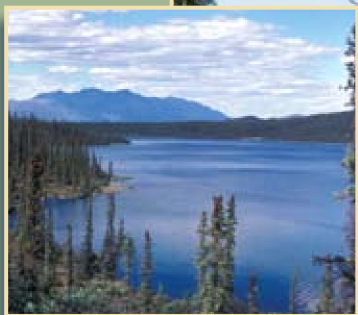


Identifying and Protecting Healthy Watersheds

Concepts, Assessments, and Management Approaches

DRAFT

Healthy Watersheds

EPA

Main front cover photo courtesy of Kristin Godfrey. Inset front cover photos courtesy of USDA NRCS (top), USFWS (middle), and Kristin Godfrey (bottom).

Identifying and Protecting Healthy Watersheds

Concepts, Assessments, and Management Approaches

DRAFT

March 2011

EPA XXX-XX-XXX

U.S. Environmental Protection Agency
Office of Wetlands, Oceans, and Watersheds
1200 Pennsylvania Avenue, N.W. (4503T)
Washington, D.C. 20460

Disclaimer

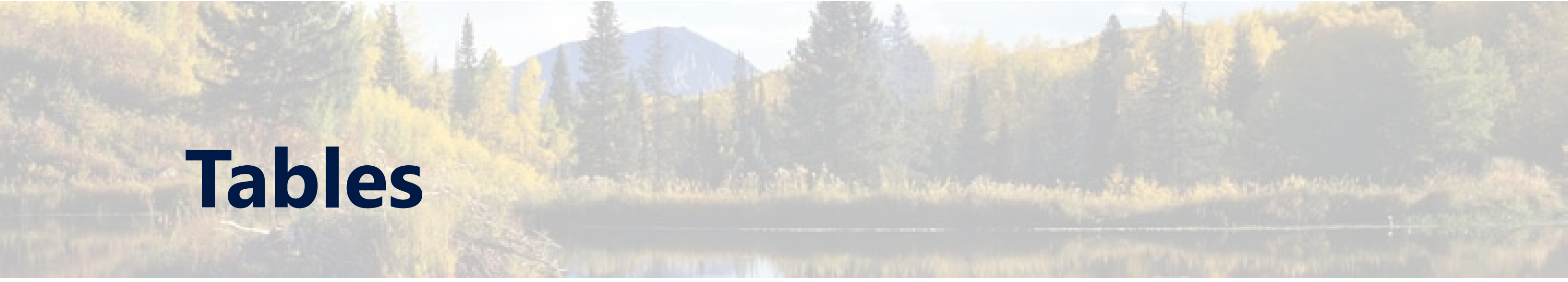
This document provides information for states, territories, and federally recognized tribes for identifying and protecting healthy watersheds. At times, this document refers to statutory and regulatory provisions, which contain legally binding requirements. This document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus it does not impose legally-binding requirements on EPA, states, territories, authorized tribes, or the public and may not apply to a particular situation based upon the circumstances. EPA, state, territory, and authorized tribe decision makers retain the discretion to adopt approaches to identify and protect healthy watersheds on a case-by-case basis that differ from this document where appropriate. EPA may change this document in the future.

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

Some of the photos, figures, tables, and other graphics that are used in this document are copyrighted material for which permission was obtained from the copyright owner for use in this document. Specific materials reproduced by permission are marked, and are still under copyright by the original authors and publishers. If you wish to use any of the copyrighted photos, figures, tables, or other graphics in any other publication, you must contact the owner and request permission.

Table of Contents

Figures



Tables

Acronyms & Abbreviations

ACC	Aquatic Community Classification
AES	Aquatic Ecological System
AFF	American Fact Finder
AHP	Analytical Hierarchy Process
ANR	Agency of Natural Resources
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
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
CRS	Community Rating System
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
FLIR	Forward Looking Infrared Remote Sensing
FPZ	Functional Process Zone
FRCC	Fire Regime Condition Class
FRG	Fire Regime Group
FWS	Fish and Wildlife Service
GAP	Gap Analysis Program
GDE	Ground water Dependent Ecosystem
GIA	Green Infrastructure Assessment
GIS	Geographic Information System
GMA	Growth Management Act
GPD	Gallons Per Day
GPS	Global Positioning System
GRP	Grassland Reserve Program
HAT	Hydrologic Assessment Tool
HEP	Habitat Evaluation Procedures
HHEI	Headwaters Habitat Evaluation Index
HIP	Hydroecological Integrity Assessment Process
HIT	Hydrologic Index Tool
HPP	Habitat Priority Planner
HSI	Habitat Suitability Index
HSPF	Hydrologic Simulation Program Fortran
HTI	Human Threat Index
HUC	Hydrologic Unit Code
IBI	Index of Biotic Integrity
IC	Impervious Cover
ICI	Invertebrate Community Index
IFIM	Instream Flow Incremental Methodology
IHA	Indicators of Hydrologic Alteration
ILWIS	Integrated Land and Water Information System
INSTAR	Interactive Stream Assessment Resource
ISAT	Impervious Surface Analysis Tool
ITI	Index of Terrestrial Integrity
IWI	Index of Watershed Indicators
KDHE	Kansas Department of Health and the Environment
LAC	Local Advisory Committee

LDW	Least Disturbed Watershed
LID	Low Impact Development
L-THIA	Long-Term Hydrologic Impact Assessment
MAIA	Mid-Atlantic Integrated Assessment
MBSS	Maryland Biological Stream Survey
mIBI	Modified Index of Biotic Integrity
MIwb	Modified Index of Wellbeing
MMI	Macroinvertebrate Multimetric Index
MRB	Major River Basins
MRTA	Meramec River Tributary Alliance
NAI	No Adverse Impact
NARS	National Aquatic Resource Surveys
NATHAT	National Hydrologic Assessment Tool
NAWQA	National Water Quality Assessment
NCDC	National Climatic Data Center
NED	National Elevation Dataset
NEMO	Nonpoint Education for Municipal Officials
NFHAP	National Fish Habitat Action Plan
NFIP	National Flood Insurance Program
NFPP	National Fish Passage Program
NHD	National Hydrography Dataset
NJHAT	New Jersey Hydrologic Assessment Tool
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
NSF	National Sanitation Foundation
NSPECT	Nonpoint Source Pollution and Erosion Comparison Tool
NWI	National Wetlands Inventory
NWIS	National Water Information System
ONRW	Outstanding National Resource Water
ORNHIC	Oregon Natural Heritage Information Center
ORV	Outstandingly Remarkable Value
OWEB	Oregon Watershed Enhancement Board
OWOW	Office of Wetlands, Oceans, and Watersheds
OWQI	Oregon Water Quality Index

PAD	Protected Areas Database
PCA	Principal Components Analysis
PDR	Purchase of Development Rights
PET	Potential Evapotranspiration
PFC	Proper Functioning Condition
PHI	Physical Habitat Index
PHWH	Primary Headwaters Habitat
PNC	Potential Natural Community
POS	Program Open Space
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RASCAL	Rapid Assessment of Stream Conditions Along Length
RBS	Relative Bed Stability
RCC	River Continuum Concept
RDBMS	Relational Database Management Systems
RES	Riverine Ecosystem Synthesis
ReVA	Regional Vulnerability Assessment
RIVPACS	River Invertebrate Prediction and Classification System
RMAC	River Management Advisory Committee
RMPP	River Management and Protection Program
RPA	River Protection Act
RPST	Recovery Potential Screening Tool
RPT	Regime Prescription Tool
RTE	Rare, Threatened, or Endangered
SAB	Science Advisory Board
SABS	Suspended and Bedded Sediments
SFI	Sustainable Forestry Initiative
SGA	Stream Geomorphic Assessment
SPARROW	Spatially Referenced Regressions On Watershed Attributes
SSURGO	Soil Survey Geographic Database
STORET	STOrage and RETrieval
SVAP	Stream Visual Assessment Protocol
SWAMP	Southern Watershed Area Management Program
SWMM	Storm Water Management Model
SYE	Sustainable Yield Estimator
TALU	Tiered Aquatic Life Use
TDR	Transfer of Development Rights
TEA	Targeted Ecological Area
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
WCA	Wetlands Conservation Act
WHIP	Wildlife Habitat Incentives Program
WIM	Watershed Integrity Model
WQI	Water Quality Index
WQS	Water Quality Standards
WQX	Water Quality Exchange
WRP	Wetlands Reserve Program
WSA	Wadeable Streams Assessment
WWAP	Water Withdrawal Assessment Process
WWF	World Wildlife Fund

Memo from EPA Management

TBD

Acknowledgements

This document was prepared by the U.S. Environmental Protection Agency (EPA), Office of Water, Office of Wetlands, Oceans, and Watersheds. The EPA Project Manager for this document was Laura Gabanski, who provided overall direction and coordination. EPA was supported in the development of this document by The Cadmus Group, Inc. Laura Blake and Corey Godfrey of The Cadmus Group, Inc. were responsible for creating most of the content of this document. Mike Wireman (EPA Region 8), Leslie Bach and Allison Aldous (The Nature Conservancy), and Christopher Carlson (U.S. Forest Service) were responsible for writing sections on hydrology, ground water, and ground water dependent ecosystems. Jonathan Higgins (The Nature Conservancy) wrote the sections on freshwater conservation priorities. Special appreciation is extended to the following individuals, who provided technical information and reviews during the preparation of this document:

