicted species richness (Figure 3-28).

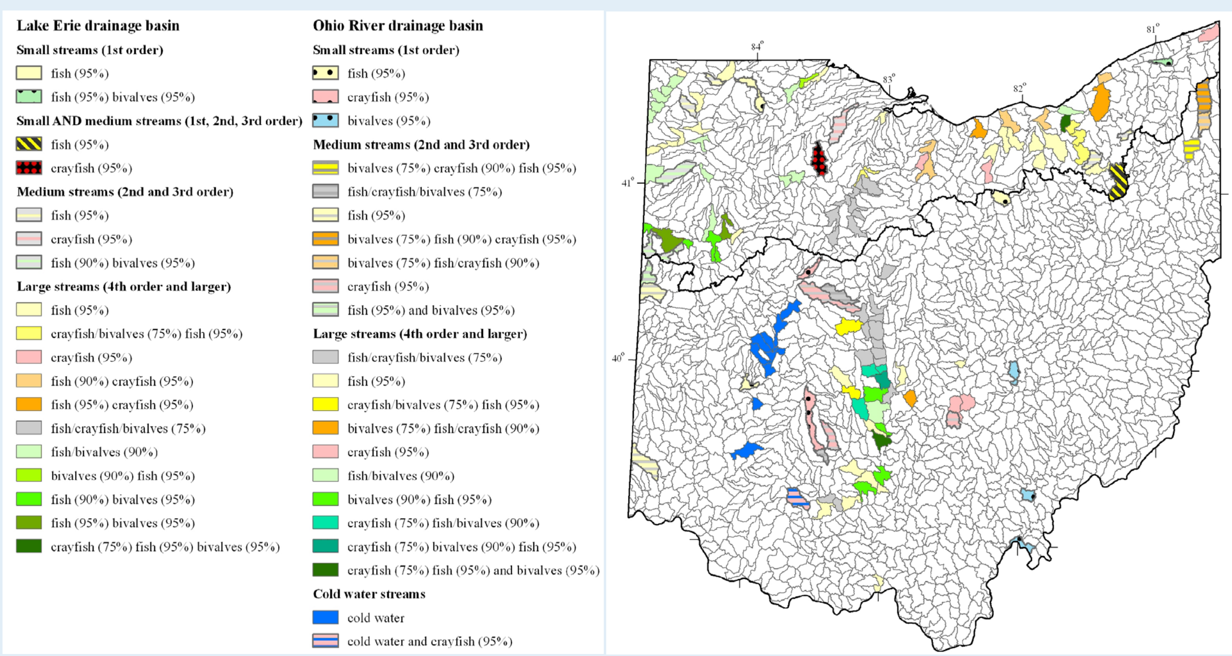



**Figure 3-28** HUC12 watersheds in Ohio. The different color watersheds represent high predicted aquatic species richness for various taxa (U.S. Geological Survey, 2006).

## Natural Heritage Program Biodiversity Assessments

**Author or Lead Agency:** NatureServe and state partners

**More Information:** http://www.natureserve.org/aboutUs/network.jsp

When it was formed in 1951, The Nature Conservancy's primary mission was the conservation of biological diversity through the establishment of nature reserves (Groves, Klein, & Breden, 1995). Realizing the need for a scientifically sound data collection and management program on which to base conservation decisions, the first state Natural Heritage Program was formed in South Carolina in 1974 (Groves, Klein, & Breden, 1995). Today, the Natural Heritage Network is comprised of 82 independent programs that are located in all 50 U.S. states, 11 provinces and territories of Canada, and in many countries and territories of Latin America and the Caribbean. These programs collect, analyze, and disseminate information about the biodiversity of their respective regions. With three decades of data collection and over 1,000 professional biologists, this network maintains the most comprehensive conservation database available in the western hemisphere. NatureServe, originally established in 1994 as the Association for Biodiversity Information, is the umbrella organization that now represents all of the state Natural Heritage Programs in the United States and Conservation Data Centers internationally.

The Natural Heritage Methodology gathers, analyzes, organizes, and manages information on biodiversity through a network of professional biologists in partner agencies who keep pace with the growth in scientific understanding while maintaining an underlying continuity in the methodology. NatureServe (2008) identifies the following characteristics of the Natural Heritage Methodology:

- It is designed to support a decentralized database network that respects the principle of local custodianship of data.
- It supports the collection and management of data at multiple geographic scales, allowing decisions to be made based on detailed local information, yet within a global context.
- It encompasses both spatial and attribute data, but emphasizes the type of fine-scale mapping required to inform on-the-ground decisions.
- It includes multiple quality control and quality assurance steps to ensure that data products have the reliability needed to inform planning and regulatory actions.
- It incorporates explicit estimates of uncertainty and targets additional inventory work to reduce levels of uncertainty.
- It integrates multiple data types, including: species and ecological communities; collections and other forms of observational data; and biological and non-biological data.


USFWS

The methodology is based upon the occurrence of "elements of biodiversity," which include both species and communities. These element occurrences are stored in spatial databases that are maintained by the local programs in each state. NatureServe maintains a central database where all local programs upload their information at least once per year. The following are the basic steps in the Natural Heritage Methodology as defined by NatureServe (2008):

1. Develop a list of the elements of biodiversity in a given jurisdiction, focusing on better-known species groups (e.g., vertebrate animals, vascular plants, butterflies, bivalve mollusks), and on the ecological communities present.
2. Assess the relative risk of extirpation or extinction of the elements to determine conservation status and set initial priorities for detailed inventory and protection.
3. Gather information from all available sources for priority elements, focusing on known locations, possible locations, and ecological and management requirements.
4. Conduct field inventories for these elements and collect data about their location, condition, and conservation needs.
5. Process and manage all the data collected, using standard procedures that will allow compilation and comparison of data across jurisdictional boundaries.
6. Analyze the data with a view toward refining previous conclusions about element rarity and risk, location, management needs, and other issues.
7. Provide access to data and information products to interested parties so that it can be used to guide conservation, management planning, and other natural resource decision-making.

The information collected, compiled, and distributed by state Natural Heritage Programs and NatureServe is used by land use and community planners, land owners, and natural area managers. Conservation groups use the data to set conservation priorities within their region. Developers and businesses use the data to comply with environmental regulations and government agencies use the data to help manage public lands and guide policy. The approach can be used to assess the biotic condition of a watershed at the local scale or aquatic ecoregions at the state scale. The general framework of the approach can also serve as a useful model for other assessment approaches that seek to identify healthy components of watersheds and prioritize sites for conservation or protection actions.

# Oregon Biodiversity Information Center

**More Information:** Oregon Biodiversity Program, 2009 (http://orbic.pdx.edu/)

The Oregon Biodiversity Information Center (ORBIC) works across agencies to identify the biological and ecological resources of the state. Formed in 1974, it was the first Natural Heritage Program in the west and is charged with the voluntary establishment of natural areas, manages the Rare and Endangered Invertebrate Program, and develops and distributes information on species and ecosystems throughout Oregon and the Pacific Northwest. ORBIC is also heavily involved in the state Gap Analysis Program and other conservation assessment and planning efforts in the state.

ORBIC typically identifies elements of biodiversity at the community or ecosystem level that represent the full range of diversity in the state. While this approach captures most species, there are times when individual species must be singled out as elements. These elements are mapped where they occur throughout Oregon, but examples are selected as Natural Areas at the ecoregional level in order to ensure that the full range of Oregon's natural areas is represented. Ecoregions are delineated areas with similar climate, vegetation, geology, geomorphology, soils, and ecosystem processes that define characteristic natural communities of plant and animal life.

When a community or ecosystem element makes a significant contribution to biodiversity within its ecoregion, it is defined as a natural area ecosystem element. Both ecosystems and species are then ranked by conservation priority according to: 1) rarity, 2) threats, 3) ecological fragility, and 4) the adequacy and viability of protected occurrences. ORBIC then works with landowners and managers to conserve a good example of these in a protected area. Classifications of terrestrial, aquatic, and wetland ecosystems are organized according to ecoregions. The current classification system used for riverine communities is based on the system used by the USGS Aquatic GAP and identifies unique "valley segment" types that contain distinct fish or aquatic species assemblages. Valley segment types are defined based on elevation, stream order, stream gradient, stream sinuosity, and the geology of the basin.

A unique aspect of the Oregon Natural Areas Program's approach is that, in addition to the identification and ranking of ecosystem cells, natural disturbance processes are also identified and prioritized for conservation. Ecosystem process elements are identified as areas containing landscape scale disturbance processes that occur with a frequency that is shorter than the life cycle of the affected communities. Wildfires are the most common type of natural disturbance in Oregon and typically require protected areas of several thousand acres to maintain. Special species lists are also created to ensure that rare, threatened, and endangered species receive the level of protection that they require.

ORBIC pursues a variety of conservation strategies on both public and private lands. Lands can be dedicated as State Natural Areas, Research Natural Areas, Marine Reserves, Biosphere Reserves, Nature Conservancy Preserves, as well as many other designations. ORBIC also seeks out donations of land from individuals and works with state and federal land managers to promote the acquisition of those private lands which are critical for conservation.

### Virginia Interactive Stream Assessment Resource and Healthy Waters Program

**Author or Lead Agency:** Virginia Department of Conservation and Recreation, Virginia Commonwealth University Center for Environmental Studies

**More Information:** www.dcr.virginia.gov/healthywaters and http://instar.vcu.edu

The Virginia Department of Conservation and Recreation and Virginia Commonwealth University Center for Environmental Studies are collaborating in the development and implementation of a statewide Healthy Waters program to identify and protect healthy streams. The Interactive Stream Assessment Resource (INSTAR) is an online, interactive database application that evaluates the ecological integrity of Virginia's streams using biological and habitat data. This web-mapping application is available to the public as a free resource to help planners, advocacy groups, and individuals to make wise land use decisions.

The INSTAR and Healthy Waters program would not be possible without the substantial investment Virginia has made in the collection of biological and habitat field data. Watershed biotic integrity is evaluated with a modified Index of Biotic Integrity (mIBI) that uses the following six metrics:

- Native species richness.
- Number of rare, threatened, or endangered species.
- Number of non-indigenous species.
- Number of significant species (ecologically or economically important).
- Number of tolerant species.
- Number of intolerant species.

The mIBI score can range from 6-30 and scores greater than 16 are considered to represent high watershed integrity. This analysis has been completed for all HUC12 watersheds across the entire State of Virginia (Figure 3-29). The ecological health of individual stream reaches is also evaluated based on their comparability to virtual reference streams. These virtual reference streams are modeled for each ecoregion and stream order and eliminate many of the limitations of other bioassessment approaches (e.g., finding appropriate reference sites) by relying on an objective reference condition based on fish and macroinvertebrate assemblage structure, instream habitat, and geomorphology. A virtual stream assessment is then conducted by evaluating the comparability of the empirical data to the appropriate virtual reference stream. Streams that are >70% comparable are considered healthy and those that are >80% comparable are considered "Excellent." Due to lack of data in the western part of the state, most of the healthy waters have so far been identified in eastern Virginia, but the goal is to expand sampling across the state (Figure 3-30).

The Virginia Healthy Waters program promotes the protection of headwater areas, riparian buffers, and maintenance of natural stream flow as management strategies for its high quality streams and watersheds. The INSTAR assessment identified Dragon Run as one of the highest quality streams in Virginia. The watershed is primarily forested, with some agricultural land uses as well, and there are only a few bridge crossings in the whole watershed. Maintenance of the wide riparian buffers, core forests, and wildlife corridors will be critical in maintaining Dragon Run as a high quality stream. Virginia is working with The Nature Conservancy and the residents of the watershed to ensure that this stream remains healthy.

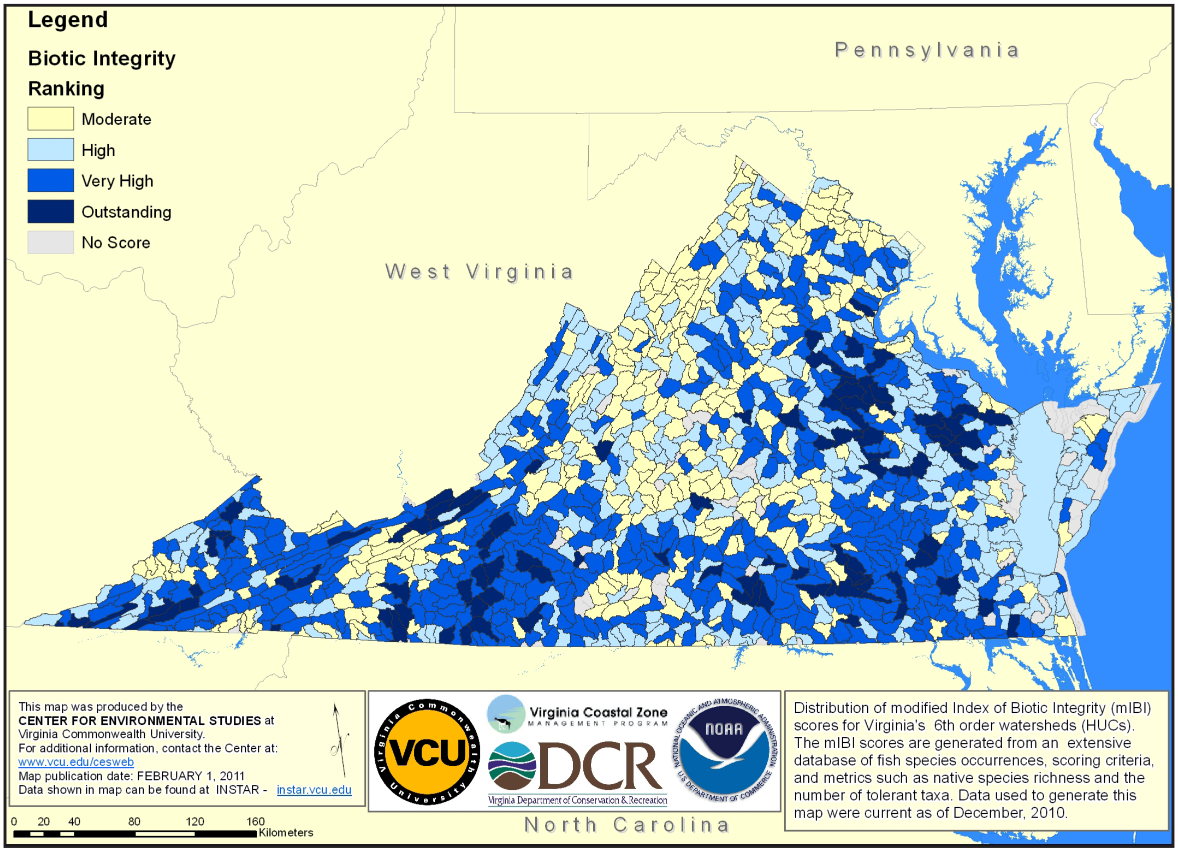



**Figure 3-29** Map of watershed integrity in Virginia based on modified Index of Biotic Integrity scores (Greg Garman, Virginia Commonwealth University, Personal Communication).

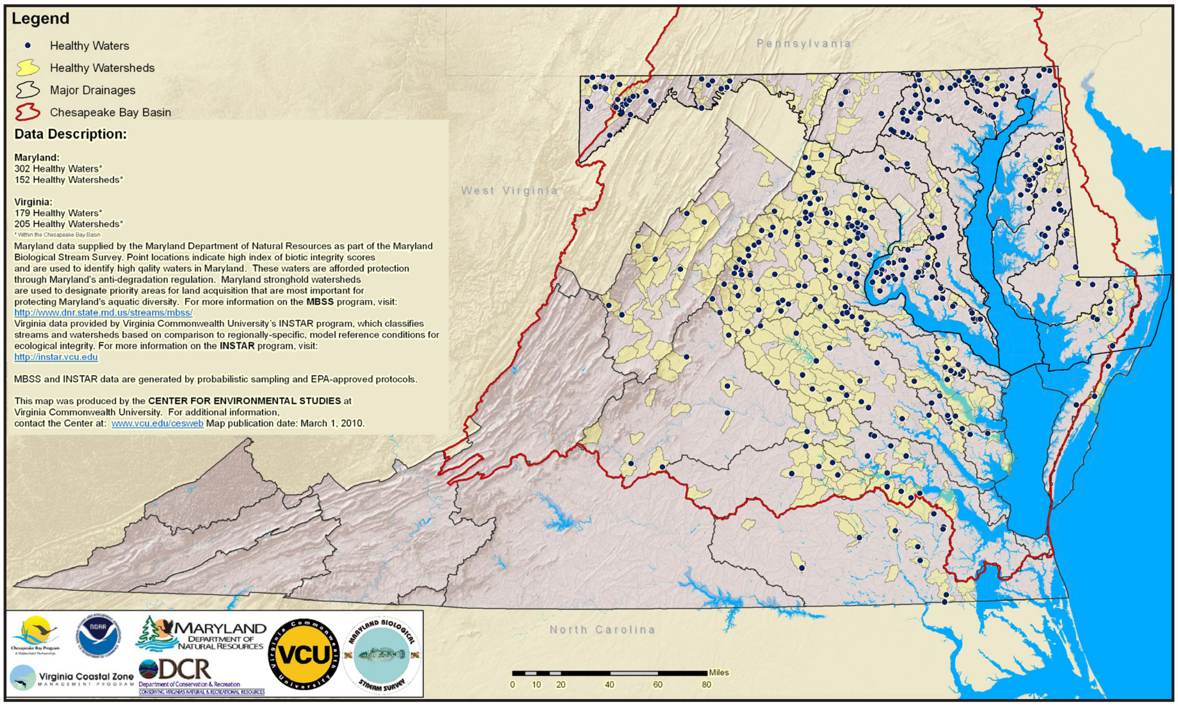
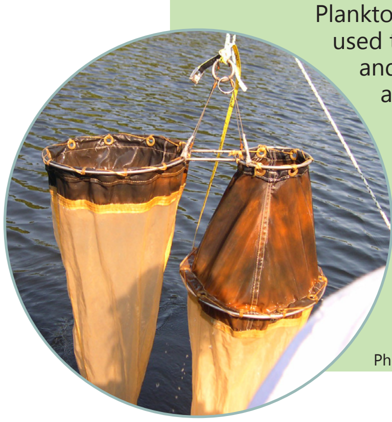



**Figure 3-30** Status of healthy waters and watersheds in Maryland and Virginia (Greg Garman, Virginia Commonwealth University, Personal Communication).

## 3.7 National Aquatic Resource Assessments

This section provides summaries for some examples of national programs that monitor and assess aquatic resources, including water quality, biology, and habitat. Working with state, tribal, and other federal agency partners, EPA is conducting statistical surveys of the nation's streams and rivers, lakes and reservoirs, coastal waters, and wetlands. Because different organizations use differing monitoring designs, indicators, and methods, EPA cannot combine their information to effectively answer questions about the quality of the nation's waters or track changes over time. EPA and its state, tribal, and federal partners are implementing a series of aquatic resource surveys to address this national information gap. These National Aquatic Resource Surveys (NARS) use randomized sampling designs, core indicators, and consistent monitoring methods and lab protocols to provide statistically-defensible assessments of water quality at the national scale. Additionally, the national surveys are helping build stronger monitoring programs across the country by fostering collaboration on new methods, new indicators, and new water quality research. EPA implements the surveys on a five year rotation. As the surveys repeat, EPA will be able to track changes over time and advance our understanding of important regional and national patterns in water quality. USGS' National Water Quality Assessment (NAWQA) Program also conducts national and regional assessments of status and trends of aquatic ecological condition. These national programs can serve as sources of biological, geological, chemical, geospatial, and physical data, which can be used to assess water quality conditions within a watershed.



Plankton nets are used to collect and evaluate for abundance and diversity of phytoplankton and zooplankton, which form the base of a lake's food chain.

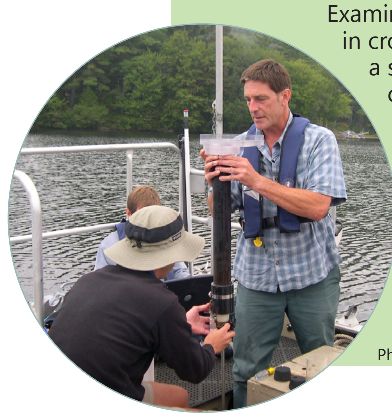
Photo: NEIWPCC.

Water quality multiprobes are often used to collect data in the field on temperature, dissolved oxygen, conductivity, pH, and other parameters.

Photo: USFWS.

Working with partner organizations increases access to the specialized equipment that can be needed for water quality monitoring.

Photo: USGS.



Examination of diatoms in cross sections of a sediment core can provide insight on a lake's historical chemical and physical characteristics, such as total phosphorus and clarity.

Photo: NEIWPCC

## National Rivers and Streams Assessment

**Author or Lead Agency:** U.S. EPA

**More Information:** http://water.epa.gov/type/rsl/monitoring/riverssurvey/riverssurvey_index.cfm

In 2006, EPA released a report on the Wadeable Streams Assessment (WSA), which was the first statistically valid national survey of the biological condition of small streams throughout the United States (U.S. Environmental Protection Agency, 2006c). The WSA uses macroinvertebrate communities to report on biological condition and measures other key parameters such as riparian and instream habitat, sediments, nutrients, salinity, and acidity. With 1,392 randomly selected sites, a representative sampling of the condition of streams in all ecoregions established a national baseline of biological condition. The WSA found that, compared to best available reference sites in their ecological regions, 42% of U.S. stream miles are in poor condition, 25% are in fair condition, and 28% are in good condition (Figure 3-31). The National Rivers and Streams Assessment (NRSA) expands on the WSA by including larger streams and rivers. The NRSA is designed specifically to:

- Assess the condition of the nation's rivers and streams.
- Help build state and tribal capacity for monitoring and assessment.
- Promote collaboration across jurisdictional boundaries.
- Establish a baseline to evaluate progress.
- Evaluate changes in condition since the first Wadeable Streams Assessment.

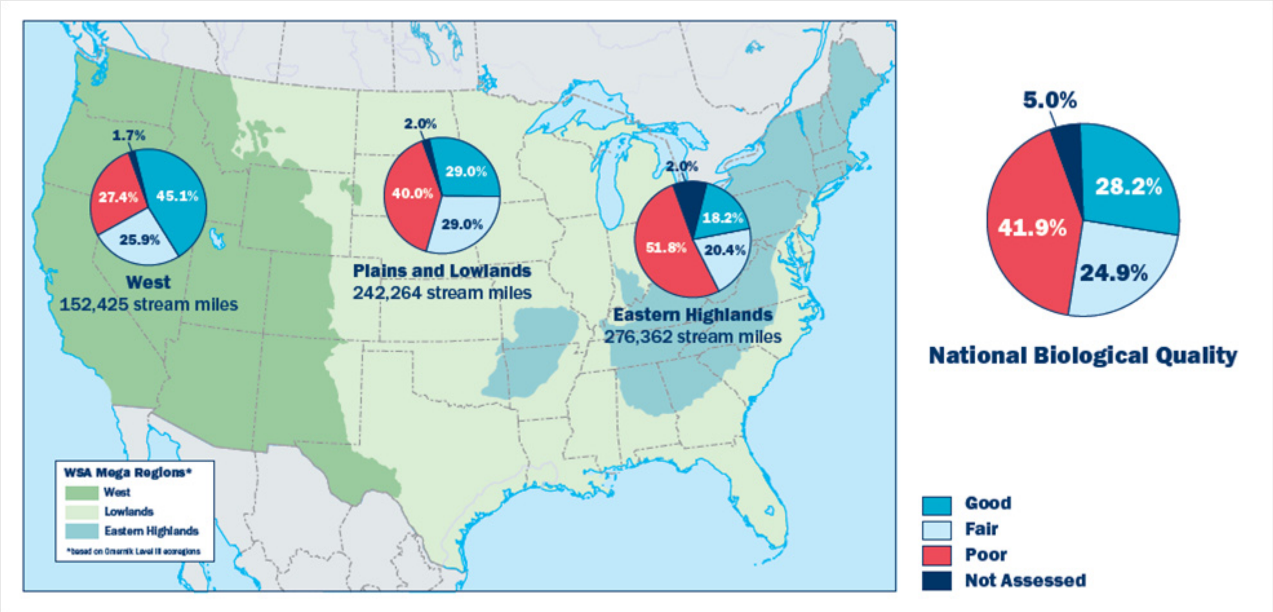



**Figure 3-31** Biological quality results from EPA's Wadeable Streams Assessment (U.S. Environmental Protection Agency, 2008c).

The sampling design for the NRSA survey is a probability-based network that provides statistically valid estimates of condition for a population of rivers and streams with a known confidence. A total of 1,800 sample sites were selected to represent the condition of rivers and streams across the country (Figure 3-32), 900 in each of two categories of waters: wadeable and non-wadeable. The survey is measuring a wide variety of variables intended to characterize the chemical, physical, and biological condition of the nation's flowing waters. These include water chemistry, nutrients, chlorophyll *a*, sediment enzymes, *enterococci*, fish tissue, physical habitat characteristics, and biological assessments including sampling of phytoplankton, periphyton, benthic macroinvertebrates, and fish communities. Sample collection was completed in 2009 and a final report is scheduled for 2012. Data collected through the NRSA will be made available through EPA's Water Quality Exchange (WQX) (see Appendix B). These data can be used by state and local watershed managers for targeting of more intensive monitoring plans and for regional comparisons of water quality.

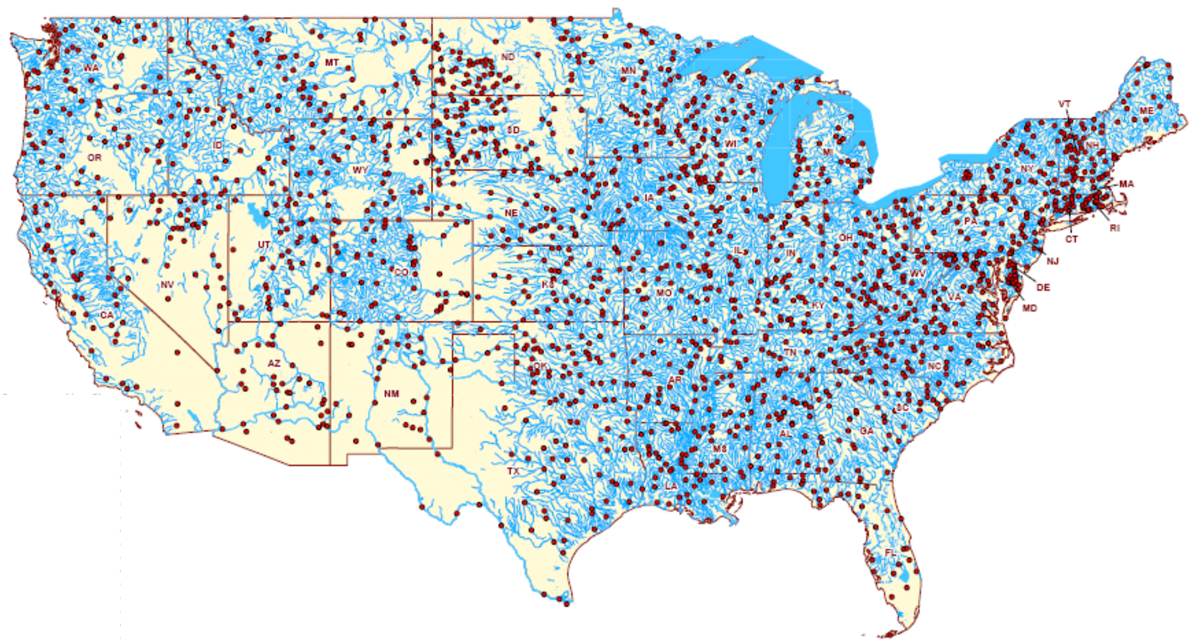



**Figure 3-32** National Rivers and Streams Assessment sample sites (U.S. Environmental Protection Agency, 2011d).

# Case Study

## Oklahoma National Rivers and Streams Assessment

**More information:** http://www.owrb.ok.gov/studies/reports/reports_pdf/REMAP-OKStreamRiver_ProbMonitorNetwork.pdf

Several agencies, including the Oklahoma Water Resources Board and the Oklahoma Conservation Commission, conduct water quality monitoring in the State of Oklahoma. Since the early 1990s, monitoring programs have developed complementary monitoring objectives that support the management of Oklahoma's surface waters, including a long-term, fixed-station water quality monitoring network on rivers and lakes, and a small-watershed rotating basin monitoring program that targets smaller streams. As part of Oklahoma's long-term water quality monitoring strategy, a probabilistic approach to resources has been in development since 2001, with the primary objective to compliment other programs.

Due to funding and resource constraints, full implementation of probabilistic monitoring has taken a number of years to reach full maturation. As late as 2003, Oklahoma agencies remained unable to initiate further planning and make a long-term commitment, even though the need for the approach had already been accepted. However, in 2004, Oklahoma took part in the National WSA, and from 2004-2008, the Oklahoma Water Resources Board received several grants to study the feasibility of, and to implement, a probabilistic monitoring approach in rivers, streams, and lakes. These projects included CWA 104(b)3 grants, a Regional Environmental Monitoring and Assessment grant, and CWA 106 monies to perform the NARS monitoring in lakes (2007) and rivers/streams (2008-2009). Over this five year span, a probabilistic approach was fully integrated into the Oklahoma Water Resources Board's monitoring strategy and has been adopted by the Oklahoma Conservation Commission as part of their long-term monitoring approach. With the assistance of continued NARS funding and supplemental 106 monitoring funds coupled with the leveraging of state dollars, the various programs have grown to include monitoring of various resource types and sizes. The statewide rivers and streams probabilistic program will enter its fourth study cycle in 2013 and considers both small and large water bodies separately. The program has also integrated several studies to investigate regional needs. Additionally, a statewide lakes program entered its second study cycle in 2010. The design considers both large lakes (>500 surface acres) and small lakes (>50 surface acres). Lastly, using CWA 319 funds, the Oklahoma Conservation Commission has implemented a probabilistic component as part of its rotating basin monitoring program.

In terms of water quality management, the most obvious outcome of probabilistic design has been the inclusion of statistically valid surveys for creation of the state's 305(b) report. However, several technological enhancements developed through NARS are being used to benefit the state in several ways. First, biological indicator development has taken a dramatic leap forward with the inclusion of probabilistic data. Although Oklahoma has used both invertebrate and fish indicators in wadeable streams assessments for years, probabilistic collections will facilitate refinement of reference conditions, improvement of metrics, and development of other indicators, such as phytoplankton and zooplankton. Also, indicator collection methods and eventually assessment indices developed through NARS for both large rivers and lakes are being implemented widely throughout Oklahoma. Second, the enhancement of indicator-stressor relationships through NARS is being used in Oklahoma studies. Concepts of relative risk have been included in several studies and can be used to develop long-term strategies for toxic monitoring, nutrient criteria development, and refinement of sediment and in-situ water quality criteria. Additionally, the NARS quantitative habitat methodologies have been combined with rapid bioassessment protocols to develop more sensitive habitat metrics. Lastly, use of multiple design strategies (fixed and probabilistic) will improve the ability to identify regional hotspots for resource allocations.

### National Lakes Assessment

**Author or Lead Agency:** U.S. EPA

**More Information:** http://water.epa.gov/type/lakes/lakessurvey_index.cfm

Lakes are an important water resource to monitor, because they provide, among other things, drinking water, habitat for fish and wildlife, recreational opportunities, and flood control. However, their integrity is potentially threatened by the continual expansion of lakeshore development. The National Lakes Assessment was conducted in 2007 to survey the biological condition of the nation's lakes, ponds, and reservoirs as part of the NARS Program. The NLA incorporates assessments of biological, chemical, and physical integrity; this integrated approach is expected to focus attention on the relationships between stressor levels and lake integrity and developing management strategies that foster healthy lake conditions in all three of these aspects of lake integrity.

For the NLA, indicators were selected to measure the biological, chemical, and physical integrity of lakes and their capacity to support recreational opportunities. The NLA is designed to provide information on the entire population of lakes, nationally and at other broad scales; it does not assess the quality of individual lakes. The NLA emphasizes the analysis of biological indicators and biological condition, because biological systems integrate the affects of multiple stressors over time. Biological indicators included observed versus expected (O/E) phytoplankton and zooplankton, the Lake Diatom Condition Index, benthic macroinvertebrates, algal density (chlorophyll *a*), and invasive species. Chemical indicators included phosphorus and nitrogen concentrations, characteristics of the water column profile (dissolved oxygen, temperature, pH, turbidity, acid neutralizing capacity, salinity), and sediment mercury concentrations. Indicators of physical integrity included lakeshore habitat cover and structure, shallow water habitat cover and structure, and lakeshore human disturbance. Poor lakeshore habitat was the most significant stressor among lakes studied, being both the most prevalent problem (occurring in one third of studied lakes) and the stressor that has the greatest negative impact on a lake's biological health. This finding implies a need for management strategies that protect and restore the natural state of lakeshore habitat to provide essential vegetative cover and buffering from human disturbances. Lastly, recreational suitability indicators included pathogens *(enterococci),* algal toxin concentrations (microcystins), and cyanobacteria counts.

Well-documented sample collection and analysis procedures were used to conduct the NLA. Depth profiles for temperature, pH, dissolved oxygen, water clarity, and the depth at which light penetrates the lake's water were measured over the deepest point in each lake. Single grab water samples were collected to measure nutrients, chlorophyll *a*, phytoplankton, and the algal toxin microcystin. Zooplankton samples were collected using fine and coarse plankton nets. A sediment core was taken to provide data on sediment diatoms and mercury levels. Along the perimeter of the lake, crews collected data on the physical characteristics that affect habitat suitability. Substrate composition data were recorded along the ten peripheral stations. Benthic macroinvertebrates and water samples for pathogen analysis were collected at the first and last stations, respectively.

All of these measurements were made for lakes selected through the random selection process and for a set of least disturbed lakes that exhibit the highest quality condition. The results obtained from analysis of these high quality lakes were used to define a set of reference lakes for biological condition and a set of reference lakes for nutrient condition, to which lower quality lakes were compared. Lakes which had results above the $25^{th}$ percentile of the reference range values were considered "good" (56%); those which had results between the fifth and $25^{th}$ percentiles were considered "fair" (21%); and lakes which had results below the fifth percentile of the reference range values were considered "poor" (22%) (Figure 3-33).

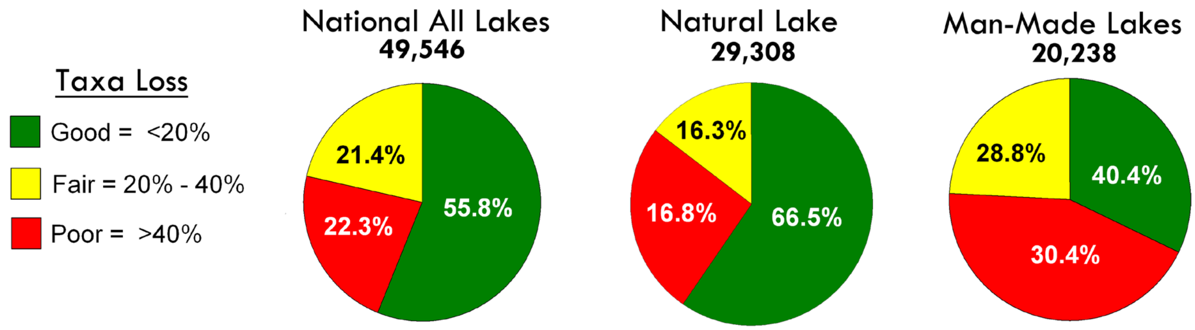
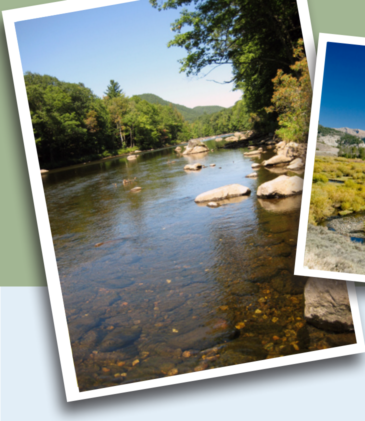



**Figure 3-33** Biological condition of lakes nationally and based on lake origin (U.S. Environmental Protection Agency, 2009a).

The data produced by the 2007 NLA and future applications of its standardized field and laboratory protocols contribute to the kind of statistically valid assessment of lakes that EPA and states need to inform their lake management policy decisions. This survey established the first nationally consistent assessment of both condition and extent of stressors to lake biological condition, which may be used to measure the impact of future management activities. EPA sees the analyses that were developed for the NLA, such as the IBI for lake diatoms and plankton O/E models, as tools that can be adapted for use within individual states. Data generated through the NLA can be used to identify regional hotspots for particular stressors and promote collaboration between jurisdictional authorities in those hotspots to reduce the stressors' impacts on lake integrity. States can also use NLA data to tailor restoration strategies to address the stressors identified for each of the lakes in their jurisdictions, making it easier for them to leverage programs such as the Environmental Quality Incentives Program and Conservation Reserve and Enhancement Programs managed by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service and the CWA Section 319 Program and National Pollutant Discharge Elimination System.


# Case Study

## Minnesota National Lakes Assessment

**More information:** http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/lake-water-quality/national-lakes-assessment-project-nlap.html?menuid=&redirect=1

Minnesota's 2007 NLA effort was led by the Minnesota Pollution Control Agency and Minnesota Department of Natural Resources (DNR). Other collaborators included the U.S. Forest Service, Minnesota Department of Agriculture, and USGS. Minnesota received 41 lakes as a part of the original draw of lakes for the national survey–the most of any of the lower 48 states. Minnesota added nine lakes to the survey to yield the 50 lakes needed for statistically-based statewide estimates of condition. In addition to the 50 lakes, 14 reference lakes were later selected and sampled by EPA as a part of the overall NLA effort. Data from the reference lakes provide an additional basis for assessing lake condition as a part of NLA. Because of its statistically-based nature, this dataset provides a good basis for describing the typical range of constituents and interrelationships in Minnesota's lakes on a statewide basis.

Previous studies have described regional patterns in lake trophic status and the NLA data reinforce these patterns and provide a basis for statistically describing trophic status on a statewide basis and providing estimates at an ecoregion basis. In terms of phosphorus-based trophic status, the distribution of Minnesota's lakes is similar to that of the Nation and about 64% of Minnesota's lakes are considered oligotrophic or mesotrophic (on a weighted basis). The Minnesota NLA phosphorus, chlorophyll *a*, and Secchi data exhibit relatively strong correlations and can be used to describe interrelationships and identify thresholds. With respect to nitrogen, the Minnesota data reveal very poor correspondence among nitrogen and chlorophyll *a*, and nitrogen:phosphorus ratios indicate that <10% of the lakes might be considered "nitrogen-limited" – both of which support the need to emphasize phosphorus over nitrogen when developing nutrient criteria in freshwater lakes.

In addition to the measurements made as a part of the overall NLA, Minnesota made several enhancements to their survey, including: collaboration with U.S. Forest Service in sampling the Boundary Waters Canoe Area Wilderness, which allowed for inclusion of hard-to-access lakes in this wilderness area; sampling in support of lake Index of Biotic Integrity (IBI) development; and a region-wide assessment of the Prairie Pothole Region conducted in conjunction with North Dakota, South Dakota, Montana and Iowa an ongoing effort with primary emphasis on identifying reference condition for this unique population of lakes.

The NLA data provide a valuable complement to data collected from other more targeted programs. This statistically-based dataset allows for extrapolation to the entire state or ecoregions. This can provide context for data collected from other programs, estimate numbers or percentages of lakes that meet water quality standards or numbers or percentages of lakes that may have a chemical make-up or other attributes that may be of interest to state or local lake managers. Minnesota's NLA reports also provide information on other lake attributes that is useful to lake managers and scientists.

## Regional and National Monitoring and Assessments of Streams and Rivers

**Author or Lead Agency:** U.S. Geological Survey

**More Information:** http://water.usgs.gov/nawqa/studies/mrb/

USGS implemented the National Water Quality Assessment (NAWQA) Program in 1991 to develop long-term, consistent and comparable information on streams, rivers, ground water, and aquatic systems in support of national, regional, state, and local information needs and decisions related to water quality management and policy. The current focus of USGS' National Water Quality Assessment Program is on regional and national scale assessments of status and trends in streams, rivers, and ground water across the nation. Under the NAWQA program, USGS collects and interprets a variety of biological, geological, chemical, geospatial, and physical data, which can be used to assess water quality conditions and trends within a watershed. Available ground water quality data are similar to surface water quality data but in addition include volatile organic compounds, major anions and cations, trace elements, and selected radionuclides. Chemical, physical, and aquatic biological parameters collected in surface waters include:

- Temperature
- Specific conductance
- Dissolved oxygen
- pH
- Alkalinity
- Chloride
- Carbonate
- Bicarbonate
- Sulfate
- Suspended sediment
- Nitrogen
- Phosphorus
- Fish
- Aquatic macroinvertebrates
- Periphyton
- Chlorophyll
- Stream habitat
- Daily stream flow

NAWQA has identified eight large geographic regions (referred to as "major river basins") as the basis for its status and trends assessments (Figure 3-34). The most recent NAWQA assessments (2002-2010) build upon previous findings generated from 1992-2001 for streams and rivers in smaller basins (referred to as "study units"). Primary goals remain the same: characterize the status of surface water quality (stream chemistry and ecology) and ground water quality; determine trends at those sites that have been consistently monitored for more than a decade; and build an understanding of how natural features and human activities affect water quality. The number of sites included in NAWQA's status and trends network totals 113 across the eight major river basins (Figure 3-34). The NAWQA monitoring network uses a fixed-site, five interval rotational sampling scheme; therefore, sampling intensity varies from every year to one in four years at the different sites. The results of regional and national scale water quality assessments are published in various USGS and journal publications. In addition, data collected through the NAWQA monitoring network are made available through USGS' National Water Information System (NWIS) and the NAWQA Data Warehouse (see Appendix B).


USGS

An important design element of the NAWQA Program is the integration of monitoring data with modeling and other scientific tools to estimate water quality at unmonitored sites based on data collected at comparable sites. Many of these tools are designed to evaluate various resource management scenarios and predict how management actions are likely to affect water quality. Some specific applications of NAWQA tools include:

- The use of a hybrid statistical, GIS, and process-based model, SPARROW (SPAtially Referenced Regressions On Watershed attributes), to estimate nutrient fluxes in unmonitored streams throughout the conterminous United States (U.S. Geological Survey, 2009d).
- The use of statistical and GIS tools for classifying watersheds into Hydrologic Landscape Regions.

These modeling tools, based on the NAWQA data, can provide watershed managers with valuable information when site-specific data are not available. National water quality monitoring and assessment programs such as NAWQA and the National Rivers and Streams Assessment are important in the development of these tools, as well as for providing information on aquatic ecosystem health.