EPA
Chris Faulkner, Office of Water
Doug Norton, Office of Water
Dov Weitman, Office of Water
Fred Leutner, Office of Water (retired)
Heather Goss, Office of Water
Jim Carleton, Office of Water
John McShane, Office of Water
Robert Goo, Office of Water
Sarah Lehmann, Office of Water
Stuart Lehman, Office of Water
Susan Jackson, Office of Water
Tommy Dewald, Office of Water
Tracy Kerchkof, Office of Water
Susan Julius, Office of Research and Development
Wayne Davis, Office of Environmental Information
Ralph Abele, Region 1
Bill Jenkins, Region 3
Sue McDowell, Region 3
Susan Spielberger, Region 3
Tom DeMoss, Region 3
Christine McKay, Region 4
John Richardson, Region 4
Stephanie Fulton, Region 4
Betsy Nightingale, Region 5
Brian Fontenot, Region 6
Leah Medley, Region 7
Jill Minter, Region 8
Mike Wireman, Region 8
Carolyn Yale, Region 9
Christina Yin, Region 9
Tracy Nadeau, Region 10

U.S. Forest Service
Christopher Carlson
John Potyondy
Nancy Stremple

U.S. Fish and Wildlife Service
Cindy Williams
Ron Nassar
Vincent Mudrak
Will Duncan

U.S. Geological Survey
Alex Covert
Donna Meyers
Stacey Archfield

The Nature Conservancy
Allison Aldous
Eloise Kendy
Jonathan Higgins
Leslie Bach
Mark Smith
Scott Sowa

The Cadmus Group, Inc.
Elisabeth Cianciola
Tracy Mehan

The Trust for Public Lands
Kelley Hart

The Conservation Fund
Will Allen

Board of Alliance for the Great Lakes
Jack Bails

Superior Watershed Partnership and Land Trust
Carl Lindquist

Wells National Estuarine Research Reserve
Christine Feurt

Massachusetts Department of Fish and Game
Russ Cohen

Minnesota Department of Natural Resources
Sharon Pfeifer
Beth Knudsen

Vermont Agency of Natural Resources
Mike Kline

Michigan Department of Natural Resources
Paul Seelbach
Troy Zorn

Oregon Watershed Enhancement Board
Ken Bierly

Maryland Department of Natural Resources
Catherine McCall
Christine Conn
Paul Kazyak
Scott Stranko

Virginia Department of Conservation and Recreation
Jennifer Ciminelli

Kansas Department of Health and Environment
Bob Angelo

Connecticut Department of Environmental Protection
Christopher Belluci

Anne Arundel County, MD
Dawn Thomas

Hampton Roads Planning District Commission, VA
Sara Kidd

Oregon State University
Jimmy Kagan

University of California at Davis
Fraser Shilling

University of Washington
James Karr

Virginia Commonwealth University
Greg Garman

University of Tennessee at Knoxville
Tracy Walker Moir-McClean

1. Introduction

1.1 Background

The objective of the Clean Water Act (CWA) is “to restore and maintain the chemical, physical, and biological integrity of the nation’s waters” (CWA § 101(a)). The House Public Works Committee report on the CWA states that the intended use of the term “integrity” in the Act was to recognize the importance of preserving natural ecosystems rather than simply improving water quality in a narrow sense (Doppelt, Scurlock, Frissell, & Karr, 1993). Since enacted in 1972, 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.

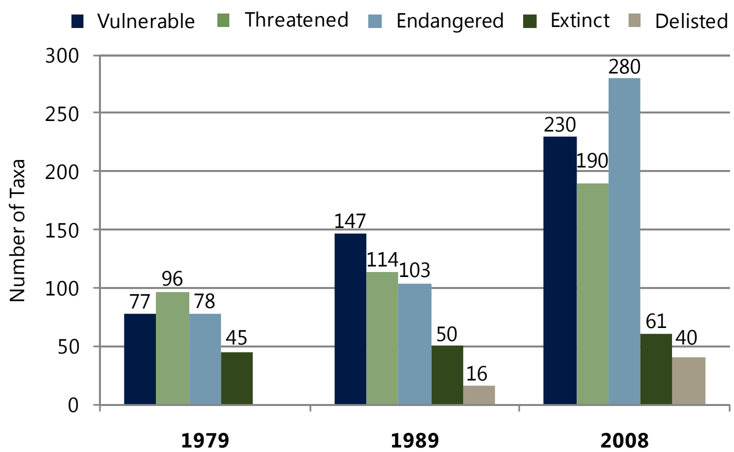


Figure 1-1 Numbers of imperiled North American freshwater and diadromous fish taxa (modified from Jelks et al., 2008).

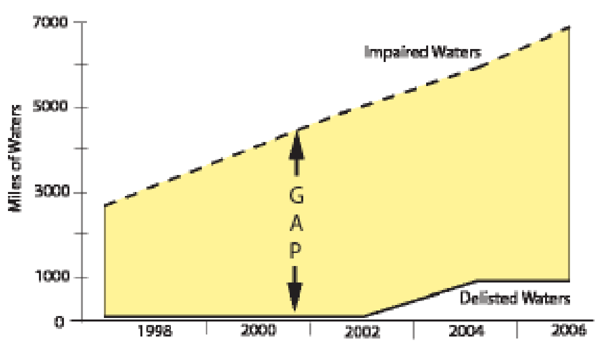


Figure 1-2 Gap between impaired and restored waters in EPA Region 3.

Despite these efforts, our aquatic ecosystems are declining nationwide (Figure 1-1). This trend has been documented by many, including the Heinz Center (2008), the American Fisheries Society (Jelks et al., 2008), and EPA (2006). 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. It is clear that a better strategy is needed if we are to achieve all of the objectives of the CWA envisioned by Congress.

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

Waterbody	Impairment	Miles	Cost	Average Cost/Mile
Corsica River, MD	Nutrients	7.6	$17,500,000	$2,300,000
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	$60,440
Thumb Run, VA	Bacteria	17	$2,450,000	$144,117
Willis River, VA	Bacteria	30	$2,794,160	$93,138
Muddy Creek, VA	Bacteria	9	$2,612,000	$290,222

1.2 EPA Healthy Watersheds Initiative

The concept of protecting healthy watersheds is based on a key, overarching principle: the integrity of aquatic ecosystems is tightly linked to the watersheds of which they are part. There is a direct relationship between land cover, key watershed processes, and the condition of aquatic ecosystems. Healthy, functioning watersheds provide the ecological infrastructure that anchors water quality restoration efforts. Components of a healthy watershed can include intact and functioning headwaters, wetlands, floodplains and riparian corridors, instream habitat and biotic refugia, biological communities, green infrastructure, natural disturbance regimes, sediment transport, and hydrology expected for its location. Without protecting this ecological support system, we will not only fail in our efforts to restore impaired waters, but will also waste limited financial resources in the process.

EPA's Healthy Watersheds Web Page

http://www.epa.gov/healthywatersheds

EPA, in partnership with others, is embarking on the new Healthy Watersheds Initiative to protect our remaining healthy watersheds, prevent them from becoming impaired, and accelerate our restoration successes. This initiative will be 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, then priorities can be set for protection and restoration, with the best chances of recovery being in waters near existing healthy aquatic ecosystems.

The key components of the Healthy Watersheds Initiative are:

1. Identify healthy watersheds and intact components of watersheds within states and on tribal lands through integrated assessments.
2. Implement state and tribal strategic protection programs.
3. Implement local protection programs based on priorities from state and local assessments.
4. Inform restoration priorities for both impaired and ecologically degraded waters.

While the Healthy Watersheds Initiative is intended to be implemented to support strategic statewide and tribal decisions, the assessment data and information can be used at the basin or local watershed levels to inform management approaches, including implementing water quality and other programs. The anticipated outcomes of the Healthy Watersheds Initiative are integrated ecosystem protection programs that result in both maintaining and increasing the number of healthy watersheds.


BLM

1.3 Benefits of Protecting Healthy Watersheds

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 dollar 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 could meet their 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 supplies 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.

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 many valuable commodities and services to society (Baron et al., 1997). 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 into ecosystem services indicates that the short-term economic benefits from exploiting natural resources pale in comparison to the lasting damage done to ecosystem services (Baron et al., 1997).

In addition to avoiding the need for expensive restoration activities in the future, there are many other economic benefits to protecting healthy watersheds. Healthy watersheds preserve recreation opportunities, such as fishing and water-related recreation (e.g., boating) and contribute to tourism (e.g., hiking and birding). Vulnerability to floods, fires, and other natural disasters is minimized, thereby reducing costs to communities. By protecting aquifer recharge zones and surface water sources, costs of drinking water treatment may be reduced. A survey of 27 drinking water utilities finds 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-Maîte, & 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 will help to mitigate increased carbon dioxide emissions.