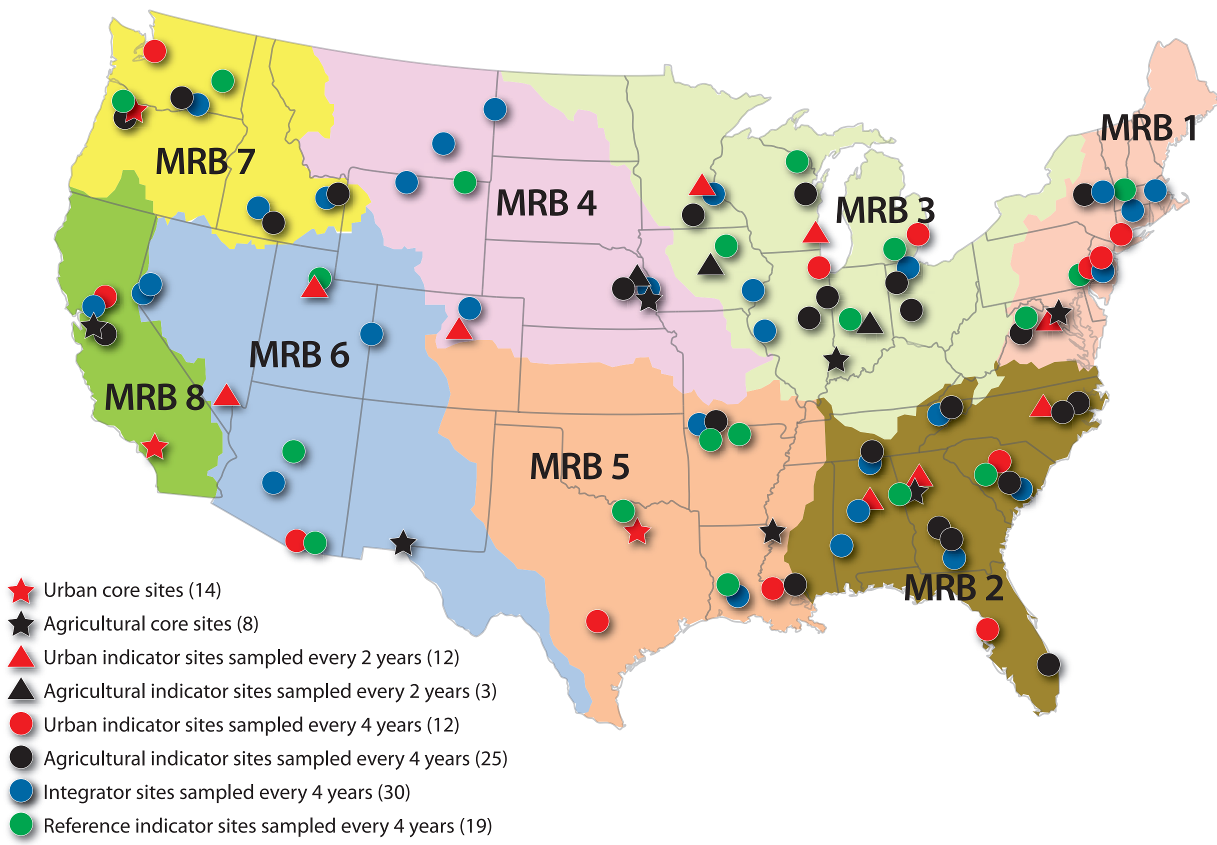



**Figure 3-34** Sites for Regional and National Monitoring and Assessments of Streams and Rivers within Major River Basins (MRB) (U.S. Geological Survey, 2009c).

# 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.

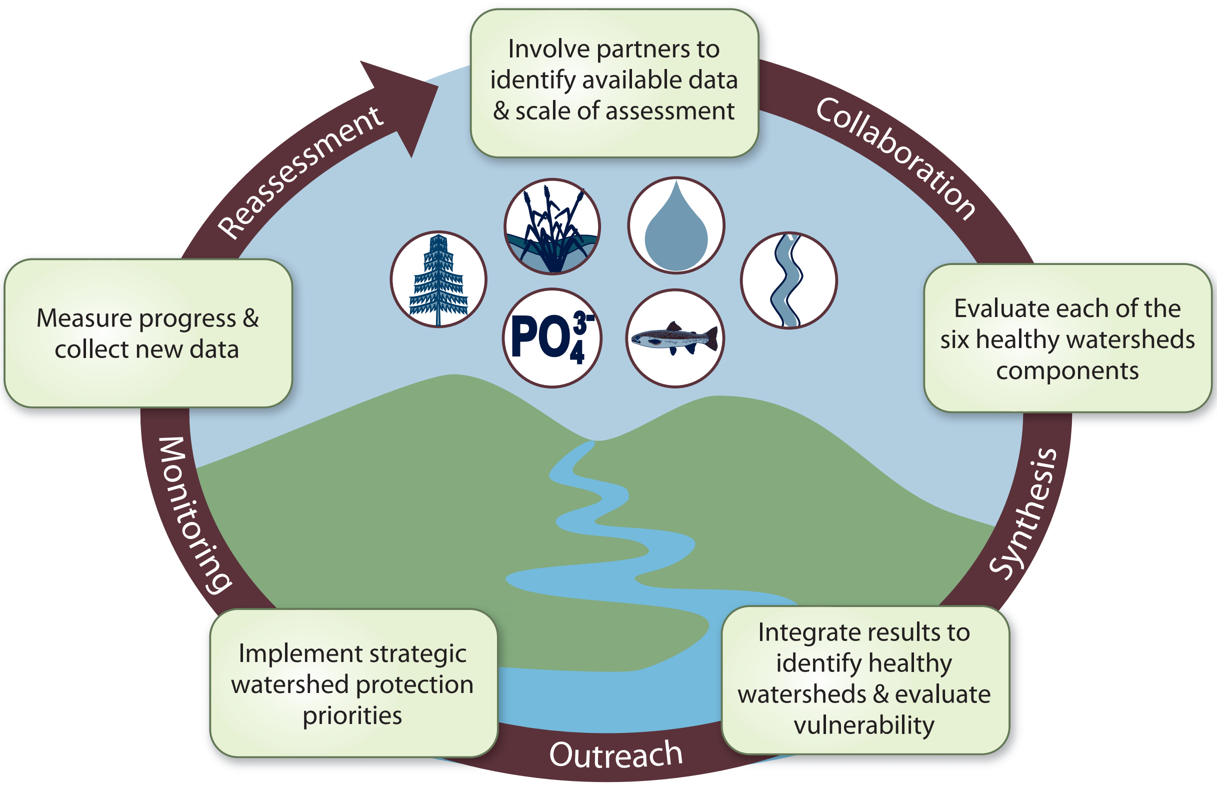



**Figure 4-1** Healthy watersheds integrated assessment and management framework.

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.

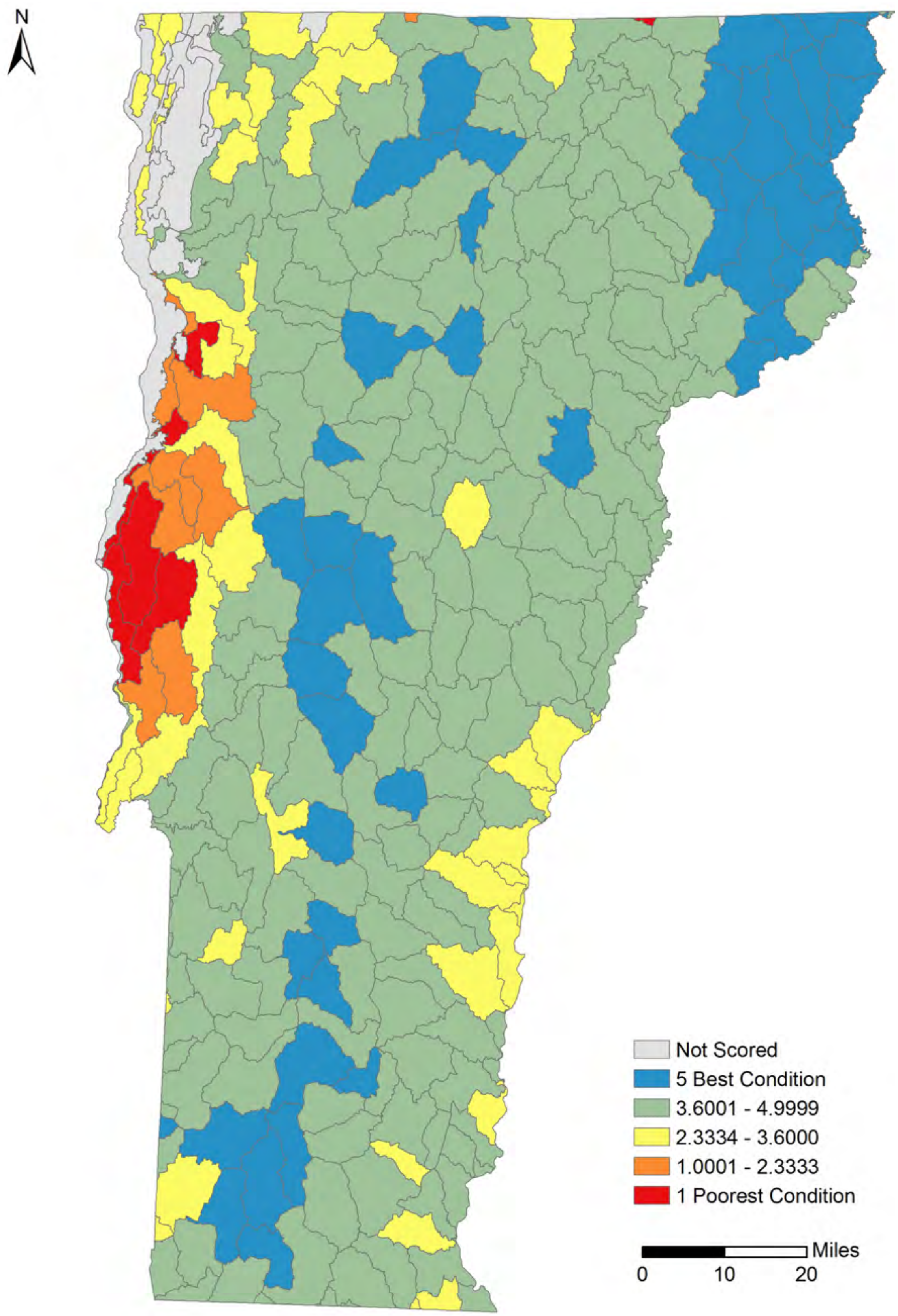



**Figure 4-2** National Fish Habitat Assessment (NFHA) scores at the 12 digit hydrologic unit code (HUC) scale for Vermont (courtesy of the National Fish Habitat Board).

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<br>Percent natural land cover within the Active River Area |
| Habitat | Dam density (#/mi)<br>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:

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

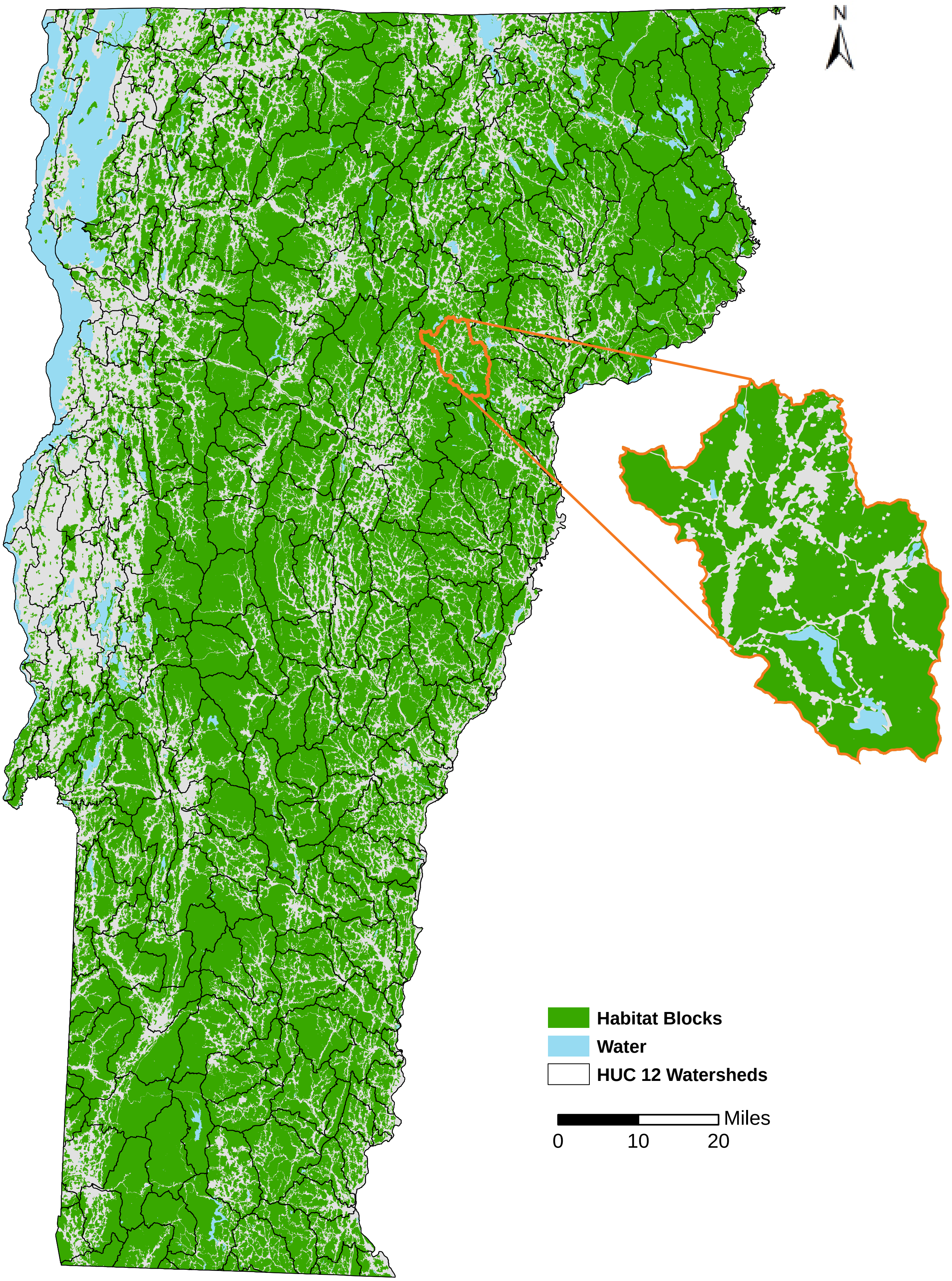



**Figure 4-3** Blocks of contiguous natural land cover in Vermont (courtesy of Vermont Fish and Wildlife Department).

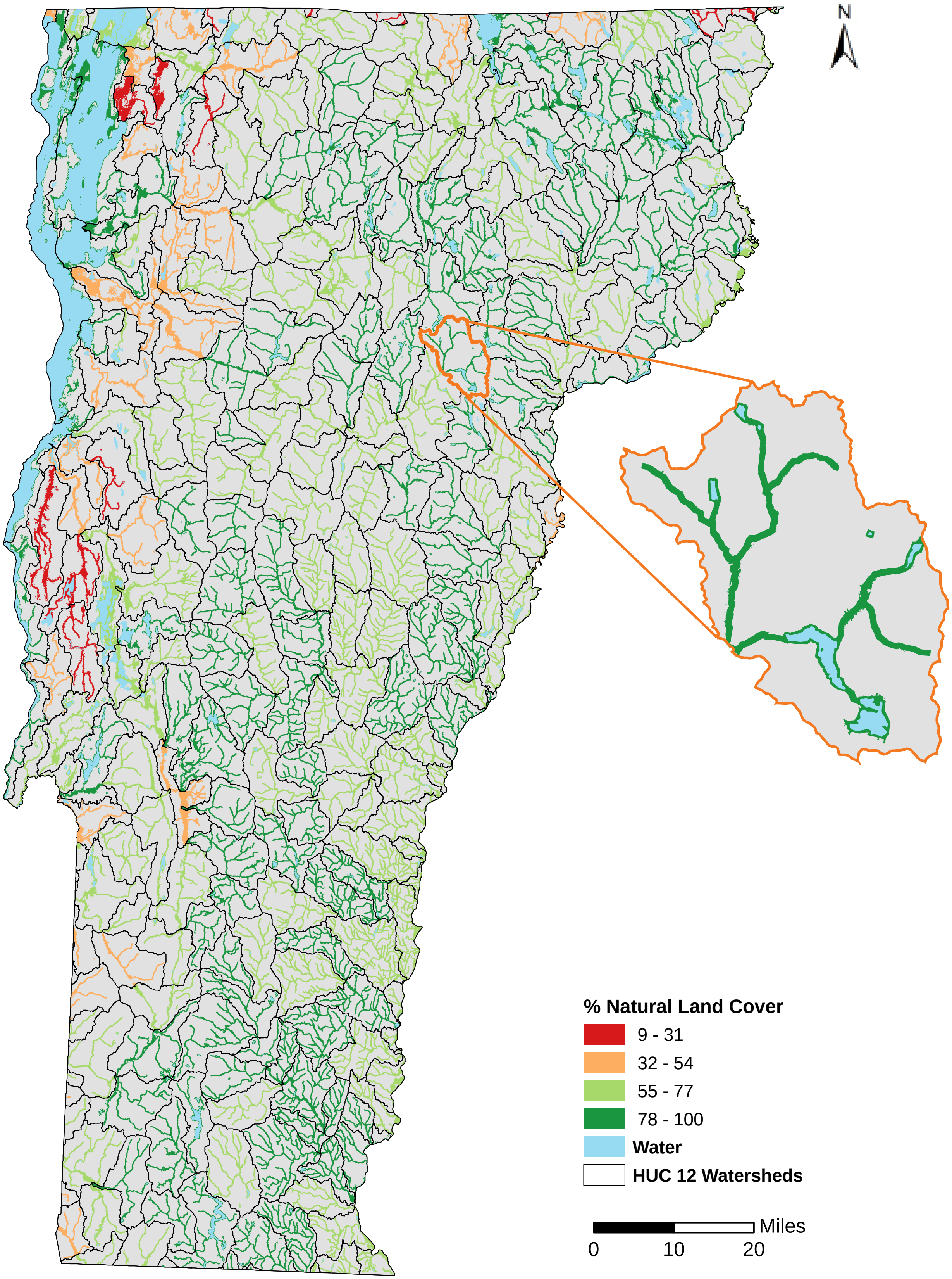



**Figure 4-4** Percent natural land cover in the Active River Area of Vermont (Active River Area delineation courtesy of The Nature Conservancy)..

**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:

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

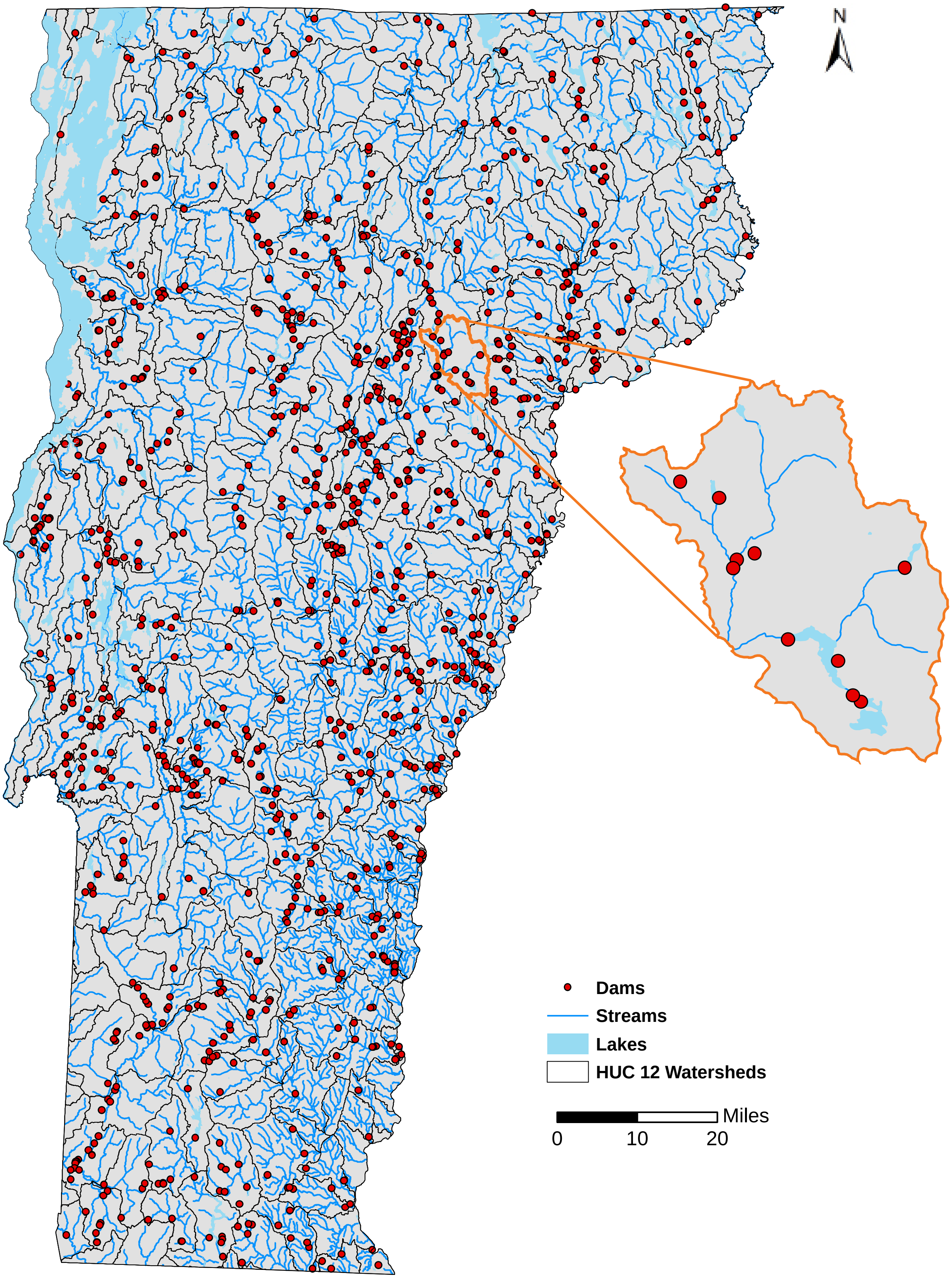



**Figure 4-5** Location of dams in Vermont (courtesy of Vermont Department of Environmental Conservation).

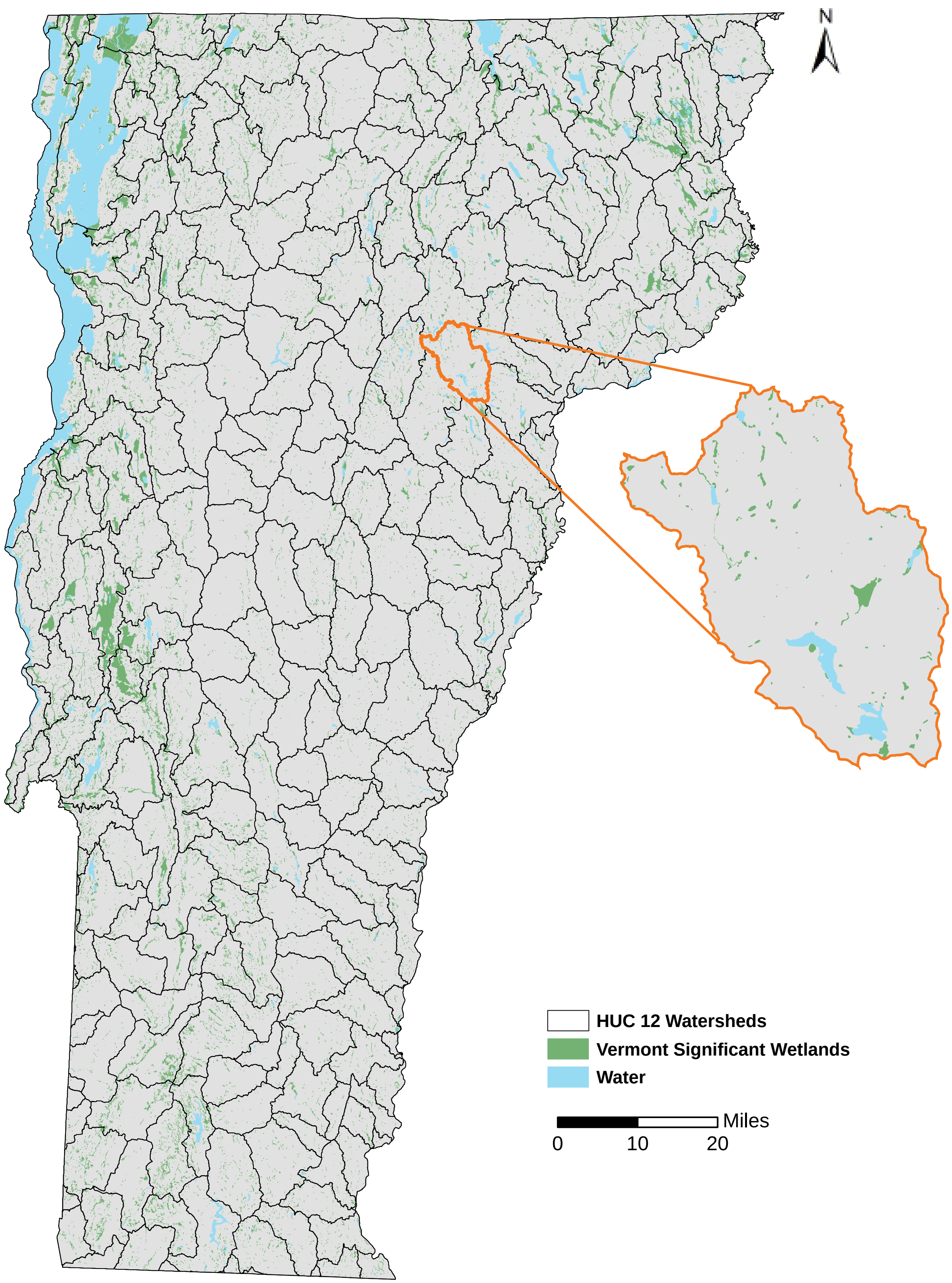



**Figure 4-6** Class I and Class II significant wetlands in Vermont (courtesy of Vermont Department of Environmental Conservation).

## 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. |

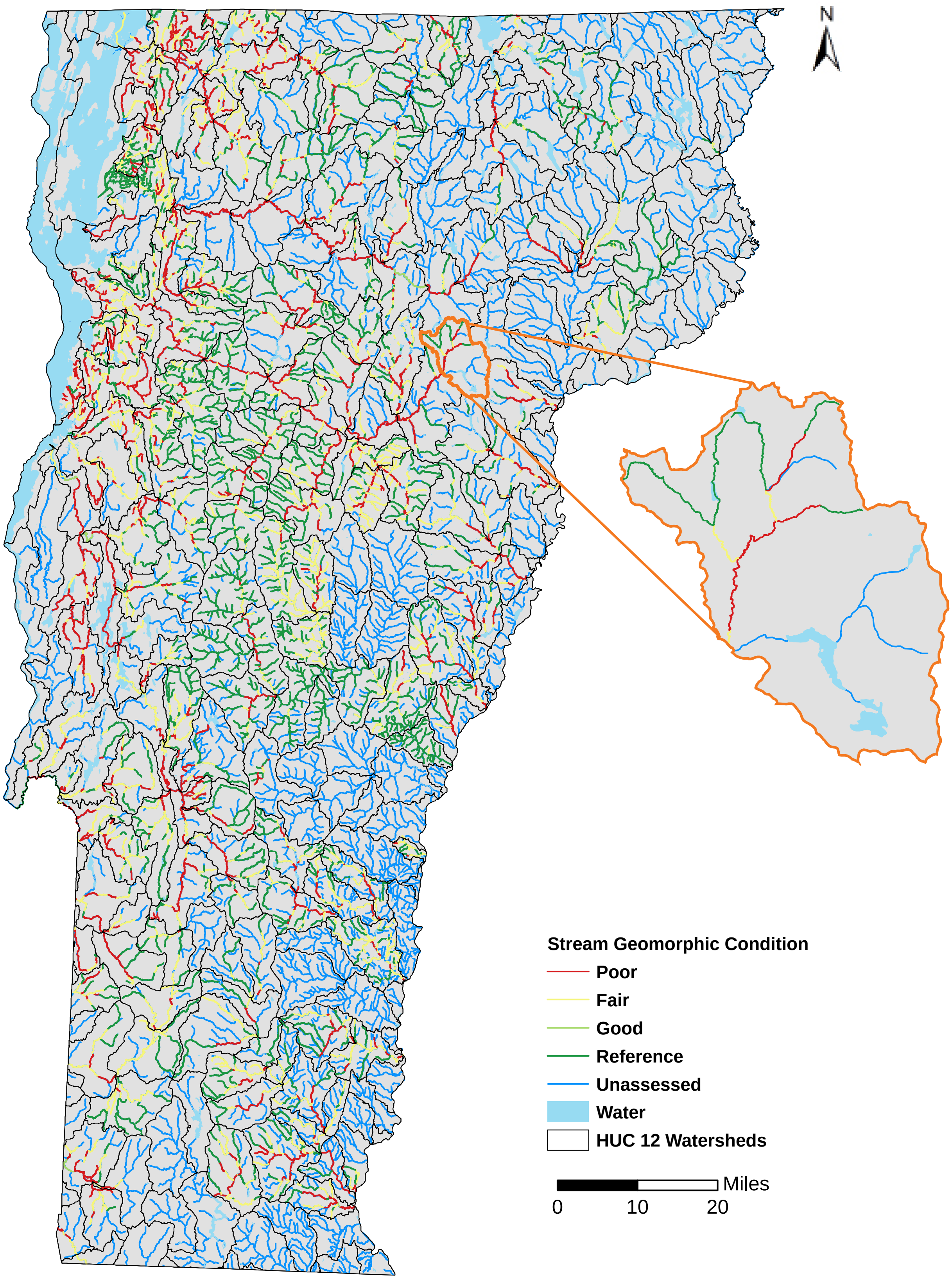



**Figure 4-7** Phase 1 stream geomorphic assessment results for Vermont (courtesy of Vermont Department of Environmental Conservation).

### Evaluate Water Quality

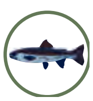
Water quality can be evaluated in a number of ways, ranging from statewide probabilistic monitoring to the use of complex watershed loading models and empirical analyses of the relationship between landscape characteristics and water quality. As part of the National Wadeable Streams Assessment and National 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:

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

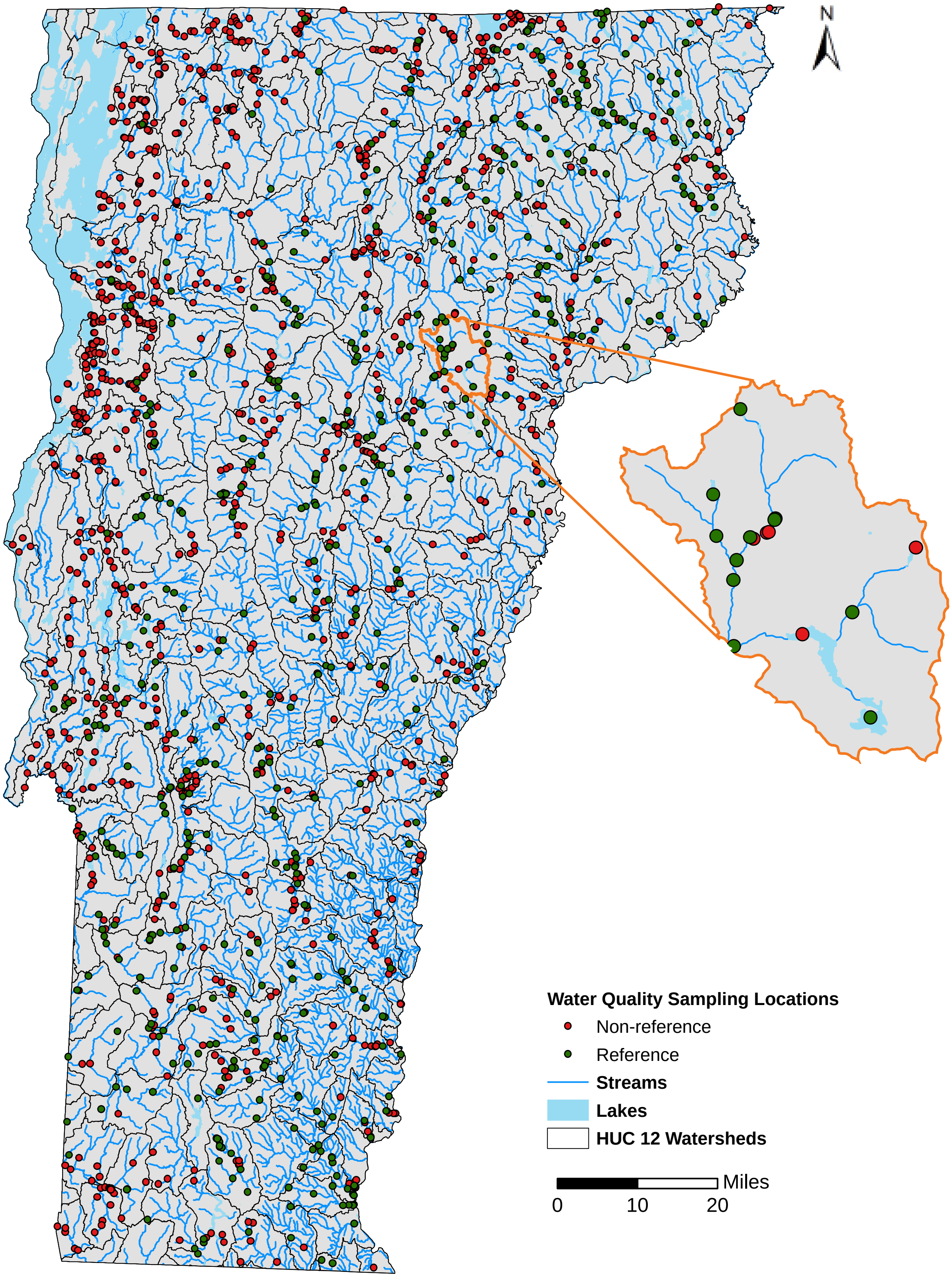



**Figure 4-8** Reference and non-reference water quality sites in Vermont (courtesy of Vermont Department of Environmental Conservation).

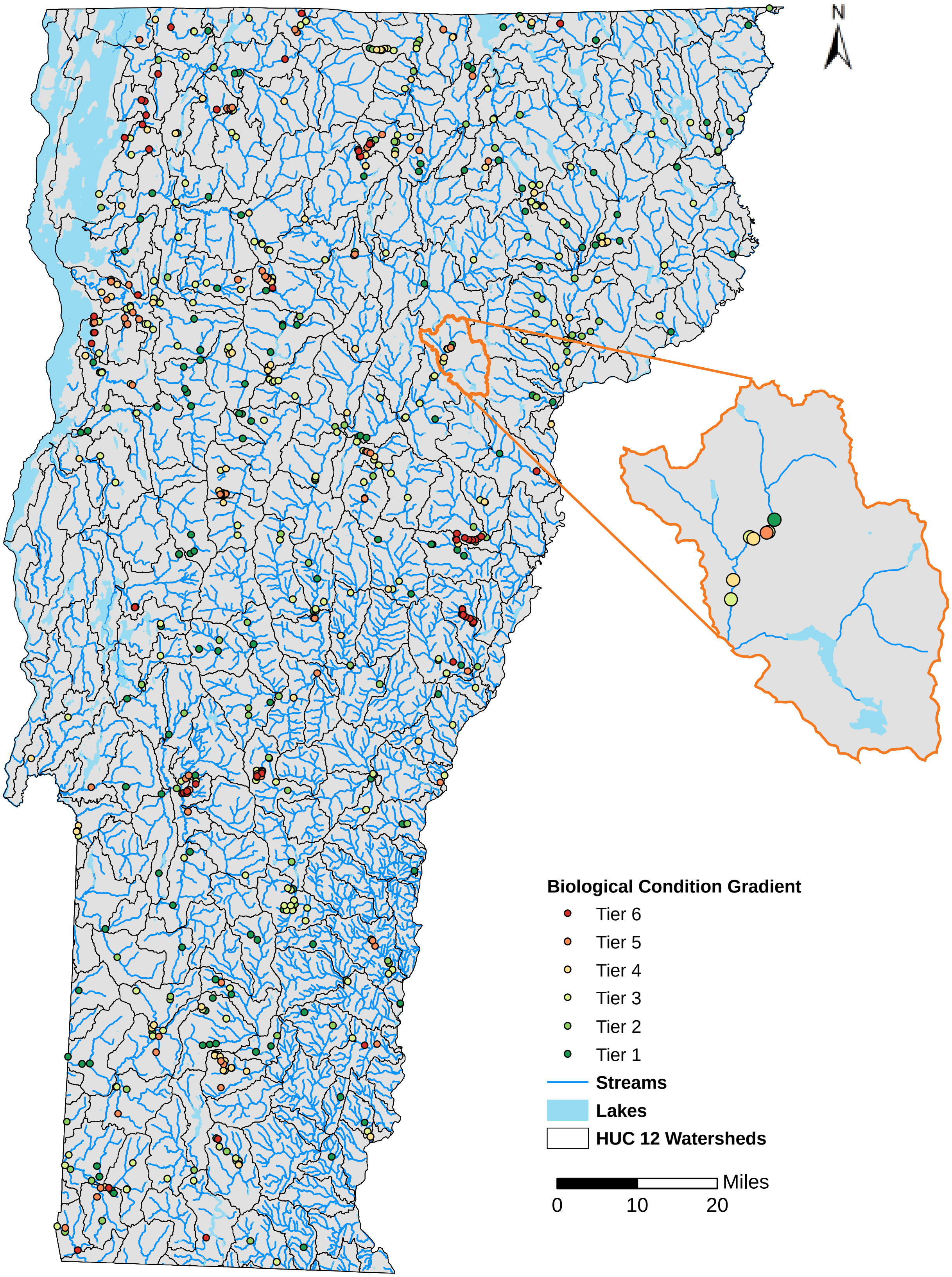



**Figure 4-9** Combined results of fish and macroinvertebrate bioassessment scores at stream monitoring sites in Vermont (courtesy of Vermont Department of Environmental Conservation).

### 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:

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

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

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

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.