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 and seasons of the year. Wetlands and forested areas have a profound effect on watershed hydrology, regulating flows during such 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).

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.

1.4 Purpose and Target Audience

The purpose of this document is to provide state aquatic resource scientists and managers with an overview of the key concepts behind the Healthy Watersheds approach, examples of approaches for assessing components of healthy watersheds, an integrated assessment framework to identify healthy watersheds, examples of management measures, and key assessment tools and sources of data. With this information, watershed scientists and managers will be able to conduct healthy watersheds assessments and initiate protection programs. The document can be used by local government land use managers to help develop protection priorities for using conservation and growth management tools. The document does not provide step-by-step instructions, but it does identify a number of approaches and sources for watershed 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 on the Healthy Watersheds approach, including assessment and protection practices.

1.5 How Does 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 approach presented in this document expands the value of existing 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 very similar to the Healthy Watersheds approach, and this document highlights their projects as examples.

1.6 How to Use this Document

The general framework for identifying and protecting healthy watersheds is represented in Figure 1-3. In theory, a new Healthy Watersheds program would progress sequentially through these six stages. However, in reality, different organizations will begin at different stages depending on work they may have already completed. The information presented in this document follows this framework. It is recommended that all users read Chapter 2 (stage 1) to familiarize or refresh themselves with the concepts underlying the Healthy Watersheds Initiative. Chapter 3 (stage 2) provides examples of assessment approaches in use across the country, and Chapter 4 (stages 3, 4, and 5) provides options for an integrated assessment framework to enable the identification of healthy watersheds and to set protection priorities. Chapter 5 (stage 6) organizes the many management approaches that can be used at the national, state, or local level to protect healthy watersheds. Appendix A contains key assessment tools, and Appendix B identifies sources of data. Readers can navigate between these chapters depending on their needs and priorities.

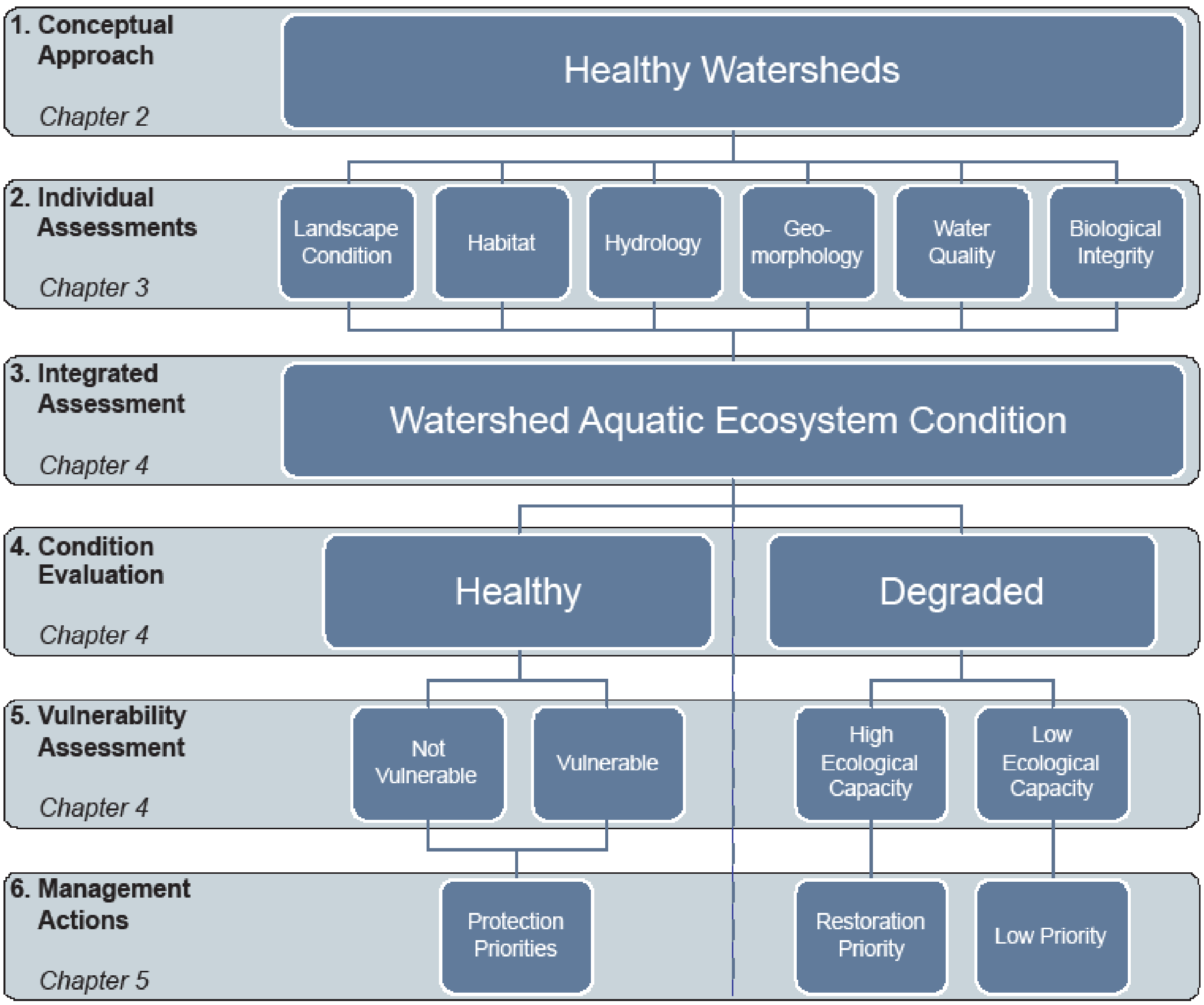


Figure 1-3 Healthy Watersheds Framework. Healthy watersheds are identified through an integrated assessment and prioritized for different protection strategies depending on vulnerability. The approach can also help to prioritize degraded watersheds for restoration actions based on their ecological capacity for recovery.

2. Overview of Key Concepts and Assessment Approaches

1. Conceptual Approach

Chapter 2

Healthy Watersheds

This chapter presents an overview of the Healthy Watersheds conceptual framework and assessment approaches. The Healthy Watersheds conceptual framework is based on a holistic systems approach to watershed assessment and protection that recognizes the spatiotemporal 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 (Figure 2-1).

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 2-2). Therefore, assessment and management must also occur at multiple spatial and temporal scales. With basins or watersheds as the organizing unit, the linkages between multiple spatiotemporal scales must be addressed in an integrated approach to assessing healthy watersheds.

Although the 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. 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 all of these assessment approaches is necessary for a comprehensive understanding of watershed ecosystem health.

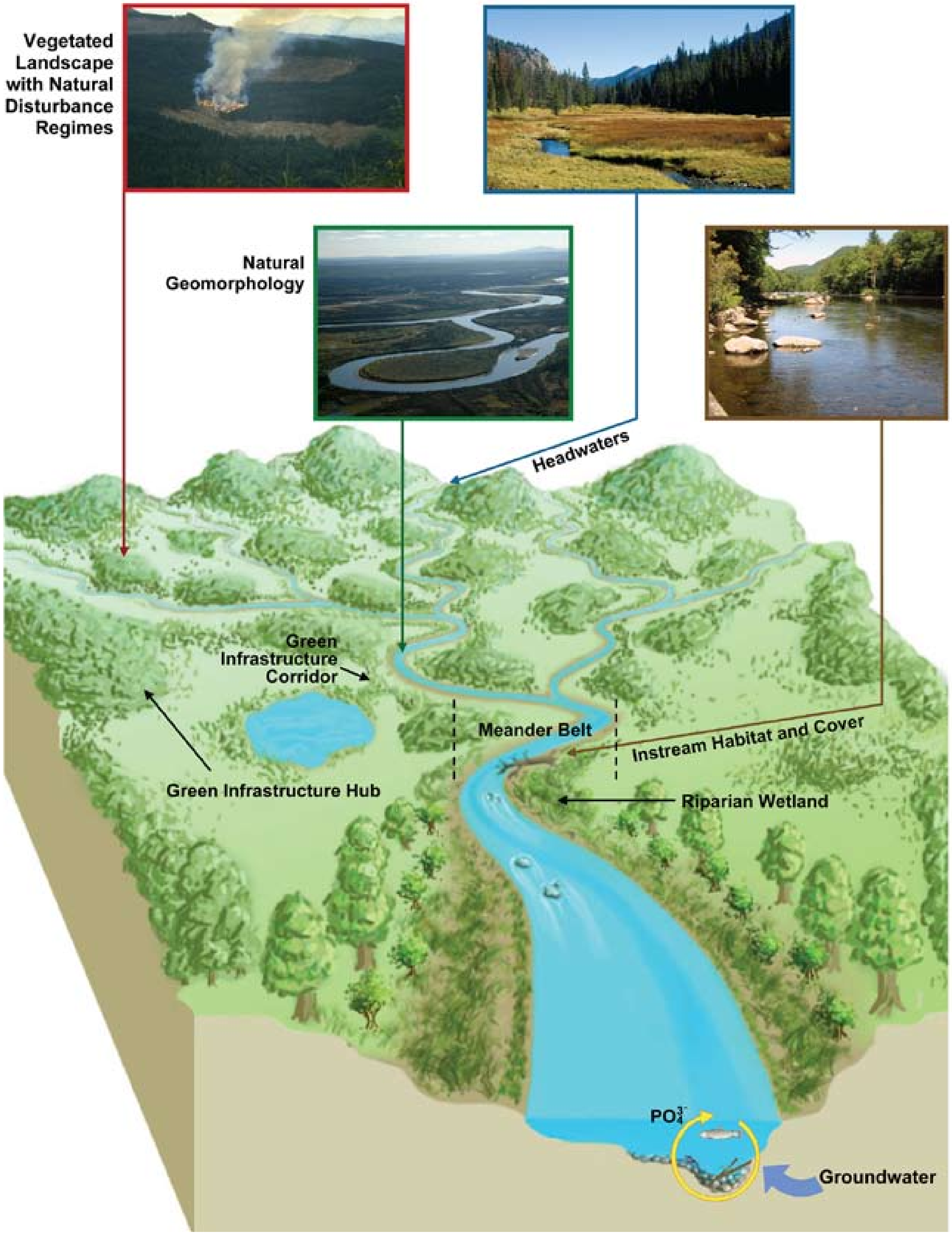


Figure 2-1 Healthy watersheds have landscapes with vegetated hubs and corridors; intact headwaters, wetlands, and riparian corridors; stream channels with natural geomorphic dynamics; a natural hydrologic regime; good water quality and biological integrity; and a variety of habitat types. Photo credits, clockwise from left: BLM, EPA, Kristin Godfrey, USFWS.

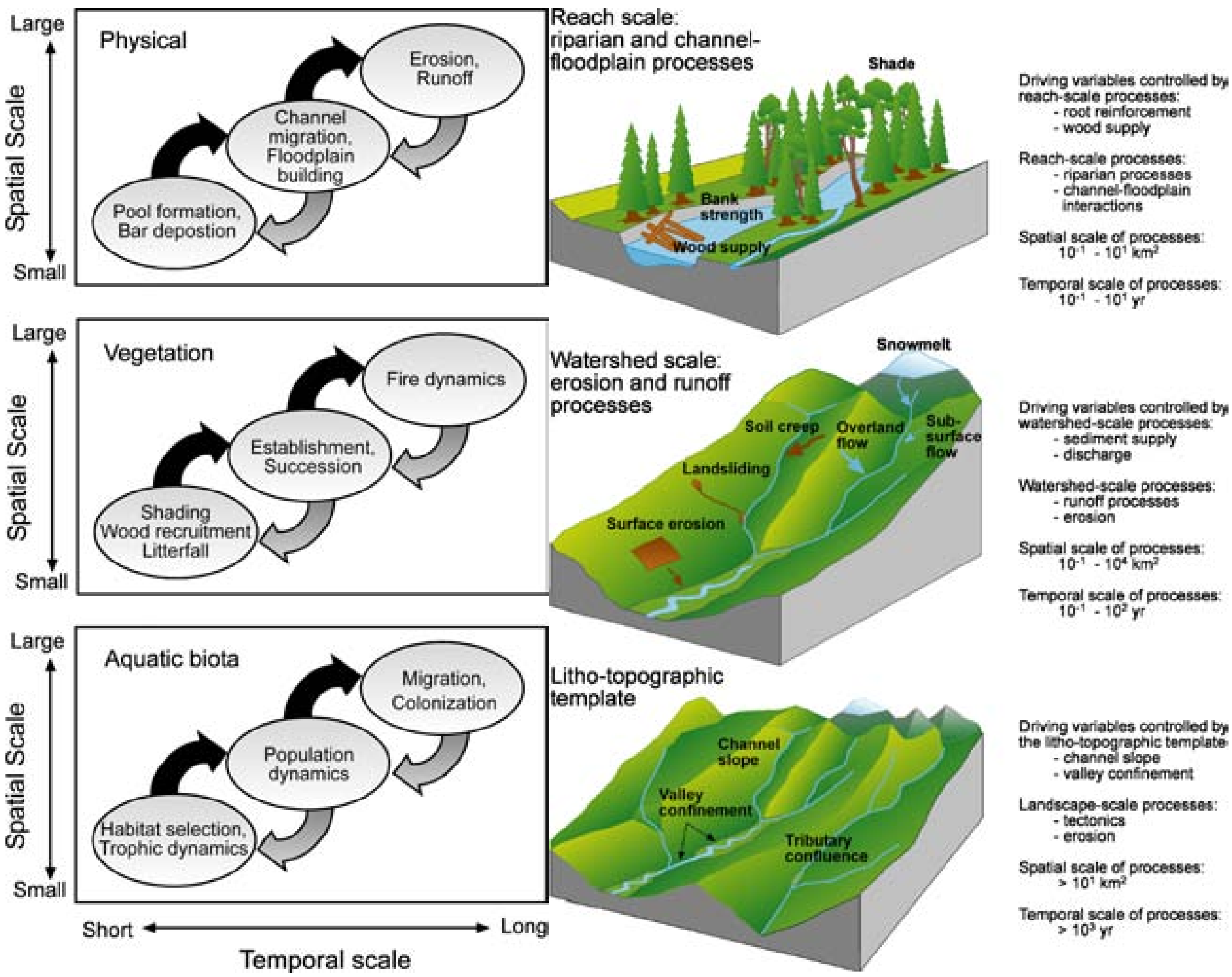


Figure 2-2 Spatial and temporal scales of watershed processes. Watershed and ecosystem processes operate at a variety of spatial and temporal scales, with processes operating at larger spatial scales generally influencing processes operating at smaller scales. In some instances, processes operating at 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.

2.1 A Systems Approach to Watershed Protection

The conceptual framework used in this document to assess ecosystem health is consistent with recommendations by EPA's Science Advisory Board (SAB) (U.S. EPA Science Advisory Board, 2002). The EPA SAB identified six categories, or 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 processes (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. Planning for protection can be aided by taking a holistic systems approach to understand these diverse processes that affect aquatic ecology.

The systems approach to watershed protection outlined here is based on an integrated evaluation of: 1) Landscape Condition, 2) Habitat, 3) Hydrology, 4) Geomorphology, 5) Water Quality, and 6) Biological Integrity. Ecological processes and natural disturbance regimes are addressed in the context of these six categories. Table 2-1 provides a brief description of each of these categories as well as the linkage with the EEAs. Watershed ecological attributes are interrelated, and assessing one attribute in isolation ignores this relationship. Thus, an integrated assessment approach is needed to manage watershed ecosystems.

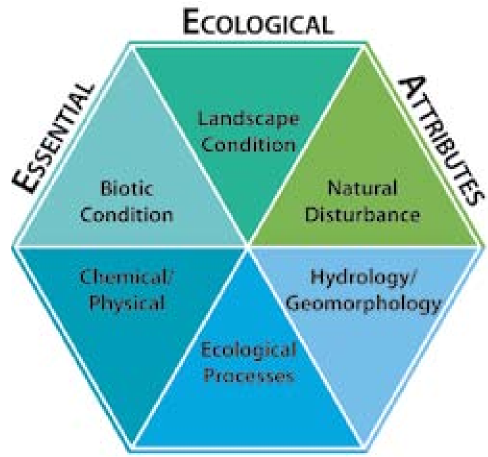


Figure 2-3 Essential Ecological Attributes (U.S. EPA Science Advisory Board, 2002).

Table 2-1 Healthy Watersheds components and relevant Essential Ecological Attributes.

Healthy Watersheds Assessment Component	Description	Relevant Essential Ecological Attributes
Landscape Condition	Patterns of natural land cover, natural disturbance regimes, lateral and longitudinal connectivity of the aquatic environment, and continuity of landscape processes.	Landscape Condition, Natural Disturbance Regime
Habitat	Aquatic, wetland, riparian, floodplain, lake, and shoreline habitat. Hydrologic connectivity.	Biotic Condition, Landscape Condition, Hydrologic/ Geomorphic Condition
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.	Hydrologic/Geomorphic Condition, Natural Disturbance Regime
Geomorphology	Stream channels with natural geomorphic dynamics.	Hydrologic/Geomorphic Condition
Water Quality	Chemical and physical characteristics of water.	Chemical/Physical Condition, Ecological Processes
Biological Integrity	Biological community diversity, composition, relative abundance, trophic structure, condition, and sensitive species	Biotic Condition, Ecological Processes

2.1.1 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 water 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 wide range of aquatic ecosystem types is a widely accepted conservation approach (Noss, LaRoe III, & Scott, 1995). The Center for Watershed Protection (2008) 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. As an integral part of a watershed assessment, 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 2-4 illustrate the difference between intact habitat in the landscape and fragmented habitat.