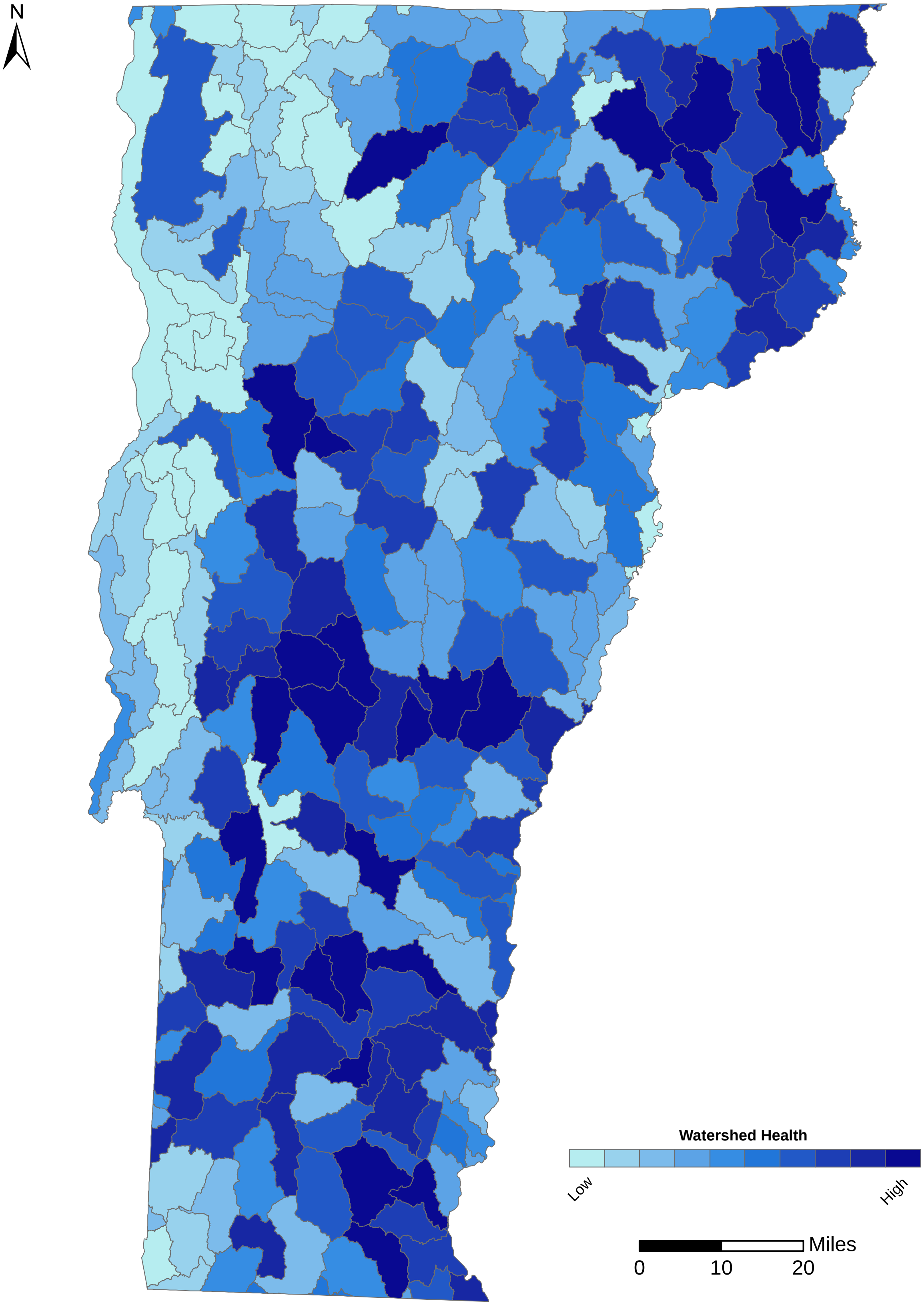



**Figure 4-10** Relative watershed health scores for Vermont.

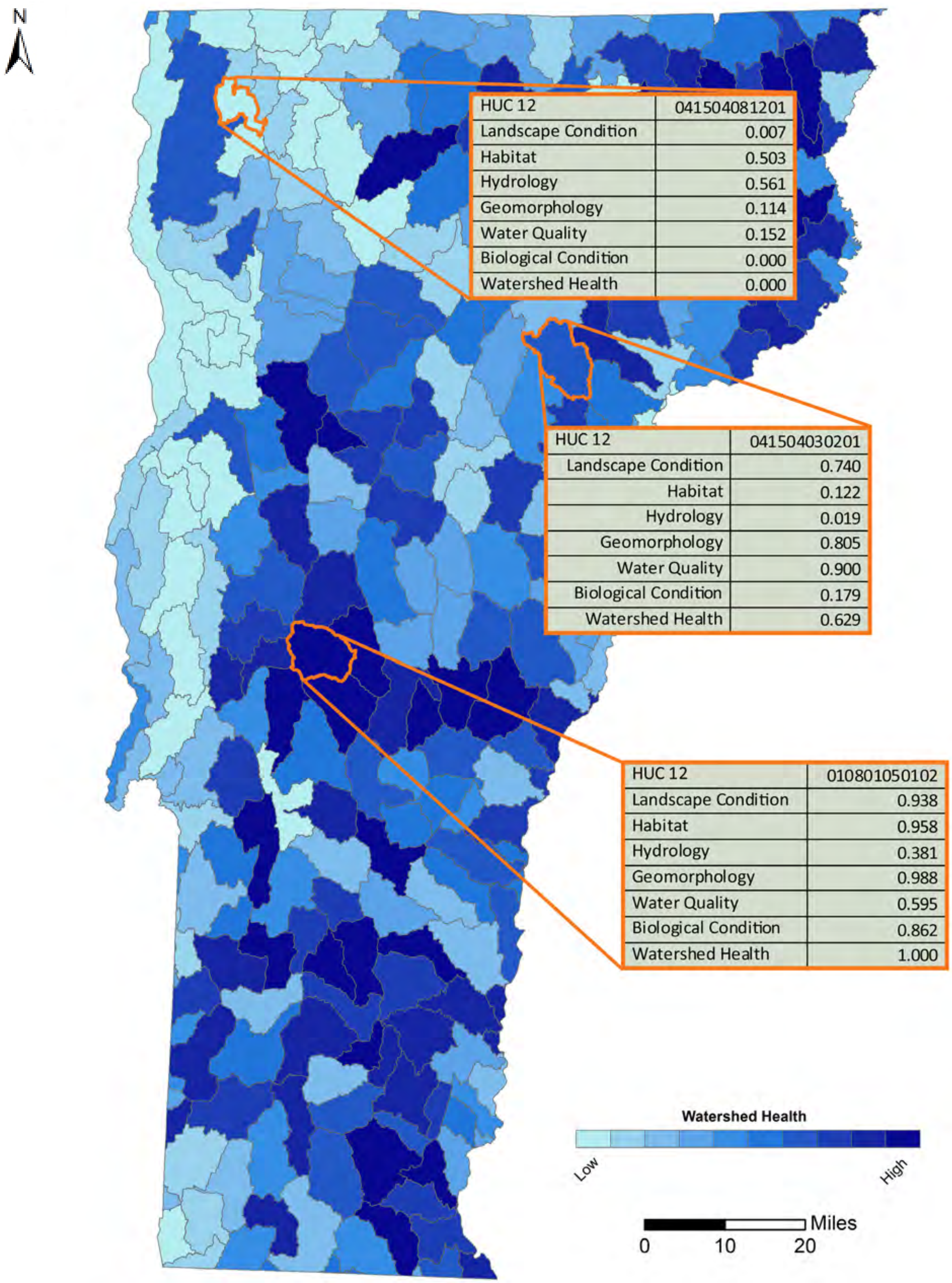



**Figure 4-11** Normalized watershed health scores for Vermont, with normalized attribute scores displayed for select HUC12s. To facilitate communication of the results, all scores were normalized to range from 0 to 1. The final watershed health index scores, for example, were transformed from a minimum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

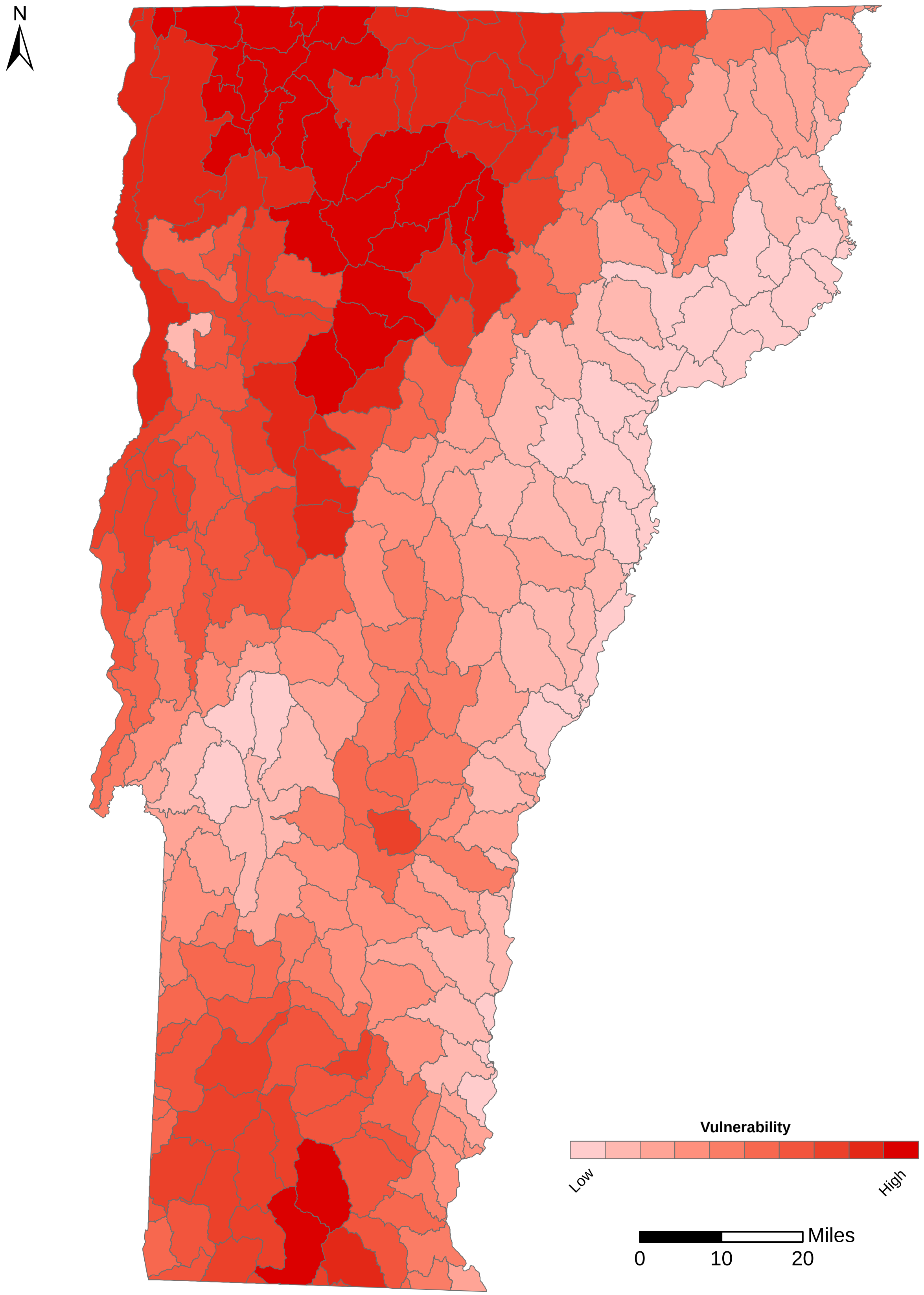



**Figure 4-12** Relative watershed vulnerability scores for Vermont.

### 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.

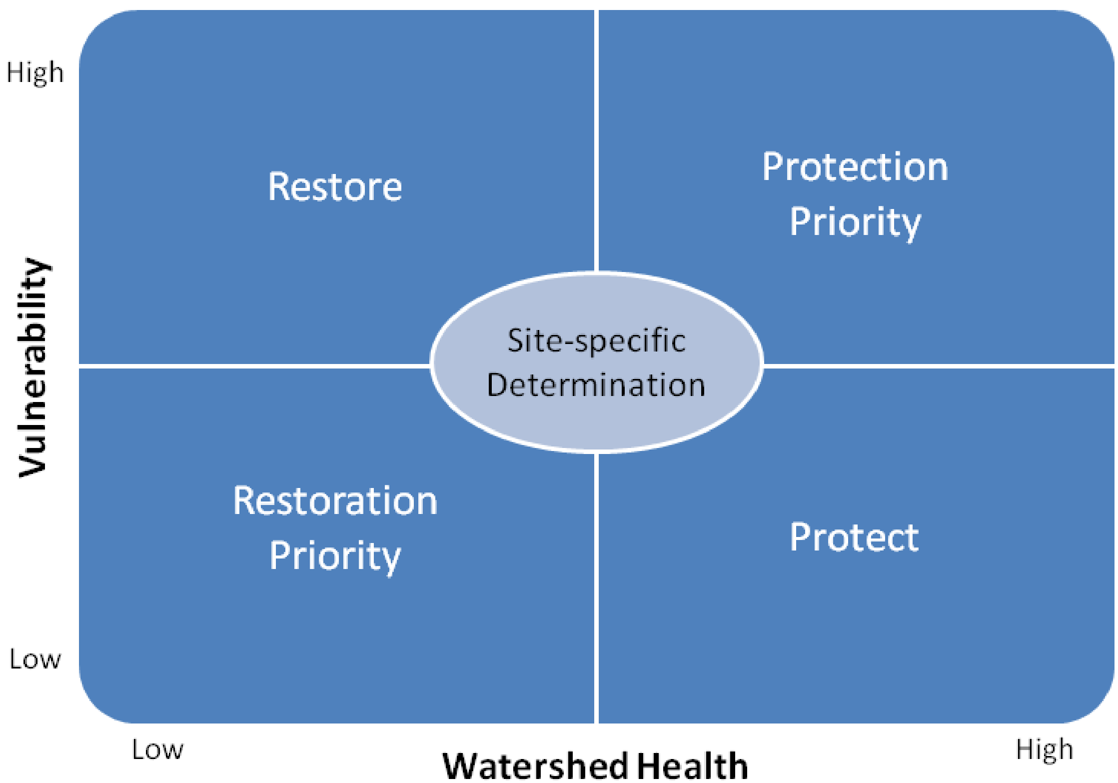



**Figure 4-13** Example of a management priorities matrix for setting protection and restoration priorities using watershed health and vulnerability scores.

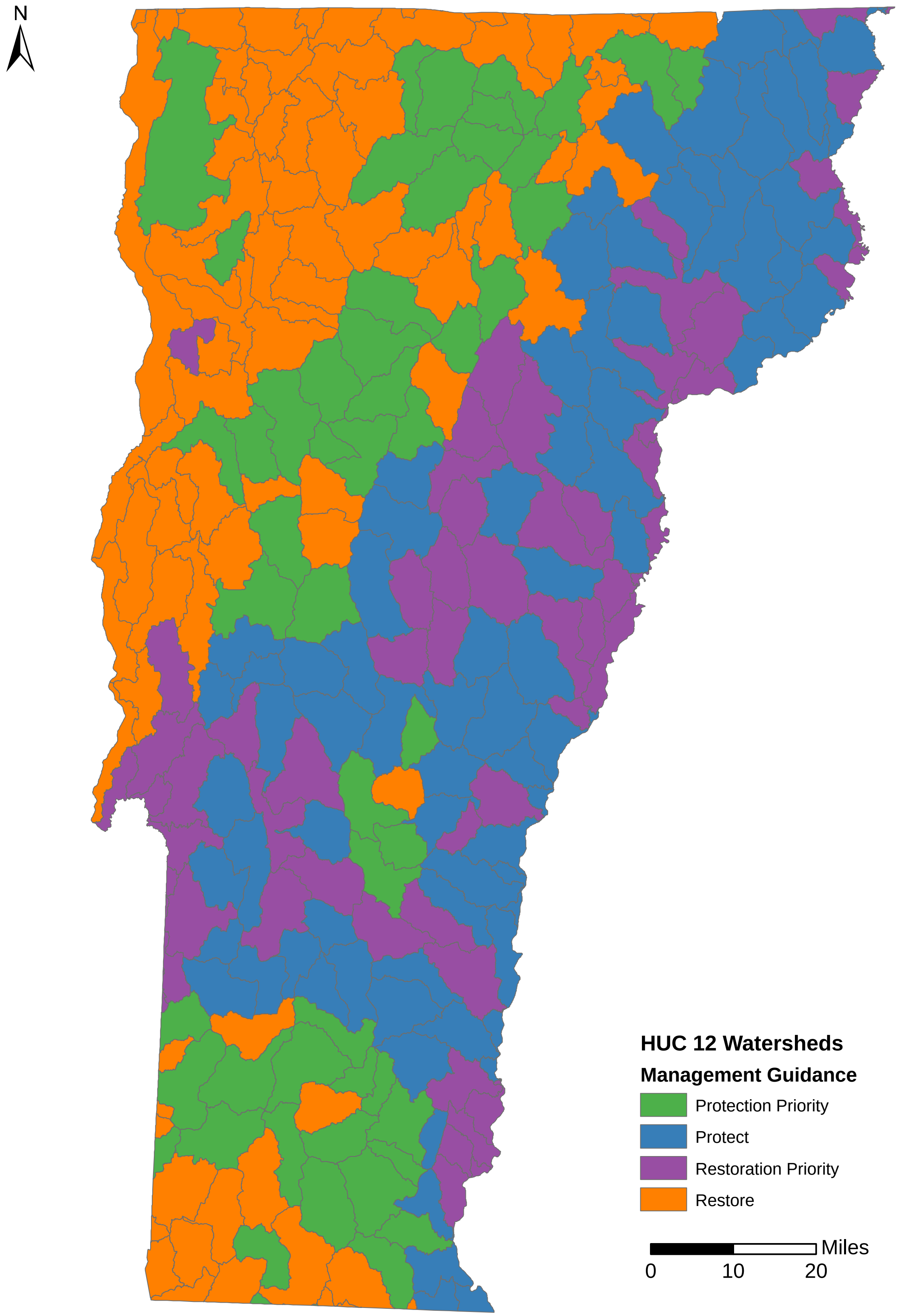



**Figure 4-14** Example of potential management guidance based on combined watershed health and vulnerability scores for Vermont.

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.

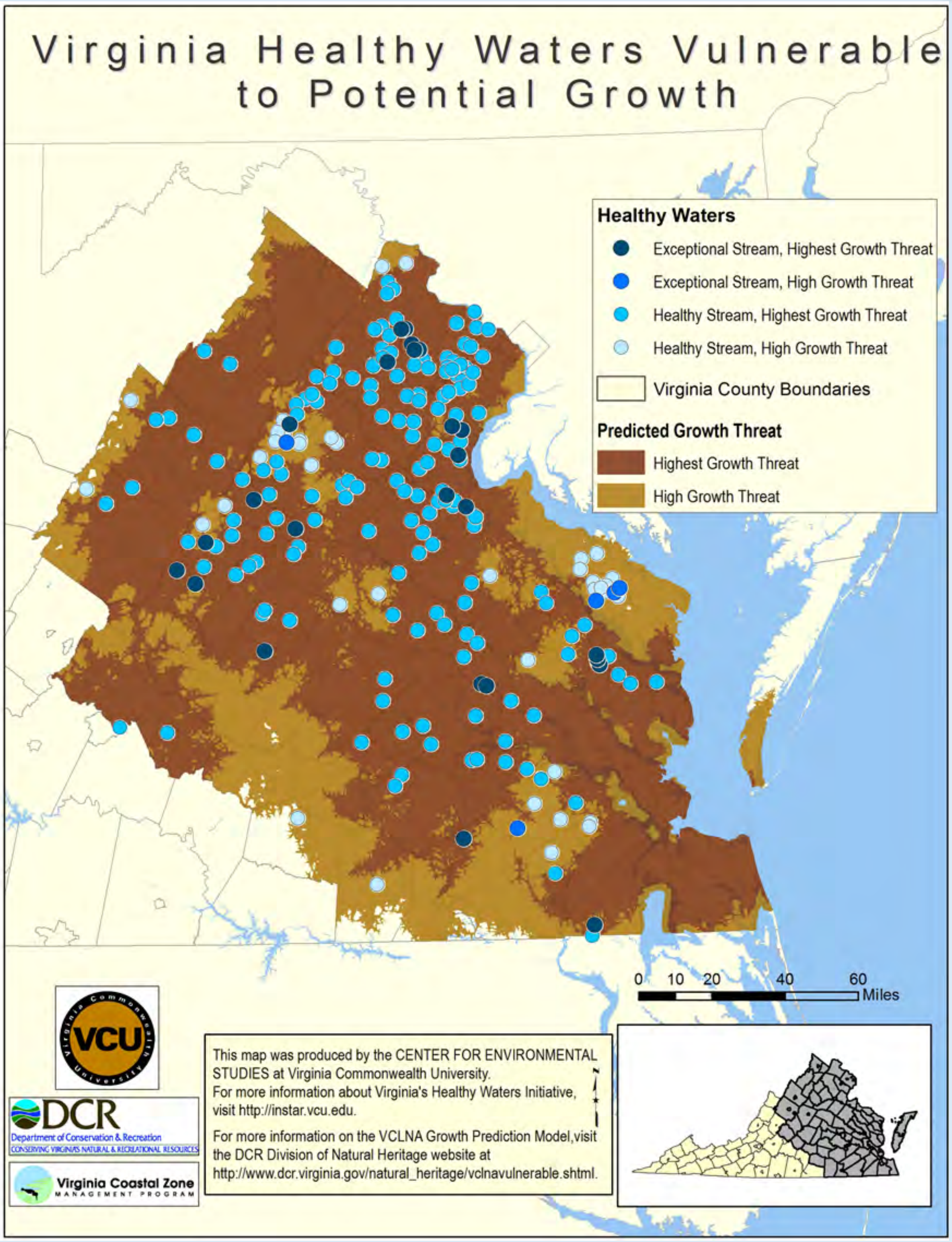



**Figure 4-15** Regional results of the VCLNA Vulnerability Model overlain with results from Virginia's Healthy Waters program (Greg Garman, Virginia Commonwealth University, Personal Communication).


# 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.

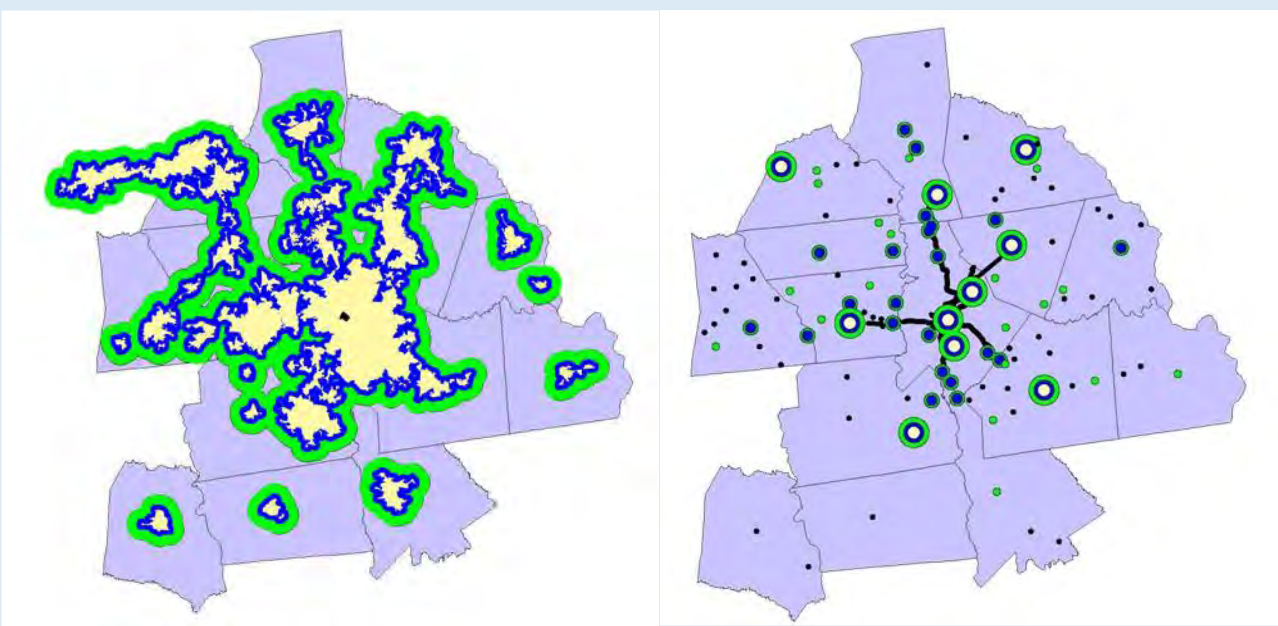


**Figure 4-16** Business as usual development pattern (left) and compact center scenario (right) used for the alternative growth scenario evaluations (U.S. Environmental Protection Agency, 2011e).

# 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.

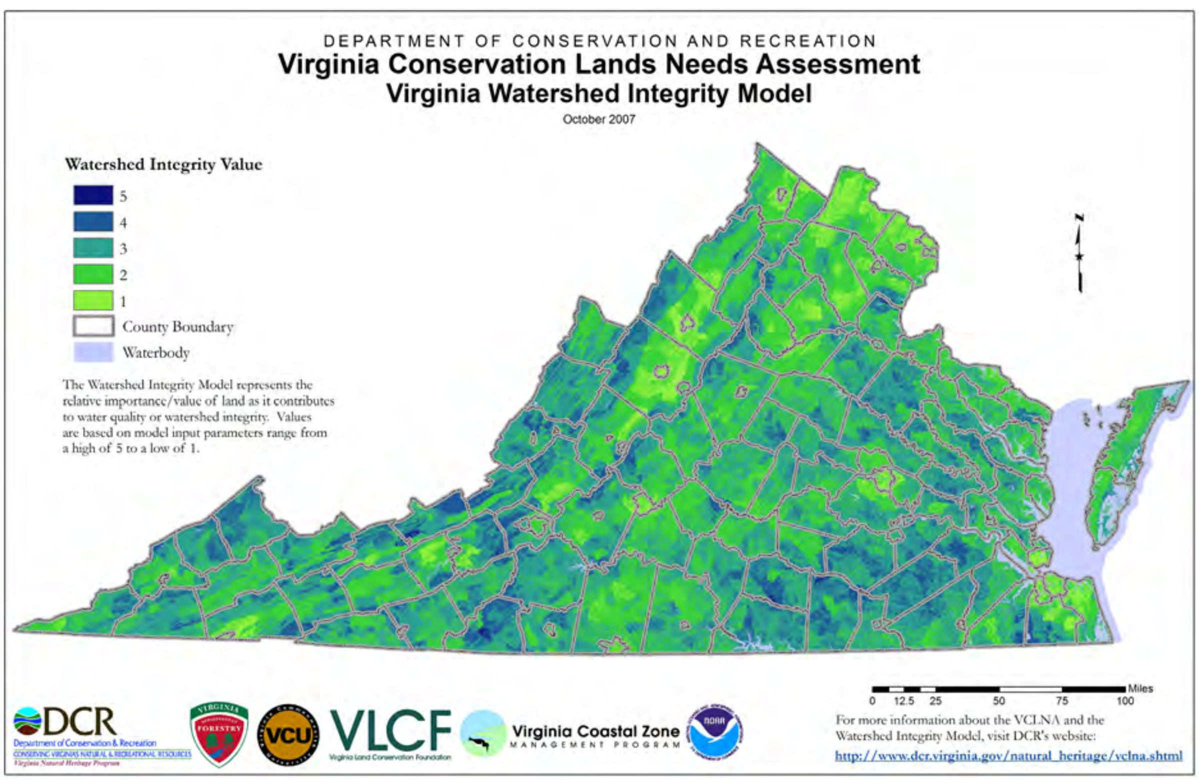



**Figure 4-17** Virginia Conservation Lands Needs Assessment Watershed Integrity Model final output (Virginia Department of Conservation and Recreation, 2008).

## 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.

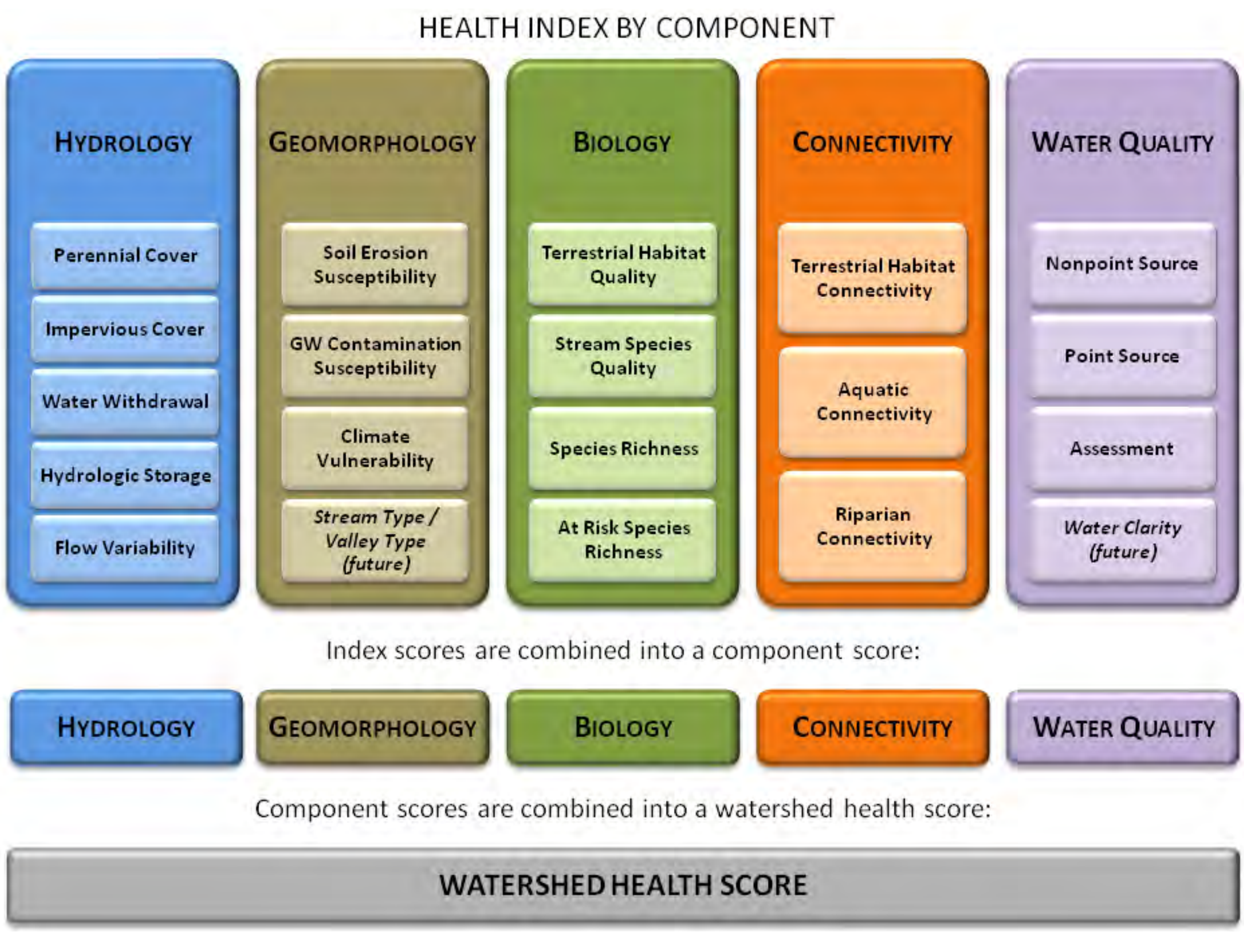



**Figure 4-18** Indicators used by the Watershed Assessment Tool for calculating watershed health scores (Minnesota Department of Natural Resources, 2011).

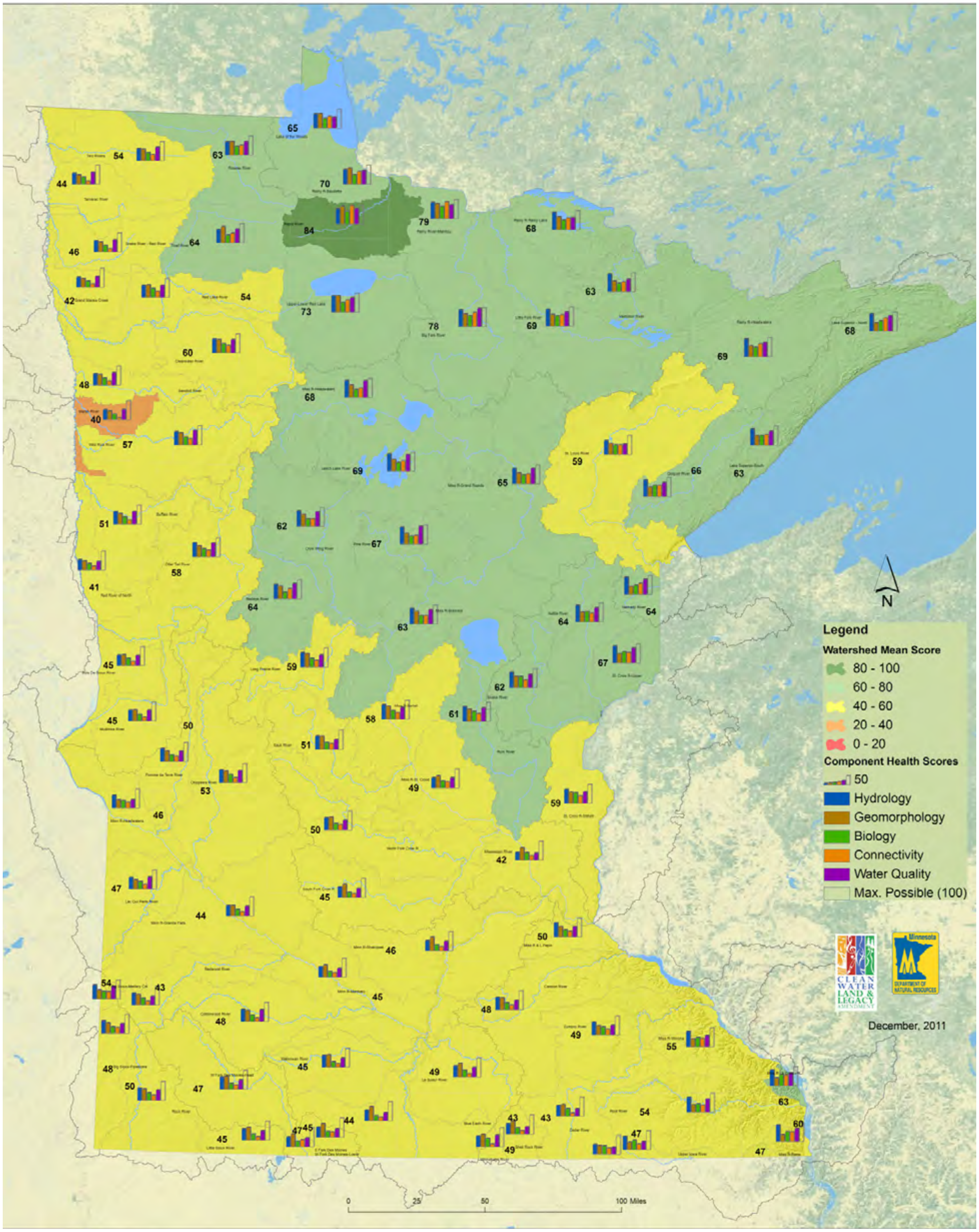



**Figure 4-19** Results of the statewide watershed health assessment conducted with the Watershed Assessment Tool (Beth Knudsen, Minnesota Department of Natural Resources, Personal Communication).

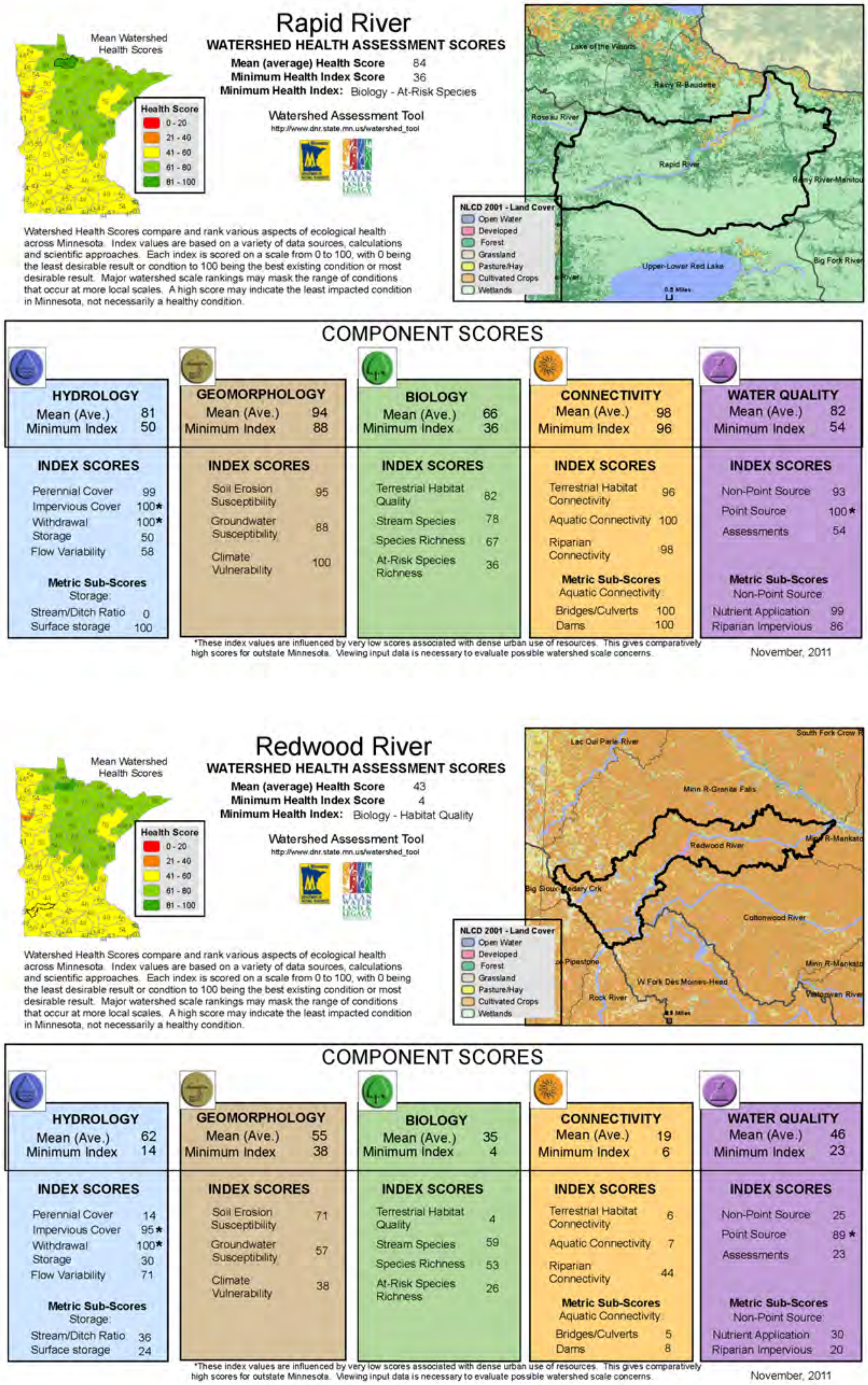



**Figure 4-20** Minnesota's watershed health assessment results for the Rapid River (top) and Redwood River (bottom) watersheds.

## 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.

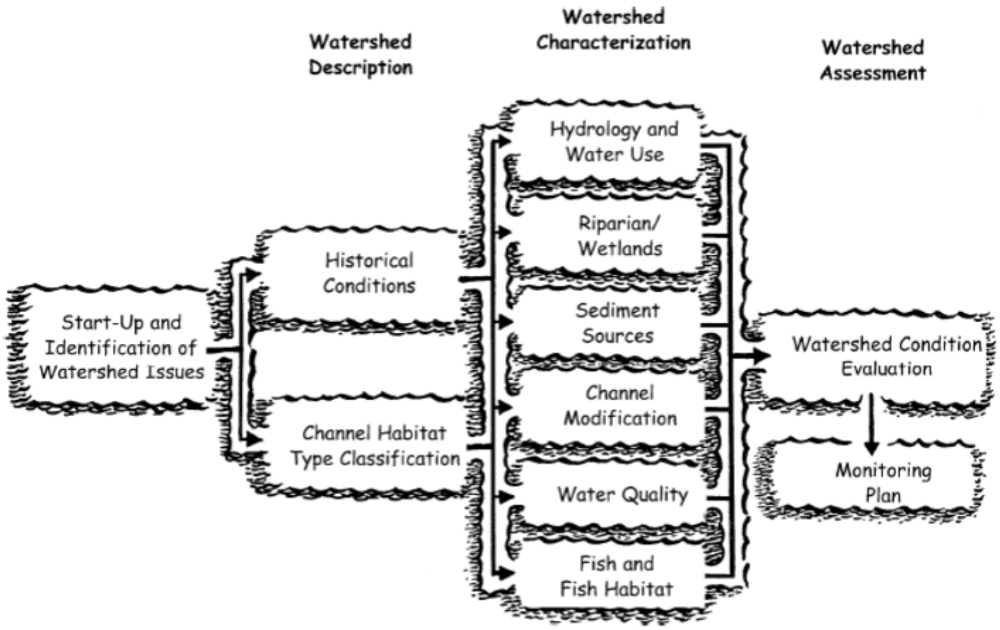



**Figure 4-21** The Watershed Assessment Manual methodology framework (Watershed Professionals Network, 1999).

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.

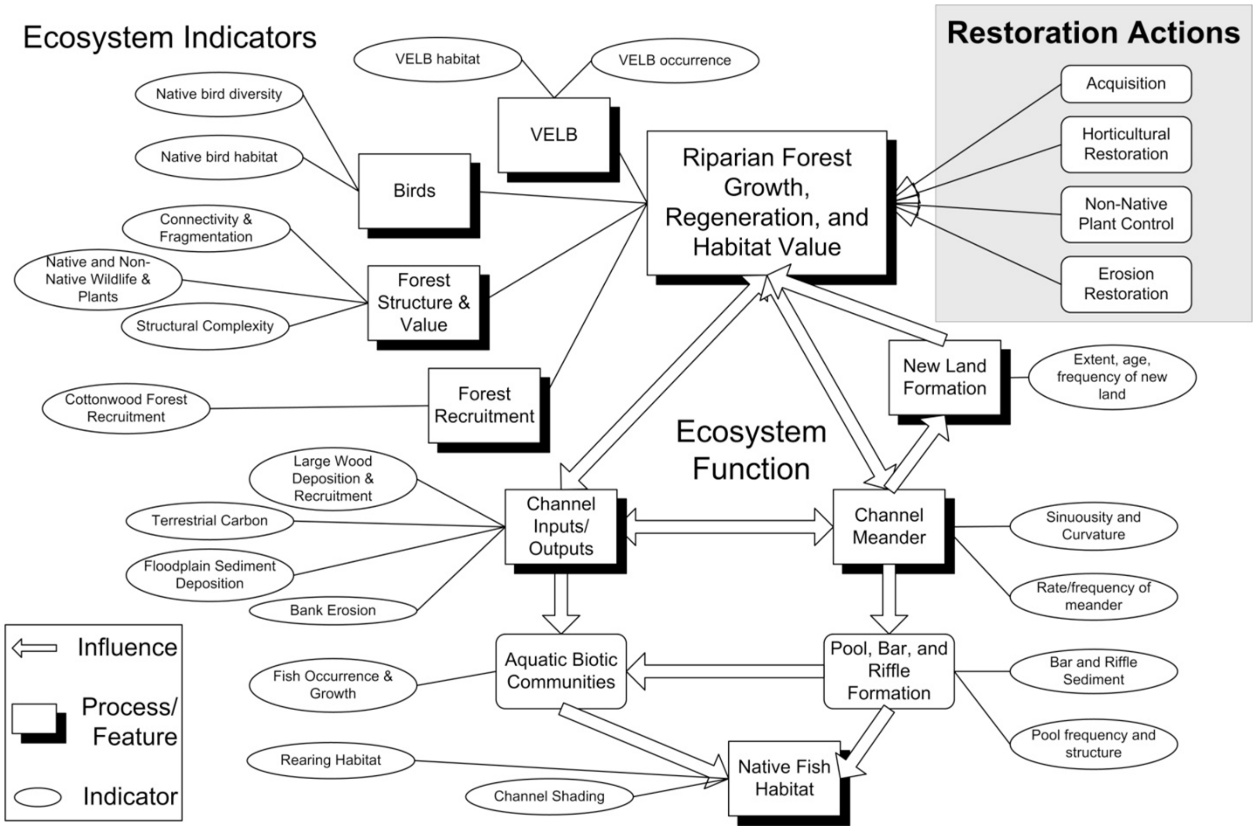



**Figure 4-22** Example conceptual model for riparian forest indicator selection (Shilling, 2007).

## 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.

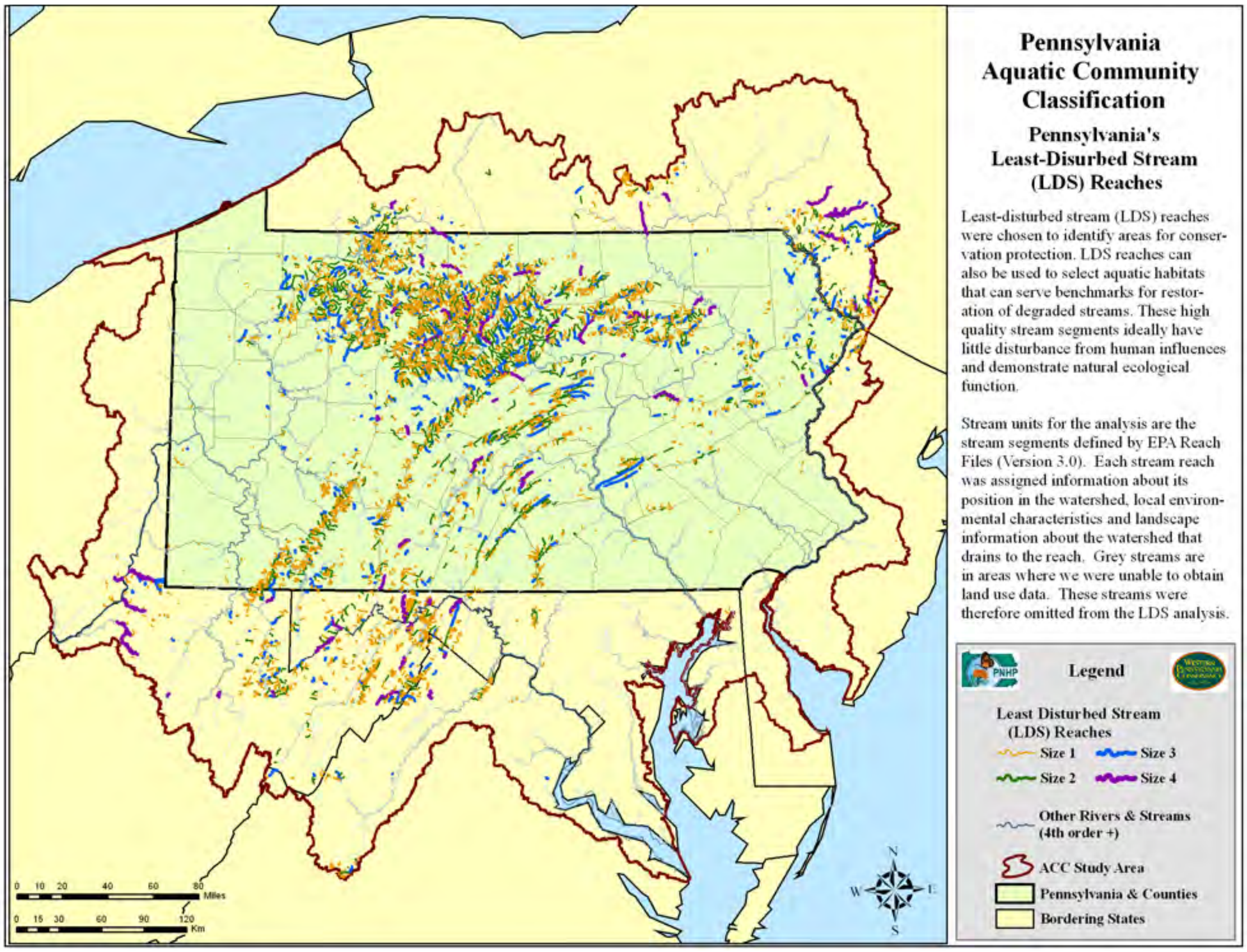



**Figure 4-23** Map of Pennsylvania's least disturbed streams (Walsh, Deeds, & Nightingale, 2007).

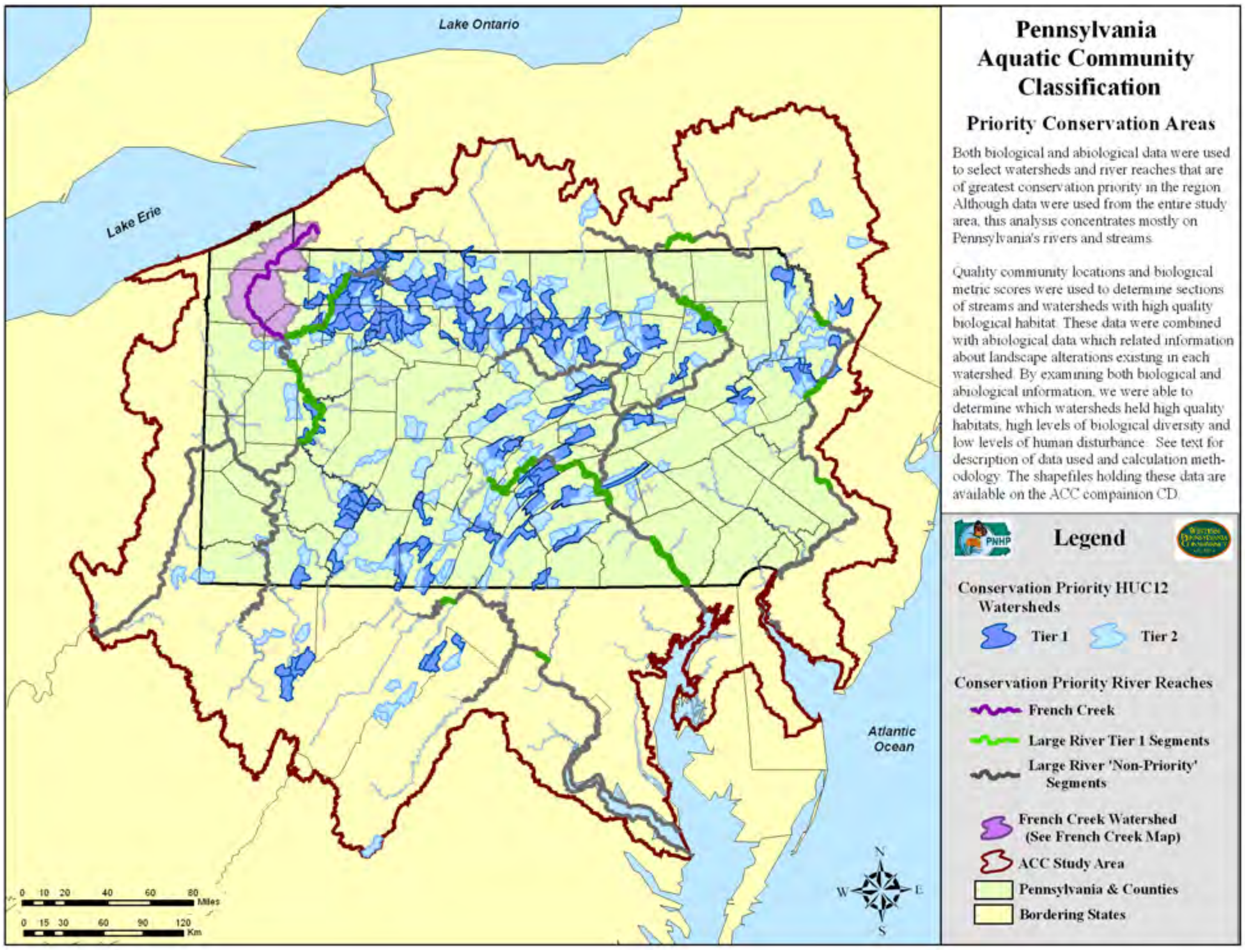



**Figure 4-24** Watershed conservation priorities in Pennsylvania (Walsh, Deeds, & Nightingale, 2007).

### 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.

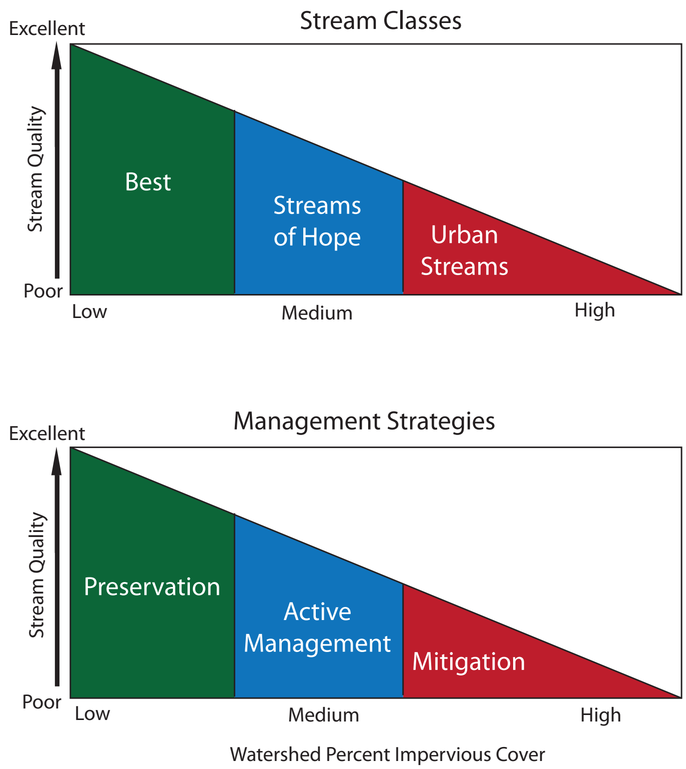



**Figure 4-25** Conceptual model of the effect of impervious cover on stream quality. Watershed percent impervious cover is used to identify stream classes (top) and potential management strategies (bottom) (Bellucci, Beauchene, & Becker, 2009).