The landscape approach to conservation and ecosystem assessment is relatively new. Not until the 1980s did scientists begin to view ecosystems in the context of their surrounding landscapes. Planning of conservation areas prior to this time was typically carried out in an isolated manner focusing on individual species. Since the focus was on individual species, the interconnections between habitat patches were often not considered. Similarly, most planners and landscape architects typically did not consider the potential ecological benefits of connectivity among recreational areas such as parks. As conservation biologists began to develop reserve selection and design criteria for protecting wildlife habitat, the underlying concept of ecological networks began to play out in conservation actions (Benedict & McMahon, 2006). US

Figure 2-4 These photos provide an example of intact landscape condition (on the left) and fragmented landscape condition (on the right).

2.1.1.1 Green Infrastructure

This 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 2-5). 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. The State of Maryland is using a green infrastructure approach to identify undeveloped lands throughout the state that are most critical to long-term ecological health (Figure 2-6) (Maryland Department of Natural Resources, 2003b). Similarly, the Green Infrastructure Vision of Chicago Wilderness identifies 1.8 million acres of potential areas for protection and restoration throughout the region, and it provides information to guide land use decisions to be more compatible with ecosystem health (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" 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, development, etc. These hubs are often 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.

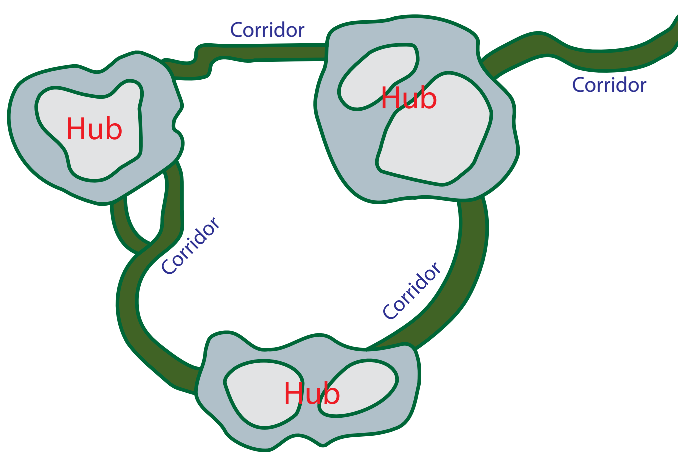


Figure 2-5 Green Infrastructure Network Design (modified from Maryland Department of Natural Resources, 2003b).

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

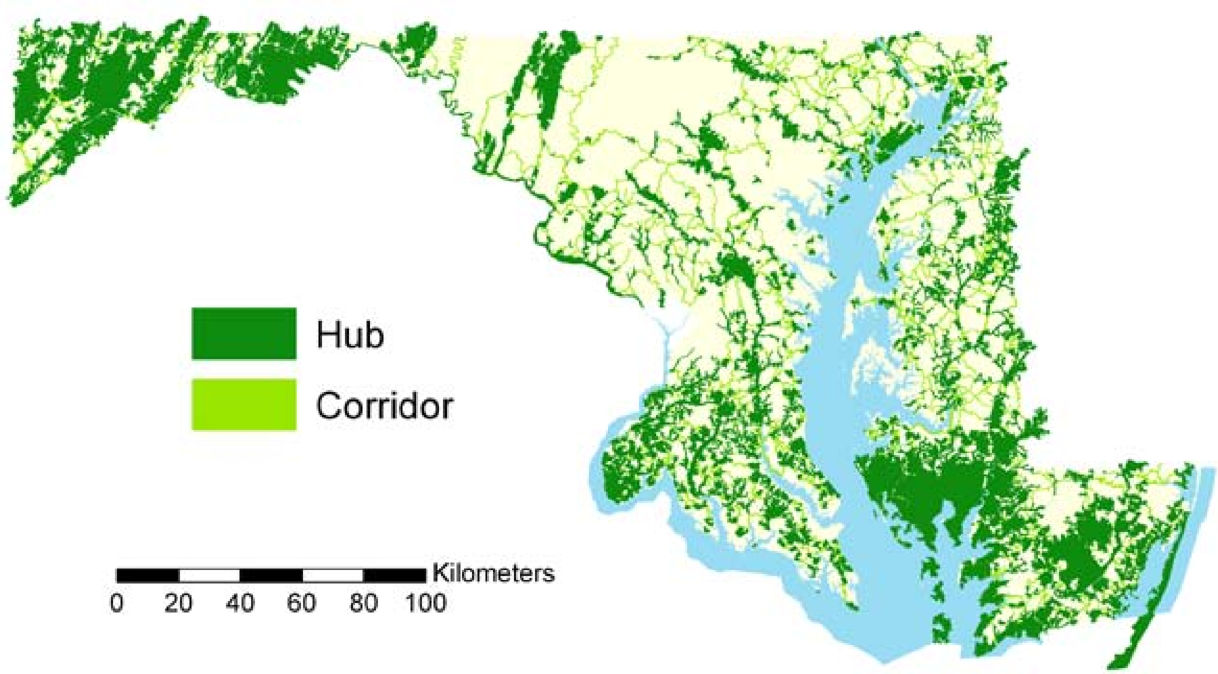


Figure 2-6 Green infrastructure in Maryland (Maryland Department of Natural Resources, 2003b).

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, 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.

2.1.1.2 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 2-7), 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. 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 numerous social and economic benefits, as well as a variety of ecosystem services, such as flood prevention and hazard avoidance, recreation and open space, and other habitat values. Preserving riparian wetlands and a river channel's connection with its floodplain provides surface and subsurface floodwater storage and reduction of stream power during flood events. This will become even more important in temperate regions, where climate change is predicted to increase average annual precipitation and frequency of extreme storm events. 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. The Active River Area is essential to healthy and productive fish populations, providing opportunities for anglers and increasing tax and local business revenues.

2.1.1.3 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, debris flows, and insect infestations, to name a few. The frequency, intensity, extent, and duration of such events are collectively referred to as the disturbance regime (U.S. EPA Science Advisory Board, 2002). The natural fire regime, particularly in forests of the western United States, 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. For example, 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. The continuous build-up of nutrients on the forest floor can provide 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 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.

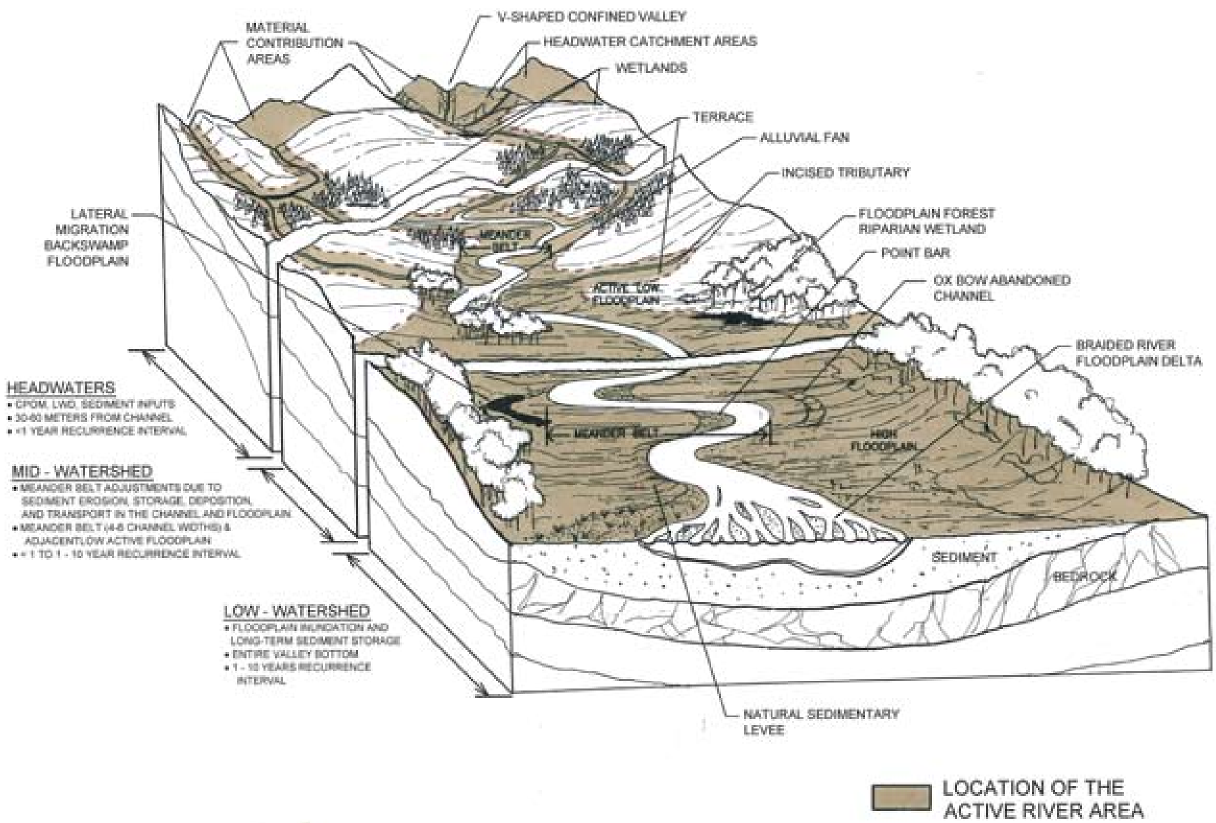


Figure 2-7 Components and dominant processes of the Active River Area (Smith et al., 2008).

2.1.1.4 Connectivity and Redundancy

Connectivity of landscape elements, including aquatic ecosystems, helps to ensure that organisms have access to all 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, and that populations have the ability to respond to environmental (including climate) change (Poiani, Richter, Anderson, & Richter, 2000). Physical barriers, such as dams, or polluted stream reaches 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, on the other hand, 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. Since these ecosystems are not hydrologically connected, the spread of an invasive species or disease is less likely to affect nearby systems. This can allow populations of the same species to persist in the presence of disturbance or environmental change.

2.1.2 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 the 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 integrity is highly dependent.

Figure 2-8 Cool water rivers provide important trout foraging habitat.

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 2-8), 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).

2.1.2.1 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 2-9) (Vannote et al., 1980). Changes in biological communities generally correspond with this physical gradient. For example, due to the degree of shading and the amount of large woody debris provided by riparian vegetation in headwater streams, a characteristic community of macroinvertebrates dependent on inputs of terrestrial vegetation is expected there. 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. As a river becomes much larger and wider, fine particulate matter from upstream becomes much more important as an energy source for the macroinvertebrate community.

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 RCC. 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.

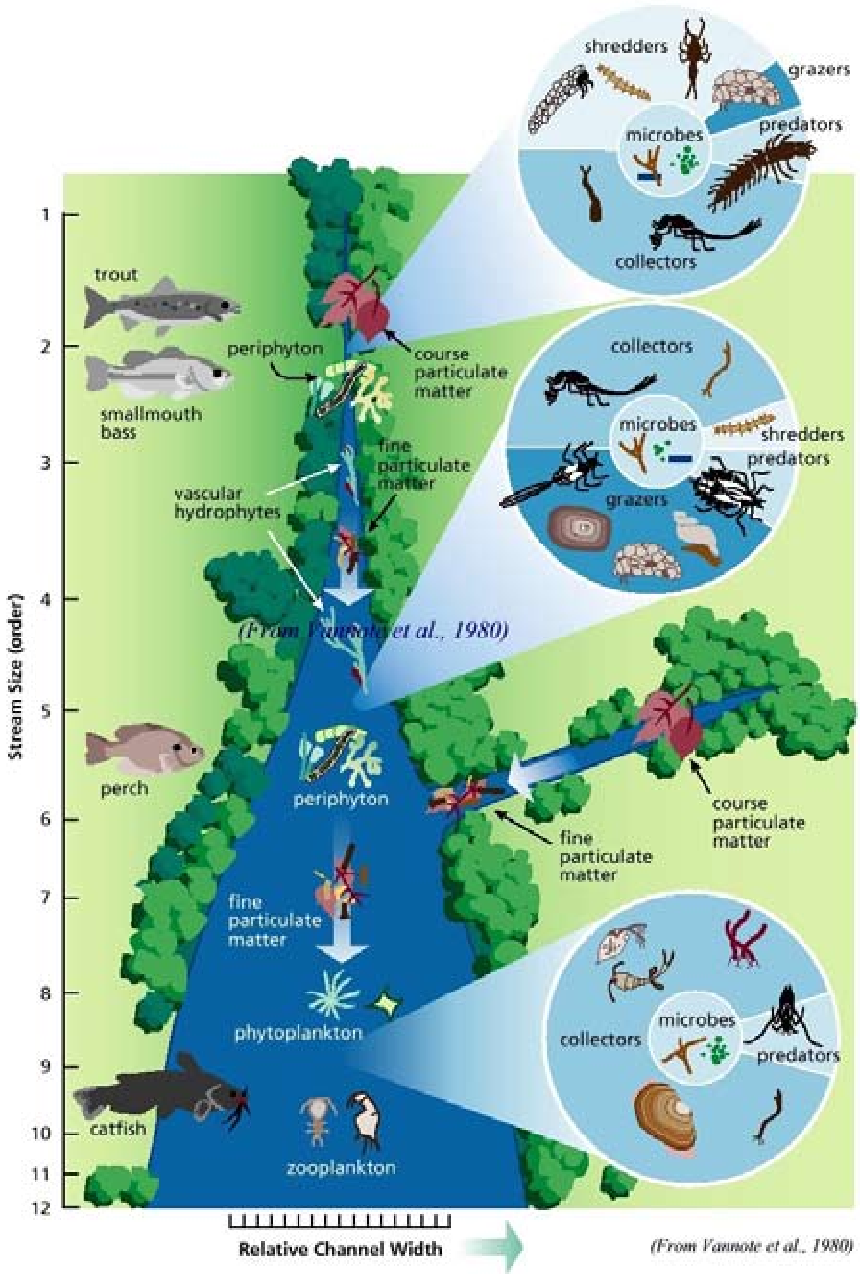


Figure 2-9 The River Continuum Concept (Vannote et al., 1980). © 2008 NRC Canada

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 2-10). 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 2-11). Rather, all four dimensions of the riverine system influence their distribution.

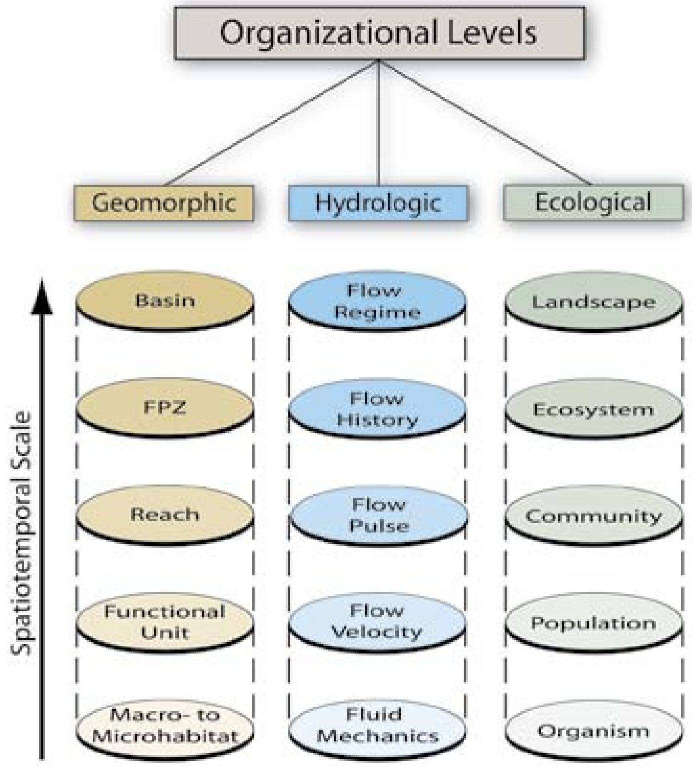


Figure 2-10 Hierarchy defining spatiotemporal scales of hydrogeomorphic patches (Thorp, Thoms, & Delong, 2008). Reprinted with permission of Elsevier.

A collaborative effort between EPA and the University of Kansas has resulted in 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 allows the distinct FPZ types to emerge on their own using multivariate cluster analysis. This results in a classification with minimal human bias. See Figure 2-12 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.

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.

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. Headwater streams, in particular, provide sediment, nutrient, and flood control and help to maintain baseflow 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 (Cohen, 1997).