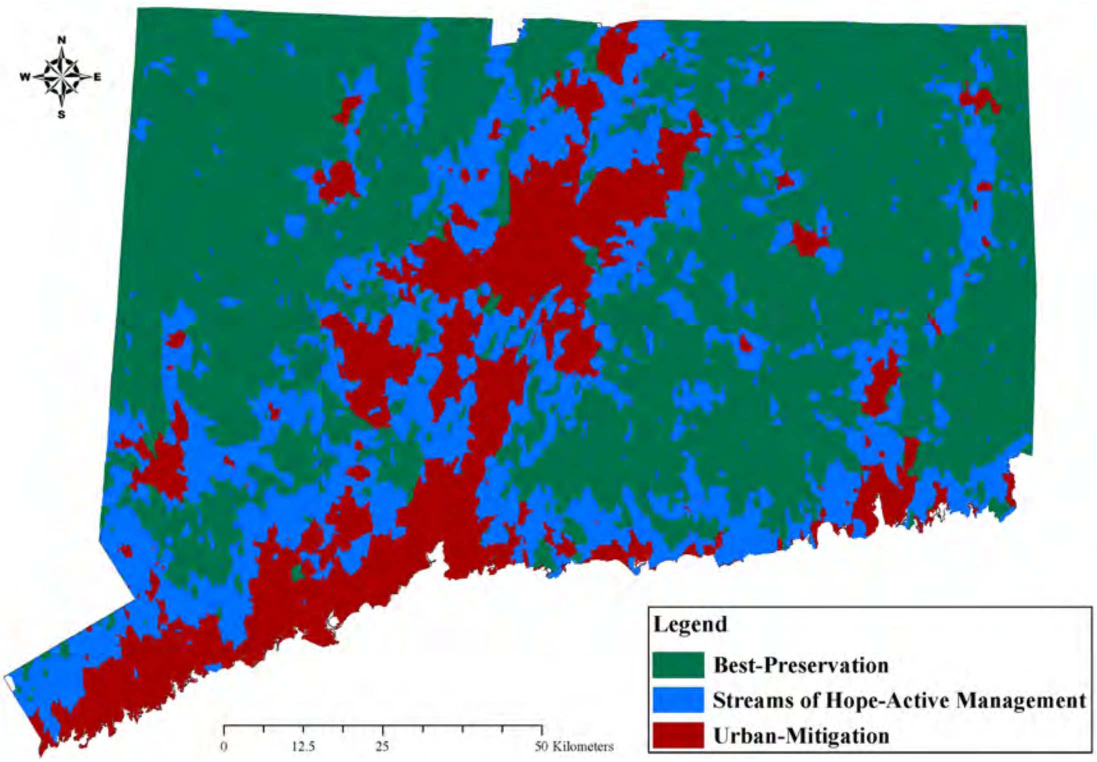



**Figure 4-26** Map of Connecticut showing stream classes and management classes by watershed (Bellucci, Beauchene, & Becker, 2009).

### 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.

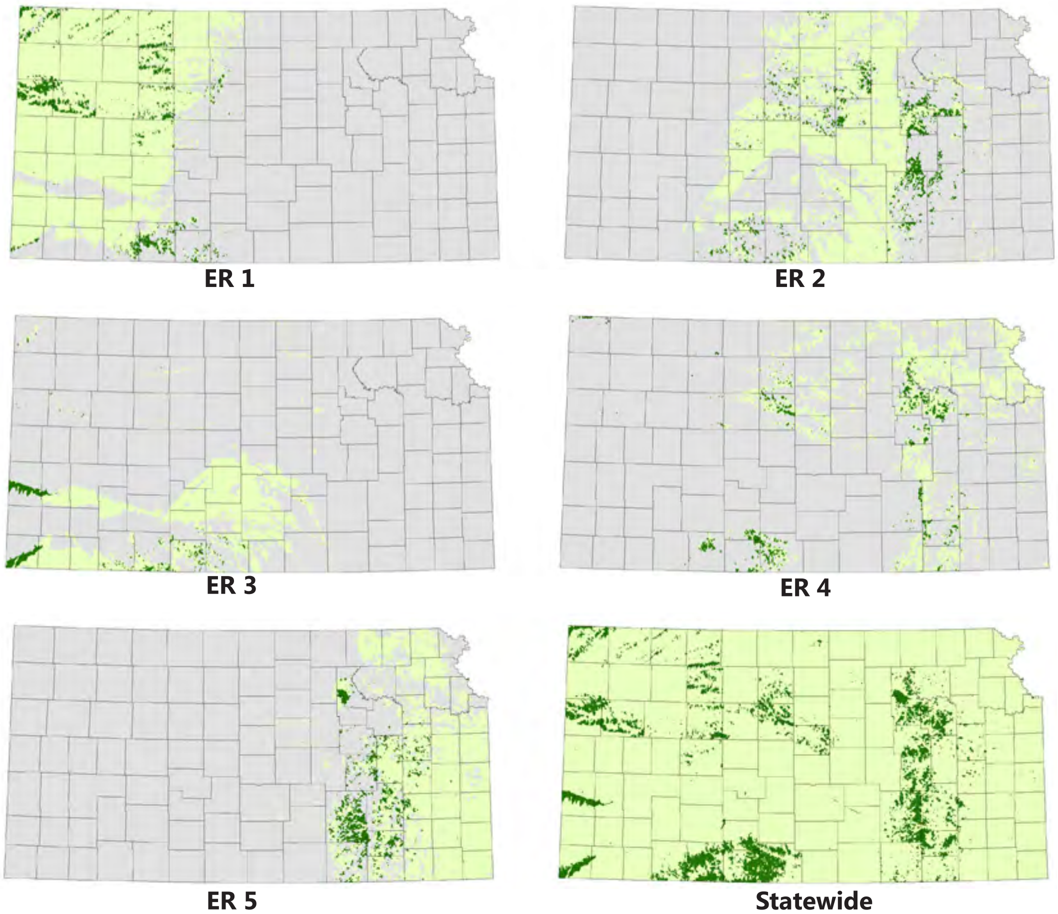



**Figure 4-27** Location of least disturbed watersheds within individual quantitative ecoregions (ER) (k = 5) (Angelo, Knight, Olson, & Stiles, 2010). Rankings are based on the disturbance index derived via principal components analysis. Highlighted watersheds rank in the lowest (best) 10th percentile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

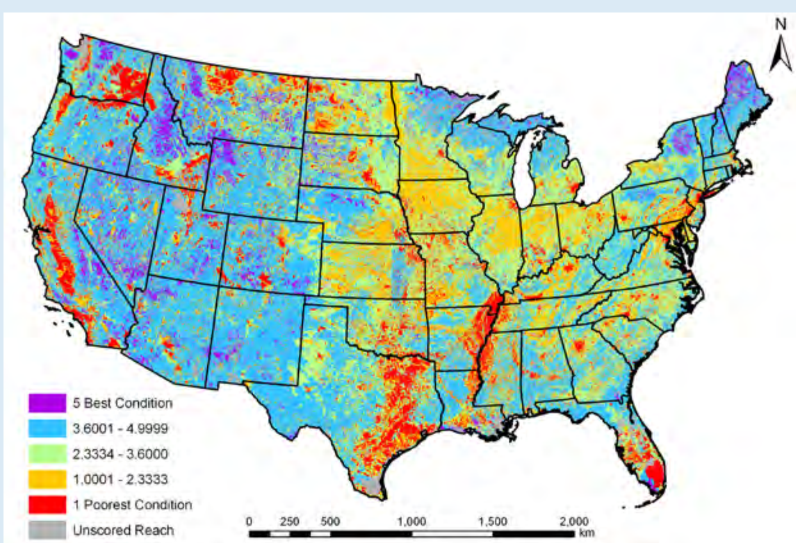



**Figure 4-28** Reach cumulative landscape disturbance scores summarized by local catchments for the United States. Scores are presented in five percentile categories, each containing 20% of the reaches (Esselman et al., 2011).

### 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 |

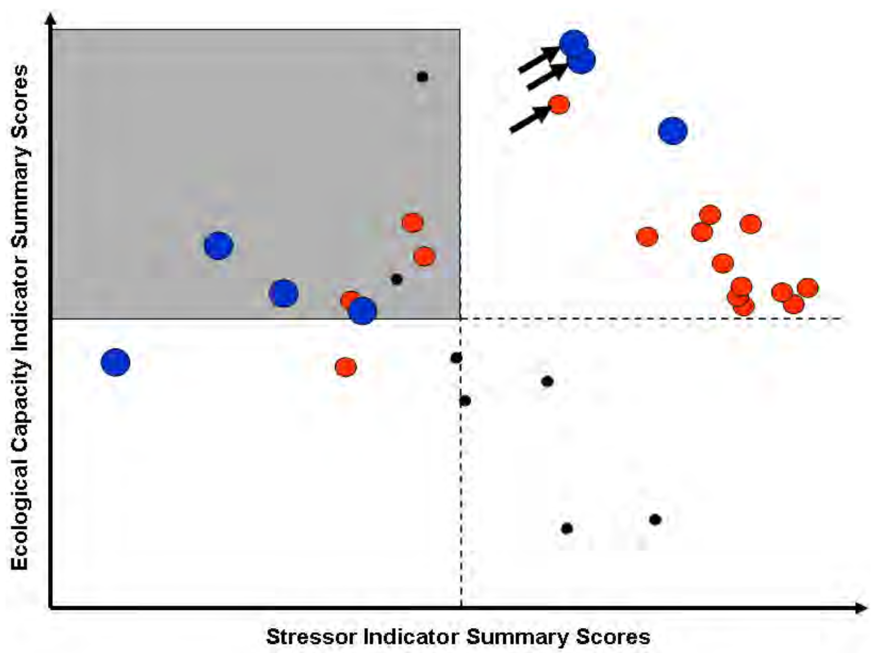



**Figure 4-29** Three-dimensional bubble plot comparing recovery potential among subwatersheds. Dots represent subwatersheds plotted by summary score relative to the ecological and stressor axes. Social context scores (higher = better) are incorporated as dot size and color. Median values for ecological 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 |

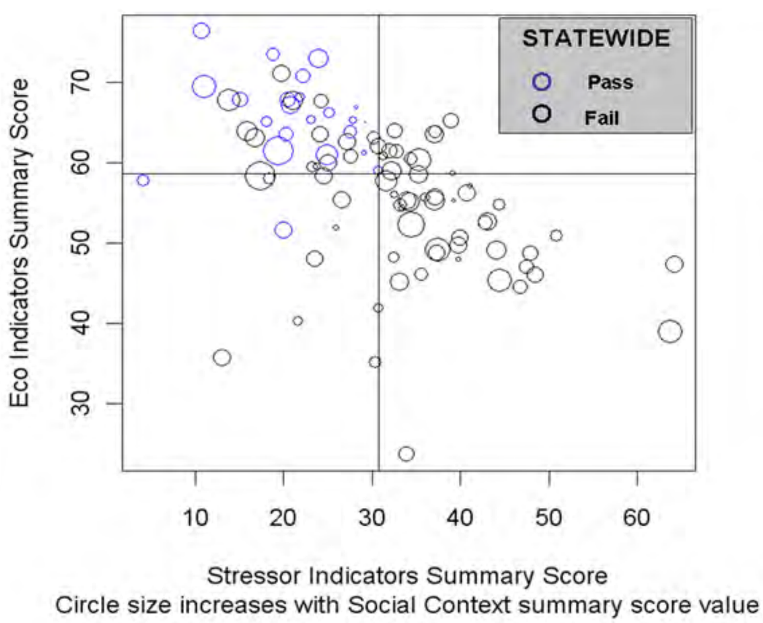



**Figure 4-30** Bubble plot of recovery potential screening of 94 non-tidal watersheds in Maryland. Colors signify whether watersheds passed the state's watershed bio-assessment. Although indicators were selected to compare recovery potential of impaired waters, the output also contrasts healthy watershed 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 | | ✓ | | | | | | |

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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** | | | | | | | | ✓ |

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## 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** | | | | ✔ | | | | |

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## 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** | | | | ✔ | | | | ✔ |

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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** | | | | | | | | ✔ |

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## 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 $mi^2$) | | | | | ✓ | | | |

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## 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** | | | | | | ✓ | | |

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## 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 | | | | | | ✔ | | |

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## 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** | | | | ✓ | | ✓ | | |

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## 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** | | | | | | | ✓ | |

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# 5. Management Approaches


## 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.

**Table 5-1** Management approaches and case studies summarized in Chapter 5.

| National | Page |
|---|---|
| The Nature Conservancy: Setting Freshwater Conservation Priorities | 5-5 |
| Wild and Scenic Rivers | 5-9 |
| Wildlife Action Plans | 5-9 |
| The National Flood Insurance Program | 5-10 |
| The U.S. Forest Service's Forest Legacy Program | 5-10 |
| The Trust for Public Land's Center for Land and Water | 5-10 |
| **State/Interstate** | **Page** |
| Minnesota Healthy Watersheds Program | 5-3 |
| Virginia Healthy Waters Program | 5-4 |
| California Healthy Streams Partnership | 5-4 |
| NatureServe's Conservation Priorities for Freshwater Biodiversity in the Upper Mississippi River Basin | 5-7 |
| Antidegradation | 5-12 |
| Instream Flow Protection | 5-12 |
| Using Antidegradation to Protect Instream Flows in Tennessee | 5-14 |
| Source Water Protection | 5-14 |
| Growth Management | 5-15 |
| State River and Habitat Protection Programs | 5-15 |
| Minnesota Department of Natural Resources' Fen Protection Program | 5-15 |
| Delaware River Basin Commission's Use of Antidegradation | 5-16 |
| Washington's Critical Areas Growth Management Act | 5-18 |
| Michigan's Water Withdrawal Assessment | 5-19 |
| Vermont Agency of Natural Resources River Corridor Protection Program | 5-21 |
| Michigan's Natural Rivers Program | 5-23 |
| Wyoming Wetlands Conservation Strategy | 5-24 |
| Maryland's GreenPrint Program | 5-25 |
| Enabling Source Water Protection in Maine | 5-27 |
| **Local** | **Page** |
| National Wild and Scenic Rivers: Lumber River, North Carolina | 5-11 |
| Land Protection | 5-28 |
| The Central Texas Greenprint for Growth: A Regional Action Plan for Conservation and Economic Opportunity | 5-28 |
| Land Protection and Climate Change | 5-28 |
| Land Use Planning | 5-29 |
| Green Infrastructure and Master Plans Alachua County, Florida | 5-29 |
| Watershed-Based Zoning in James City County, Virginia | 5-31 |
| River Corridor and Headwaters Protection | 5-32 |
| Headwaters: A Collaborative Conservation Plan for the Town of Sanford, Maine | 5-33 |
| Lower Meramec Drinking Water Source Protection Project | 5-35 |
| Cecil County, Maryland Green Infrastructure Plan | 5-37 |
| Sustainable Agriculture | 5-39 |
| Sustainable Forestry | 5-39 |
| Invasive Species Control | 5-40 |
| Ground Water Protection | 5-40 |

## 5.1 Implementing Healthy Watersheds Programs in States

A number of states are making protection of healthy watersheds, especially using a systems approach, an important part of their state programs. The restoration of impaired water bodies has long been a focus of many state water quality programs. This is due to the fact that 40-50% of the nation's assessed waters are listed as impaired (U.S. Environmental Protection Agency, 2008a). However, successful restoration and protection efforts work hand in hand. As important as restoration of impaired water bodies is, success in restoring ecological integrity will largely depend on pollution prevention and the protection of healthy aquatic ecosystems that provide the ecological infrastructure that supports restoration. The goal of the Healthy Watersheds Initiative is to help interested states and other partners identify and protect this critical natural infrastructure and inform restoration priorities, and increase awareness of how these states and other partners are using these approaches and techniques to improve aquatic ecosystems.

Interested states are now using Healthy Watershed Programs that complement the traditional focus on single problem management by utilizing a systems-based approach to meet the cross-disciplinary, cross-agency demands and challenges of aquatic ecosystem protection. This integrated approach to protecting aquatic ecosystems can help to achieve environmental results quickly and cost-effectively. This technical document and the complementary Healthy Watersheds Initiative website (www.epa.gov/healthywatersheds) are two resources that EPA has developed to help states accomplish this.

The following are examples of the efforts that three states (Minnesota, Virginia, and California) are taking to develop and implement state-specific Healthy Watersheds Programs.

**Minnesota Healthy Watersheds Program**

"*What happens on our lands impacts our waters; what happens to our waters impacts our habitats, ecosystems, and biodiversity*."

Recognizing the need to connect management of the state's land and water resources, the Minnesota Department of Natural Resources (DNR) made a significant change to their organizational structure, which transformed their programs, operations, and research in order to increase focus on, and enhance support for, healthy watersheds throughout the state. Specifically, Minnesota DNR created a new Division of Ecological and Water Resources by integrating its former Division of Ecological Resources and Division of Waters. Integration of the two divisions into one will foster and accelerate the development of integrated approaches for improving the health of Minnesota's land and water at local, watershed, and landscape scales. Minnesota DNR recognizes that an integrated approach to resource management is necessary to effectively address multiple resource issues at multiple scales. This new division will better position Minnesota DNR to address the multiple pressures facing the state's land, water, fish and wildlife, and ecological resources, by leveraging existing systems of analysis and frameworks in complementary, rather than competing ways.

The new Division of Ecological and Water Resources is not just a merger of the work by the former Division of Ecological Resources and Division of Waters. Minnesota DNR's intention from the onset was to use this new division to facilitate "systems-oriented natural resources management" throughout the entire department. To initiate this department-wide transformation toward systems management, the new division is focusing its attention on their most threatened natural resources: water, biodiversity, and ecosystem services. By focusing their work around the central vision of "Healthy Watersheds," DNR believes it can deliver even stronger protections for biodiversity and water resources (both ground and surface) than they were previously structured to provide. With this new division, Minnesota DNR will be able to better shape their management goals and strategies around protection and maintenance of vital ecosystem services—the natural processes that provide benefits to humans, such as water purification, biodiversity maintenance, flood mitigation, and soil fertility.

More information: http://files.dnr.state.mn.us/aboutdnr/reports/legislative/2010_healthy_watersheds.pdf

**Virginia Healthy Waters Program**

"*At a time when so much of the news about the environment is negative, some biologists have been wading through Virginia's streams in search of some positive information. What they've found suggests that there is another very important story*."

Virginia's Healthy Waters Initiative was designed to raise awareness about the need to maintain ecological balance and protect the state's critical healthy waters before they become impaired. Healthy Waters broadens existing conservation efforts to include the nearly 200 ecologically healthy streams, creeks, and rivers identified throughout the state thus far, as well as the many more expected to be identified in the future (streams throughout the state will continue to be assessed and added to the list as resources become available).

Healthy waters in Virginia are generally defined as those having the following characteristics: high number of native species and a broad diversity of species; few or no non-native species; few generalist species that are tolerant of degraded water quality; high number of native predators; migratory species whose presence indicates that river or stream systems are not blocked by dams or other impediments; low incidence of disease or parasites; and intact buffers of vegetation in the riparian zone. The current list of about 200 healthy waters in Virginia were identified and ranked (as "exceptionally healthy," "healthy," or "restoration candidate") based on these and other characteristics, using a stream ecological integrity assessment method known as the Interactive Stream Assessment Resource, or InSTAR (see Section 3.6).

The Healthy Waters Initiative expands the existing water quality programs' focus on restoring degraded water quality to protecting everything from aquatic insect larvae and bugs hidden in gravelly stream bottoms, to fish and amphibians, to forested buffers alongside streams, to natural stream flow, to the water that people drink. The identification and protection of healthy waters is expected to reduce the number of waters that will become degraded in the future.

More information: www.dcr.virginia.gov/healthywaters

**California Healthy Streams Partnership**

Led by the California State Water Board's Surface Water Ambient Monitoring Program, the Healthy Streams Partnership seeks to promote improved ecological conditions of California's streams by encouraging a paradigm shift from concern about impaired streams to an understanding of healthy stream systems and their ecological characteristics. By expanding this understanding, the Healthy Streams Partnership hopes to contribute to a change in perspective and thinking about natural resource management. With a strong focus on connecting science and policy, the Healthy Streams Partnership supports hypothesis driven data collection, analysis, and reporting to provide more useful and more integrated information to decision makers.

The Healthy Streams Partnership consists of representatives from the State and Regional Water Boards, the Department of Fish and Game, the State and Federal Contractors Water Agency, and the Coast Keeper Alliance. Coordination among these water quality data generating organizations is expected to increase the rigor of the state's assessment capacity and to provide more contextual information to managers and decision-makers who may have an impact on stream conditions. They are currently working to gather various data sources into a "web portal" and online application for developing indices that translate various data types into a report card format that provides an assessment of overall stream condition. The effort focuses on including and synchronizing as many monitoring efforts as possible, striving for compatibility and comparability, and emphasizing the need for monitoring to be hypothesis driven, in support of statewide adaptive management effectiveness.

More information: http://www.swrcb.ca.gov/mywaterquality/monitoring_council/meetings/2011jun/hsp_outreach.pdf

## 5.2 Protection Programs

The following are examples of some of the many programs and strategies available for protecting healthy watersheds. The strategies and programs are identified as national, regional, state, or local scale approaches. These categories should not be considered rigid or constraining. They merely serve to organize the diversity of techniques that can be used to maintain and improve watershed health at different geographic scales.

### 5.2.1 National

**Freshwater Conservation Priorities**

Creating a set of freshwater conservation priorities helps to develop a common vision for galvanizing partners and stakeholders to implement a wide range of strategies in many places, allowing those with specific capacities, expertise, geographic, and programmatic responsibilities to contribute to that vision of success. The Nature Conservancy works with others to develop and implement approaches and tools to identify regional and basin-wide freshwater conservation priorities (Higgins J. V., 2003; Higgins, Bryer, Khoury, & Fitzhugh, 2005; Higgins & Esselman, 2006). These and similar approaches and tools have been applied across parts of five continents (Nel et al., 2009), including the vast majority of the United States (Higgins & Duigan, 2009). Examples from the United States include Smith et al. (2003), Weitzell et al. (2003), and Khoury et al. (2010) (see http://www.conservationgateway.org/content/ecoregional-reports for access to all currently available reports and data).

The Nature Conservancy has generally used a six-step conservation planning process to identify priorities for conserving the full range of freshwater habitats, processes, and biodiversity in a given region or basin. The first step is to define the assessment region. The region is defined using units that delineate environmental patterns and processes that result in freshwater ecological patterns. The region may be a collection of catchments within an ongoing terrestrial-focused assessment, a freshwater ecoregion, or a basin of a large freshwater system. Abell et al. (2008) provide a global coverage of freshwater ecoregions for conservation planning that is useful for defining assessment regions, or subregions within very large assessment regions.

The second step is to define and spatially represent the variety of biodiversity elements or ecosystems, which characterize environmental patterns, processes, and habitats that support the broad range of biodiversity in the region of interest. A subset of species and natural communities that require focused attention to ensure that rare, endangered, declining, keystone, and migratory species are appropriately represented in the plan are also identified in this step. Ecosystems are defined and mapped using a freshwater ecosystem classification approach (Appendix A).

Goals are set for defining the numerical redundancy and environmental stratification of elements thought to be necessary to maintain ecological and evolutionary potential across the region of interest. Most regions that are evaluated are large and contain subregions that differ in broad patterns of environmental characteristics (e.g., climate, geology, drainage density, presence of lakes) and species composition. Therefore, subregions are often delineated, and goals are set for each subregion using additional criteria such as conservation status and range of elements. Often, different sets of goals are created, generating different risk scenarios for sustaining biodiversity, where higher numerical goals represent lower risks to extirpation.

All of the occurrences of the biodiversity elements are then evaluated for their relative condition/integrity. Condition is assessed using best available information, commonly using abundance, density, or spatial extent of freshwater species, and the condition of the ecosystems, including: the intactness of species composition, ecological processes, physical processes, habitat ratings, and landscape context (includes but not limited to: degree of connectivity of habitats, locations and densities of dams, stream crossings, catchment and local contributing area, patterns of current and future land use/cover, and protected and managed areas).

Through working with partners and stakeholders to review and refine analytical products, priority catchments and connectivity corridors are selected to represent the areas of biodiversity significance (the best examples of each type of biodiversity element in each stratification unit) to best achieve goals in a comprehensive, yet efficient solution. Connectivity is especially important in aquatic systems, where connectivity of habitats is vital to maintain many ecological processes, species, and ecosystem services. The Active River Area approach described in Chapter 4 explicitly identifies areas important for processes and sources of water and material inputs for freshwater ecosystems. These areas include headwaters, riparian corridors, and floodplain wetlands. The Active River Area approach has been applied to many areas in the northeastern and southeastern United States (Contact The Nature Conservancy's Freshwater program for more information: http://www.nature.org/ourinitiatives/habitats/riverslakes/index.htm). Additional criteria considered in assessments include existing conservation opportunities, potential return on investments, ecosystem services, and climate change adaptation.

The last step of the conservation planning process defines the major threats that occur regionally and in each of those areas of significance, and develops strategies to address them. This process can be conducted on a regional scale and/or at the scale of each area. Regional strategy development is becoming more common, and defining strategies to address large scale threats and opportunities to leverage successful interventions requires a regional perspective. The selection of a subset of high priority areas based on risks of conditional change, opportunities to implement strategies, or leverage efforts to broaden their impact is recommended. Strategies can include managing dams for environmental flows and other water resource management activities, best management practices (BMPs), purchasing and/or reconnecting floodplain habitats to rivers, protection and rehabilitation of natural land cover, etc. Using this framework, The Nature Conservancy and its partners have developed regional freshwater conservation plans that cover the majority of the United States. Many GIS tools are available to use to define a suite of priorities. Priorities exist for the majority of the United States, and these provide a good place to start (http://www.conservationgateway.org/topic/setting-freshwater-priorities).


Amy Draut

# Case Study

## Conservation Priorities for Freshwater Biodiversity in the Upper Mississippi River Basin

**More Information:** Weitzell, Khoury, Gagnon, Schreurs, Grossman, & Higgins, 2003 (http://www.natureserve.org/library/uppermsriverbasin.pdf)

The Upper Mississippi River Basin (UMRB) is home to approximately 25% of the freshwater fish species in the United States and 20% of the mussel species found in the United States and Canada. NatureServe ranks 69 of these species as at-risk. Using the freshwater ecosystem classification approach described in Appendix A, the UMRB was divided into 22 subregions (Ecological Drainage Units). There were 153 species and 36 ecological systems defined and mapped as conservation elements. Goals were set for each species based on its proportional range representation and spatial distribution. The minimum goal for aquatic ecological systems was to conserve at least one of each unique system type in each ecological drainage unit it occurred in.

Relative condition/ecological integrity of the ecosystems was evaluated using land cover/use, impervious cover, road density, stream crossing density, dams, point sources, mines, and impaired stream designations. Local scientists and resource managers were consulted to provide additional information for use in the assessment and to review and adapt the examples that were chosen to best represent each biodiversity element.

The network of Areas of Biodiversity Significance was then constructed (Figure 5-1). Priority for inclusion was given to those ecological systems that captured species elements, had the highest relative ecological integrity, and were expert recommended and/or included in already existing conservation plans. Inclusion of additional ecological systems and connectivity to support environmental processes was conducted by including all headwater ecological systems upstream of areas of biodiversity significance in the network. The medium rivers immediately downstream of each selected small river system were also included in the network. Finally, ecological system types that had not yet been included were added to ensure representation of all types. Goals were met for all ecological system types. The areas that were selected included representation of 102 of the species elements. Goals were met or exceeded for 45% of these species elements, including for 71% of the fish species and 55% of the mussel species. A subset of 47 areas that overlapped with terrestrial priorities were mapped to identify areas where conservation resources may be used more efficiently and outcomes may be more effective through cooperative and synergistic freshwater and terrestrial conservation actions.

A variety of strategies are being implemented across the UMRB by a range of partners and stakeholders. These strategies include demonstrations of floodplain protection and restoration, flow/water level management, alternative land use management and agricultural BMPs, restoring natural wetlands and creating artificial wetlands for processing land-based sources of nutrients, and retiling agricultural lands to manage soil moisture and nutrient applications, among others.

*Continued on page 5-8*

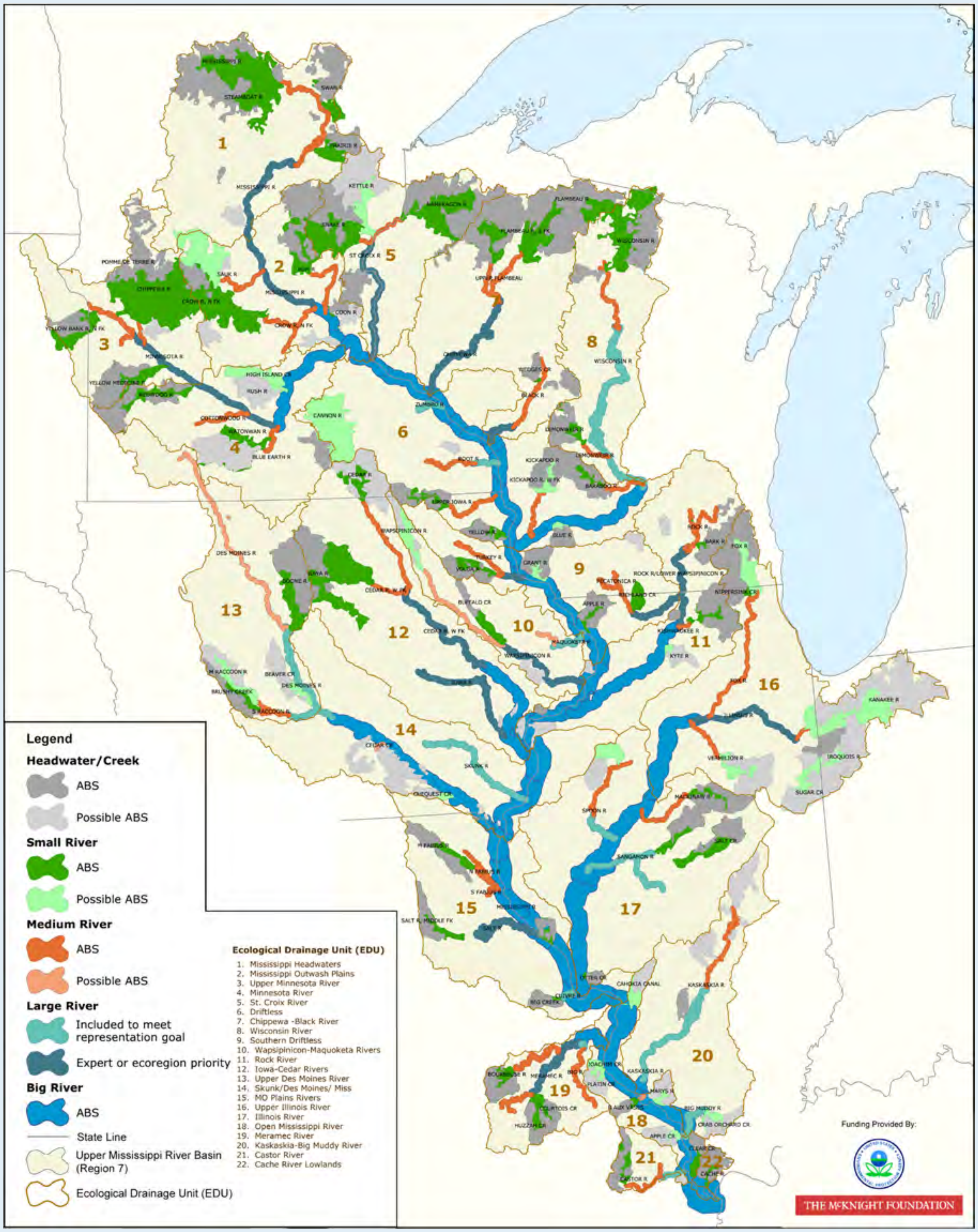



**Figure 5-1** Areas of Freshwater Biodiversity Significance in the Upper Mississippi River Basin (Weitzell et al., 2003).

**Wild and Scenic Rivers**

Enacted in 1968, the Wild and Scenic Rivers Act protects free-flowing rivers from new hydropower projects, federal water resource development projects, and other federally assisted water resource projects (Interagency Wild and Scenic Rivers Council, 2009). Among other factors, to qualify for designation, a river must be free-flowing and have one or more "outstandingly remarkable" values. Outstandingly remarkable values are defined loosely, but typically include scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values (Interagency Wild and Scenic Rivers Council, 2009). Rivers have traditionally been designated as a wild, scenic, or recreational river area through congressional designation. However, Section 2(a)(ii) of the Wild and Scenic Rivers Act authorizes the Secretary of the Interior to include a river already protected by a state river protection program in the National System upon the request of that state's governor. Many states already have their own river protection programs in place. Inclusion in the National Wild and Scenic Rivers System ensures that (American Rivers, 2009b):

- A river's "outstandingly remarkable" values and free-flowing character are protected.
- Existing uses of the river are protected.
- Federally licensed dams and any other federally assisted water resource projects are prohibited if they would negatively impact the river's outstanding values.
- A quarter mile protected corridor on both sides of the river is established.
- A cooperative river management plan that addresses resource protection, development of lands and facilities, user capacities, etc. is developed.

Outside of federal lands, the federal government has little or no control over certain river resource threats, such as land use. Thus, it is critical that state and local organizations have a clear and effective plan for managing the protected river area. Floodplain zoning and wetlands protection laws are examples of state and local management actions that can be used to protect designated river areas.

**Wildlife Action Plans**

Two programs created by Congress in 2000, the Wildlife Conservation and Restoration Program and the State Wildlife Grants Program, require the development of Wildlife Action Plans for all 50 states. These plans are meant to protect states' wildlife before it becomes endangered or threatened. The plans evaluate wildlife habitat at the landscape level and target conservation actions at the local level. Many of these plans include aquatic resource protection. The plans are being implemented in all 50 states and receive funding from the U.S. Fish and Wildlife Service. Information from these plans can be used in the development of strategies to protect healthy watersheds. Partnerships with the many organizations involved in the development and implementation of wildlife action plans can be formed to the mutual benefit of both programs. Wildlife action plans can be used by local land use agencies and sewer and water utilities in facility siting determinations (to prevent habitat loss), land maintenance (to prevent the spread of invasive species), and other infrastructure decisions, including water withdrawal and discharge decisions (to prevent pollution) (Environmental Law Institute, 2007b). Some strategies that utilities have pursued include acquiring land to protect water recharge areas, putting land into conservation easements, initiating stream clean-ups, carrying out environmental education, and conducting biological research (Environmental Law Institute, 2007b).

### The National Flood Insurance Program

The National Flood Insurance Program (NFIP) can contribute significantly toward protecting healthy watersheds. The program is intended primarily to protect human life and property through requiring participating communities to adopt certain standards in their floodplain development ordinances. By participating in the program and complying with the standards, the communities receive insurance and assistance for flood-related disasters. The minimum requirements of the NFIP serve the purpose of protecting human life and property. However, through the Community Rating System, communities can implement floodplain management policies that exceed the NFIP minimum requirements and receive a significant discount in their flood insurance premiums. Many strategies using the No Adverse Impact approach promoted by the Association of State Floodplain Mangers qualify for credit under the Community Rating System. Adverse impacts can be defined as increases in flood stages, velocity, or flows, the potential for erosion and sedimentation, degradation of water quality, or increased cost of public services (Vermont Law School Land Use Institute, 2009). The No Adverse Impact approach extends development management beyond the floodplain to include managing development in any area within the watershed that may have an adverse impact on downstream property owners. For example, it promotes limiting the amount of impervious surfaces allowed on new development sites or requiring mitigation strategies such as infiltration basins to capture the increased runoff from new impervious surfaces. Another example is the Vermont Stream Geomorphic Assessments discussed in Chapter 3, through which a fluvial erosion hazard (FEH) zone is defined. Using this approach, the state has begun assisting communities in developing and implementing FEH districts, which have qualified under the Community Rating System program for providing additional protections not provided for in the NFIP minimum requirements, which do not address fluvial erosion.

### The U.S. Forest Service's Forest Legacy Program

The U.S. Forest Service's Forest Legacy Program purchases conservation easements to protect tracts of forest lands greater than 100 acres that are vulnerable to development and growth pressures. Thirty seven state forest legacy programs have identified water quality, wetland, and riparian buffer protection as goals of their program. The program is administered in cooperation with state partners. For example, the Forest Service worked with the State of Montana and a number of other partners to protect nearly 8,000 acres in the North Swan River Valley, the most intact biological ecosystem remaining in the lower 48 states. Forest Legacy Program funding was leveraged with other funding to complete the protection of 66,000 acres in Swan Valley. Landowners must prepare a multiple resource management plan with project costs of which at least 25% must be funded by private, state, or local sources. Landowners benefit from the sale of the property rights and also from reduced taxes on the preserved open space once the sale is complete.

### The Trust for Public Land's Center for Land and Water

The Trust for Public Land's Center for Land and Water works in partnership with communities across the nation to identify and protect the most critical watershed lands for maintaining healthy aquatic resources. The Center protects these lands by designing networks of conservation lands, facilitating conservation transactions, and supporting funding and legislation for land protection. Much of the Center's efforts are focused on protecting lands surrounding drinking water sources. By assisting with land acquisition or conservation easements in the watersheds of source waters, the Center helps to minimize nonpoint sources of pollution that can threaten water supplies. The Enabling Source Water Protection in Maine and Lower Meramec Drinking Water Source Protection Project case studies at the end of this section describe specific examples of the Center's work.

# Case Study

## Wild and Scenic Rivers: Lumber River, North Carolina

**More Information:** http://www.rivers.gov/wsr-lumber.html

The Lumber River is located in south-central North Carolina, and although most of the river corridor is in private ownership, it is virtually unmodified. In 1996, North Carolina's governor petitioned the Secretary of the Interior to add 115 miles of the river to the National Wild and Scenic Rivers System. The river had previously received protection under the North Carolina Natural and Scenic Rivers Act, and a State Park Master Plan had recently been developed for the river corridor. This plan outlined a strategy for the state to work with local governments on future land use and zoning regulations and acquire riparian lands through fee simple purchase and conservation easements.

As part of the national designation process, an examination of existing zoning was conducted to determine if the river would receive adequate local protection while the master plan strategy was being implemented. The City of Lumberton amended its land use ordinance by adding the Lumber River Protection Overlay District to ensure that the river received designation as a National Wild and Scenic River, a source of pride for the community. The river was successfully designated as a result of local river protection interests, key political leaders, scientists, and the National Park Service working together throughout the process.

The Lumber River, North Carolina (The Lumber River Conservancy, 2009).