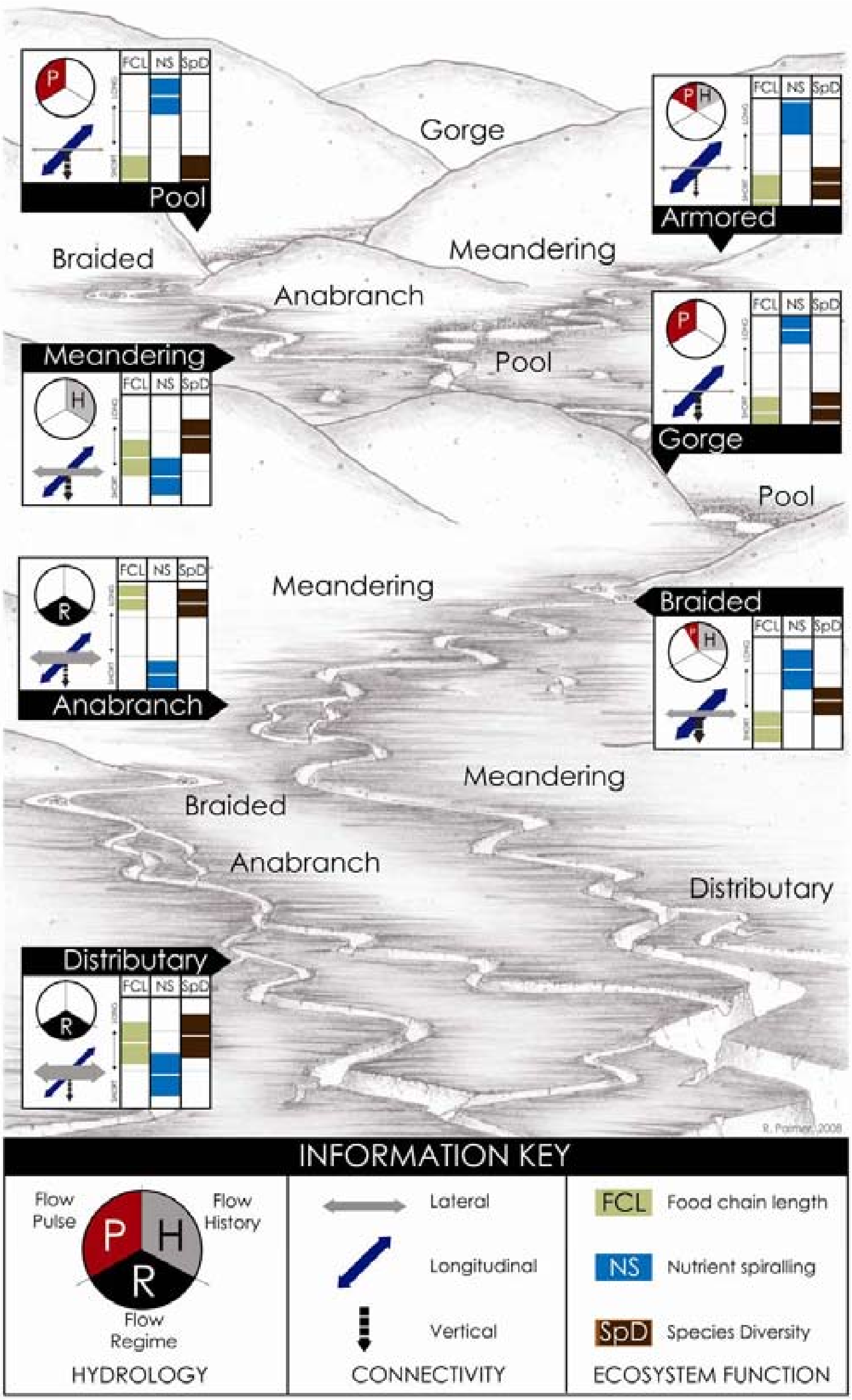


Figure 2-11 A conceptual riverine landscape is shown depicting various functional process zones (FPZ) and their possible arrangement in the longitudinal dimension. Note that FPZs are repeatable and only partially predictable in location (corrected copy from Thorp, Thoms, & Delong, 2008). Reprinted with permission of Elsevier.

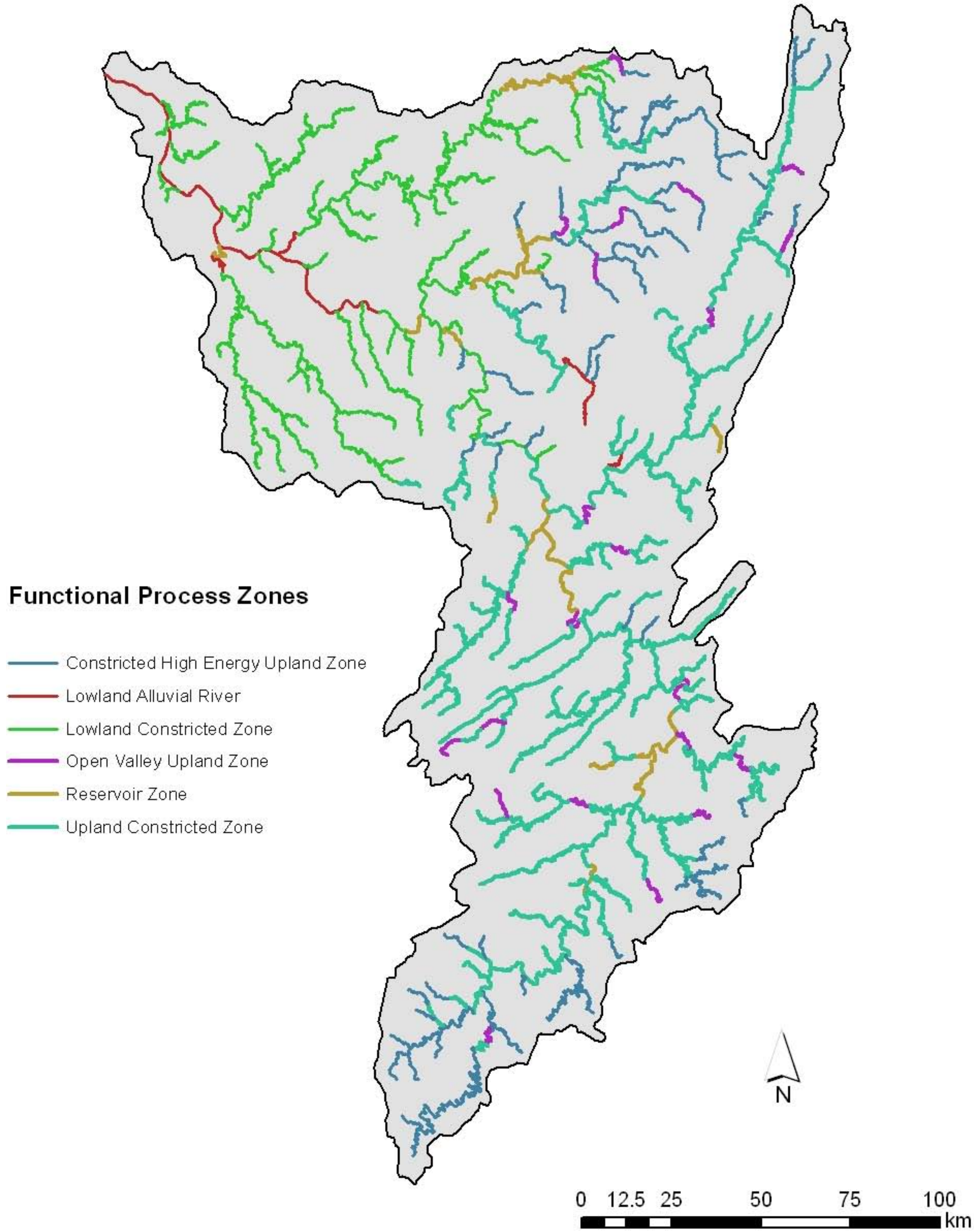


Figure 2-12 Distribution of the various Functional Process Zones in the Kanawha River, West Virginia (from in-review manuscript by J.H. Thorp, J.E. Flotemersch, B.S. Williams, and L.A. Gabanski entitled "Critical role for hierarchical geospatial analyses in the design of fluvial research, assessment, and management").

2.1.2.2 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. In EPA's National Lakes Assessment (NLA) (U.S. Environmental Protection Agency, 2009a), poor lakeshore habitat was identified as the most prominent stressor to the biological health of lakes.

Lakes are typically thought of as having three habitat zones: the littoral zone, the limnetic zone, and the benthic zone (Figure 2-13). The littoral zone is the nearshore area where sufficient sunlight reaches the substrate, allowing aquatic plants to grow. This zone provides unique 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 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 larger, 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 because they have more, and more varied, ecological niches (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.

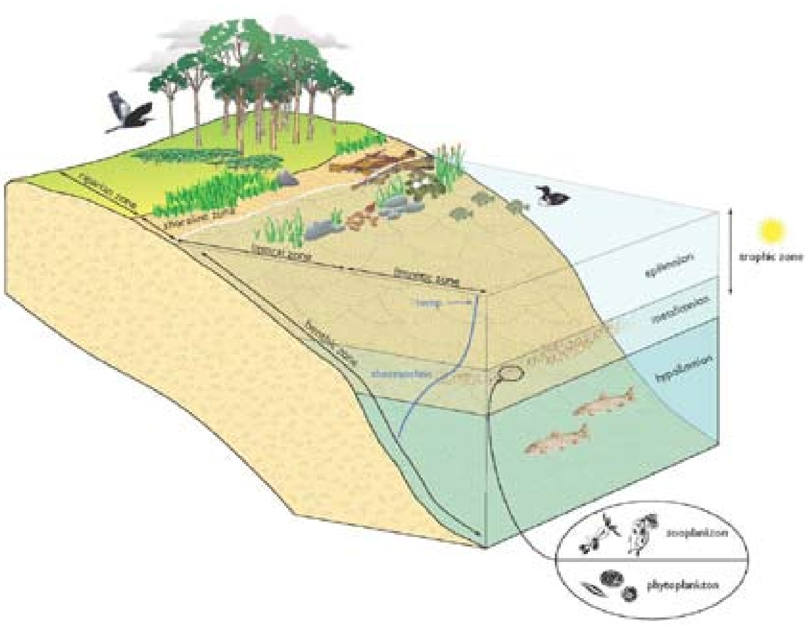


Figure 2-13 Schematic of a lakeshore and the three habitat zones of a typical lake (U.S. Environmental Protection Agency, 2009).

2.1.2.3 Wetland Habitat

Wetlands exist at the land-water interface and are thus frequently associated with lake or riverine habitats. Bayous, bogs, fens, marshes, prairie potholes, sedge meadows, and swamps are found in various parts of the United States. Wetland habitat characteristics are largely affected by their hydrologic connectivity to surrounding landscape features. This is especially the case with bogs, which depend on rainwater and are typically acidic as a result. The biological communities that occur in wetlands are closely 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).