## 5.2.2 State and Interstate

**Antidegradation**

In addition to defining designated uses and identifying water quality criteria, states and authorized tribes are required to develop and adopt statewide antidegradation policies that protect and maintain: existing instream uses and their associated water quality; high quality waters, unless the state or tribe finds that allowing lower water quality is necessary to accomodate important economic or social development; and outstanding national resource waters (ONRW), as designated by the state or tribe. They are also required to identify implementation methods for the antidegradation policy. These implementation methods typically define how the high quality waters will be identified, what activities will trigger the antidegradation review process, and the components of an antidegradation review. All waters of a state should be categorized into one of three protection Tiers. Tier 1 is the minimum baseline of protection afforded to all waters of a state and requires that existing uses and their associated water quality be maintained and protected. Tier 2, high quality waters, are those waters that exceed the minimum quality necessary to support the CWA's "fishable/swimmable" goals and can only have their water quality lowered when the state or tribe finds the lowering to be "necessary to accommodate important economic or social development," as determined through the antidegradation review process. No degradation is allowed in Tier 3 waters, ONRWs, except on a short-term, temporary basis, as identified by the state's or tribe's policies and procedures. Antidegradation applies when an activity lowers water quality and is, therefore, an attractive option for states or tribes to pursue in the protection of healthy watersheds. Healthy watersheds assessments can help strengthen and inform Tier 2 and Tier 3 designations.

**Instream Flow Protection**

With the ever increasing demands that humans place on freshwater resources for drinking water, power generation, and industrial and agricultural uses, aquatic biota are experiencing not only lower flows, but a loss of the natural variability in flows. Historical methods for determining instream flow needs focused on single species, often leading to decreased health of the larger ecosystem (Poff N., 2009). Scientists now understand that the natural flow regime must be maintained to ensure aquatic ecological integrity. This understanding is beginning to be integrated into flow management by the U.S. Army Corps of Engineers, who have been working with The Nature Conservancy on pilot projects like those on the Savannah River in Georgia (Richter, Warner, Meyer, & Lutz, 2006), and utilities like the Rivanna Water and Sewer Authority, also working with The Nature Conservancy on developing environmental flow management practices (Richter B., 2007). Both projects defined flow prescriptions for a river segment by evaluating ecological and social needs. More information on managing instream flows for humans and ecosystems can be found in Postel and Richter (2003).

Some states, such as Washington, Massachusetts, Connecticut, South Carolina, and Michigan have begun developing flow management and water allocation policies to ensure protection of instream flows. For example, Michigan uses its Water Withdrawal Assessment Tool, described in Chapter 3, to develop flow alteration-ecological response curves for various classes of rivers, and the effects of proposed surface water and ground water withdrawals can be estimated with an online user interface. Use of this tool is required for all new >100,000 gallons per day withdrawal applications as part of the implementation of a variety of Michigan water allocation policies intended to protect and restore instream flows. Similarly, Connecticut has developed draft stream flow regulations based on expert consensus and best available science to set flow standards for six seasonal bioperiods. The regulations apply to surface water withdrawals and reservoir releases. The Massachusetts Water Policy is a comprehensive approach to water management that seeks to maintain sufficient quantity and quality of water for aquatic life and human use. It leverages the benefits of Smart Growth to "keep water local" by: allowing for infiltration of precipitation onsite, instead of sending it across impervious surfaces and down storm drains; encouraging municipalities to live within their water budgets and not import water from other basins; and increasing treated wastewater recharge and reuse. These actions help to maintain natural river flow conditions. South Carolina passed the Surface Water Withdrawal and Reporting Act in 2010 that sets water-permitting requirements for withdrawals greater than 3 million gallons per month; establishes statewide, seasonally variable minimum flows to protect aquatic life, recreation, and water supply; and requires new users to have contingency plans so that they can cease their consumptive use of water when stream flows get too low.

The Columbia Basin Water Transactions Program uses a variety of mechanisms to ensure sufficient instream flows throughout the basin in Washington, Oregon, Montana, and Idaho. Some of the tools used include (National Fish and Wildlife Foundation; Bonneville Power Administration, 2004):

- Water Acquisitions:
  - Short and long-term leases.
  - Permanent purchase.
  - Split Season — A portion of a water right is used for irrigation in the spring and the remainder is left instream in late summer/fall.
  - Dry Year Option — An opportunity to lease a water right during a particularly dry year.
  - Forbearance agreement.
  - Diversion reduction agreement.
- Boosting Efficiency:
  - Switching from a flood to sprinkler irrigation system.
  - Modernizing headgates.
  - Improving ditch efficiency.
- Conserving Habitat:
  - Protecting/restoring stream habitat and changing a portion of the associated water right.
- Rethinking the Source:
  - Changing the point of diversion from a tributary to a main stem in order to improve stream flows.
  - Switching from surface to ground water source.
- Pools:
  - Rotational pool — A group of irrigators take turns leaving a portion of their water in stream.
- Banks:
  - Water Banking — Producers in an irrigation district "bank" water they may not need so it can be available for other uses.

### Using Antidegradation to Protect Instream Flows

The Tennessee Division of Water Pollution Control regulates water withdrawals that can lower water quality or affect designated use support in waters of the state. Most regulated water withdrawals in the state are for public water supply. Tennessee's permit process under antidegradation requires an alternatives analysis, which includes social, economic, and environmental considerations. Regional water supply planning conducted by the community is an important tool to help identify water supply alternatives that avoid or minimize degradation. From the regulatory perspective, an environmental review should seek to avoid and minimize degradation. From the community's perspective, an environmental review should include the affected public and represent their interests. The alternatives analysis helps encourage avoidance and minimization, while the intergovernmental coordination and public participation provisions help ensure that the community has input on potentially important economic or social development.

The alternatives analysis process has led to the development of regional, coordinated water supply planning to address permit application requirements and the Division of Water Pollution Control has assisted in the completion of two such pilot efforts. In one case, the regional plan showed that the raising of an existing dam would serve as a regional supply for the stated planning horizon and was therefore justified under antidegradation; and that other water supply development proposals within the region were therefore not justified. In the other case, the impoundment and lowering of water quality of a tier two stream was shown to be unjustified; and that purchase of treated water from a nearby utility who obtained their raw water from the Cumberland River was feasible.

Other innovations in water supply planning are occurring throughout Tennessee. For example, the Huntsville utility district operates an existing withdrawal on a tier two stream, the New River, a tributary of the Big South Fork National Recreational River. The Huntsville utility district has recently applied for a permit to increase their withdrawal rate and volume from the New River. However, they propose to change their operation to harvest water based on the amount of flow in the river and subsequently withdraw no more than 5% of the flow at any time. This minimization of impact was driven, in part, by Tennessee's de-minimis flow reduction standard, serving as a presumptive flow standard.

**Source Water Protection**

The Safe Drinking Water Act (SDWA) Amendments of 1996 require states to develop and implement source water assessment programs (SWAPs) to analyze existing and potential threats to the safety of public drinking water sources throughout the state. States have completed source water assessments for virtually every public water system in the nation, from major metropolitan areas to the smallest towns. A source water assessment is a water system-specific study and report that provides basic information about the source water used to provide drinking water. Many of the biggest threats to source waters identified in SWAPs are related to land use practices. These include stormwater and nonpoint source runoff (e.g., from fertilized crop lands), septic systems, and chemical storage tanks at commercial and industrial sites. Drawing from resources such as EPA's Drinking Water State Revolving Fund (DWSRF) and Clean Water State Revolving Fund (CWSRF), states can assist local water suppliers with source water protection measures, including a variety of land use management tools, to address the threats identified in the SWAP. These two EPA financing programs are administered by each of the states and may provide funding to projects that support compliance with SDWA drinking water standards (DWSRF) or protect, enhance, or restore water quality (CWSRF). The interest rates on loans under these programs are typically well below market rates and have flexible repayment terms that can be extended up to 20 years.

Land trusts have also taken advantage of both the DWSRF and CWSRF for land acquisition. Aligning State Land Use and Water Protection Programs is an EPA-funded initiative that will have strategies and lessons learned to share with other states. Initiative partners (The Trust for Public Land, Smart Growth Leadership Institute, River Network, and the Association of State Drinking Water Administrators) are working with a small group of states to identify opportunities to work across political and programmatic boundaries to better align planning, economic development, regulation, and conservation to protect drinking water sources at the local and watershed level (see www.landuseandwater.org).

**Growth Management**

Some states have growth management laws, which typically provide more specific guidance to localities in the development of land use plans than do the more typical land use planning enabling laws. In addition to providing specific guidance and requirements, growth management laws also sometimes include a state land use plan to guide local land use planning (Environmental Law Institute; Defenders of Wildlife, 2003). However, the primary authority to regulate land use remains with the local government. Some growth management laws establish mechanisms for adjoining jurisdictions to coordinate their planning activities (Environmental Law Institute; Defenders of Wildlife, 2003). The State of Washington is protecting "critical areas" through the use of its Growth Management Act (see case study at end of section).

**State River and Habitat Protection Programs**

Many state agencies maintain habitat protection programs and river protection programs that seek to protect riparian areas and river corridors. Some examples include: Vermont's integrated river corridor protection program, which is used to protect riverine and riparian habitat, in addition to protecting human infrastructure from flood and fluvial erosion hazards; Michigan's Natural Rivers Program that protects riverine and riparian habitats; Wyoming's statewide planning process to protect wetland-associated habitats; Maryland's GreenPrint Program; and Minnesota's state legislation for fen protection.

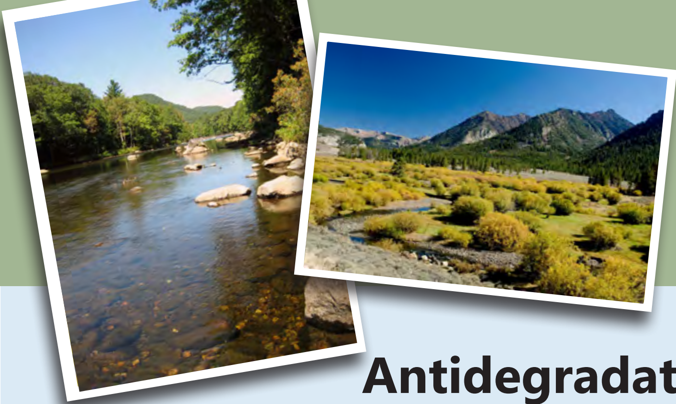
Both voluntary and regulatory techniques are frequently used to implement these programs, and collaboration with local governments and organizations is key to their success. For example, the New Hampshire River Management and Protection Program is administered by the New Hampshire Department of Environmental Services and a statewide River Management Advisory Committee. However, protection hinges upon partnerships between the state and local municipalities. Local individuals or organizations nominate rivers when sufficient local support is demonstrated. Once approved by the state, designated rivers receive protection from potential threats according to the classification they were given at the time of designation: natural, rural, rural community, or community. Protection measures consider channel alterations, dams, hydroelectric energy facilities, interbasin water transfers, protected instream flows, siting of solid and hazardous waste facilities, recreational river use, and water quality. A local advisory committee consisting of representatives from all riverfront municipalities develops and implements a management plan for the designated river with assistance from the Department of Environmental Services. Local advisory committees also comment on activities requiring state or federal permits that may impact the river. The intent of the River Management and Protection Program is to balance competing demands for river resources for the benefit of present and future generations.

The Massachusetts Rivers Protection Act takes a somewhat different approach to river protection. The Act protects the 200 feet of land adjacent to either bank of every perennial river, stream, or brook, with a few exceptions in densely populated urban areas, where only 25 feet on either side of the perennially flowing water body is protected. These tracts of land, referred to as riverfront areas, are protected from any new development unless the developer can prove to the local conservation commission or the Massachusetts Department of Environmental Protection that there is no practicable alternative for the development or that the development will not have a significant adverse impact on the river. As a result, the Rivers Protection Act protects a seamless network of the state's perennially flowing water bodies.

**Minnesota Fen Protection**

http://www.dnr.state.mn.us/eco/wetlands/index.html

Calcareous fens are a wetland type characterized by a non-acidic peat substrate and dependent on a constant supply of cold, oxygen-rich ground water with high concentrations of calcium and magnesium bicarbonates. Calcareous fens are some of the rarest natural communities in the United States and are highly susceptible to disturbance. The Minnesota Wetlands Conservation Act protects calcareous seepage fens from being "filled, drained, or otherwise degraded, wholly or partially, by any activity, unless the commissioner of natural resources, under an approved management plan, decides some alteration is necessary" (Minnesota Department of Natural Resources, 2008). In addition, any state-threatened plants occurring on a calcareous fen are protected under Minnesota's endangered species law.



# Case Study

## Antidegradation: Delaware River Basin Commission Special Protection Waters

**More Information:** http://www.state.nj.us/drbc/spw.htm

The Delaware River Basin Commission adopted Special Protection Waters regulations in 1992, 1994, and 2005 to protect existing high quality waters in areas of the Delaware River Basin deemed "to have exceptionally high scenic, recreational, ecological and/or water supply values."

The Special Protection Waters regulations adopted in 1992 and 1994 initially applied to a 121-mile stretch of the Delaware River from Hancock, NY downstream to the Delaware Water Gap, and its drainage area. This corridor includes the two sections of the river federally designated as "Wild and Scenic" in 1978, as well as an eight-mile reach between Milrift and Milford, PA which is not federally designated.

In 2000, federal legislation was enacted adding key segments of the Lower Delaware and selected tributaries to the National Wild and Scenic Rivers System. This designation was followed in April 2001 with a petition from the Delaware Riverkeeper Network to the Delaware River Basin Commission to classify the Lower Delaware as a Special Protection Water. Extensive water quality data were collected from 2000 through 2004 at over 26 tributary and main-stem Delaware River locations. The resulting water quality data confirmed that existing water quality in this stretch of river exceeded most state and federal standards, making it a worthy candidate for the Delaware River Basin Commission's anti-degradation program.

Based in part upon these findings, in 2008 the Delaware River Basin Commission permanently designated the 76-mile stretch of the non-tidal lower Delaware River between the Delaware Water Gap and the head of tide at Trenton, NJ as Special Protection Waters (Figure 5-2). The entire 197-mile non-tidal Delaware River is now protected by Special Protection Waters anti-degradation regulations.

The primary focus for the Special Protection Waters Program is to ensure that the existing high quality waters are not measurably changed as a result of point source discharges and to mitigate the impacts of nonpoint source pollution from new service areas. In order to evaluate point source discharge projects for conformance with the Special Protection Waters Program, Commission staff prioritized water quality model development in those watersheds that have a high number of existing point source discharges as well as in those watersheds that were expected to have new growth and associated wastewater discharge needs.

The water quality models are used to predict changes to water quality as all of the existing and proposed point source discharges reach their permitted flow/loads. These cumulative impact models are then utilized to identify effluent limitations for the point source discharges to prevent a measurable water quality change to Special Protection Waters.

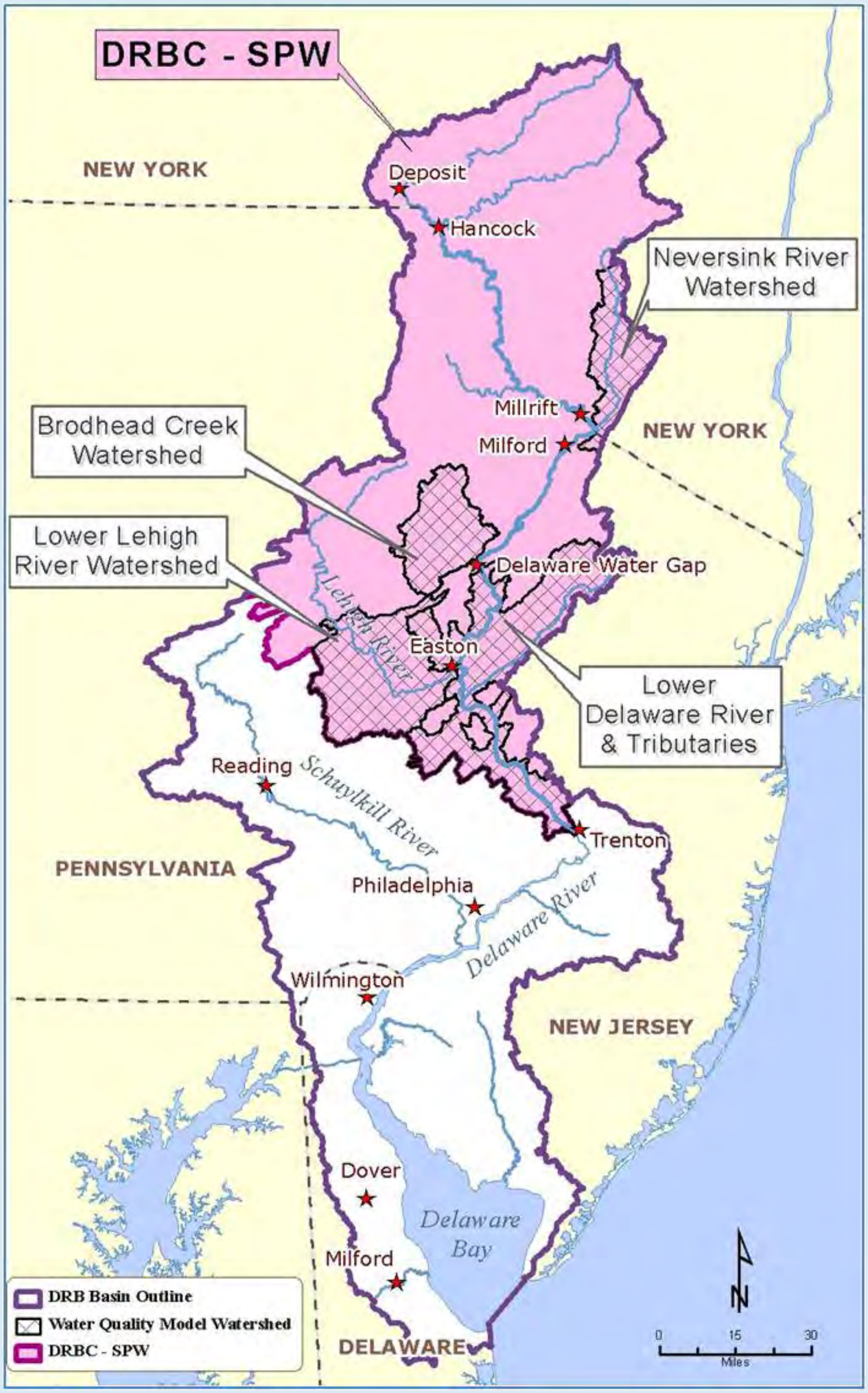



**Figure 5-2** The Delaware River Basin Commission (DRBC) permanently designated the entire 197-mile non-tidal Delaware River as a Special Protection Water (SPW) subject to anti-degradation regulations (image courtesy of Robert Tudor, DRBC).


# Case Study

## Washington Critical Areas Growth Management Act

**More Information:** http://www.commerce.wa.gov/site/418/default.aspx

The State of Washington adopted its Growth Management Act (GMA) in 1990 in response to rapid, uncoordinated, and unplanned growth that was threatening the environment, sustainable economic development, and the health, safety, and high quality of life afforded to its citizens. The Act requires all Washington counties and cities to designate and protect critical areas and natural resource areas. Critical areas include wetlands, fish and wildlife habitat conservation areas, aquifer recharge areas, frequently flooded areas, and geologically hazardous areas. Natural resource areas include forest, agricultural, and mineral lands. The Act has 14 goals that include reducing sprawl by focusing growth in urban areas, maintenance of natural resource based industries and encouragement of sustainable economic development, and protection of the environment by retaining open space and habitat areas. Based on county population and growth rate, some counties (and all cities within them) are required to fully plan under the GMA, while others can choose to plan. However, all cities and counties are required to designate and protect critical areas.

Although each city and county is required to designate and protect critical areas, functions, and values under the GMA, they are given wide latitude in how they do so. The State of Washington provides guidance and technical assistance, including example codes and ordinances, but continues the tradition of allowing local government to control its own land use decisions by allowing them to choose the particular strategies and tools they will use. However, designation and protection of critical areas must include the "best available science" and must give special consideration to protection of anadromous fish habitat. A variety of regulatory and non-regulatory tools are available to communities for protection of critical areas, including zoning, subdivision codes, clearing and grading ordinances, critical areas regulations, conservation easements, public education, and transfer of development rights. The focus is on performance measures designed to protect the functions and values of each critical area. Although critical areas can be protected with a number of regulations, many communities in Washington include a separate critical areas chapter in their development regulations. The State Environmental Policy Act, Shoreline Master Program, Storm Water Management, and Clearing and Grading Ordinances are also useful for protecting critical areas, and any critical areas regulations should be consistent with these programs.

In 2008, Snohomish County conducted an effectiveness monitoring study to determine how well it was protecting the functions and values of critical areas. The county uses regulatory (critical areas regulations), non-regulatory (best management practices), and monitoring and adaptive management to protect its critical areas. The critical areas regulations have science-based standards for techniques such as buffer widths around wetlands and streams. Alternative and innovative approaches are permitted when they can be shown to achieve the same level of protection as the regulations. A combination of permit tracking, enhancement project tracking, remote sensing, shoreline inventories, and intensive catchment studies are being used to determine the impacts of development on critical areas, with a focus on fish and wildlife habitat (Haas, Ahn, Rustay, & Dittbrenner, 2009).

# Case Study

## Michigan Water Withdrawal Assessment Process

**More Information:** http://web2.msue.msu.edu/bulletins/Bulletin/PDF/WQ60.pdf

In response to the Great Lakes – St. Lawrence River Basin Water Resources Compact of 2005, the Michigan State Legislature enacted new laws to manage large-quantity water withdrawals based on hydroecological principles. Public Act 179 of 2008 defines a large-quantity water withdrawal as an average of 100,000 gpd over any consecutive 30 day period. Using a process that parallels the Ecological Limits of Hydrologic Alteration, Michigan has classified river segments, determined flow-ecology relationships, and identified environmental flow targets based on socially acceptable ecological conditions. To implement its policy, Michigan has created a statewide water withdrawal assessment tool (Chapter 3).

The water withdrawal assessment tool uses "fish response curves" to evaluate the impact of a water withdrawal on fish populations in the 11 different stream types defined for Michigan (Figure 5-3). The stream types are defined based on habitat characteristics such as catchment size, base flow yield, and July mean water temperature. The fish response curves were developed using fish abundance and stream flow data to determine relationships between flow reduction and change in fish populations for all 11 stream types. Using the water withdrawal assessment tool, the user inputs the proposed location and quantity of their withdrawal, and the tool estimates the level of impact. Depending on the

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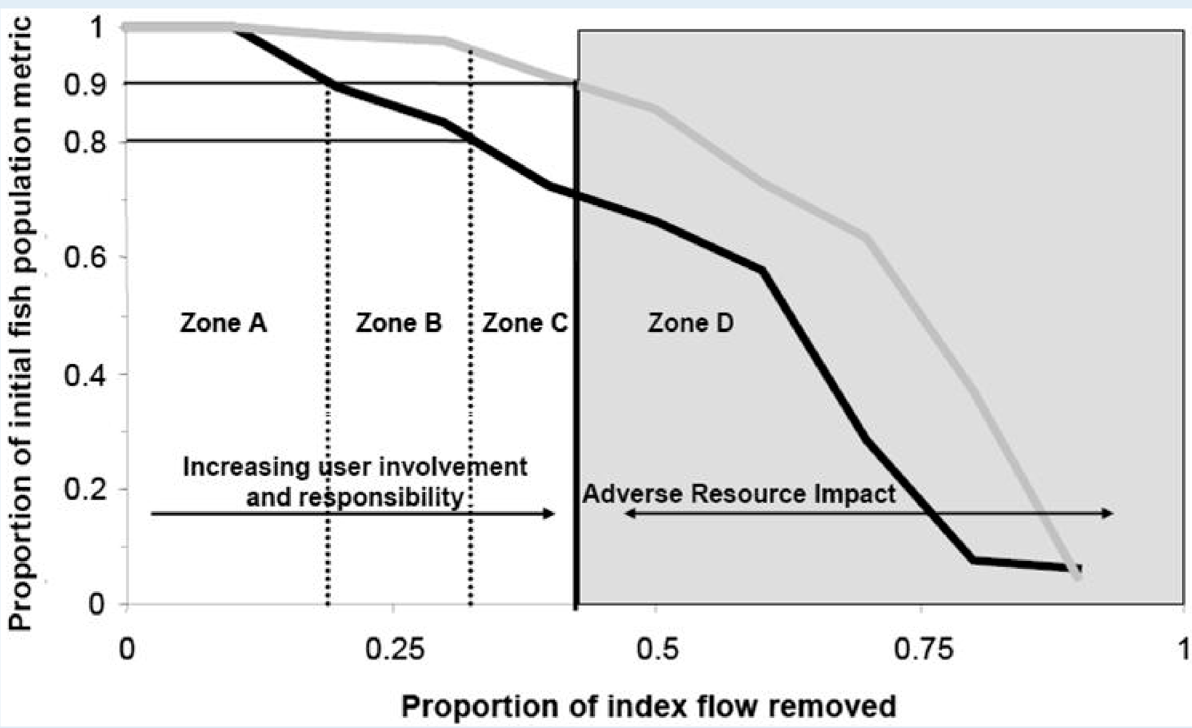
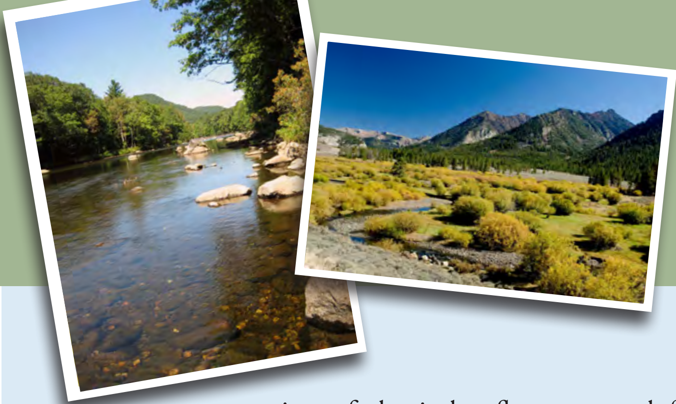



**Figure 5-3** Example fish response curves. The dark curve represents "thriving species still thriving" at incremental reductions in index flow. The light curve represents "characteristic species still present and abundant." (Troy Zorn, MI DNR, Personal Communication).



proportion of the index flow removed for a given stream type, the proportion of the fish population remaining can be determined through the use of the fish response curves. Four zones of index flow reduction have been defined for each stream type. These zones represent different policy actions as shown in Figure 5-4.

The water withdrawal assessment tool is considered a screening tool. When appropriate, site-specific analyses can be conducted to determine the appropriate zone and consequent action. A new Water Resources Conservation Advisory Council was created to evaluate and oversee the state's water management programs, including the Water Withdrawal Assessment Process. The council ensures that the process is inclusive and collaborative and that it is based on the best available science.

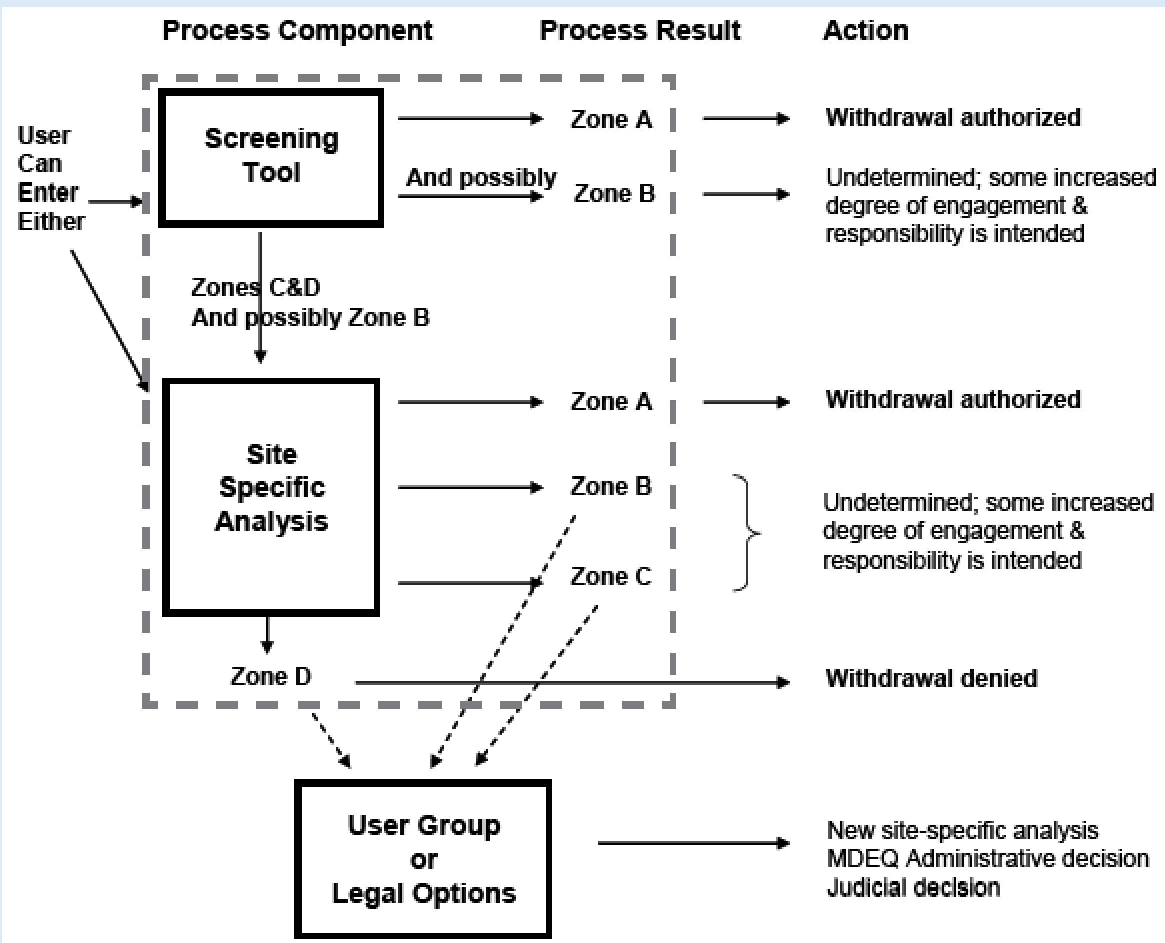



**Figure 5-4** Illustration of the water withdrawal assessment process and resulting actions. (Troy Zorn, MI DNR, Personal Communication).

# Case Study

## Vermont River Corridor Protection Program

**More Information:** Kline, 2010 (http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_restoration.htm)

The Vermont River Corridor Protection Program is a program of the Department of Environmental Conservation, within the Agency of Natural Resources (ANR), that seeks to restore and protect the natural values of rivers and minimize flood damage. Achieving natural stream stability over time through a reduction in riparian infrastructure can minimize cost from flood damage and improve aquatic and riparian ecological integrity. Vermont ANR provides technical assistance to communities throughout the state to help delineate river corridors, develop municipal fluvial erosion hazard zoning districts, and implement river corridor easements. Delineation of the river corridor is carried out using the stream geomorphic assessment protocols described in Chapter 3. The primary purpose of this delineation, with respect to river corridor planning, is to capture the meander belt and other active areas of the river that are likely to be inundated or erode under flooding flows. As part of the stream geomorphic assessment, a stream sensitivity rating is assigned to each reach based on existing stream type and geomorphic condition.

Based on the river corridor delineations, Vermont ANR works with communities to develop river corridor plans that analyze geomorphic condition, identify stressors and constraints to stream equilibrium, and prioritize management strategies such as:

- Protecting river corridors.
- Planting stream buffers.
- Stabilizing stream banks.
- Arresting head cuts and nick points.
- Removing berms and other constraints to flood and sediment load attenuation.
- Removing/replacing/retrofitting structures (e.g., undersized culverts, constrictions, low dams).
- Restoring incised reaches.
- Restoring aggraded reaches.

By focusing on "key attenuation assets," flood and fluvial erosion hazards, water quality, and habitat are improved at minimum cost. Attenuation areas are captured in the corridor delineation process and include Active River Area components such as floodplains, wetlands, and riparian vegetation that store flood flows and sediments and reduce watershed nutrient and organic matter inputs.

The river corridor plans are incorporated into existing watershed plans, and ANR also works with municipalities to develop Fluvial Erosion Hazard Area Districts in their bylaws or zoning ordinances. A River Corridor Easement Program has also been established to purchase river channel management rights (Figure 5-5). This prevents land owners from dredging and armoring the channel and gives the easement holder the right to establish vegetated buffers in the river corridor.

The Town of Hinesburg, Vermont developed a stream corridor plan for the LaPlatte River in 2007 to take advantage of the stream geomorphic assessments that had already been completed and to develop river corridor protection projects. The plan development process began with outreach and education activities including landowner contact through direct mailing of informative letters followed up by telephone calls to each landowner. Meetings were scheduled with each landowner to discuss the planning process and reach condition details specific to each landowner's parcel. Presentations were also given to the Select Board, Conservation Commission, and Planning Commission at the beginning and end of the planning process.

*Continued on page 5-22*

The LaPlatte Watershed Partnership used the stream geomorphic assessment results and conducted a stressor, departure, and sensitivity analysis to prioritize planning and management strategies for each reach. They identified strategies such as properly sizing stream crossings (i.e., bridges and culverts) when these structures are up for replacements or repairs, implementation of a Water Resources Overlay District (which encompasses the FEH zone), planting of stream buffers, and restoration of incised reaches. The Town of Hinesburg adopted stream buffers and setback requirements in its zoning regulations that prevent encroachment into the stream corridor, protecting property and the ecological integrity of the LaPlatte River.

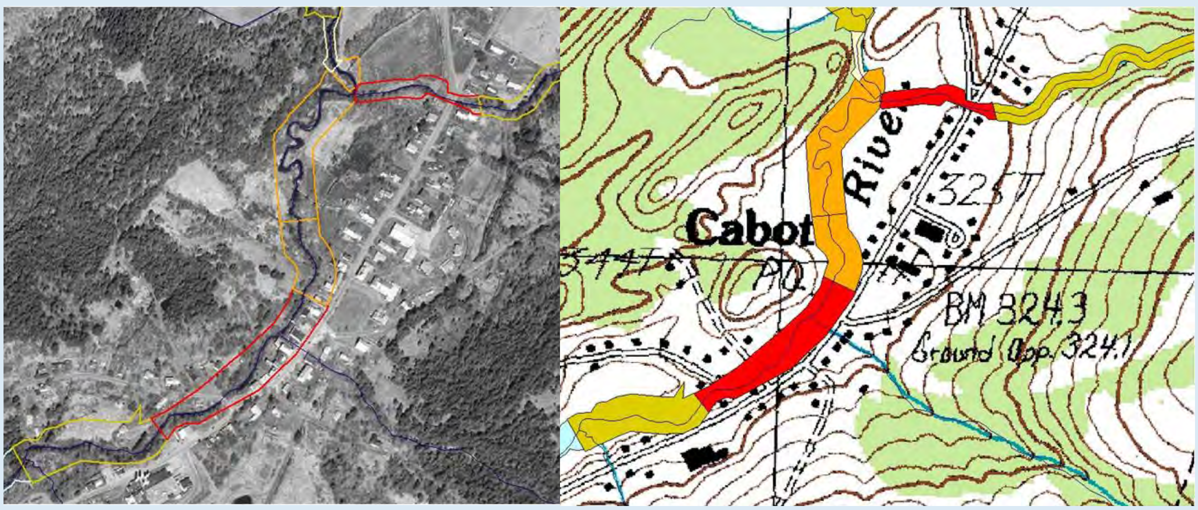



**Figure 5-5** Map and orthophoto depicting the meander belt width-based river corridor being considered for protection in the Town of Cabot, Vermont to help restore water quality, aquatic habitat, and natural channel stability of the Winooski River. The belt width corridor is designed to accommodate the geomorphology and fluvial processes associated with the river's dynamic equilibrium condition (Mike Kline, Vermont Agency of Natural Resources, Personal Communication).

# Case Study

## Michigan's Natural Rivers Program

**More Information:** http://www.michigan.gov/dnr/0,1607,7-153-30301_31431_31442---,00.html

The State of Michigan's Natural Rivers Act, passed in 1970, established The Natural Rivers Program as part of the Habitat Management Unit in the Fisheries Division of the state's Department of Natural Resources (DNR). Since the program's establishment, 2,091 miles on 16 rivers have been designated as part of Michigan's Natural Rivers System. The system serves to preserve and enhance a variety of values each river provides for current and future generations, including: aesthetics, free-flowing condition, recreation, boating, historic value, water conservation, floodplain, ecological, fisheries and other aquatic life, and wildlife habitat. In this way, the Program focuses on protecting natural river ecosystem conditions so that rivers can continue to provide ecosystem services to their local communities for many years to come.

In order to be considered for designation in the program, stakeholders must form an advisory group to develop a comprehensive management plan for a river. Management plans include baseline data describing the river's condition, defined river segments proposed for designation, and proposed standards for land development in the river's Natural River District, defined as the land area extending 400 feet from either side of the river's edge. Standards typically include structural and septic system setbacks (100-200 feet from the water's edge), natural riparian buffers (25-100 feet from the water's edge), minimum lot size and frontage requirements (one acre with 100-200 feet of frontage), and prohibitions on filling or building in the 100-year floodplain or wetlands. The standards also restrict use of the Natural River District to residential development and limit timber harvest, oil and gas activity, bank stabilization activities, intensive habitat management of fisheries and public lands, and public access. Because the Natural River District applies to both public and private lands, a river's designation into Michigan's Natural Rivers System incorporates uniform standards across all land ownerships and multiple jurisdictions, resulting in a seamlessly protected green infrastructure corridor along the river's banks.

Once a river has been designated as part of the Natural Rivers System, a permit process is used to oversee development in the Natural River District. Property owners wishing to conduct activities in Natural River Districts apply for Natural River zoning permits from the Program administrators for their districts. Program staff conduct site inspections with applicants and issue permits once it has been determined that the applicant's activity complies with development standards. The Zoning Review Board, a seven-member board consisting of representatives from each affected County and Township, NRCS, local citizens, and the DNR may grant variances in cases where standards cannot be met. Local governments may become Natural Rivers Program administrators on private lands in their jurisdictions by adopting Natural River zoning standards into a county or town ordinance. Natural Rivers Program staff support local government program administrators by reviewing ordinance language amendments, commenting on variance requests, and monitoring to ensure uniform Program administration within each river system. In addition to local governments, watershed councils, Resource Conservation and Development programs, the U.S. Forest Service, Trout Unlimited chapters, canoe livery owners, and the Michigan Department of Environmental Quality have also collaborated with the DNR to contribute to the success of Michigan's Natural Rivers Program.

# Case Study

## Wyoming Wetlands Conservation Strategy

**More Information:** http://gf.state.wy.us/habitat/WetlandConservation/Wyoming%20Wetlands%20Conservation%20Strategy%20September%207,%202010.pdf

The Wyoming Joint Ventures Steering Committee has developed a statewide wetlands conservation strategy to meet seven goals: 1) delineate important wetland and riparian habitat areas and assess their condition, 2) identify threats to the functional integrity of wetlands and riparian habitats, 3) set state and regional conservation goals and priorities, 4) develop conservation and management strategies for wetlands and riparian habitats, 5) promote partnerships among existing conservation initiatives, 6) connect with non-conservation-based funding and planning resources, and 7) build technical support for the wetland component of the Wyoming State Wildlife Action Plan. The Committee identified nine wetland complexes to be prioritized for conservation in the next 10-year planning horizon. Six of these complexes were selected for meeting two criteria: 1) a Shannon diversity rank no greater than five, and 2) "high" project opportunity. The other three complexes were selected due to their ecological uniqueness and/or a high level of public interest. Data from a 1995 Statewide Comprehensive Outdoor Recreation Plan and an assessment conducted by The Nature Conservancy in 2010 support these selections.

The first step in implementing this conservation strategy is to build the state's capacity to support wetlands conservation projects. A pooled state agency and non-governmental organization approach, a state wetlands coordinator position, and/or new funding sources may be developed to provide needed technical resources that have been historically lacking to write grant proposals and plan, permit, and oversee projects. Local and regional wetlands and riparian habitat conservation priorities will be identified in "step-down" plans for the following four areas: protection, restoration, creation and enhancement, and recreation. Priority conservation projects for each of the four areas will be identified and made publicly known through a Wyoming Wetlands Web site. In addition, the "step-down" plans will be used to set statewide objectives and priorities for the same four areas. Protection priorities will focus on acquisitions and conservation easements.

The state's highest conservation priority at this time is to ensure "no net loss" of existing wetlands and riparian habitats. This requires enforcing existing protections, effective mitigation of unavoidable losses, strategic use of federal financial incentives, and negotiating land and water use rights to protect high-risk areas. The committee is considering a variety of approaches to foster land and water use that is protective of wetlands in the private sphere. These approaches include: management and stewardship agreements, property leases (including water rights), managing the timing of when water rights are exercised, temporary water transfers, rehabilitation and improvement of irrigation systems, the development of ground water wells to supply constructed wetlands, and potentially reintroducing beaver populations. The establishment of minimum stream flows that mimic natural hydrographs, removal of barriers to stream connectivity, and discouraging floodplain development are other tactics that may become a part of Wyoming's wetlands conservation strategy. Lastly, the Committee also proposes that an effort be made to incorporate wildlife habitat creation, enhancement, maintenance or management into the state's legal definition of beneficial uses of water to expand the set of water sources that can potentially be used to support wetlands.

Wyoming's wetlands conservation strategy incorporates several prioritization techniques that can be similarly applied to prioritize healthy watersheds for protection. Wetlands identified as conservation priorities are likely to be found in healthy watersheds that would be identified as protection priorities. In these and other ways, wetlands conservation and healthy watersheds protection strategies can be developed synergistically to preserve the integrity of healthy watersheds.

# Case Study

## Maryland's GreenPrint Program

**More Information:** www.greenprint.maryland.gov

The State of Maryland has identified fragmentation and development of its natural and working lands as its biggest future conservation challenge. To address this challenge, Maryland's Program Open Space developed a tool known as GreenPrint (Figure 5-6) to identify the state's most ecologically valuable areas and track their conservation. The tool uses GIS data layers to identify overlap between areas that are priorities for the following four conservation foci: green infrastructure, water quality protection, rare species habitat, and aquatic biodiversity hotspots (Figure 5-7). Areas that are conservation priorities for several of these purposes are then designated as targeted ecological areas (TEA). It is likely that there will be overlap between areas that should be protected as healthy watersheds and TEAs because both are landscape-level approaches to protecting the integrity of freshwater systems.

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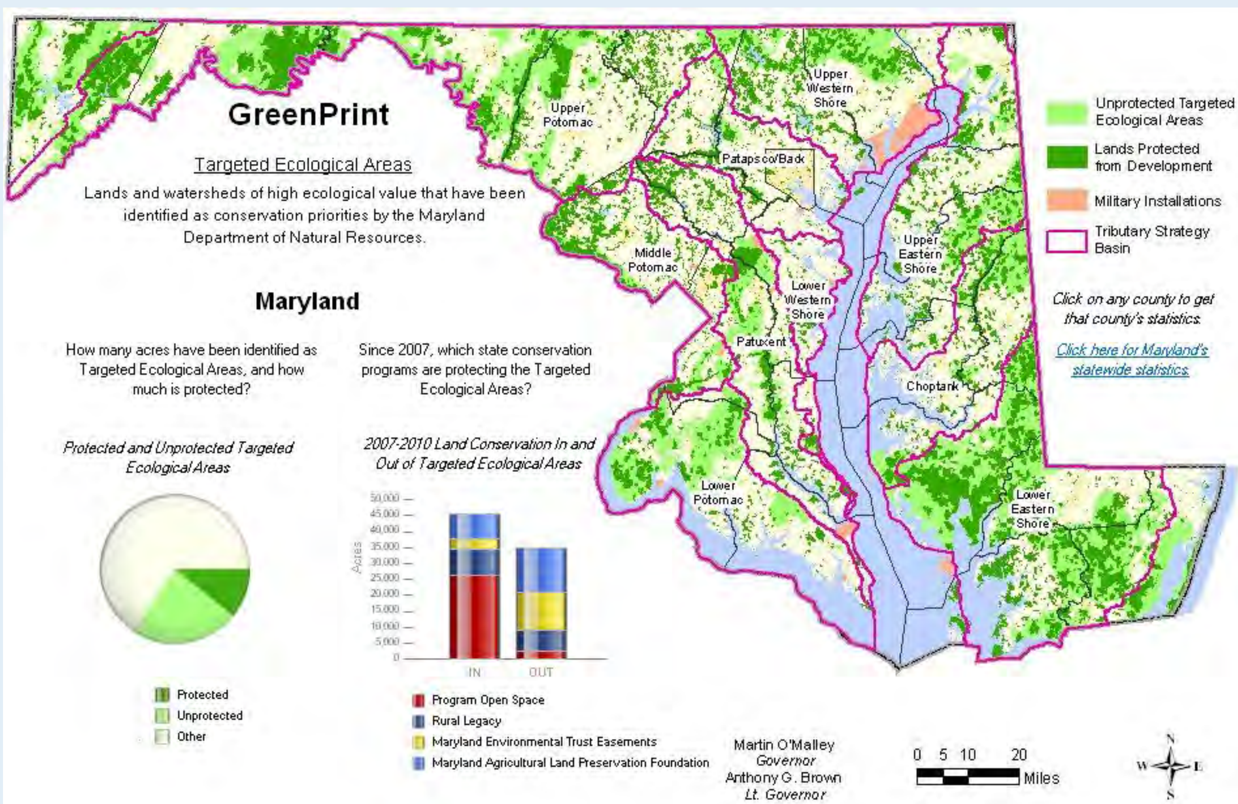


**Figure 5-6** Maryland's GreenPrint map of targeted ecological areas (Maryland Department of Natural Resources, 2011).

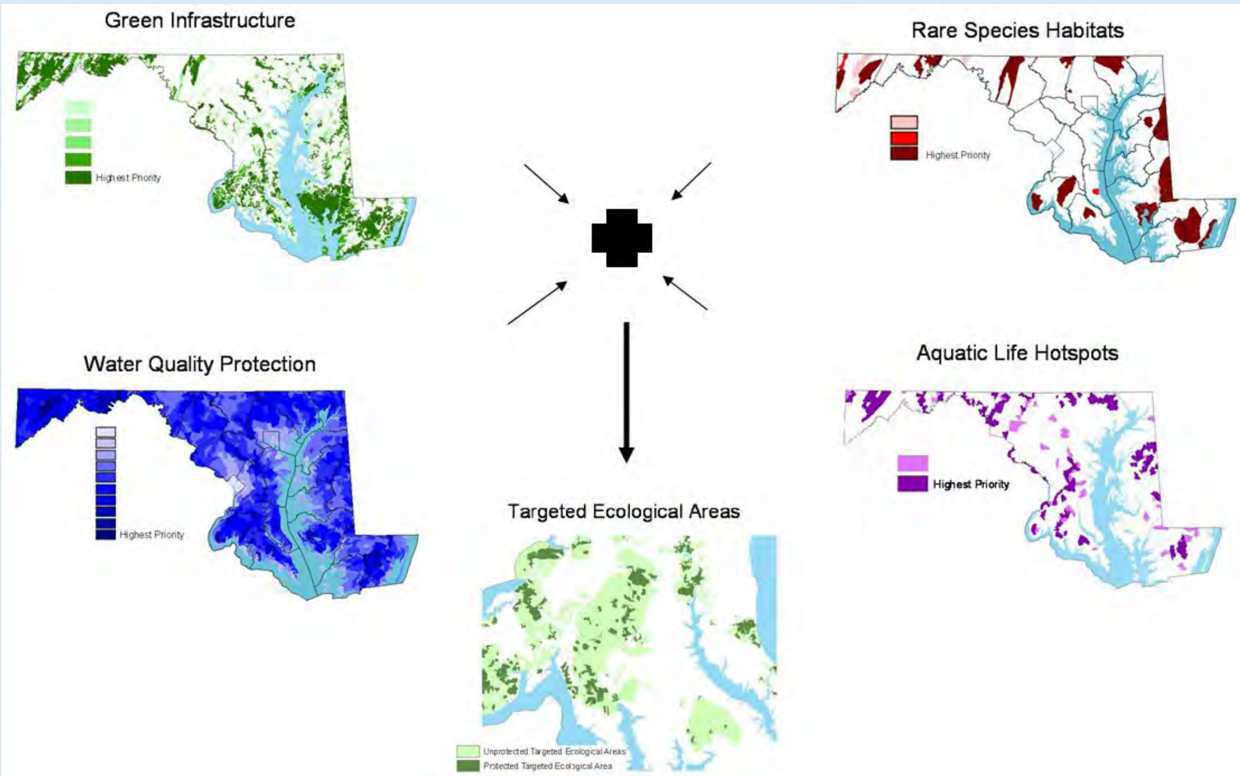


**Figure 5-7** Identification of targeted ecological areas (Maryland Department of Natural Resources, 2011).

Maryland's Board of Public Works uses an ecological ranking protocol to measure how conservation projects contribute to the protection of TEAs. The protocol requires that each conservation project be evaluated using a standard scorecard. The scorecard asks project managers to address the four aforementioned conservation priority areas used by GreenPrint in both a landscape score and a parcel ecological characteristic score. Other components that contribute to the project's final score include recreational or cultural value, restoration value, consistency with local land use, and provisions for future management of the land. The Board of Public Works also uses the scorecards to track how many projects are located in GreenPrint TEAs as a key performance measure for Program Open Space. The goal of the GreenPrint Program is to channel conservation resources into protecting TEAs, thus supporting both the green and blue infrastructure needed to maintain a complete ecological network across the state.

# Case Study

## Enabling Source Water Protection in Maine

**More Information:** http://www.landuseandwater.org/index.htm

Maine's landscape is home to an abundance of lakes, ponds, and rivers. Many of these surface waters, and associated ground waters, serve as sources of drinking water for local residents. Unlike most states, utilities in Maine are often able to provide only minimal treatment to their source waters before distribution to customers. This is due to the high quality of these source waters in their natural condition. Although Maine has already taken a number of measures to ensure that its aquifers and surface sources continue to provide clean drinking water into the future, the state decided to participate in the Enabling Source Water Protection initiative, an EPA-funded project to integrate state land and water programs. The project is a partnership among the Trust for Public Land, the Smart Growth Leadership Institute, the River Network, and the Association of State Drinking Water Administrators. The Enabling Source Water Protection project assesses state programs to recommend the best opportunities for program alignment that will support local communities in their source protection efforts.

Working with a diverse group of state agency representatives, public water systems, non-profit organizations, and other interested stakeholders, the national project team identified key opportunities for improved collaboration in the areas of smart growth, conservation, and water quality. After soliciting stakeholder input and feedback on the identified opportunities, the project team identified successful implementation efforts from other states and created a draft action plan for Maine. Using an online survey, stakeholders were asked to read the document to further refine and prioritize action items. Those steps rated as low impact, high investment and low chance of success were eliminated from consideration.

Developing a dedicated statewide funding source for drinking water source protection was identified as the action that would have the highest positive impact, but that would require long-term planning and implementation. The final action plan focuses on those action steps where the majority of respondents rated them as: having high impact on drinking water source protection; requiring low-to-moderate investment of public resources; demanding high urgency for implementation; having a short-to-medium time frame for implementation; having a moderate-to-high chance for implementation; and requiring low-to-moderate (primarily administrative) effort to implement.

In-depth analysis of existing programs and listening sessions with representatives from across the state revealed that three key short-term actions can assist with better synergy between land use and drinking water source protection: 1) Employing the State of Maine's Quality of Place Investment Strategy to strengthen drinking water source protection, using the state's ability to direct funding for infrastructure and economic development. 2) Continuing a phased investment in on-line mapping resources and information sharing to provide critical data to local governments and developers so they can make more informed land-use decisions. 3) Developing guidelines for compatible recreational opportunities in and around sensitive protection areas to provide greater access to conservation funding and a broader constituency to preserve lands and waters important for drinking water. Maine's Drinking Water Program has initiated implementation efforts in all of these areas.

## 5.2.3 Local

**Land Protection**

Land trusts are typically non-profit entities that coordinate the acquisition of land, or easements that limit development on land, for the purpose of protecting open space and conserving natural resources. Land can be donated, sold at a discount, or sold at market price to local, state, or federal government, or to land trusts that will typically then serve as the stewards of that land or entrust stewardship to a local or state government agency. A conservation easement is a tool that allows the landowner to maintain ownership of the land while entering into a legal arrangement to limit the uses of the land. For example, a farmer may own a large tract of land that can be sold on the private market and be developed, or they can work with a land trust to place an easement on the property whereby the land is permitted to remain in agricultural use or to remain idle but is not permitted to be developed. Organizations such as The Trust for Public Land, American Farmland Trust, and The Land Trust Alliance can provide information and assistance on land protection issues. Conservation easements and other types of development restrictions can be pursued by state and local governments as well. Many states provide income or other tax credits to landowners who donate land or easements for conservation purposes. This can be a useful mechanism for increasing voluntary participation in conservation.

Green infrastructure assessments, such as those described in Chapter 3, are increasingly being used as an overarching conservation framework in the comprehensive planning process of municipalities and counties. Some maintain their approach within the strict definition of green infrastructure, while others have expanded their programs to consider "working lands" such as agricultural areas, historic lands, and cultural resources. Identification of a community's green infrastructure is the first step in preserving it. The community's zoning and comprehensive plan (or master plan) can then be revised to plan for growth around the green infrastructure (see sidebar). Chapter 3 contains additional examples of green infrastructure assessments and the role that they play in local land use planning.

**The Central Texas Greenprint for Growth: A Regional Action Plan for Conservation and Economic Opportunity, Texas**

http://envisioncentraltexas.org/resources/GreenprintMkt.pdf

The City of Austin, Texas launched its smart growth program in 1998 after years of advocacy surrounding watershed protection and parks. The most sensitive third of the region's land drains into the Edwards Aquifer in Texas. This area was designated as a "Drinking Water Protection Zone" by the city's residents, and the remaining two thirds were designated a "Desired Development Zone." Since then, Travis County and surrounding counties that are part of the Austin metropolitan area have been growing quickly. The Greenprint that the Trust for Public Land, the Capitol Area Council of Governments, and Envision Central Texas developed in partnership with Travis, Hays, Bastrop, and Caldwell County residents suggests directing development towards areas with existing infrastructure and away from the sensitive lands draining to the aquifers. The Greenprint's opportunity maps identify lands that are most important for regional water quality and quantity protection for each of the counties. It includes maps for conservation lands to achieve other goals that residents identified as well. Travis County, Hays County, and City of Austin voters have repeatedly approved tax increases to purchase land and development rights in order to protect critical lands in the region.

The Protected Areas Database of the United States partnership is creating a national inventory of all public and private protected lands. The draft data layer is available for download and online viewing and can be used to identify lands already in conservation easements or some other kind of protection status (Protected Areas Database of the United States Partnership, 2009). This resource can be helpful in further prioritizing adjacent lands for protection or restoration.

**Land Protection and Climate Change**

Land protection and stewardship are critical components of protecting healthy watersheds. They are especially important in a changing climate. EPA recently evaluated the decision-making strategies of land protection programs across the country in the context of climate change impacts. Programs that focus on wildlife and watersheds were chosen for the evaluation due to the impacts that climate change is expected to have on these elements. The authors used the Trust for Public Land's LandVote database (2009), which compiles information on land protection activities across the nation, to analyze these management trends. The large majority of land protection programs evaluated did not consider climate change in their decision making process (U.S. Environmental Protection Agency, 2009b). However, the report identified strategies that might be useful for land protection programs on how to consider climate change in future transactions. These include decision support tools for advisory committees, promulgation of different land protection models (e.g., purchase, as opposed to transfer, of development rights), and educational outreach for elected officials (U.S. Environmental Protection Agency, 2009b). Land protection strategies should consider both the mitigation potential of the land through carbon sequestration and the adaptation potential of the land for protecting water resources and wildlife migration routes, as well as the potential to buffer infrastructure from storm events (U.S. Environmental Protection Agency, 2009b).

Carbon markets are an emerging approach for mitigation of climate change and conservation of forested lands, and may play an important role in land protection strategies in the coming years. Deforestation is responsible for 20% of all carbon emissions worldwide. Since forests sequester large amounts of carbon, protection of these lands is a critical element in addressing climate change. Carbon markets provide a mechanism whereby an emitter of carbon dioxide can purchase carbon credits from sellers to offset their own emissions below a "cap," usually determined by a government or international body. The sellers must be emitting less than the cap to have any credits to sell. Credits can also be determined through the use of a baseline, as opposed to a government imposed cap. By helping to prevent deforestation, land protection can generate credits based on the amount of carbon emissions avoided.

As the effects of climate change increasingly manifest themselves, adaptation strategies will become more and more important. A certain amount of climate change will occur regardless of the actions taken to reduce future greenhouse gas emissions. Consequently, adaptation strategies are an important component to addressing climate change. An important component of these strategies can be to protect the remaining natural areas. Wetlands and headwater streams, for example, regulate the downstream flow of water, retaining water in wet conditions and releasing it in dry conditions. They thereby serve as important components for protection against both floods and droughts. Riparian vegetation protects streams from the effects of increased runoff expected in many parts of the country due to increased intensity and frequency of extreme storm events. Also, vegetated riparian areas provide habitat and corridors for migration.

**Land Use Planning**

From a big picture perspective, protecting healthy watersheds has a lot to do with land use, sprawl, and development. River banks are often armored to "protect" riparian development, but this practice typically exacerbates erosion downstream. Increased impervious surfaces associated with development often increase runoff volumes and the build-up and wash-off of pollutants into surface waters. Wildlife habitat and valuable plant communities are lost when natural land cover is removed to make way for new development. The natural disturbance regime is disrupted when the natural fire regime is suppressed, large withdrawals are made from rivers or ground water, or dams are constructed to generate electricity to satisfy the ever increasing demands of residential and industrial growth.

### Green Infrastructure and Master Plans Alachua County, Florida (Alachua County, 2008)

Following the state's leadership in green infrastructure, Alachua County, Florida updated their master plan in 2005 to include specific policies that require or incentivize protection of wetlands, surface waters, floodplains, listed species habitat, significant geologic features, and the highest category of protection, "strategic ecosystems." Strategic ecosystems are specific mapped areas in Alachua County that are the 47 most significant natural communities, both upland and wetland, remaining in private ownership. Minimum conservation standards for this green infrastructure include protection of all wetlands and surface waters, protection of at least 50 percent of all upland within the strategic ecosystems, conservation easements, management plans, and environmentally friendly designs. Development rights are preserved through increased allowable densities on buildable areas or by transfer of development rights to other properties.

One of the greatest contributions to protecting healthy watersheds may come from ecologically-based land use planning. Land use regulation is primarily a local authority, with the state responsible for establishing the laws and regulations that enable local land use planning. These laws vary considerably from state to state, but generally provide guidance to localities (sometimes mandatory, sometimes voluntary) in the development of comprehensive plans (sometimes referred to as master plans). Some state land use planning laws require that natural resources are taken into account in comprehensive plans (Environmental Law Institute; Defenders of Wildlife, 2003). Others require provisions for protection of open space or require consideration of wildlife habitat (Environmental Law Institute; Defenders of Wildlife, 2003). Some states may not require these issues to be considered in the development of comprehensive plans, but may suggest it. Some state land use planning laws require the state to develop a statewide land use plan or policy (Environmental Law Institute; Defenders of Wildlife, 2003). Other states are authorized to provide support or assistance in the development or implementation of local land use plans (Environmental Law Institute; Defenders of Wildlife, 2003).

In an evaluation of the role of conservation in land use planning, the Environmental Law Institute (2007a) made six general recommendations for how to advance conservation planning:

1. Develop communications tools that convey the value of ecological knowledge and conservation planning to decision makers.
2. Develop requirements and incentives for proactive conservation planning.
3. Measure the effectiveness of conservation planning and implement adaptive management where needed.
4. Find ways to overcome the disconnect between the different scales at which land use planning and conservation are carried out.
5. Define specific conservation thresholds (e.g., minimum riparian buffer width) based on the best available science.
6. Provide a technical support infrastructure and interdisciplinary training for planners and conservation scientists.

Smart Growth is a land use planning concept that can contribute significantly towards protecting healthy watersheds. Smart Growth refers to a land use strategy to prevent sprawl and create communities with diverse transportation, employment, and housing options. It focuses on minimizing the development of natural and rural areas by directing growth within cities through rehabilitation and reuse of existing infrastructure, improving public transit and bicycling or walking options, and making urban environments more desirable places to live. The Smart Growth Network (2009) identifies 10 principles of smart growth:

1. Create a range of housing opportunities and choices.
2. Create walkable neighborhoods.
3. Encourage community and stakeholder collaboration.
4. Foster distinctive, attractive communities with a strong sense of place.
5. Make development decisions predictable, fair, and cost effective.
6. Mix land uses.
7. Preserve open space, farmland, natural beauty, and critical environmental areas.
8. Provide a variety of transportation choices.
9. Strengthen and direct development towards existing communities.
10. Take advantage of compact building design.

These principles have been adopted by numerous states in their own smart growth programs intended to assist communities in developing local strategies to prevent sprawl and minimize the loss of remaining natural areas. Transportation and land use are two closely related issues. Traditional zoning practices encourage separation of land uses, requiring motorized transport for people to travel to work, go grocery shopping, etc. Public transit options have virtually disappeared in all but the largest cities, leaving people with no choice but to purchase automobiles, exacerbating the problem even further. By encouraging mixed land uses, increasing public transit and bicycling/walking options, and directing development towards existing communities, the pressures that create sprawl can be reduced, and more of our remaining natural places can be preserved.

Higher density development has recently been recognized as a strategy that can help prevent the spread of impervious surfaces, landscape fragmentation, and overall ecological degradation (U.S. Environmental Protection Agency, 2006b). Although high density development may have higher proportions of impervious surfaces per acre, it can actually reduce the total amount of impervious surfaces in the watershed. This is partly because high density development decreases need for roads and parking lots. High density development is compatible with the 10 principles of Smart Growth.

**Watershed-Based Zoning in James City County, Virginia**

http://www.jccegov.com/environmental/index.html

James City County, Virginia completed its Powhatan Creek Watershed Management Plan in 2001. Due to the rapid development experienced in the previous two decades, the county decided to pursue a watershed-based zoning approach to protect its high quality streams from future development impacts. An impervious cover and instream/riparian habitat assessment categorized each of the county's subwatersheds as Excellent, Good, Fair, or Poor. Using a combination of innovative land use planning techniques, including transfer of development rights, conservation development, rezoning, and resource protection overlay districts, the county has directed growth away from its most sensitive and ecologically valuable subwatershed and developed strategies to minimize further impacts in those degraded subwatersheds designated for growth. Each subwatershed was also targeted for other specific management measures to either conserve, protect, or restore streams according to the level of threat imposed on each.

Conservation Development (sometimes referred to as cluster design) is a zoning strategy that decreases residential lot sizes and clusters the developed areas together, protecting the remaining areas as shared open space. This prevents large lot development, which has contributed to suburban sprawl and habitat fragmentation. By clustering development together, whether in rural cluster designs, or by taking advantage of infill development of cities, sprawl, and excessive spread of impervious surfaces are reduced. Additional information on conservation development can be found in Arendt (1999).

Watershed-based zoning is a land use planning strategy based on the boundaries of small watersheds. By directing future development towards watersheds where it will have the least negative impact, this strategy can protect watersheds with high ecological integrity. This strategy involves significant collaboration between adjacent municipalities, as watershed boundaries rarely coincide with political boundaries. A watershed-based zoning approach should include the following nine steps (Schueler, 2000):

1. Conduct a comprehensive stream inventory.
2. Measure current levels of impervious cover.
3. Verify impervious cover/stream quality relationships.
4. Project future levels of impervious cover.
5. Classify subwatersheds based on stream management "templates" and current impervious cover.
6. Modify master plans/zoning to correspond to subwatershed impervious cover targets and other management strategies identified in Subwatershed Management Templates.
7. Incorporate management priorities from larger watershed management units such as river basins or larger watersheds.
8. Adopt specific watershed protection strategies for each subwatershed.
9. Conduct long-term monitoring over a prescribed cycle to assess watershed status.

Revision of zoning regulations and/or the use of transfer of development rights are usually necessary in implementing watershed based zoning. Transfer of development rights is a technique that allows a land owner in an area designated as a priority for protection by local government to sell their development rights to another land owner in an area designated for higher density development.

In addition to zoning strategies, counties and municipalities have the ability to create a variety of other ordinances that can serve to protect valuable natural resources. The Center for Watershed Protection (2008a) and EPA (2006a) both have web sites with model ordinances available for communities to use in developing their own local ordinances to protect natural resources and ecologically valuable areas. These include ordinances to protect aquatic buffers, open space, wetlands, etc.

Low Impact Development (LID) is a stormwater management approach that focuses on managing runoff at the source through the use of design practices that allow for infiltration, storage, and evaporation. Rain gardens, pervious pavements, tree box planters, green roofs, and disconnected downspouts are all examples of LID practices. These practices have been shown to be less expensive and more environmentally friendly than more traditional stormwater management practices, such as conveyance systems (U.S. Environmental Protection Agency, 2007b). LID practices help to reduce stormwater runoff from urban areas, which can improve water quality, ground water recharge, and the biological condition of stream habitats. However, the potential for ground water contamination must also be considered, especially in areas with contaminated soils.

**River Corridor and Headwaters Protection**

As discussed in Chapter 2, natural river corridors are important for maintaining dynamic equilibrium of the river channel, providing valuable wildlife habitat, and regulating floodwaters. When designing river corridor protection strategies, it is important to remember that river channels can migrate laterally over time. When possible, the entire river corridor should be protected from development through the use of fluvial erosion hazard area districts, river corridor easements, and other local programs (Kline & Dolan, 2009). The State of Vermont is in the process of implementing a statewide river corridor protection program. Using the results of their statewide stream geomorphic assessments (Chapter 3), state staff are working with local stakeholders to identify river corridor protection options such as easements and zoning overlay districts. These strategies are designed to protect the dynamic nature of the riparian area. Simple riparian buffer protection ordinances and overlay districts are certainly beneficial for water quality and wildlife, yet they often fail to address all of the requirements of the riverine system as it meanders over time and experiences flood events. River corridor protection benefits not only water quality and wildlife, but also public safety (Kline & Cahoon, 2010).


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As described in the River Continuum Concept (Vannote, Minshall, Cummins, Sedell, & Cushing, 1980), headwater streams contain unique assemblages of organisms that begin the processing of coarse particulate organic matter, providing the energy required by other assemblages of organisms downstream. Healthy headwater stream areas provide valuable wildlife habitat and corridors for migration of wildlife. They also provide sediment, nutrient, and flood control in much the same way that wetlands do. Headwater streams also help to maintain base flow in larger rivers downstream. Fundamental to a healthy watershed, properly functioning headwater streams are one of the primary determinants of downstream flow, water quality, and biological communities. Protection of these areas through land use planning and protection is particularly important.

# Case Study

## Headwaters: A Collaborative Conservation Plan for the Town of Sanford, Maine

**More Information:** http://swim.wellsreserve.org/results.php?article=828Conservation%20Strategy%20September%207,%202010.pdf

The Town of Sanford, Maine is located at the headwaters of five critically important watersheds in southern Maine and New Hampshire. Using community input and science-based conservation principles to implement the conservation goals of its comprehensive plan, the town is protecting these regional resources. Over the course of three stakeholder workshops, and using innovative GIS and keypad polling techniques, the community developed the following core conservation values:

- Water quality protection.
- Conserving productive land for agriculture.
- Conserving significant wildlife habitat and biodiversity.
- Protecting human health and safety through conservation of floodplains, water supply buffers and wetlands.
- Conserving scenic, cultural and recreational resources.

The community recognizes that these values are provided by Sanford's green infrastructure. Using a GIS software program called Community Viz (www.communityviz.com), the community mapped the green infrastructure that is important for protecting each of these values (Figure 5-8). Once this community-based assessment phase was completed, the town developed recommendations and strategies for protecting each of the five conservation values. One of these strategies was to identify "focus areas" by considering the relative importance placed on each conservation value by community members. Keypad polling techniques, which use electronic keypads (similar to television remote controls) to allow large numbers of community members to place their vote on which conservation values are most important to them, were critical for ensuring participatory decision-making without slowing down the process. The focus areas were identified from the polling results, which are automatically tallied by a computer and displayed through a projector. These high-priority conservation sites were evaluated for the amount of protected land that they currently contain and the specific threats posed to each focus area by human activities. These focus areas are considered the priorities for action.

Outside of the focus areas, there are additional locations that contain one or more of the five conservation values. These areas were prioritized for protection based on a ranking of land parcels according to their relative value. For example, a parcel containing both exemplary wildlife habitat and water resources would receive a higher priority for protection than a parcel that only contains wildlife habitat.

The following strategies were identified as options to implement the Sanford conservation plan:

- Fee simple purchase.
- Conservation easements.
- Conservation subdivisions.
- Current use program.
- Land use ordinances.
- Community education and outreach.

Responsibilities for implementation of the plan were assigned to each participating stakeholder group, funding sources were identified, and a monitoring and evaluation process was put in place to ensure effectiveness of the plan.

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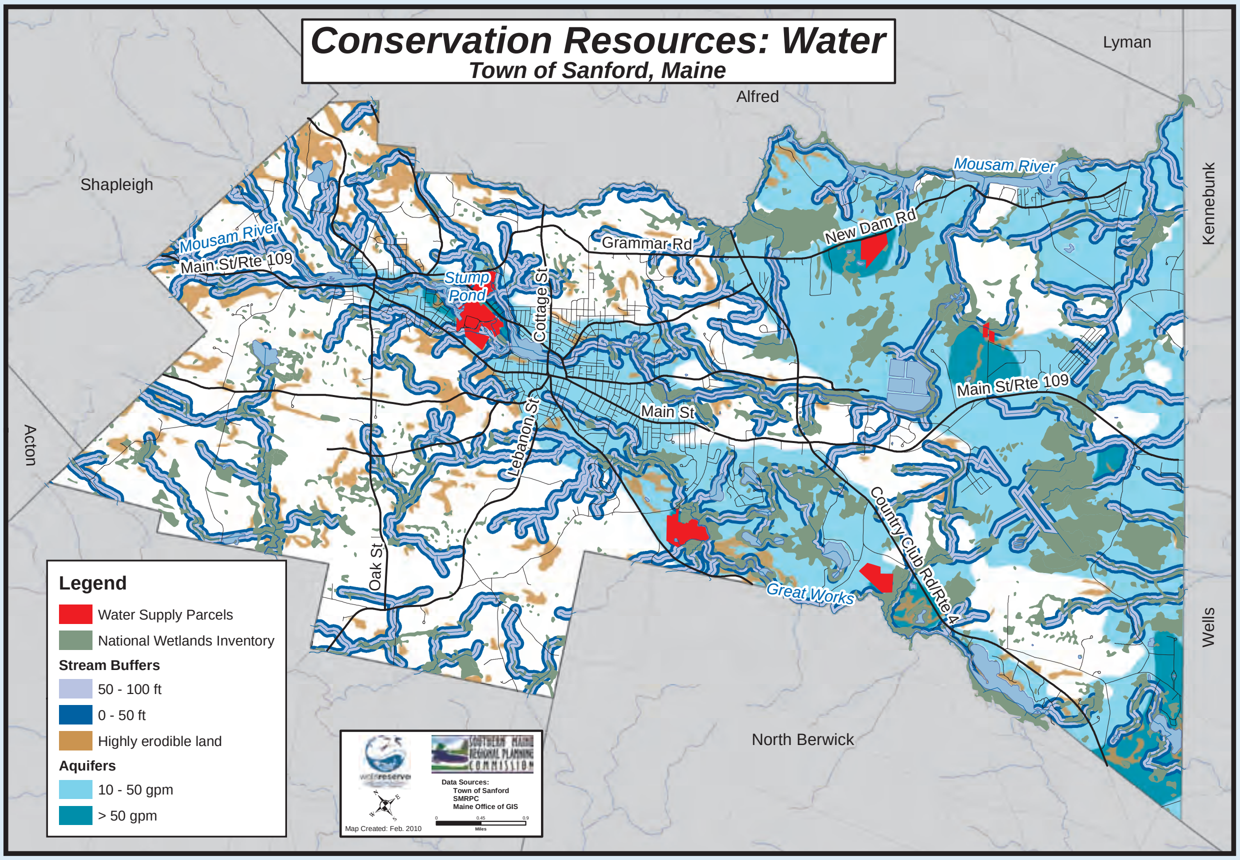


**Figure 5-8** Green infrastructure identified for water quality protection (Wells National Estuarine Research Reserve; Southern Maine Regional Planning Commission, 2009)

Case Study

## Lower Meramec Drinking Water Source Protection Project

**More Information:** http://cloud.tpl.org/pubs/landwater-lowermer-swp-brochure.pdf

The U.S. Forest Service and the Trust for Public Land (TPL) initiated the Lower Meramec Drinking Water Source Protection Project to expand the reach of forest protection projects in drinking supply watersheds in the northeastern United States to the Midwest region. The Meramec River is a drinking water source for the City of St. Louis, Missouri and its suburbs. Although the river's water is currently high-quality, the watershed is highly susceptible to degradation due to development pressures. Preserving the natural land that drains into drinking water supplies is an ecosystem-level strategy for protecting water quality. In addition to providing drinking water, the Meramec River provides wildlife habitat and recreational opportunities.

The Meramec River Tributary Alliance, a partnership of more than 30 organizations interested in protecting the river, provided local knowledge over the course of the project. In the first phase of the project, the U.S. Forest Service, TPL, and the Meramec River Tributary Alliance refined the project area to focus on the Fox-Hamilton-Brush Creek watersheds. GIS data layers were used to score 30 meter landscape cells for their physical characteristics, such as proximity to water features, and current land use. Raw scores were used to produce a conservation priority index map (Figure 5-9) and a restoration priority index map. Local units of government and real estate experts use these maps to identify opportunities for land protection, restoration, and implementation of stormwater best management practices. The project steering committee also developed a brochure describing the project for local governments, water suppliers, and conservation groups to use and distribute.

The project's second phase, referred to as the strategy exchange, took place over the course of five days. The strategy exchange was a discussion of drinking water source education, stormwater best management practices, septic system improvements, and land conservation with state and local governments, as well as other local actors. As an outcome of the exchange, regional and national experts contributed strategy recommendations to a report addressing these four topics.

In the project's third and final phase, subcommittees of the Meramec River Tributary Alliance incorporated the exchange team's recommendations for each of the four topics into action plans for immediate implementation that included both voluntary and regulatory or enforcement tactics. Although low-budget tactics were identified, some tactics will require additional funding for implementation. The land conservation subcommittee has started to implement recommendations from TPL's conservation finance team to attract and retain funding for land acquisition. Successful implementation of the action plans will protect the ecological integrity of the Lower Meramec so that it can provide not only clean drinking water, but also all of the diverse services Meramec River Tributary Alliance member groups have individually set out to protect.

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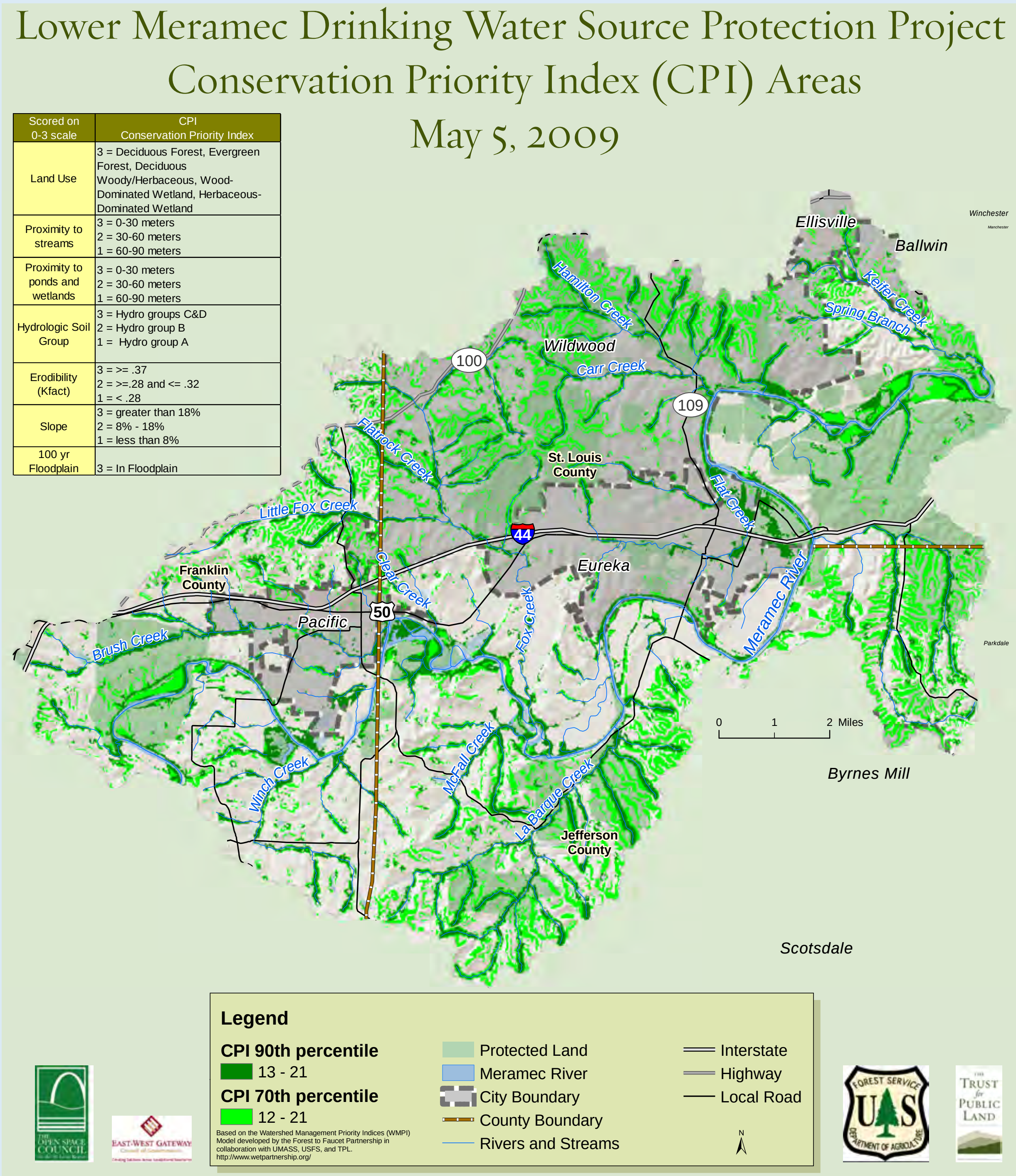



**Figure 5-9** Map of Lower Meramec Drinking Water Source Protection Project Conservation Priority Index Areas (Trust for Public Land, 2010).

# Case Study

## Cecil County, Maryland Green Infrastructure Plan

**More Information:** http://www.conservationfund.org/sites/default/files/CecilCounty01.22.08.pdf

The Conservation Fund is a national organization that partners with local communities to help them fulfill their conservation priorities. In 2007, The Conservation Fund partnered with Cecil County, Maryland to develop a green infrastructure plan. This plan includes a green infrastructure network design, water quality maintenance and enhancement analysis, ecosystem services assessment, and implementation quilt analysis. As described in Chapter 3, a green infrastructure assessment identifies a network of lands, composed of ecological core areas and corridors connecting these hubs. The water quality and ecosystem service assessments demonstrate the importance of protecting the green infrastructure network. For example, 81% of the value of the county's ecosystem services ($1.7 billion/year) are contained within the network. The implementation quilt analysis outlines a comprehensive approach to protection of Cecil County's green infrastructure network. Specific protection strategies were identified to address the county's tremendous growth rate and land use change and the fact that only 23% of the network is in some form of protected status.

Based on the assessment, a number of strategies for protecting water quality were identified. Sixteen Conservation Focus Watersheds were identified where existing land cover is greater than 50% forest and wetland (Figure 5-10). Natural land cover in these priority watersheds could be maintained through comprehensive plan objectives, performance zoning standards, and other land use planning programs. Ten Reforestation Focus watersheds were also identified. These watersheds have between 30-40% forest and wetland cover and thus have high ecological capacity for recovery. Agricultural BMPs such as riparian fencing, nutrient management, reduced phosphorus in animal feed, and conservation tillage were also identified as management measures for improving water quality. A comprehensive zoning program using performance standards for site plan review was recommended for improving development site design. The performance zoning code would reward projects using LID techniques.

In addition to the management strategies already identified, the implementation quilt analysis identified additional opportunities for protection. These include use of Program Open Space funds for acquisition of high priority properties in the green infrastructure network; purchase of conservation easements through the Rural Legacy Program; participation in the Maryland Agricultural Land Preservation Foundation's Agricultural Preservation District program; donation of conservation easements through the Maryland Environmental Trust program, which provides tax credits and other incentives to donors of easements; and a number of federal programs. The County also recently implemented a Transfer of Development Rights and Purchase of Development Rights program to protect ecologically valuable lands from development. The Conservation Fund specifically recommended that Cecil County enhance its cluster development option and create a Green Infrastructure Network Overlay with performance standards in its zoning. The County is now using the Green Infrastructure Plan as an advisory document in its comprehensive planning process.

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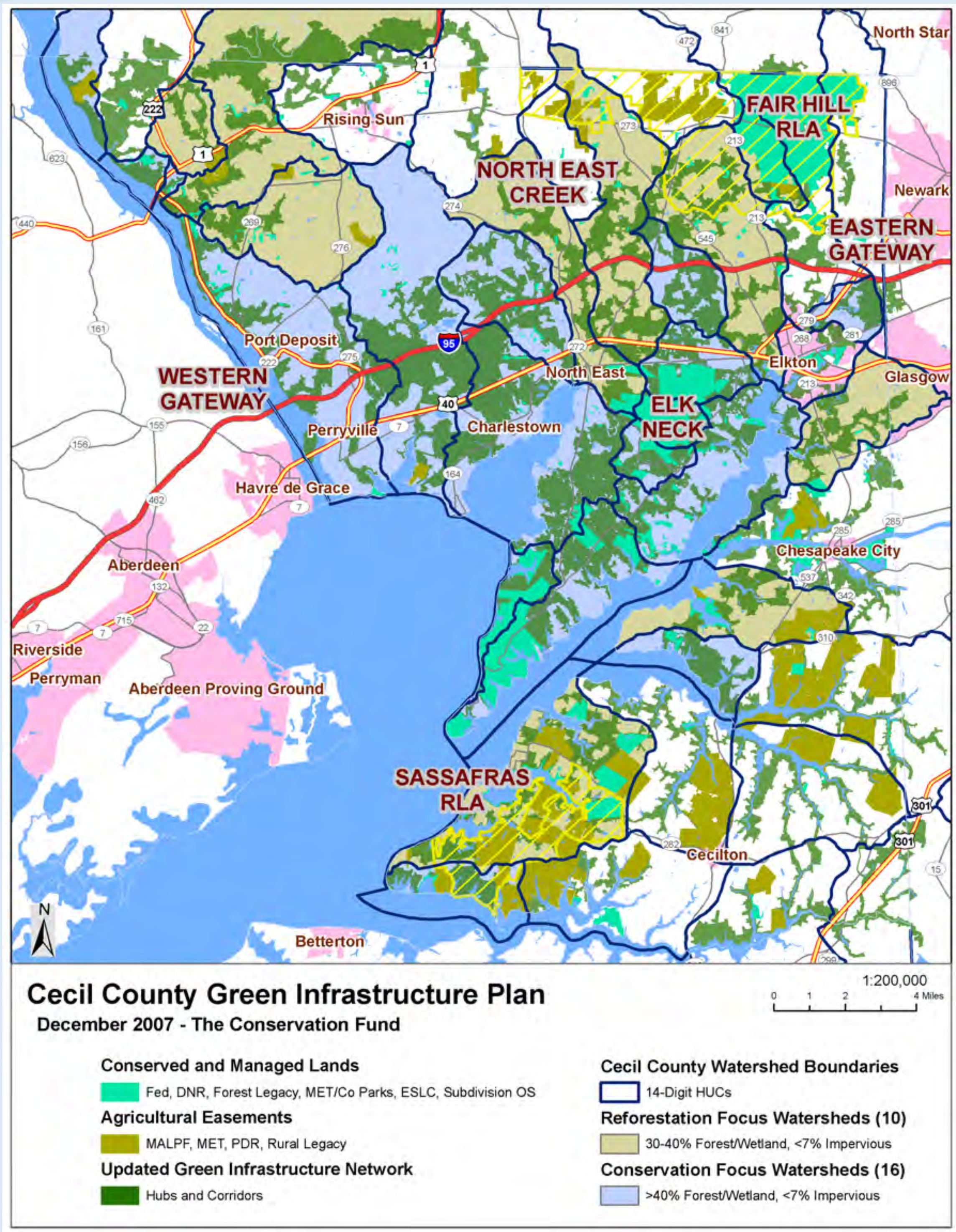



**Figure 5-10** Map of Cecil County Green Infrastructure Plan (Will Allen, The Conservation Fund, Personal Communication).

## 5.2.4 Other Protection

**Sustainable Agriculture**


Agriculture is an important economic and cultural activity in many communities across the United States. Similar to residential development, careful management of agricultural areas can ensure that the aquatic ecosystem is not degraded and that terrestrial habitat is maintained. Designing a green infrastructure network is one method of identifying the most critical lands to protect from conversion to agriculture and can also include certain appropriate agricultural lands as cultural protection priorities. The USDA National Organic Program develops and implements standards for organic agricultural products in the United States. Organic agriculture avoids the use of synthetic pesticides and fertilizers, both of which impact water quality. It also reduces erosion and sequesters carbon dioxide in the soil. Individual growers and producers can contact accredited certifying agents in their states to become certified (U.S. Department of Agriculture, 2009). Participation in certification programs can help to ensure that agricultural activities are conducted in an ecologically sensitive manner.

Sustainable agricultural management practices include nutrient management, which refers to the application of fertilizers in appropriate amounts and at appropriate times; conservation tillage or continuous no-till; cover crops to reduce erosion and keep nutrients in the field; and vegetative buffers, which protect aquatic ecosystems from agricultural runoff and provide wildlife habitat. The Conservation Effects Assessment Project is a multi-agency effort to evaluate and quantify the effects of these and other agricultural conservation techniques on the environment. The USDA leads this effort, which focuses on watersheds, wetlands, and wildlife. The USDA also leads the Environmental Quality Incentives Program, Conservation Reserve Program, Wetlands Reserve Program, Wildlife Habitat Incentives Program, Conservation Security Program, and Grassland Reserve Program, all of which are described under Section 5.3.

**Sustainable Forestry**

Forestry is an important economic and cultural activity in many parts of the country. Organizations such as the Forest Stewardship Council provide certification of sustainable forestry practices in the United States and abroad. The Sustainable Forestry Initiative is an independent organization, originally developed as a program of the American Forest and Paper Association, which works to improve sustainable forest management practices through third-party certification audits. The principles of the Sustainable Forestry Initiative include requirements for sustainable forestry practices, long-term forest health and productivity, prompt reforestation, protection of water quality and the promotion of sustainable forestry on private nonindustrial lands (Barneycastle, 2001).

### Invasive Species Control

When a non-native species is introduced into an ecosystem, it can cause a tremendous amount of damage to native species. This is because the native species evolved over hundreds of thousands of years to compete with the unique combination of other species native to its ecosystem. When a non-native species is suddenly introduced (i.e., through human intervention), the native species do not have time to evolve strategies to compete. Additionally, if ecosystems are degraded, it is easier for non-native species to take hold. Many such introductions do not cause significant harm. However, a number of introduced species become invasive, which means that they are directly harming or outcompeting native species. Invasive species can decrease biodiversity and ecosystem resilience. Many of these species, such as Salt Cedar, replace native vegetation and form monocultures (stands of only one tree species). Salt Cedar specifically replaces native riparian vegetation such as willows and cottonwoods and also uses a tremendous amount of water. It uses so much water in fact, that it can lower ground water levels to such a degree that instream flows are affected and native vegetation is unable to reach the subsurface water for its own nourishment. The best strategy for controlling invasive species is prevention. Education campaigns about invasive species are key to prevention. Even simple signs at public boat landings can help. Once an invasive species becomes established, it is difficult to eradicate. Early detection and action is critical. Chemical, mechanical, and biological control techniques exist for eradication. The most extreme cases may require restoration actions, such as controlled burning to remove the non-native species, followed by reintroduction of the native species.

### Ground Water Protection

Any approach to healthy watershed management should incorporate ground water in addition to surface water components. In the case of ground water dependent ecosystems (GDE), direct habitat protection, ground water discharge to the GDE, and the temperature and chemistry requirements of ground water supplying the GDE must be considered. Specific management strategies can be identified to protect each of these attributes. GDE habitats can be protected by establishing buffer zones to separate them from resource extraction and trampling. Ground water discharge to GDEs can be protected by establishing maximum limits for ground water extraction or establishing minimum distances from GDEs from which ground water wells could be sited. Ground water quality can be protected by limiting or eliminating land use activities in recharge zones that could impact water quality. To date, most ground water management in the United States has largely been developed and implemented with the objective of protecting ground water supplies for human consumption. Additional focus is needed to ensure protection for GDEs.

#### Protection of Ground Water Dependent Ecosystems on Range Land

In many regions, focused discharge of ground water to the surface supports critical biodiversity. On at least a seasonal basis, in the semi-arid western United States, these GDEs may have the only available water. When located on range land, the water and associated wetland vegetation make GDEs very inviting to livestock and can result in the damage or destruction of these features.

In order to protect the integrity of GDEs on range land, the Forest Service and others have developed techniques to limit the effects of grazing. Since the availability of water is critical to the success of ranching in many areas, any approach to protecting GDEs should address the need for livestock to access water. One approach the Forest Service has used with some success involves the development of a small-scale water diversion or withdrawal from the GDE, the siting of a stock tank or trough at a distance outside the GDE, and the development of an exclosure fence surrounding the GDE to exclude livestock from the GDE itself.

This approach accomplishes several key range management goals, including: discouraging livestock use of the GDE by providing a consistent, readily available source of water away from the spring; allowing for a better distribution of livestock across the allotment by reducing the incentive to congregate at the GDE; taking pressure off of the sensitive soils and vegetation adjacent to the water and improving overall GDE conditions by limiting grazing effects; improving water quality by improving soil and vegetation conditions within the GDE and eliminating livestock excrement from the water; and improving water availability to wildlife.

## 5.3 Restoration Programs

Restoration strategies are an essential component of managing healthy watersheds. As development pressures have expanded their reach to more and more pristine landscapes, entire healthy watersheds are less common. In addition, even the watersheds that can be classified as healthy often have room for improvement. For example, a healthy watershed may contain culverts. Replacing a dropped or undersized culvert with a larger, open-bottom culvert will enhance fish and wildlife passage along the stream. When planning restoration efforts, it is generally helpful to consider the "protect the best first" strategy. This strategy prioritizes restoration of the systems that are most likely to maintain their health post-restoration (as in improving healthy watersheds) before investing resources in systems that may be degraded beyond their recovery potential.

Much of aquatic ecosystem restoration to date has focused on the symptoms, rather than the causes, of ecosystem degradation. Altered geomorphology, impaired water quality, and degraded biotic communities are typically the result of processes occurring in the watershed. Restoration of stream channel form must begin at the watershed scale, focusing on *processes* such as watershed hydrology and sediment supply. Restoration of water quality must focus on the landscape condition that is affected by the socioeconomic drivers of land use. Restoration of biotic communities must focus on the natural flow regime necessary for the different life stages of the aquatic biota, the physical habitat determined by the geomorphic condition, and the water quality that is largely determined by the landscape condition.

Ecological restoration is a new and growing field that, broadly defined, seeks to return degraded ecosystems to a state closer to their original, natural conditions. EPA's Principles for the Ecological Restoration of Aquatic Resources (2007a) emphasize, amongst other things, working within a watershed or landscape context, restoring ecological integrity based on a system's natural potential, and the use of passive restoration and natural fixes. A system's natural potential can be determined in a number of ways, including the use of appropriate reference sites for the ecoregional setting. Passive restoration refers to a reduction or elimination in the sources of degradation, as opposed to active approaches such as alum treatment. There are cases when active restoration is necessary, but passive restoration is often sufficient and more cost-effective. In addition, active restoration can sometimes have unintended and unforeseen effects on other system components. A small sampling of national, state, and local restoration programs are described below.

### 5.3.1 National

**The National Fish Habitat Action Plan** is a nationally linked, yet locally driven effort to improve fish habitat across the country (www.fishhabitat.org). Fish habitat partnerships are formed voluntarily and collaborate to protect, restore, and enhance fish habitat through, federal, state, and locally funded projects.

**The National Fish Passage Program** was initiated by the USFWS to reconnect aquatic species with their historic habitats. Through the National Fish Passage Program USFWS leverages federal funds to secure donations from partners and provides technical assistance to remove or bypass artificial barriers to fish movement.

**The Partners for Fish and Wildlife Program** provides technical and financial assistance to private landowners and tribes who agree to work with the US Fish and Wildlife Service and other partners on a voluntary basis to help meet the habitat needs of Federal Trust Species (migratory birds; threatened and endangered species; inter-jurisdictional fish; certain marine mammals; and species of international concern).

**The Restoration Center** is the only office within the National Oceanic and Atmospheric Administration (NOAA) devoted solely to restoring the nation's coastal, marine, and migratory fish habitat. They fund and implement restoration projects to ensure healthy, productive, sustainable fisheries; employ technical staff to help improve project design, ensure environmental compliance, and advance restoration techniques; engage the local community and encourage stewardship of the nation's coastal habitat; fund projects that engage local people and resources, supporting the economy through restoration activities, expertise, and materials; collaborate with public, private, and government partners to prioritize projects and leverage resources; use scientific monitoring to evaluate restoration project success and maximize the use of tax dollars; and conduct socioeconomic research that demonstrates the benefits of coastal restoration for community and environmental purposes.

**Total Maximum Daily Loads** (TMDL) are a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. They are watershed assessments that are conducted for impaired water bodies as designated under section 303(d) of the Clean Water Act. TMDLs are required for all pollutant-impaired water bodies and can be considered the beginning of a watershed restoration plan focused on water quality. Most TMDLs now use a watershed approach for assessment and implementation. However, implementation of a TMDL and watershed restoration plan is critical if water quality is to be restored.

**The Nonpoint Source Management Program** was established under section 319 of the Clean Water Act to support a variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects, and monitoring to design and assess the success of nonpoint source programs and projects. In particular, the program provides funding for the implementation of TMDLs and watershed management plans. The watershed management plans, though federally funded, are implemented at the state and local level, typically by county governments, conservation districts, and watershed councils.

**The Conservation Reserve Enhancement Program** is a USDA program that protects ecologically sensitive land, wildlife habitat, and aquatic ecosystems through retirement of agricultural lands. The program provides payments to farmers and ranchers who agree to keep their land out of agricultural production for at least 10-15 years. The program has been used to establish riparian buffers, restore wetlands, and create wildlife habitat through reforestation.

**The Wetlands Reserve Program**, another USDA program, assists landowners in restoring agricultural wetlands. NRCS may fund 75-100% of project costs on lands that are under a permanent conservation easement, and 50-75% of restoration costs on lands under temporary easements or cost-share agreements.

**The USDA Wildlife Habitat Incentives Program** assists private landowners in creating and improving wildlife habitat through cost-share assistance up to 75% of project costs.

**The Environmental Quality Incentives Program** is a USDA program that provides cost-share assistance to farmers in implementing various conservation measures including erosion control, forest management, comprehensive nutrient management plans, etc.

**The USDA Conservation Security Program** provides technical and financial assistance for conservation purposes on working lands, including cropland, grassland, prairies, pasture and range land, and incidental forest lands on agricultural properties.

**The Grasslands Reserve Program** is a voluntary program to limit future development and cropping uses on grazing lands to support protection of these areas. This USDA program establishes grazing management plans for all participants.

## 5.3.2 State and Interstate

### Restoration of Flow and Connectivity

Historically, straightening and armoring of stream channels was a common practice to protect floodplain development from a meandering river and for navigation purposes. Unfortunately, this practice increases a stream's energy, which is sent to a downstream reach where significant erosion of the stream channel can occur. Depending on the current riparian land uses, it may be possible to remove the bank armoring and allow the stream channel to reclaim some of its original floodplain. Similarly, many dams have been built across the United States over the past 200 years. While many of these dams are essential for providing drinking water, hydroelectric power generation, and agricultural irrigation water, a large number of them have been decommissioned or abandoned. These dams are often prime candidates for removal to restore the natural flow regime and improve aquatic habitat connectivity. Dam removal projects are a significant undertaking and involve physical, chemical, hydrological, ecological, social, and economic considerations (American Rivers, 2009a). Where it is not feasible to remove a dam, reservoir release rules that mimic the natural flow regime can improve the ecological function of the river (Richter et al., 2006). However, when working in riverine ecosystems that have been highly modified, managers must often rely on site-specific flow-ecology relationships to inform restoration decisions. Some possible strategies identified by The Nature Conservancy for flow restoration include:

- Dam reoperation.
- Conjunctive ground-water/surface-water management.
- Drought management planning.
- Demand management (conservation).
- Water transactions (exchangeable water rights).
- Diversion point relocation.

**Meeting Urban Water Demands While Protecting Rivers: Rivanna River, Virginia (Richter B. , 2007)**

The Rivanna Water and Sewer Authority, working with The Nature Conservancy, has developed a new water supply plan that meets growing water demands and improves river ecosystem health. The new plan mimics natural flow regimes through controlled dam releases while ensuring adequate water supplies during drought. The releases are calculated as varying percentages of the inflow to the reservoir.

Aquatic ecosystems are dependent on sufficient instream flows for maintaining their vitality. For example, Pacific Salmon require specific gravels, water depths, and velocities during spawning to build their nests. Alteration of the natural flow regime can change water depth, velocity, and the substrate on which the spawning salmon depend. Anadromous fish, such as Pacific Salmon, also require stream connectivity for migration between the headwaters streams, where they are born, to the ocean, where they live out most of their lives. Where dams and other structures disrupt aquatic habitat connectivity and removal of these structures is not feasible or desirable, fish ladders and other upstream or downstream passage facilities can be used to ensure that fish retain access to habitat (U.S. Fish and Wildlife Service, 2009). This is especially important for anadromous fish species (e.g., salmon, alewife). States such as Oregon, Washington, and Pennsylvania have created fish passage rules that require stream crossings and other artificial obstructions to allow for the passage of migratory fish.

### 5.3.3 Local

**Greenways**, discussed in Chapter 2, are recreational corridors of natural vegetation that can be fit into existing developed areas to create or improve wildlife habitat, scenic and aesthetic values, and outdoor activities such as walking, running, and cycling (American Trails, 2009).

**Wetland construction and restoration** is typically a site-based restoration approach. However, when viewed in its landscape context, wetland restoration can improve wildlife habitat and connectivity, nutrient retention, hydrologic regulation, and pollutant removal. The benefits of wetland restoration are maximized when conducted in a landscape context (U.S. Environmental Protection Agency, 2007c).

**Reforestation** is a technique that can be conducted at a stand (site) or landscape scale and improves wildlife habitat and connectivity, infiltration of rainfall, and regulation of surface temperatures. Riparian reforestation can be especially beneficial to aquatic ecosystems, as riparian forests are important components of the Active River Area. Riparian forests in headwater catchments provide coarse particulate organic matter and large woody debris that supply the unique assemblage of organisms in headwater streams with the food and habitat they require. Organisms in lower reaches of the watershed depend on this upstream supply of energy as well. Floodplain forests in the lower reaches of the watershed provide valuable spawning grounds for some aquatic species during floods, provide habitat to terrestrial and semi-aquatic species, serve as buffers to attenuate nutrient delivery to the streams, and provide shading to the aquatic habitat which regulates water temperatures (Center for Watershed Protection; U.S. Forest Service, 2008b).

## 5.4 Education, Outreach, and Collaboration

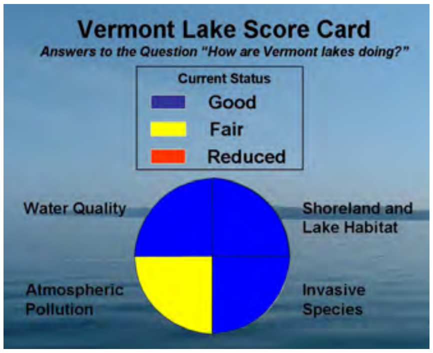
Outreach and education are two protection strategies whose importance cannot be overstated. Efforts to protect healthy watersheds are more likely to succeed if understood and supported by the local community. Communicating the results of healthy watersheds integrated assessments using plain language and graphical elements, such as watershed report cards or simple maps, facilitates the outreach and education process. Most community members will not be interested in fluvial geomorphology or flow duration curves. However, they will be interested in maintaining local fish populations and protecting their properties from flooding. Examples of outreach and education activities include:

- Presentations to local governments and to the general public.
- Newspaper articles describing the benefits of protecting healthy watersheds, and alerting the public to the sensitivity of healthy watersheds to degradation.
- Development and distribution of informative fact sheets or flyers.
- Development of a slide show and script for stakeholders to present with.
- Field trips (e.g., fishing, hiking, canoeing) that enable the public to see and appreciate examples of healthy watersheds firsthand.

Reaching out to the local community and educating stakeholders early in the process can lead to increased support for environmental protection as a result of an increased understanding of the resource and threats, a sense of shared responsibility for maintaining the resource, and cooperation in the implementation of management measures. Examples of actions that communities can take to protect healthy watersheds include integrating green infrastructure and habitat protection into comprehensive plans, protecting the Active River Area from development through zoning, preventing landscape fragmentation through the use of conservation subdivisions, and many other techniques discussed in this chapter. Collaborating with local watershed groups or land trusts can be an effective way to reach community members and share resources in outreach and education campaigns. These groups also often have the capacity and willingness to organize volunteers in performing field monitoring and assessment of water quality, biological condition, habitat condition, etc.

Heal the Bay is a non-profit organization in California that uses a report card approach for communicating the health status of the state's beaches, giving each beach a grade representing the relative risk of fecal coliform exposure posed to beachgoers (Heal the Bay, 2009). A report card approach is also used to communicate the health of the Chesapeake Bay to stakeholders and watershed residents and to increase their awareness of aquatic ecological health (University of Maryland Center for Environmental Science; National Oceanic and Atmospheric Administration, 2009). The report card results are also displayed on a map (Figure 5-11). Another example is the Vermont Lake Score Card that rates the condition of Vermont's lakes with regards to water quality, aquatic invasive species, atmospheric pollution, and shoreland and lake habitat. A similar technique can be used to rate watersheds across a state, county, or region.

A report card, or another format for communicating monitoring and assessment results, can also include information on how local land owners and other stakeholders can help protect or improve the health of their watershed. Providing stakeholders with the knowledge necessary for appreciating the importance of aquatic ecosystems and their watersheds, and tools for protecting those resources, is an important component of healthy watersheds protection. Establishing a local volunteer monitoring network is another potential approach for getting more people involved and concerned about protecting these ecosystems. Such a network could involve training on, and participation in, shoreline monitoring surveys, biomonitoring, water quality monitoring, etc. Annual river cleanups, environmental education campaigns, and meetings or presentations with local communities can all help to increase public awareness and understanding of healthy watersheds.



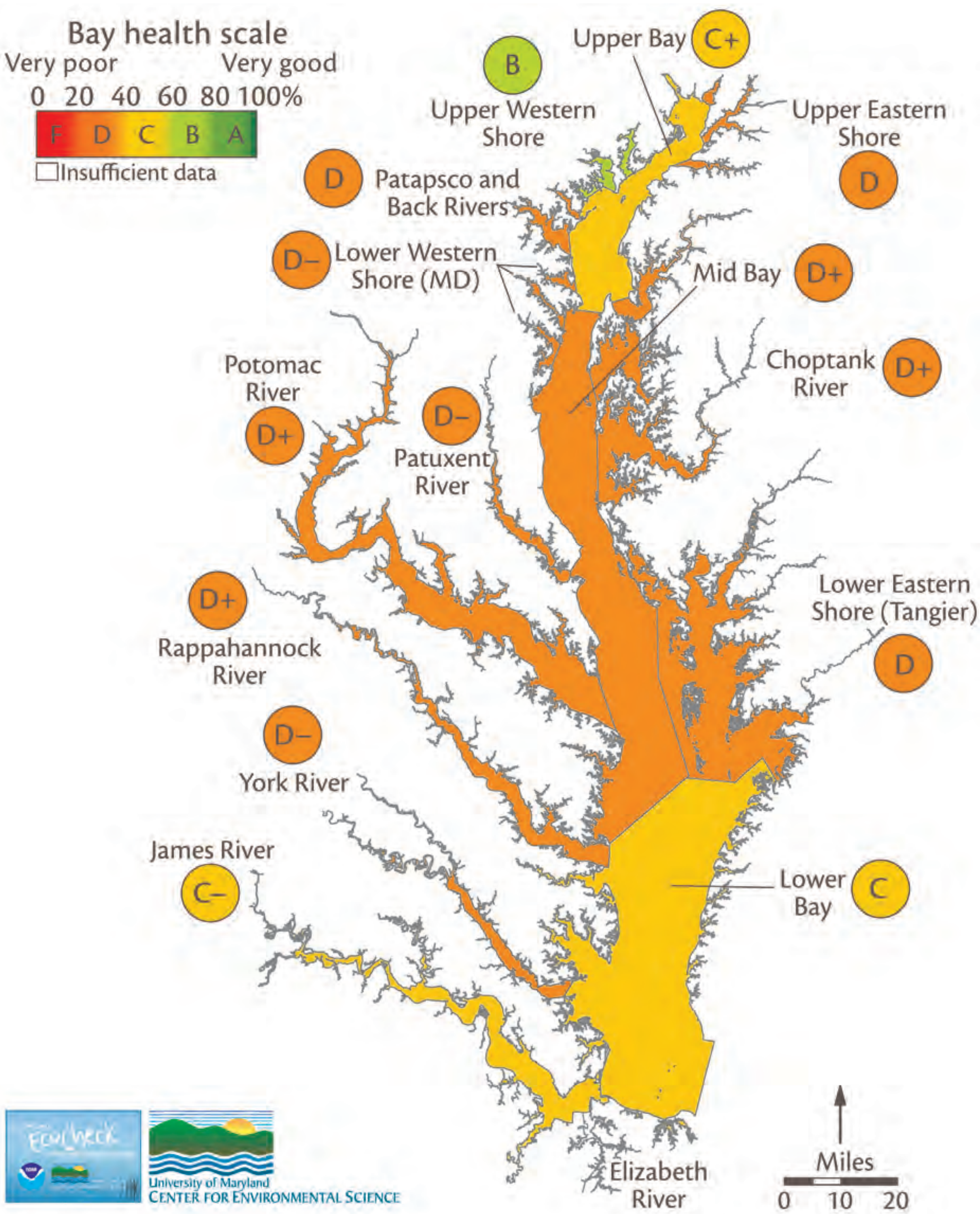



**Figure 5-11** Chesapeake Bay report card results for 2007 (University of Maryland Center for Environmental Science; National Oceanic and Atmospheric Administration, 2009).

The various outreach and education options should not be viewed as mutually exclusive. Success in outreach campaigns can be determined by the number of people that hear your message and the number of times they hear it. Exposing people to your message through multiple types of media will help ensure that the message sticks. Tools such as EPA's Getting in Step: A Guide for Conducting Watershed Outreach Campaigns (U.S. Environmental Protection Agency, 2003) and Ohio's Watershed Toolshed (Ohio Watershed Network, 2009) provide practitioners with the resources needed to get started on some of these approaches. The Conservation Campaign Toolkit (http://www.conservationcampaign.org/wizard/index.cfm?ID=125) provides a free online space for communities and citizen groups to organize their campaign to protect land and water resources.

Millions of Americans are outdoor enthusiasts, and many belong to organizations that provide substantial protection to natural resources. Collaboration with outdoor recreation organizations has been shown to increase support for conservation time and time again. For example, Trout Unlimited is a national organization that supports the protection and restoration of coldwater fisheries and their supporting ecosystems. Members belong to local chapters and are often, though not always, recreational anglers. By promoting responsible stewardship of the resource, Trout Unlimited and similar organizations provide recreational and educational opportunities for individuals to participate in the protection of healthy aquatic ecosystems. Recreational use of ecologically intact aquatic systems and their watersheds is an important consideration in the management of healthy watersheds. Encouraging compatible recreational uses often enhances public acceptance and understanding of the conservation process.

Partnerships with less traditional groups can be just as rewarding as outreach to groups that have historically supported environmental protection. For example, the community and public health benefits of protecting healthy watersheds are often valued by groups such as community service clubs, chambers of commerce, religious organizations, and public health advocacy groups. These nontraditional partners can provide access to new audiences and bring new resources to watershed protection efforts. Furthermore, unconventional partnerships can be effective in garnering media attention. When individuals who do not necessarily align themselves with community organizations see the breadth of interests represented by watershed protection efforts, they may be more likely to deem the efforts worthy of their individual support as well. The greater the diversity of groups that collaborate on these efforts, the less likely that the momentum will be lost.

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# Acronyms & Abbreviations

| | |
|---|---|
| AES | Aquatic Ecological System |
| ANR | Agency of Natural Resources |
| BBASC | Basin and Bay Area Stakeholder Committee |
| BBEST | Basin and Bay Expert Science Team |
| BASINS | Better Assessment Science Integrating point & Nonpoint Sources |
| BCG | Biological Condition Gradient |
| BMP | Best Management Practice |
| CADDIS | Causal Analysis/Diagnosis Decision Information System |
| CHT | Channel Habitat Type |
| CRAM | California Rapid Assessment Method |
| CREP | Conservation Reserve Enhancement Program |
| CRP | Conservation Reserve Program |
| CSP | Conservation Security Program |
| CWA | Clean Water Act |
| CWAM | California Watershed Assessment Manual |
| CWSRF | Clean Water State Revolving Fund |
| DCR | Department of Conservation and Recreation |
| DEM | Department of Environmental Management or Digital Elevation Model |
| DEP | Department of Environmental Protection |
| DEQ | Department of Environmental Quality |
| DES | Department of Environmental Services |
| DNR | Department of Natural Resources |
| DWSRF | Drinking Water State Revolving Fund |
| EDU | Ecological Drainage Unit |
| EEA | Essential Ecological Attribute |
| ELOHA | Ecological Limits of Hydrologic Alteration |
| EMAP | Environmental Monitoring and Assessment Program |
| EMDS | Ecosystem Management Decision Support System |
| EPA | Environmental Protection Agency |
| EPT | Ephemeroptera, Plecoptera, Trichoptera |
| EQIP | Environmental Quality Incentive Program |
| ESRI | Environmental Systems Research Group |
| FDC | Flow Duration Curve |

| | |
|---|---|
| FEH | Fluvial Erosion Hazard |
| FEMA | Federal Emergency Management Agency |
| FPZ | Functional Process Zone |
| FRCC | Fire Regime Condition Class |
| FWS | Fish and Wildlife Service |
| GAP | Gap Analysis Program |
| GDE | Ground water Dependent Ecosystem |
| GIS | Geographic Information System |
| GMA | Growth Management Act |
| GPD | Gallons Per Day |
| GPS | Global Positioning System |
| GRP | Grassland Reserve Program |
| HAT | Hydrologic Assessment Tool |
| HEFR | Hydrology-based Environmental Flow Regimes |
| HHEI | Headwaters Habitat Evaluation Index |
| HIP | Hydroecological Integrity Assessment Process |
| HIT | Hydrologic Index Tool |
| HSPF | Hydrologic Simulation Program Fortran |
| HUC | Hydrologic Unit Code |
| IBI | Index of Biotic Integrity |
| IC | Impervious Cover |
| ICLUS | Integrated Climate and Land Use Scenarios |
| IFIM | Instream Flow Incremental Methodology |
| IHA | Indicators of Hydrologic Alteration |
| ILWIS | Integrated Land and Water Information System |
| INSTAR | Interactive Stream Assessment Resource |
| IIPCC | Intergovernmental Panel on Climate Change |
| ITI | Index of Terrestrial Integrity |
| KDHE | Kansas Department of Health and the Environment |
| LID | Low Impact Development |
| L-THIA | Long-Term Hydrologic Impact Assessment |
| MBSS | Maryland Biological Stream Survey |
| mIBI | Modified Index of Biotic Integrity |
| MMI | Macroinvertebrate Multimetric Index |
| MRB | Major River Basins |
| NARS | National Aquatic Resource Surveys |
| NAWQA | National Water Quality Assessment |

| | |
|---|---|
| NCDC | National Climatic Data Center |
| NED | National Elevation Dataset |
| NEMO | Nonpoint Education for Municipal Officials |
| NFHA | National Fish Habitat Assessment |
| NFIP | National Flood Insurance Program |
| NFPP | National Fish Passage Program |
| NHD | National Hydrography Dataset |
| NLA | National Lakes Assessment |
| NLCD | National Land Cover Database |
| NOAA | National Oceanic and Atmospheric Administration |
| NPDES | National Pollutant Discharge Elimination System |
| NRCS | Natural Resources Conservation Service |
| NRSA | National Rivers and Streams Assessment |
| NSPECT | Nonpoint Source Pollution and Erosion Comparison Tool |
| NWI | National Wetlands Inventory |
| NWIS | National Water Information System |
| ONRW | Outstanding National Resource Water |
| ORAM | Oregon Rapid Assessment Method |
| ORBIC | Oregon Biodiversity Information Center |
| OWEB | Oregon Watershed Enhancement Board |
| OWOW | Office of Wetlands, Oceans, and Watersheds |
| PAD | Protected Areas Database |
| PCA | Principal Components Analysis |
| PFC | Proper Functioning Condition |
| PHI | Physical Habitat Index |
| PHWH | Primary Headwaters Habitat |
| PRISM | Parameter-elevation Regressions on Independent Slopes Model |
| RASCAL | Rapid Assessment of Stream Conditions Along Length |
| RCC | River Continuum Concept |
| RES | Riverine Ecosystem Synthesis |
| ReVA | Regional Vulnerability Assessment |
| RIVPACS | River Invertebrate Prediction and Classification System |
| RPST | Recovery Potential Screening Tool |
| RPT | Regime Prescription Tool |
| RSRA | Rapid Stream and Riparian Assessment |
| RTE | Rare, Threatened, or Endangered |
| SAB | Science Advisory Board |

| | |
|---|---|
| SABS | Suspended and Bedded Sediments |
| SGA | Stream Geomorphic Assessment |
| SDWA | Safe Drinking Water Act |
| SPARROW | Spatially Referenced Regressions On Watershed Attributes |
| SSURGO | Soil Survey Geographic Database |
| STORET | STOrage and RETrieval |
| SWAP | Source Water Assessment Program |
| SWMM | Storm Water Management Model |
| SYE | Sustainable Yield Estimator |
| TCEQ | Texas Commission on Environmental Quality |
| TALU | Tiered Aquatic Life Use |
| TDR | Transfer of Development Rights |
| TEA | Targeted Ecological Area |
| TIFP | Texas Instream Flow Program |
| TMDL | Total Maximum Daily Load |
| TNC | The Nature Conservancy |
| TPL | Trust for Public Land |
| UMRB | Upper Mississippi River Basin |
| USA | United States of America |
| USDA | United States Department of Agriculture |
| USFWS | United States Fish & Wildlife Service |
| USGS | United States Geological Survey |
| VCLNA | Virginia Conservation Lands Needs Assessment |
| VSP | Visual Sample Plan |
| VST | Valley Segment Types |
| WAM | Watershed Assessment Manual |
| WAT | Watershed Assessment Tool |
| WATERS | Watershed Assessment, Tracking & Environmental ResultS |
| WHIP | Wildlife Habitat Incentives Program |
| WQI | Water Quality Index |
| WQS | Water Quality Standards |
| WQX | Water Quality Exchange |
| WRP | Wetlands Reserve Program |
| WSA | Wadeable Streams Assessment |
| WWF | World Wildlife Fund |

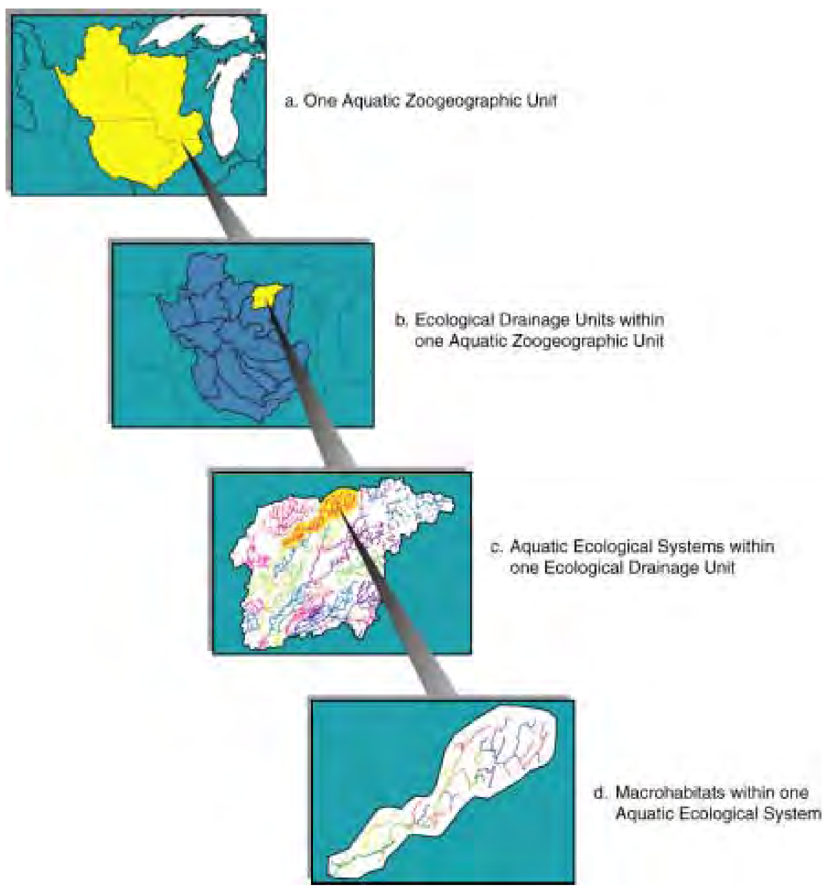
# Appendix A. Examples of Assessment Tools

**Classifying Freshwater Ecosystems**

**Developer:** The Nature Conservancy

**More Information:** http://www.conservationgateway.org/topic/ecoregional-assessment

Freshwater systems are comprised of a variety of ecosystems that differ in geophysical, hydrological and ecological characteristics. Classifying and mapping these distinctions is critical to defining the variety of habitats and processes that comprise a large and complex freshwater system. Classification products are used in biodiversity planning as “coarse-filter” conservation elements to “capture” many common, untracked, and unknown species, and to identify the variety of environments and processes that support species and natural communities across a region of interest. They can also be used to identify specific ecosystem attributes for targeting strategies to protect and restore watershed health, such as identifying areas of high ground water potential, or areas that provide high water yields from surface runoff and are sensitive to a variety of land uses.




The Nature Conservancy’s Freshwater Classification System (Weitzell et al., 2003).

### MapWindow

**Developer**: Idaho State University Geospatial Software Lab

**More Information:** http://www.mapwindow.org/

The MapWindow application is a free GIS that can be used for the following:

- As an alternative desktop GIS.
- To distribute data to others.
- To develop and distribute custom spatial data analyses.

MapWindow is free to use and redistribute to other users. Unlike other free tools, MapWindow is more than just a data viewer; it is an extensible geographic information system. This means that plug-ins can be created to add additional functionality (e.g., models, special viewers, hot-link handlers, data editors, etc.) and these can be passed along to other users.

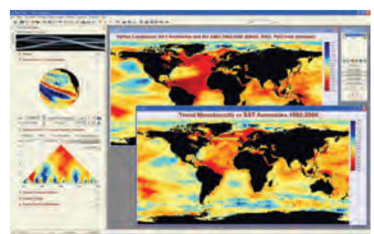
### ArcGIS

**Developer:** Environmental Systems Research Institute (ESRI)

**More Information:** http://www.esri.com/index.html

ArcGIS is software for visualizing, managing, creating, and analyzing geographic data. Using ArcGIS, one can understand the geographic context of data, allowing the user to see relationships and identify patterns.

### IDRISI Taiga



**Developer:** Clark Labs

**More Information:** http://www.clarklabs.org/products/product-features.cfm

IDRISI Taiga is an integrated GIS and Image Processing software solution providing nearly 300 modules for the analysis and display of digital spatial information. IDRISI offers an extensive set of GIS and Image Processing tools in a single package. With IDRISI, all analytical features come standard—there is no need to buy add-ons to extend research capabilities.

### Integrated Land and Water Information System (ILWIS)

**Developer:** World Institute for Conservation and Environment

**More Information:** http://52north.org/

ILWIS is free remote sensing and GIS software, which integrates image, vector, and thematic data in one unique and powerful desktop package. ILWIS delivers a wide range of features including import/export, digitizing, editing, analysis and display of data, as well as production of quality maps. ILWIS software is renowned for its functionality, user-friendliness and low cost, and has established a wide user community over the years of its development.

### Ecosystem Management Decision Support (EMDS)

**Developer:** U.S. Forest Service, InfoHarvest, Rules of Thumb, The Redlands Institute (University of Redlands)

**More Information:** http://www.institute.redlands.edu/emds/

The EMDS system is an application framework for knowledge-based decision support of environmental analysis and planning at any geographic scale. EMDS integrates state-of-the-art GIS, as well as knowledge-based reasoning and decision modeling technologies to provide decision support for the adaptive management process of ecosystem management.

**NetMap**

**Developer:** Earth Systems Institute

**More Information:** http://www.netmaptools.org/

NetMap is a community based watershed science system comprised of a digital watershed database, analysis tools, and forums. The state-of-the-art desktop GIS analysis tools, containing approximately 50 functions and 60 parameters, address watershed attributes and processes such as fluvial geomorphology, fish habitat, erosion, watershed disturbance, road networks, wildfire, hydrology, and large woody debris, among others. NetMap is designed to integrate with ESRI ArcMap 9.2. Key features include:

NetMap

- **Decision support**. NetMap can inform fish habitat management, forestry, pre and post fire planning, restoration, monitoring, research, and education.
- **Uniform data structure**. Channel segments (and tributary confluence nodes) are defined as the spatial relationship between segments and hillsides. All watershed information is routed downstream revealing patterns of watershed attributes at any spatial scale defined by stream networks.
- **Universal, region-wide database**. A large and expanding region-wide watershed database allows users easy access to hundreds of watersheds for rapid analyses and to facilitate comparative analyses across landscapes, states and regions.
- **A new analysis paradigm and methods framework**. In the context of watershed analysis, software tools are distributed with the analysis allowing stakeholders to conduct custom analyses as new questions arise, as new data becomes available (or as more accurate data becomes available), or as watershed conditions change (wildfires or land use activities).
- **A "living analysis."** NetMap watershed databases do not become dated over time because "field link" tools allow rapid validation of predicted attributes and thus databases are made more accurate with use.
- **NetMap is community based**. As new watershed databases are developed and new tools are created, they become immediately available to all users.

**Analytical Tools Interface for Landscape Assessments (ATtILA)**

**Developer:** U.S. Environmental Protection Agency

**More Information:** http://www.epa.gov/esd/land-sci/attila/index.htm

ATtILA is an easy to use ArcView extension that calculates many commonly used landscape metrics. By providing an intuitive interface, the extension provides the ability to generate landscape metrics to a wide audience, regardless of their GIS knowledge level. ATtILA is a robust, flexible program. It accepts data from a broad range of sources and is equally suitable for use across all landscapes, from deserts to rain forests to urban areas, and may be used at local, regional, and national scales.

**Impervious Surface Analysis Tool**

**Developer:** NOAA Coastal Services Center and the University of Connecticut Nonpoint Education for Municipal Officials (NEMO) Program

**More Information:** http://www.csc.noaa.gov/digitalcoast/tools/isat/

The Impervious Surface Analysis Tool is used to calculate the percentage of impervious surface area of user-selected geographic areas (e.g., watersheds, municipalities, subdivisions). The tool is available as an ArcView 3.x, ArcGIS 8.x, or ArcGIS 9.x extension.

### Land Change Modeler

**Developer:** Clark Labs

**More Information:** http://www.clarklabs.org/products/Land-Change-Modeler-Overview.cfm

The Land Change Modeler is land cover change analysis and prediction software that also incorporates tools that allows one to analyze, measure, and project the impacts on habitat and biodiversity. Land Change Modeler includes a suite of tools that address the complexities of change analysis, resource management, and habitat assessment while maintaining a simple and automated workflow. The Land Change Modeler is included within the IDRISI GIS and Image Processing software and is available as a software extension for use with ESRI's ArcGIS product.

### CommunityViz

**Developer:** Placeways

**More Information:** www.placeways.com/communityviz

CommunityViz planning software is an extension for ArcGIS Desktop. Planners, resource managers, local and regional governments, and many others use CommunityViz to help make planning decisions about development, land use, transportation, and conservation. A GIS-based decision-support tool, CommunityViz "shows" the implications of different plans and choices. Both flexible and robust, it supports scenario planning, sketch planning, 3-D visualization, suitability analysis, impact assessment, growth modeling, and other popular techniques. Its many layers of functionality make it useful for a wide range of skill levels and applications.

### NatureServe Vista

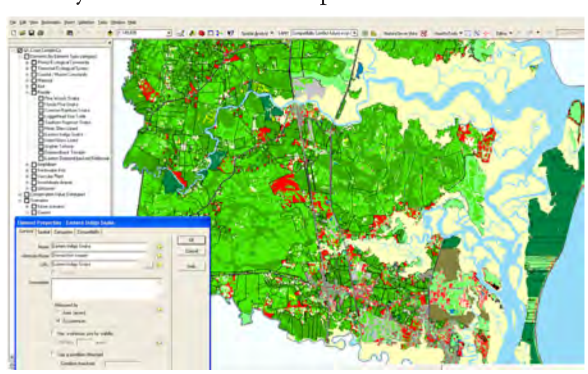
**Developer:** NatureServe

**More Information:** http://www.natureserve.org/prodServices/vista/overview.jsp

NatureServe Vista is a powerful, flexible, and free decision support system that helps users integrate conservation with land use and resource planning of all types. Planners, resource managers, scientists, and conservationists can use NatureServe Vista to:

- Conduct conservation planning and assessments.
- Integrate conservation values with other planning and assessment activities, such as land use, transportation, energy, natural resource, and ecosystem-based management.
- Evaluate, create, implement, and monitor land use and resource management scenarios designed to achieve conservation goals within existing economic, social, and political contexts.

Version 2.5 of NatureServe Vista now integrates interoperability with NOAA's Nonpoint Source Pollution and Erosion Comparison Tool (NSPECT), as well as other hydrologic models to support integrated land-water assessment and planning. NatureServe Vista operates on the ESRI ArcGIS platform. NatureServe Vista supports quantitative and defensible planning approaches that incorporate science, expert opinion, community values, and GIS. It works with a number of other useful software tools to incorporate land use, economics, and ecological and geophysical modeling. The flexible approach and structure of Vista is suitable for planning and GIS experts, as well as those with minimal training and support.



### Miradi

**Developer:** Conservation Measures Partnership

**More Information:** http://www.miradi.org

Miradi is a user-friendly program that allows nature conservation practitioners to design, manage, monitor, and learn from their projects to more effectively meet their conservation goals. The program guides users through a series of step-by-step interview wizards, based on the Open Standards for the Practice of Conservation. As practitioners go through these steps, Miradi helps them to define their project scope, and design conceptual models and spatial maps of their project site. The software helps users to prioritize threats, develop objectives and actions, and select monitoring indicators to assess the effectiveness of their strategies. Miradi also supports the development of workplans, budgets, and other tools to help practitioners implement and manage their project. Users can export Miradi project data to reports or, in the future, to a central database to share their information with other practitioners.

### Habitat Priority Planner

**Developer:** National Oceanic and Atmospheric Administration (NOAA)

**More Information:** http://www.csc.noaa.gov/digitalcoast/tools/hpp/

The Habitat Priority Planner is a spatial decision-support tool (for ArcGIS) designed to assist users in identifying high-priority areas in the landscape or seascape for land use, conservation, climate change adaptation, or restoration action. The Habitat Priority Planner packages several landscape-based spatial analyses for the intermediate GIS user. Scenarios can be easily displayed and changed, making this a helpful companion tool when working with a group. In addition to the scenarios, the tool also generates reports, maps, and data tables.

### Causal Analysis/Diagnosis Decision Information System (CADDIS)

**Developer:** U.S. Environmental Protection Agency

**More Information:** http://cfpub.epa.gov/caddis/

CADDIS is an online application that helps scientists and engineers find, access, organize, use, and share information to conduct causal evaluations in aquatic systems. It is based on EPA's Stressor Identification process, which is a formal method for identifying causes of impairments in aquatic systems.

### Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)

**Developer:** U.S. Environmental Protection Agency

**More Information:** http://water.epa.gov/scitech/datait/models/basins/index.cfm

BASINS is a desktop-based, multipurpose environmental analysis system designed for use by regional, state, and local agencies in performing watershed and water quality-based studies. This system makes it possible to quickly assess large amounts of point source and nonpoint source data in a format that is easy to use and understand. BASINS allows the user to assess water quality at selected stream sites or throughout an entire watershed. This tool integrates environmental data, analytical tools, and modeling programs to support development of cost-effective approaches to watershed management and environmental protection.

### Visual Sample Plan (VSP)

**Developer:** U.S. Department of Energy

**More Information:** http://vsp.pnl.gov/index.stm

VSP is a software tool that supports the development of a defensible sampling plan based on statistical sampling theory and the statistical analysis of sample results to support confident decision making. VSP couples visualization capabilities with optimal sampling design and statistical analysis strategies.

### Nonpoint Source Pollution and Erosion Comparison Tool (NSPECT)

**Developer:** National Oceanic and Atmospheric Administration (NOAA)

**More Information:** http://www.csc.noaa.gov/digitalcoast/tools/nspect/

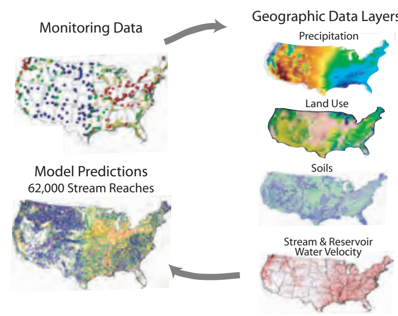
NSPECT helps predict potential water quality impacts to rivers and streams from nonpoint source pollution and erosion. Users first enter information about their study area (land cover, elevation, precipitation, and soil characteristics) to create the base data layer. They can then add different land cover change scenarios (such as a new developed area) to obtain information about potential changes in surface water runoff, nonpoint source pollution, and erosion.

### Spatially Referenced Regressions On Watershed Attributes (SPARROW)

**Developer:** U.S. Geological Survey

**More Information:** http://water.usgs.gov/nawqa/sparrow/

SPARROW is a modeling tool for the regional interpretation of water quality monitoring data. The model relates instream water quality measurements to spatially referenced characteristics of watersheds, including contaminant sources and factors influencing terrestrial and aquatic transport. SPARROW empirically estimates the origin and fate of contaminants in river networks and quantifies uncertainties in model predictions.




### ArcHydro

**Developer:** University of Texas at Austin Center for Research in Water Resources

**More Information:** http://resources.arcgis.com/content/hydro-data-model

The ArcHydro Data Model can be defined as a geographic database containing a GIS representation of a Hydrological Information System under a case-specific database design, which is extensible, flexible, and adaptable to user requirements. It takes advantage of the next generation of spatial data in Relational Database Management Systems, the geodatabase model. Conceptually, it is a combination of GIS objects enhanced with the capabilities of a relational database to allow for relationships, topologies, and geometric networks. ArcHydro facilitates a variety of GIS-based hydrologic analyses including watershed delineation, stream network mapping, and watershed modeling.

### Indicators of Hydrologic Alteration

**Developer:** The Nature Conservancy

**More Information:** http://www.nature.org/initiatives/freshwater/conservationtools/art17004.html

IHA is a software program that provides useful information for those trying to understand the hydrologic impacts of human activities or trying to develop environmental flow recommendations for water managers. This software program assesses 67 ecologically-relevant statistics derived from daily hydrologic data. For instance, IHA can calculate the timing and maximum flow of each year's largest flood event or lowest flows, then calculate the mean and variance of these values over a selected period of time. IHA's comparative analysis can then help statistically describe how these patterns have changed for a particular river or lake, due to abrupt impacts such as dam construction, or more gradual trends associated with land and water use changes.

## Water Budget Tools

A water budget is a conceptual model for understanding different water inflows and outflows of any given system. It can be developed in order to evaluate the relative importance of surface water and ground water inflows and outflows to a particular aquatic ecosystem or a conservation area as a whole. The relationships between the system and its inflows and outflows are depicted using a figure to represent the system and arrows pointed toward or away from the figure and scaled in size to match their direction and magnitude, respectively. Where flow values have not been measured, estimates can be developed from sources such as local climate stations, flow gaging stations, the Parameter-elevation Regressions on Independent Slopes Model (PRISM), or monthly average reference evapotranspiration values from the U.S. Bureau of Reclamation. In the case of wetland water budgets, for example, there are four potential water inputs, each of which has a corresponding potential output:

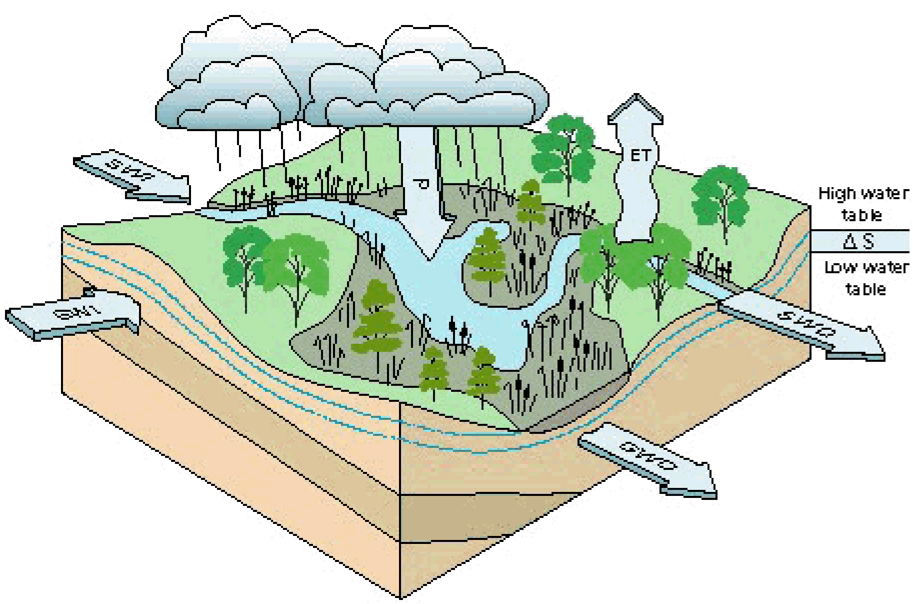
Inputs:

1. Surface water inflow (SWI).
2. Ground water inflow (GWI).
3. Tidal inflow (TI).
4. Precipitation (P).

Outputs:

1. Surface water outflow (SWO).
2. Ground water outflow (GWO).
3. Tidal outflow (TO).
4. Evapotranspiration (ET).

Although a water budget alone typically does not incorporate enough detail to form the basis for management plans or policy decisions, a water budget can be a helpful tool for identifying data gaps and research needs and planning future directions for resource management (Brown J., Wyers, Aldous, & Bach, 2007).




Components of the wetland water budget. (P+SWI+GWI=ET+SWO+GWO+ΔS, where P is precipitation, SWI is surface water inflow, SWO is surface water outflow, GWI is ground water inflow, GWO is ground water outflow, ET is evapotranspiration, and ΔS is change in storage (Carter, 1996).

## Hydrologic Engineering Center Regime Prescription Tool (HEC-RPT)

**Developer:** The Nature Conservatory, U.S. Army Corps of Engineers

**More Information:** http://www.nature.org/initiatives/freshwater/conservationtools/hecrpt.html

HEC-RPT is a visualization tool that is designed to complement existing software packages by facilitating entry, viewing, and documentation of flow recommendations in real-time, public settings. The software was developed in support of the Sustainable Rivers Project, a national partnership between the U.S. Army Corps of Engineers and TNC to improve the health of rivers by changing the operations of Corps dams.

### Hydrologic Engineering Center Geospatial Hydrologic Modeling Extension (HEC-GeoHMS)

**Developer:** Army Corps of Engineers

**More Information:** http://www.hec.usace.army.mil/software/hec-geohms/

The HEC-GeoHMS has been developed as a geospatial hydrology toolkit for engineers and hydrologists with limited GIS experience. HEC-GeoHMS uses ArcView and the Spatial Analyst extension to develop a number of hydrologic modeling inputs for the Hydrologic Engineering Center's Hydrologic Modeling System, HEC-HMS. Analyzing digital terrain data, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the drainage network. The program allows users to visualize spatial information, document watershed characteristics, perform spatial analysis, and delineate subbasins and streams. HEC-GeoHMS' interfaces, menus, tools, buttons, and context-sensitive online help allow the user to expediently create hydrologic inputs for HEC-HMS.

### The Hydroecological Integrity Assessment Process (HIP) Tools

**Developer:** U.S. Geological Survey

**More Information:** http://www.fort.usgs.gov/Resources/Research_Briefs/HIP.asp

USGS scientists developed the HIP and a suite of tools for conducting a hydrologic classification of streams, addressing instream flow needs, and assessing past and proposed hydrologic alterations on stream flow and/or other ecosystem components. The HIP recognizes that stream flow is strongly related to many critical physiochemical components of rivers, such as dissolved oxygen, channel geomorphology, and water temperature, and can be considered a "master variable" that limits the disturbance, abundance, and diversity of many aquatic plant and animal species.

The HIP is intended for use by any federal or state agency, institution, private firm, or nongovernmental entity that has responsibility for or interest in managing and/or regulating streams to restore or maintain ecological integrity. In addition, the HIP can assist researchers by identifying ecologically relevant, stream-class-specific hydrologic indices that adequately characterize the five major components of the flow regime (magnitude, frequency, duration, timing, and rate of change) by using 10 nonredundant indices. The HIP is developed at a state or other large geographical area scale but is applied at the stream reach level.

### StreamStats

**Developer:** U.S. Geological Survey

**More Information:** http://water.usgs.gov/osw/streamstats/

StreamStats is a web-based GIS that provides users with access to an assortment of analytical tools that are useful for water resources planning and management, and for engineering design applications, such as the design of bridges. StreamStats allows users to easily obtain monthly stream flow statistics, drainage basin characteristics, and other information for user-selected sites on streams. StreamStats users can choose locations of interest from an interactive map and obtain information for these locations. If a user selects the location of a USGS data collection station, the user will be provided with a list of previously published information for the station. If a user selects a location where no data are available (an ungaged site), StreamStats will delineate the drainage basin boundary, measure basin characteristics and estimate monthly stream flow statistics for the site. These estimates assume natural flow conditions at the site. StreamStats also allows users to identify stream reaches that are upstream or downstream from user-selected sites, and to identify and obtain information for locations along the streams where activities that may affect stream flow conditions are occurring.

### Massachusetts Sustainable Yield Estimator

**Developer:** U.S. Geological Survey

**More Information:** http://pubs.usgs.gov/sir/2009/5227/pdf/sir2009-5227-508.pdf; http://ma.water.usgs.gov/sarch/software/sye_mainpage.htm

The Massachusetts Sustainable-Yield Estimator is a decision-support tool that calculates a screening-level approximation of a basin's sustainable yield, defined as the difference between natural stream flow and the flow regime required to support desired uses, such as aquatic habitat. A spatially-referenced database of permitted surface water and ground water withdrawals and discharges is used to calculate daily stream flows at ungaged sites; however, impacts from septic-system discharge, impervious area, non-public water-supply withdrawals less than 100,000 gpd, and impounded surface water bodies are not accounted for in these stream flow estimates. Because this tool was developed with considerations specific to the hydrology of Massachusetts, it can potentially be adapted for use in other New England states, but may not be applicable outside this geographic region.

### Tools for Understanding Ground Water and Biodiversity

**Developer:** The Nature Conservancy

**More Information:** http://www.srnr.arizona.edu/nemo/WebDocs/Groundwater%20Methods%20Guide%20TNC%20Jan08.pdf

This appendix offers a brief discussion of several tools that can be used with the assistance of experts in the field to develop an understanding of the relationship between ground water and biodiversity. The tools discussed address the following topics: modeling recharge areas, seepage runs, base flow as a percentage of annual stream flow, water table data, Forward Looking Infrared Remote Sensing, water chemistry analysis, and environmental tracer analysis. Both motivations and data requirements for using these tools as well as the limitations of the tools are considered.

### Long-Term Hydrologic Impact Assessment (L-THIA)

**Developer:** Local Government Environmental Assistance Network

**More Information:** http://www.ecn.purdue.edu/runoff/lthianew/

The L-THIA model was developed as an online tool to support the assessment of land use changes on water quality. Based on community-specific climate data, L-THIA estimates changes in recharge, runoff, and nonpoint source pollution resulting from past or proposed development. As a quick and easy-to-use approach, L-THIA's results can be used to generate community awareness of potential long-term problems and to support planning aimed at minimizing disturbance of critical areas. L-THIA assists in the evaluation of potential effects of land use change and identifies the best location of a particular land use so as to have minimum impact on a community's natural environment.

### Low Impact Development (LID) Urban Design Tools Web site

**Developer:** Low Impact Development Center (through a cooperative assistance agreement with EPA)

**More Information:** http://www.lid-stormwater.net/index.html

The LID Urban Design Tools website was developed to provide guidance to local governments, planners, and engineers for developing, administering, and incorporating LID into their aquatic resource protection programs. LID technology is an alternative comprehensive approach to stormwater management. It can be used to address a wide range of wet weather flow issues, including combined sewer overflows, stormwater runoff, and pollutant loading.

### GeoTools

**Developer:** Brian Bledsoe

**More Information:** http://www.engr.colostate.edu/~bbledsoe/GeoTool/

To improve watershed management in the context of changing land uses, GeoTools estimates long-term changes in stream erosion potential, channel processes, and instream disturbance regime. The models include a suite of stream/land use management modules designed to operate with either continuous or single event hydrologic input in a variety of formats. The tools can also be used as a post-processor for the Storm Water Management Model (SWMM) and Hydrologic Simulation Program Fortran (HSPF) model (included in EPA's BASINS), as well as for any general time series of discharges. Based on the two input channel geometry and flow series, the various modules can provide users with estimates of the following characteristics for pre and post land use change conditions: (1) the temporal distribution of hydraulic parameters including shear stress, specific stream power, and potential mobility of various particle sizes; (2) effective discharge/sediment yield; (3) potential changes in sediment transport and yield as a result of altered flow and sedimentation regimes; (4) frequency, depth, and duration of bed scour; and (5) several geomorphically relevant hydrologic metrics relating to channel form, flow effectiveness, and "flashiness."

### Regional Vulnerability Assessment (ReVA) Environmental Decision Toolkit

**Developer:** U.S. Environmental Protection Agency

**More Information:** http://amethyst.epa.gov/revatoolkit/Welcome.jsp

EPA's ReVA program is designed to produce the methods needed to understand a region's environmental quality and its spatial pattern. The objective is to assist decision makers in making better-informed decisions and in estimating the large-scale changes that might result from their actions.

# Appendix B. Sources of National Data

### Watershed Boundary Dataset

**Source:** U.S. Geological Survey and Natural Resources Conservation Service

**More Information:** http://www.ncgc.nrcs.usda.gov/products/datasets/watershed/

Watershed boundaries define the aerial extent of surface water drainage to a point. Hydrologic Unit Codes (HUCs) are used to identify each hydrologic unit and are organized in a hierarchical fashion. The first level of classification divides the nation into 21 major geographic areas, or regions. The second level of classification divides the 21 regions into 221 subregions. The third level of classification subdivides the subregions into 378 hydrologic accounting units. The fourth level of classification subdivides the hydrologic accounting units into 2,264 cataloging units. The fifth level of classification subdivides these into watersheds and the sixth level subdivides watersheds into sub-watersheds. A hydrologic unit has a single flow outlet except in coastal or lakefront areas. However, multiple hydrologic units must be combined to represent the true hydrologic watershed in many instances.

### National Hydrography Dataset (NHD)

**Source:** U.S. Geological Survey

**More Information:** http://nhd.usgs.gov/

Subbasin 02070010 covering Washington DC

The NHD is a comprehensive set of spatial data representing the surface water of the United States using common features such as lakes, ponds, streams, rivers, canals, and oceans. These data are designed to be used in general mapping and in the analysis of surface water systems using GIS.

### National Elevation Dataset (NED)

**Source:** U.S. Geological Survey

**More Information:** http://ned.usgs.gov/

The NED replaces Digital Elevation Models (DEMs) as the primary elevation data product of the USGS. The NED is a seamless dataset with the best available raster elevation data of the conterminous United States, Alaska, Hawaii, and territorial islands. The NED is updated on a nominal two month cycle to integrate newly available, improved elevation source data. All NED data are public domain. The NED is derived from diverse source data that are processed to a common coordinate system and unit of vertical measure. NED data are available nationally (except for Alaska) at resolutions of 1 arc-second (about 30 meters) and 1/3 arc-second (about 10 meters), and in limited areas at 1/9 arc-second (about 3 meters).

### Soil Survey Geographic Database (SSURGO)

**Source:** Natural Resources Conservation Service

**More Information:** http://soils.usda.gov/survey/geography/ssurgo/

SSURGO is the most detailed level of soil mapping performed by the NRCS. The soil maps in SSURGO are created using field mapping methods based on national standards. SSURGO digitizing duplicates the original soil survey maps. This level of mapping is designed for use by landowners, townships, and county natural resource planning and management. The user should be knowledgeable of soils data and their characteristics.

### National Land Cover Database (NLCD)

**Source:** Multi-Resolution Land Characteristics Consortium

**More Information:** http://www.mrlc.gov/

NLCD is a national land cover database with several independent data layers, which allow users a wide variety of potential applications. The data are provided at a resolution of 30 meters and include 21 classes of land cover, estimates of impervious cover, and tree canopy cover.

### Fire Regime Condition Class (FRCC)

**Source:** U.S. Department of the Interior

**More Information:** http://frcc.gov/

LANDFIRE Rapid Assessment FRCC delineates a standardized index to measure the departure of current conditions from reference conditions. FRCC is defined as a relative measure describing the degree of departure from the reference fire regime. This departure results in changes to one (or more) of the following ecological components: vegetation characteristics; fuel composition; fire frequency, severity, and pattern; and other associated disturbances. These data can be downloaded for any region of the country to evaluate the degree of departure from the natural fire regime.

### National Climate Data Center (NCDC)

**Source:** National Oceanic and Atmospheric Administration

**More Information:** http://www.ncdc.noaa.gov/oa/ncdc.html

NCDC is the world's largest active archive of weather data. NCDC produces numerous climate publications and responds to data requests from all over the world. Accurate weather data are required by many watershed modeling programs and can be obtained from NCDC.

### Climate Wizard

**Source:** The Nature Conservancy, University of Washington, University of Southern Mississippi

**More Information:** http://www.climatewizard.org/

ClimateWizard enables technical and non-technical audiences alike to access leading climate change information and visualize the impacts anywhere on Earth. The first generation of this web-based program allows the user to choose a state or country and both assess how climate has changed over time and to project what future changes are predicted to occur in a given area. ClimateWizard represents the first time ever the full range of climate history and impacts for a landscape have been brought together in a user-friendly format.

### Integrated Climate and Land Use Scenarios (ICLUS)

**Source:** U.S. Environmental Protection Agency

**More Information:** http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=205305

ICLUS is an ArcGIS extension that derives land use change projections that are consistent with Special Report on Emissions Scenarios (SRES) driving global circulation models and other land-use change modeling efforts. The residential housing and impervious surface datasets provide a substantial first step toward comprehensive national land use/land cover scenarios, which have broad applicability for integrated assessments as these data and tools are publicly available.

### Water Quality Exchange (WQX)

**Source:** U.S. Environmental Protection Agency

**More Information:** http://www.epa.gov/storet/wqx/index.html

EPA developed the National STOrage and RETrieval (STORET) Data Warehouse in 2001 to store and make available water quality data collected by federal agencies, states, tribes, watershed organizations and universities. A chief goal of the national data warehouse has always been to encourage data sharing and to support national, regional, and local analyses of water quality data collected around the country. Until now, to upload water quality data into STORET, users needed to operate the Oracle-based STORET database. This was cumbersome and difficult for many users. The Water Quality Exchange (WQX) is a new framework that makes it easier to submit and share water quality monitoring data over the Internet. EPA will continue to maintain STORET to ensure that data of documented quality are available across jurisdictional and organizational boundaries. However, with WQX, groups who collect water quality data no longer need to use STORET to submit their information to the National STORET Data Warehouse. Ease of use will encourage more groups to transfer their data to the Warehouse, where it will be of value to federal, state, and local water quality managers as well as the public.

### National Water Information System (NWIS)

**Source:** U.S. Geological Survey

**More Information:** http://waterdata.usgs.gov/nwis/help?nwisweb_overview

The USGS maintains a distributed network of computers and fileservers for the acquisition, processing, review, dissemination, and long-term storage of water data collected at over 1.5 million sites around the country and at some border and territorial sites. This distributed network of computers is called the National Water Information System (NWIS). Many types of data are stored in NWIS, including comprehensive information for site characteristics, well construction details, time-series data for gage height, stream flow, ground water level, precipitation, and physical and chemical properties of water. Additionally, peak flows, chemical analyses for discrete samples of water, sediment, and biological media are accessible within NWIS. NWISWeb provides a framework to obtain data on the basis of category, such as surface water, ground water, or water quality, and by geographic area. Further refinement is possible by choosing specific site-selection criteria and by defining the output desired. NWIS includes data from as early as 1899 to present.

### Distribution of Native U.S. Fishes by Watershed

**Source:** NatureServe

**More Information:** http://www.natureserve.org/getData/dataSets/watershedHucs/index.jsp

NatureServe has compiled detailed data on the current and historic distributions of the native freshwater fishes of the United States, excluding Alaska and Hawaii. Lists of the native fish species of each small watershed (8-digit cataloging unit) are provided to facilitate biological assessments and interpretation.

### Protected Areas Database of the United States (PAD-US)

**Source:** National Biological Information Infrastructure

**More Information:** http://www.protectedlands.net/padus/

The PAD-US is a national database of federal and state conservation lands. The protected areas included in the PAD-US include lands that are dedicated to the preservation of biological diversity and to other natural, recreational and cultural uses, and managed for these purposes through legal or other effective means. These lands are essential for conserving species and habitat. The lands in PAD-US also include other types of publicly owned open space areas, whether used for recreational, managed resource development, water quality protection, or other uses.

### NatureServe Data

**Source:** NatureServe

**More Information:** http://www.natureserve.org/getData/index.jsp

NatureServe and its network of member programs are a leading source for reliable scientific information about species and ecosystems of the Western Hemisphere. This site serves as a portal for accessing several types of publicly available biodiversity data including the Natural Heritage data for all states.

### The Nature Conservancy's Spatial Data Resources

**Source:** The Nature Conservancy

**More Information:** http://maps.tnc.org/

Spatial data and related information plays a vital role in conservation at The Nature Conservancy. A wealth of data are generated across the organization throughout various parts of the process from setting priorities through ecoregional assessments to developing strategies, taking action and tracking results as part of conservation projects to managing information on properties they purchase to protect. The primary purpose of this site is to make this core conservation data publically available through easy-to-use web map viewers for non-GIS users, as well as in raw form via map services for more experienced GIS professionals.

### FactFinder

**Source:** United States Census Bureau

**More Information:** http://factfinder.census.gov/home/saff/main.html?_lang=en

American FactFinder is an online source for population, housing, economic and geographic data that presents the results from four key data programs:

- Decennial Census of Housing and Population - 1990 and 2000.
- Economic Census 1997 and 2002.
- American Community Survey - 2005-2007.
- Population Estimates Program - July 1, 2003 to July 1, 2007.

Results from each of these data programs are provided in the form of datasets, tables, thematic maps, and reference maps. These data can be useful for identifying threats to watershed ecosystems.

### Watershed Assessment, Tracking & Environmental ResultS (WATERS)

**Source:** U.S. Environmental Protection Agency

**More Information:** http://www.epa.gov/waters/

WATERS is an integrated information system for the nation's surface waters. The EPA Office of Water manages numerous programs in support of the Agency's water quality efforts. Many of these programs collect and store water quality related data in databases. These databases are managed by the individual Water Programs and this separation often inhibits the integrated application of the data they contain. Under WATERS, the Water Program databases are connected to a larger framework. This framework is a digital network of surface water features, known as the National Hydrography Dataset (NHD). By linking to the NHD, one Water Program database can reach another, and information can be shared across programs.

### LandScope

**Source:** NatureServe, National Geographic

**More Information:** http://www.landscope.org/

LandScope America is an online resource for the land protection community and the public. By bringing together maps, data, photos, and stories about America's natural places and open spaces, LandScope's goal is to inform and inspire conservation of land and water.

### National Atlas

**Source:** U.S. Department of the Interior

**More Information:** http://www.nationalatlas.gov/index.html

The National Atlas is an online map containing data layers available for viewing and download for the entire United States. These data layers include agricultural, biological, climate, political, economic, environmental, geological, historical, and other major categories. It is a convenient source of data for many watershed assessment applications.

### National Fish Habitat Action Plan Spatial Framework

**Source:** National Fish Habitat Action Plan

**More Information:** http://fishhabitat.org

The Science and Data Team of the National Fish Habitat Action Plan has developed a national spatial framework to facilitate summary and sharing of available national datasets in support of conservation and management of fish habitats in the conterminous United States. The framework is based upon the National Hydrography Dataset Plus (NHDPlus), and data are summarized for local and network catchments of individual stream reaches. Currently, 17 natural and anthropogenic disturbance variables have been attributed to local catchments and aggregated for network catchments and are available across various geographic extents incorporated into the spatial framework.

# Appendix C. Cited Assessment and Management Examples

## Assessment and Management Examples Organized Nationally and by State

| National |
|---|
| http://water.epa.gov/healthywatersheds |
| Biological Condition Gradient and Tiered Aquatic Life Uses<br>http://www.epa.gov/bioindicators/html/bcg.html |
| Ecological Limits of Hydrologic Alteration<br>http://www.conserveonline.org/workspaces/eloha |
| Enabling Source Water Protection<br>www.landuseandwater.org |
| Index of Biotic Integrity (IBI)<br>http://www.epa.gov/bioiweb1/html/ibi_history.html |
| Interagency Fire Regime Condition Class<br>http://frames.nbii.gov/documents/frcc/documents/FRCC+Guidebook_2008.10.30.pdf |
| Process for Assessing Proper Functioning Condition<br>ftp://ftp.blm.gov/pub/nstc/techrefs/Final%20TR%201737-9.pdf |
| National Fish Habitat Assessment<br>www.fishhabitat.org |
| NatureServe's Natural Heritage Program Biodiversity Assessments<br>http://www.natureserve.org/aboutUs/network.jsp |
| The Nature Conservancy's Approach to Setting Freshwater Conservation Priorities<br>http://www.conservationgateway.org/topic/setting-freshwater-priorities |
| Conservation Priorities for Freshwater Biodiversity in the Upper Mississippi River Basin<br>http://www.natureserve.org/library/uppermsriverbasin.pdf |
| The Nature Conservancy's Active River Area<br>http://conserveonline.org/workspaces/freshwaterbooks/documents/active-river-area-a-conservation-framework-for/view.html |
| The Nature Conservancy's Ground Water Dependent Ecosystem Assessment<br>http://tinyurl.com/GDE-Workspace |
| U.S. Environmental Protection Agency's National Lakes Assessment<br>http://water.epa.gov/type/lakes/lakessurvey_index.cfm |
| U.S. Environmental Protection Agency's National Rivers and Streams Assessment (NRSA)<br>http://water.epa.gov/type/rsl/monitoring/riverssurvey/riverssurvey_index.cfm |
| U.S. Environmental Protection Agency's Recovery Potential Screening Tools<br>http://www.epa.gov/recoverypotential |
| U.S. Environmental Protection Agency's Regional Vulnerability Assessment Program<br>http://www.epa.gov/reva/ |
| U.S. Geological Survey's Aquatic GAP Analysis Program<br>http://www.gap.uidaho.edu/projects/aquatic/default.htm |
| U.S. Geological Survey's Regional and National Monitoring and Assessments of Streams and Rivers<br>http://water.usgs.gov/nawqa/studies/mrb/ |

| California |
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| California Healthy Streams Partnership<br>http://www.swrcb.ca.gov/mywaterquality/monitoring_council/meetings/2011jun/hsp_outreach.pdf |
| California Rapid Assessment Method<br>http://www.cramwetlands.org/ |
| California Watershed Assessment Manual<br>http://cwam.ucdavis.edu/ |
| **Connecticut** |
| Connecticut Department of Environmental Protection's Least Disturbed Watersheds<br>http://www.ct.gov/dep/lib/dep/water/water_quality_management/ic_studies/least_disturbed__rpt.pdf |
| **Delaware** |
| Delaware River Basin Commission's use of Antidegradation<br>http://www.state.nj.us/drbc/spw.htm |
| **Kansas** |
| Kansas Department of Health and Environment's Least Disturbed Watersheds Approach<br>http://www.kdheks.gov/befs/download/bibliography/Kansas_reference_stream_report.pdf |
| **Maine** |
| Enabling Source Water Protection in Maine<br>http://www.landuseandwater.org/index.htm |
| Headwaters: A Collaborative Conservation Plan for the Town of Sanford, Maine<br>http://swim.wellsreserve.org/results.php?article=828Conservation%20Strategy%20September%207,%202010.pdf |
| Maine Department of Environmental Protection's Tiered Aquatic Life Uses<br>http://www.maine.gov/dep/water/monitoring/biomonitoring/index.html |
| **Maryland** |
| Anne Arundel County's Greenways Master Plan<br>http://www.aacounty.org/PlanZone/MasterPlans/Greenways/Index.cfm |
| Cecil County, Maryland Green Infrastructure Plan<br>http://www.conservationfund.org/sites/default/files/CecilCounty01.22.08.pdf |
| Maryland Department of Natural Resources Green Infrastructure Assessment<br>http://www.greenprint.maryland.gov/ |
| Maryland Department of Natural Resources' Physical Habitat Index for Freshwater Wadeable Streams<br>http://www.dnr.state.md.us/irc/docs/00014357.pdf |
| **Michigan** |
| Michigan's Natural Rivers Program<br>http://www.michigan.gov/dnr/0,1607,7-153-30301_31431_31442---,00.html |
| Michigan's Regional Scale Habitat Suitability Model to Assess the Effects of Flow Reduction on Fish Assemblages in Michigan Streams<br>http://www.michigan.gov/documents/dnr/RR2089_268570_7.pdf |
| Michigan's Water Withdrawal Assessment<br>http://web2.msue.msu.edu/bulletins/Bulletin/PDF/WQ60.pdf |

## Minnesota

Minnesota Department of Natural Resources' Fen Protection Program

http://www.dnr.state.mn.us/eco/wetlands/index.html

Minnesota Department of Natural Resources Watershed Assessment Tool

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

Minnesota Healthy Watersheds Program

http://files.dnr.state.mn.us/aboutdnr/reports/legislative/2010_healthy_watersheds.pdf

Minnesota National Lakes Assessment

http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/lake-water-quality/national-lakes-assessment-project-nlap.html?menuid=&redirect=1

## Missouri

The U.S. Forest Service and Trust for Public Land's Lower Meramec Drinking Water Source Protection Project

http://cloud.tpl.org/pubs/landwater-lowermer-swp-brochure.pdf

## North Carolina

National Wild and Scenic Rivers: Lumber River, North Carolina

http://www.rivers.gov/wsr-lumber.html

## Ohio

Ohio Environmental Protection Agency's Primary Headwaters Habitat Assessment

http://www.epa.state.oh.us/dsw/wqs/headwaters/index.aspx

Ohio Environmental Protection Agency's Statewide Biological and Water Quality Monitoring and Assessment

http://www.epa.state.oh.us/dsw/bioassess/ohstrat.aspx

Ohio Rapid Assessment Method

http://www.epa.ohio.gov/dsw/wetlands/WetlandEcologySection.aspx#ORAM

U.S. Geological Survey's Ohio Aquatic GAP Analysis: An Assessment of the Biodiversity and Conservation Status of Native Aquatic Animal Species

http://pubs.er.usgs.gov/usgspubs/ofr/ofr20061385

## Oklahoma

Oklahoma National Rivers and Streams Assessment

http://www.owrb.ok.gov/studies/reports/reports_pdf/REMAP-OKStreamRiver_ProbMonitorNetwork.pdf

## Oregon

Identifying GDEs and Characterizing their Ground Water Resources in the Whychus Creek Watershed

http://tinyurl.com/GDE-Workspace

Oregon Department of Environmental Quality's Oregon Water Quality Index

http://www.deq.state.or.us/lab/wqm/wqimain.htm

Oregon Natural Heritage Information Center

http://orbic.pdx.edu/

Oregon Watershed Enhancement Board's Oregon Watershed Assessment Manual

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

## Pennsylvania

Pennsylvania Natural Heritage Program's Aquatic Community Classification and Watershed Conservation Prioritization

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

## Tennessee

Beaver Creek Green Infrastructure Plan (Knox County, TN)

http://ww2.tdot.state.tn.us/sr475/library/bcgitdot.pdf

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| **Texas** | |
| San Antonio River Basin Instream Flow Assessment | http://www.twdb.state.tx.us/instreamflows/sanantonioriverbasin.html |
| Texas Instream Flow Program | http://www.tceq.state.tx.us/permitting/water_supply/water_rights/eflows/resources.html |
| The Central Texas Greenprint for Growth: A Regional Action Plan for Conservation and Economic Opportunity | http://envisioncentraltexas.org/resources/GreenprintMkt.pdf |
| **Utah** | |
| Rapid Stream Riparian Assessment | http://wildutahproject.org/files/images/rsra-ug2010v2_wcover.pdf |
| **Vermont** | |
| Geomorphic Assessment and River Corridor Planning of the Batten Kill Main-Stem and Major Tributaries, Vermont | http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassess.htm |
| Vermont Agency of Natural Resources River Corridor Protection Program | http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_restoration.htm |
| Vermont Agency of Natural Resources' Stream Geomorphic and Reach Habitat Assessment Protocols | http://www.vtwaterquality.org/rivers/htm/rv_geoassess.htm |
| **Virginia** | |
| Green Infrastructure in Hampton Roads, Virginia | http://www.hrpdc.org/PEP/PEP_Green_InfraPlan2010.asp |
| Virginia Conservation Lands Needs Assessment Vulnerability Model | http://www.dcr.virginia.gov/natural_heritage/vclnavulnerable.shtml |
| Virginia Department of Conservation and Recreation's Healthy Waters Program | www.dcr.virginia.gov/healthywaters |
| Virginia Department of Conservation and Recreation's Interactive Stream Assessment Resource (INSTAR) | http://instar.vcu.edu |
| Virginia Department of Conservation and Recreation Natural Landscape Assessment | http://www.dcr.virginia.gov/natural_heritage/vclnavnla.shtml |
| Virginia Department of Conservation and Recreation Watershed Integrity Model | http://www.dcr.virginia.gov/natural_heritage/vclnawater.shtml |
| Virginia Land Conservation Data Explorer | www.vaconservedlands.org |
| Watershed-Based Zoning in James City County, Virginia | http://www.jccegov.com/environmental/index.html |
| **Washington** | |
| Washington's Critical Areas Growth Management Act | http://www.commerce.wa.gov/site/418/default.aspx |
| **Wyoming** | |
| Wyoming Department of Environmental Quality's Aquifer Sensitivity and Ground Water Vulnerability Assessment | http://waterplan.state.wy.us/plan/green/techmemos/swquality.html |
| The Wyoming Joint Ventures Steering Committee's Wetlands Conservation Strategy | http://gf.state.wy.us/habitat/WetlandConservation/Wyoming%20Wetlands%20Conservation%20Strategy%20September%207,%202010.pdf |

## Assessment Examples

| Landscape Condition |
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| Anne Arundel County's Greenways Master Plan<br>http://www.aacounty.org/PlanZone/MasterPlans/Greenways/Index.cfm |
| Beaver Creek Green Infrastructure Plan (Knox County, TN)<br>http://ww2.tdot.state.tn.us/sr475/library/bcgitdot.pdf |
| Green Infrastructure in Hampton Roads, Virginia<br>http://www.hrpdc.org/PEP/PEP_Green_InfraPlan2010.asp |
| Interagency Fire Regime Condition Class<br>http://frames.nbii.gov/documents/frcc/documents/FRCC+Guidebook_2008.10.30.pdf |
| Maryland Department of Natural Resources Green Infrastructure Assessment<br>http://www.greenprint.maryland.gov/ |
| The Nature Conservancy's Active River Area<br>http://conserveonline.org/workspaces/freshwaterbooks/documents/active-river-area-a-conservation-framework-for/view.html |
| Virginia Department of Conservation and Recreation's Natural Landscape Assessment<br>http://www.dcr.virginia.gov/natural_heritage/vclnavnla.shtml |
| Virginia Land Conservation Data Explorer<br>www.vaconservedlands.org |
| **Habitat** |
| California Rapid Assessment Method<br>http://www.cramwetlands.org/ |
| Maryland Department of Natural Resources' Physical Habitat Index for Freshwater Wadeable Streams<br>http://www.dnr.state.md.us/irc/docs/00014357.pdf |
| Ohio Environmental Protection Agency's Primary Headwaters Habitat Assessment<br>http://www.epa.state.oh.us/dsw/wqs/headwaters/index.aspx |
| Ohio Rapid Assessment Method<br>http://www.epa.ohio.gov/dsw/wetlands/WetlandEcologySection.aspx#ORAM |
| Process for Assessing Proper Functioning Condition<br>ftp://ftp.blm.gov/pub/nstc/techrefs/Final%20TR%201737-9.pdf |
| Rapid Stream Riparian Assessment<br>http://wildutahproject.org/files/images/rsra-ug2010v2_wcover.pdf |

| Hydrology |
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| Ecological Limits of Hydrologic Alteration<br>http://www.conserveonline.org/workspaces/eloha |
| Identifying GDEs and Characterizing their Ground Water Resources in the Whychus Creek Watershed<br>http://tinyurl.com/GDE-Workspace |
| Michigan's Regional Scale Habitat Suitability Model to Assess the Effects of Flow Reduction on Fish Assemblages in Michigan Streams<br>http://www.michigan.gov/documents/dnr/RR2089_268570_7.pdf |
| San Antonio River Basin Instream Flow Assessment<br>http://www.twdb.state.tx.us/instreamflows/sanantonioriverbasin.html |
| Texas Instream Flow Program<br>http://www.tceq.state.tx.us/permitting/water_supply/water_rights/eflows/resources.html |
| The Nature Conservancy's Ground Water Dependent Ecosystem Assessment<br>http://tinyurl.com/GDE-Workspace |
| **Geomorphology** |
| Vermont Agency of Natural Resources' Stream Geomorphic and Reach Habitat Assessment Protocols<br>http://www.vtwaterquality.org/rivers/htm/rv_geoassess.htm |
| Geomorphic Assessment and River Corridor Planning of the Batten Kill Main-Stem and Major Tributaries, Vermont<br>http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_battenkillreport.pdf |
| **Water Quality** |
| Oregon Department of Environmental Quality's Oregon Water Quality Index<br>http://www.deq.state.or.us/lab/wqm/wqimain.htm |
| **Biological Condition** |
| Biological Condition Gradient and Tiered Aquatic Life Uses<br>http://www.epa.gov/bioindicators/html/bcg.html |
| Index of Biotic Integrity (IBI)<br>http://www.epa.gov/bioiweb1/html/ibi_history.html |
| Maine Department of Environmental Protection's Tiered Aquatic Life Uses<br>http://www.maine.gov/dep/water/monitoring/biomonitoring/index.html |
| Natural Heritage Program Biodiversity Assessments<br>http://www.natureserve.org/aboutUs/network.jsp |
| Ohio Environmental Protection Agency's Statewide Biological and Water Quality Monitoring and Assessment<br>http://www.epa.state.oh.us/dsw/bioassess/ohstrat.aspx |
| Oregon Natural Heritage Information Center<br>http://orbic.pdx.edu/ |
| U.S. Geological Survey's Aquatic GAP Analysis Program<br>http://www.gap.uidaho.edu/projects/aquatic/default.htm |
| U.S. Geological Survey's Ohio Aquatic GAP Analysis: An Assessment of the Biodiversity and Conservation Status of Native Aquatic Animal Species<br>http://pubs.er.usgs.gov/usgspubs/ofr/ofr20061385 |
| Virginia Department of Conservation and Recreation's Interactive Stream Assessment Resource (INSTAR)<br>http://instar.vcu.edu |

| National Aquatic Resource Assessments |
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| Minnesota National Lakes Assessment<br>http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/lake-water-quality/national-lakesassessment-project-nlap.html?menuid=&redirect=1 |
| Oklahoma National Rivers and Streams Assessment<br>http://www.owrb.ok.gov/studies/reports/reports_pdf/REMAP-OKStreamRiver_ProbMonitorNetwork.pdf |
| U.S. Environmental Protection Agency's National Lakes Assessment<br>http://water.epa.gov/type/lakes/lakessurvey_index.cfm |
| U.S. Environmental Protection Agency's National River and Streams Assessment (NRSA)<br>http://water.epa.gov/type/rsl/monitoring/riverssurvey/riverssurvey_index.cfm |
| U.S.Geological Survey's Regional and National Monitoring and Assessments of Streams and Rivers<br>http://water.usgs.gov/nawqa/studies/mrb/ |
| **Integrated Assessments** |
| California Watershed Assessment Manual<br>http://cwam.ucdavis.edu/ |
| Connecticut Department of Environmental Protection's Least Disturbed Watersheds<br>http://www.ct.gov/dep/lib/dep/water/water_quality_management/ic_studies/least_disturbed_rpt.pdf |
| U.S. Environmental Protection Agency's Recovery Potential Screening Tool<br>www.epa.gov/recoverypotential/ |
| Kansas Department of Health and Environment's Least Disturbed Watersheds Approach<br>http://www.kdheks.gov/befs/download/bibliography/Kansas_reference_stream_report.pdf |
| Minnesota Department of Natural Resources' Watershed Assessment Tool<br>http://www.dnr.state.mn.us/watershed_tool/index.html |
| National Fish Habitat Assessment<br>http://fishhabitat.org/ |
| Oregon Watershed Enhancement Board's Watershed Assessment Manual<br>http://www.oregon.gov/OWEB/docs/pubs/OR_wassess_manuals.shtml#OR_Watershed_Assessment_Manual |
| Pennsylvania Natural Heritage Program's Aquatic Community Classification and Watershed Conservation Prioritization<br>http://www.naturalheritage.state.pa.us/aquaticsIntro.aspx |
| Virginia Department of Conservation and Recreation's Watershed Integrity Model<br>http://www.dcr.virginia.gov/natural_heritage/vclnawater.shtml |
| **Vulnerability** |
| U.S. Environmental Protection Agency's Regional Vulnerability Assessment Program<br>http://www.epa.gov/reva/ |
| Virginia Conservation Lands Needs Assessment Vulnerability Model<br>http://www.dcr.virginia.gov/natural_heritage/vclnavulnerable.shtml |
| Wyoming Department of Envrionmental Quality's Aquifer Sensitivity and Ground Water Vulnerability Assessment<br>http://waterplan.state.wy.us/plan/green/techmemos/swquality.html |

## Management Examples

| National |
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| Enabling Drinking Water Source Protection<br>http://www.landuseandwater.org/ |
| The Nature Conservancy's Approach to Setting Freshwater Conservation Priorities<br>http://www.conservationgateway.org/topic/setting-freshwater-priorities |
| U.S. Environmental Protection Agency's Healthy Watersheds Initiative Website<br>http://water.epa.gov/healthywatersheds |
| **State/Interstate** |
| California Healthy Streams Partnership<br>http://www.swrcb.ca.gov/mywaterquality/monitoring_council/meetings/2011jun/hsp_outreach.pdf |
| Delaware River Basin Commission's use of Antidegradation<br>http://www.state.nj.us/drbc/spw.htm |
| Enabling Source Water Protection in Maine<br>http://www.landuseandwater.org/maine.html |
| Maryland's GreenPrint Program<br>www.greenprint.maryland.gov |
| Minnesota Department of Natural Resources' Fen Protection Program<br>http://www.dnr.state.mn.us/eco/wetlands/index.html |
| Minnesota Healthy Watersheds Program<br>http://files.dnr.state.mn.us/aboutdnr/reports/legislative/2010_healthy_watersheds.pdf |
| NatureServe's Conservation Priorities for Freshwater Biodiversity in the Upper Mississippi River Basin<br>http://www.natureserve.org/library/uppermsriverbasin.pdf |
| Michigan's Natural Rivers Program<br>http://www.michigan.gov/dnr/0,1607,7-153-30301_31431_31442---,00.html |
| Michigan's Water Withdrawal Assessment<br>http://web2.msue.msu.edu/bulletins/Bulletin/PDF/WQ60.pdf |
| The Wyoming Joint Ventures Steering Committee's Wetlands Conservation Strategy<br>http://gf.state.wy.us/habitat/WetlandConservation/Wyoming%20Wetlands%20Conservation%20Strategy%20September%207,%202010.pdf |
| Vermont Agency of Natural Resources River Corridor Protection Program<br>http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_restoration.htm |
| Virginia Department of Conservation and Recreation's Healthy Waters Program<br>www.dcr.virginia.gov/healthywaters |
| Washington's Critical Areas Growth Management Act<br>http://www.commerce.wa.gov/site/418/default.aspx |

| Local |
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| Cecil County, Maryland Green Infrastructure Plan<br>http://www.conservationfund.org/sites/default/files/CecilCounty01.22.08.pdf |
| Headwaters: A Collaborative Conservation Plan for the Town of Sanford, Maine<br>http://www.wellsreserve.org/blog/63-headwaters_a_collaborative_conservation_plan_for_the_town_of_sanford |
| National Wild and Scenic Rivers: Lumber River, North Carolina<br>http://www.rivers.gov/wsr-lumber.html |
| The Central Texas Greenprint for Growth: A Regional Action Plan for Conservation and Economic Opportunity<br>http://envisioncentraltexas.org/resources/GreenprintMkt.pdf |
| The U.S. Forest Service and Trust for Public Land's Lower Meramec Drinking Water Source Protection Project<br>http://cloud.tpl.org/pubs/landwater-lowermer-swp-brochure.pdf |
| Watershed-Based Zoning in James City County, Virginia<br>http://www.jccegov.com/environmental/index.html |

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Healthy Watersheds