2.1.3 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 or snowmelt from a given weather event moves through a variety of surface and subsurface pathways as it flows towards ground water discharge areas and the drainage network and eventually exits 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). Such a budget can be developed for any hydrologic feature and accounts for all water inputs and outputs (changes in water content). A watershed scale water budget includes the following components:

$$P + G_{in} - (Q + ET + G_{out}) = \Delta S,$$

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 ΔS is change in storage over a given 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 and snowmelt. Hydrographs for streams dominated by snowmelt and baseflow follow a more predictable pattern than 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.

Flow at a given point on a stream can be affected by surface runoff, interflow discharge, and baseflow discharge. The contribution of ground water to streamflow 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 2-14) and the ground water contribution can vary over an annual hydrograph.

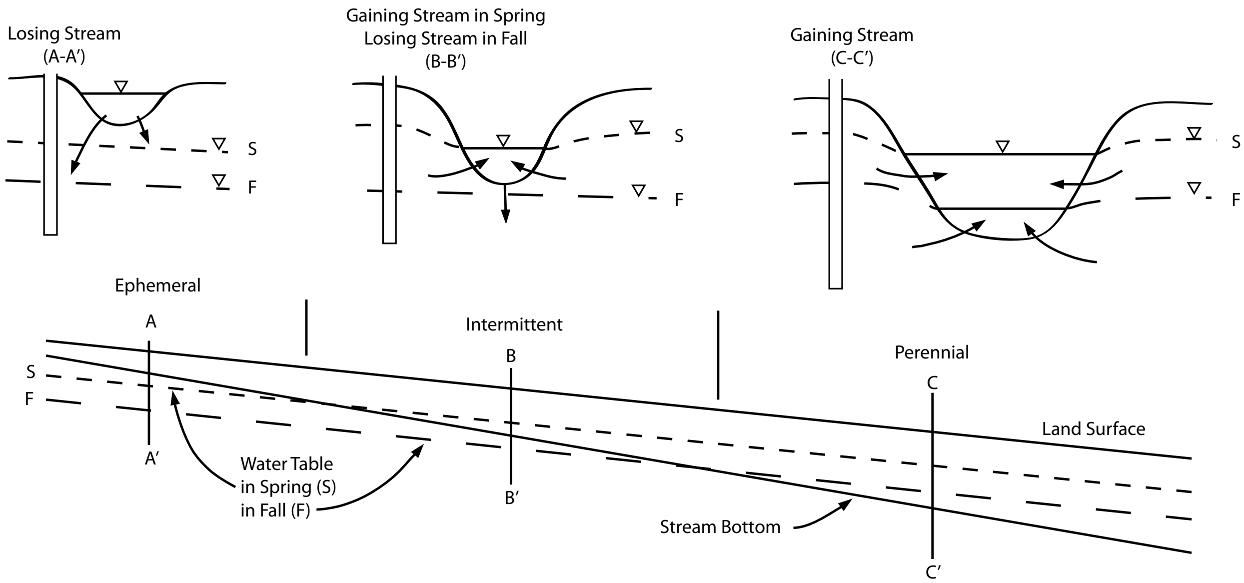


Figure 2-14 Relation between water table and stream type (U.S. Environmental Protection Agency, 1987).

2.1.3.1 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 assessing instream flow requirements initially led to the development of "rule of thumb" hydrologic statistics being set as minimum flows (Annear, et al., 2004). The 7Q10 rule is an example of this kind of thinking. 7Q10 refers to the lowest flow that lasts for seven days and occurs once every 10 years on average. 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 resource management agencies consider alternative water development and management schemes (Stalnaker et al., 1995). IFIM was designed to maintain the habitat availability currently existing under various alternative flow management scenarios for select species. This method is very data intensive, requiring substantial fieldwork and multidisciplinary expertise.

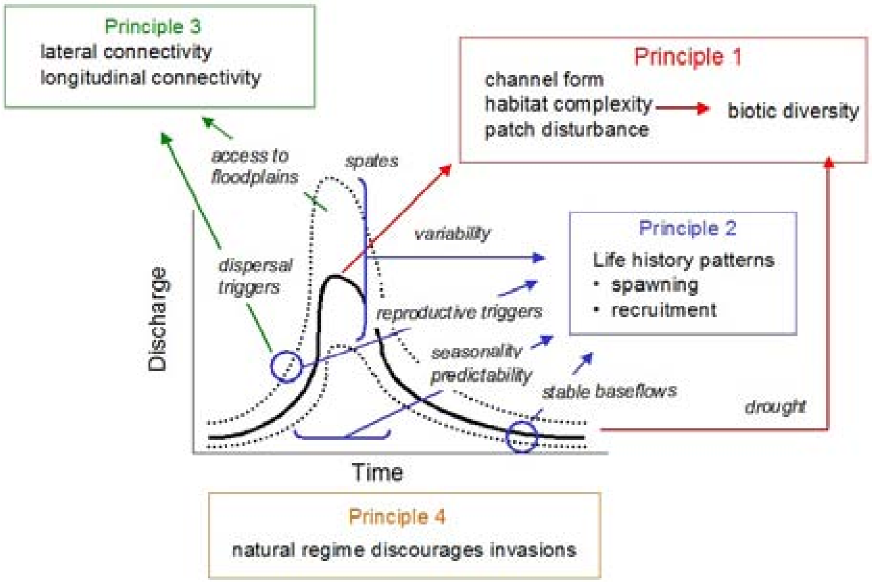


Figure 2-15 Different components of the natural flow regime support different ecological processes and functions (Bunn & Arthington, 2002). Reprinted with permission of Springer Science and Business Media B.V.

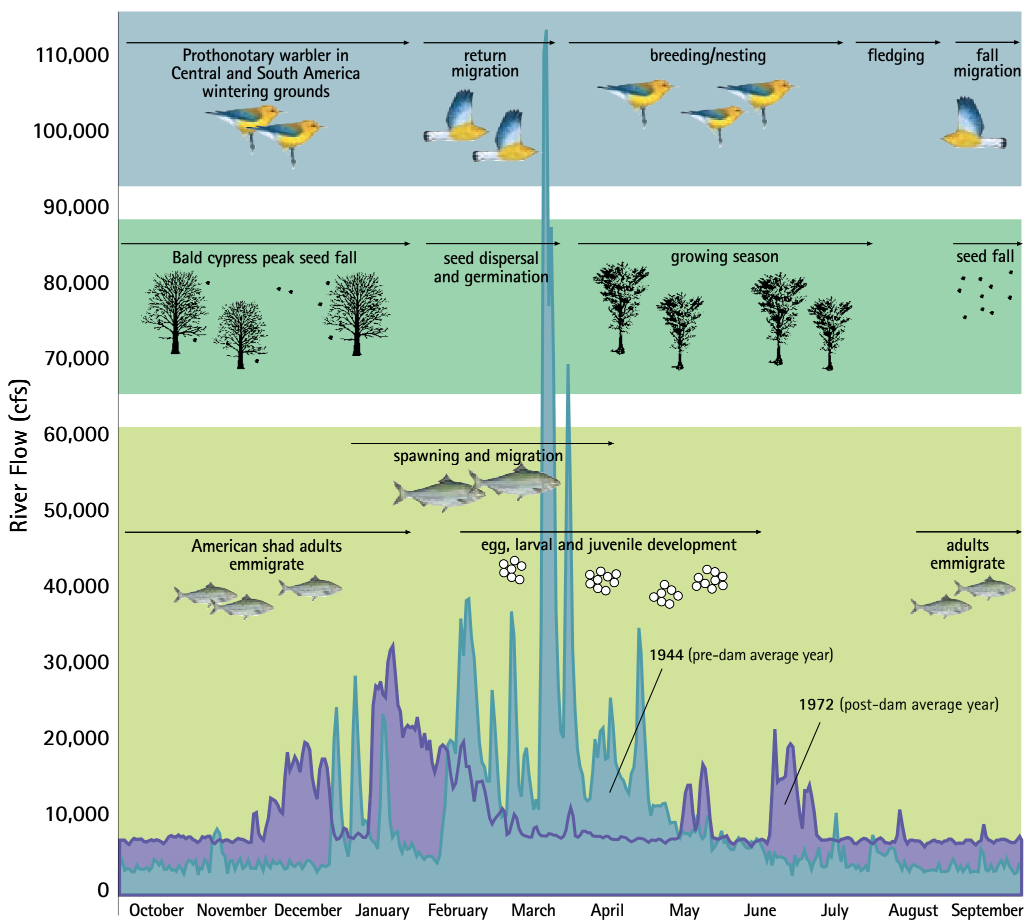


Figure 2-16 Ecological model of the Savannah River, Georgia illustrating the ecological importance of the natural flow regime. Note the loss of high and low flows during critical bioperiods for the post-dam hydrograph (The Nature Conservancy). Reprinted with permission of Andrew Stewart Publishing.

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, baseflows, 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 2-15 and Figure 2-16). 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 streamflow statistics, based on daily streamflow 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 streamflow 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 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 2-17). 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

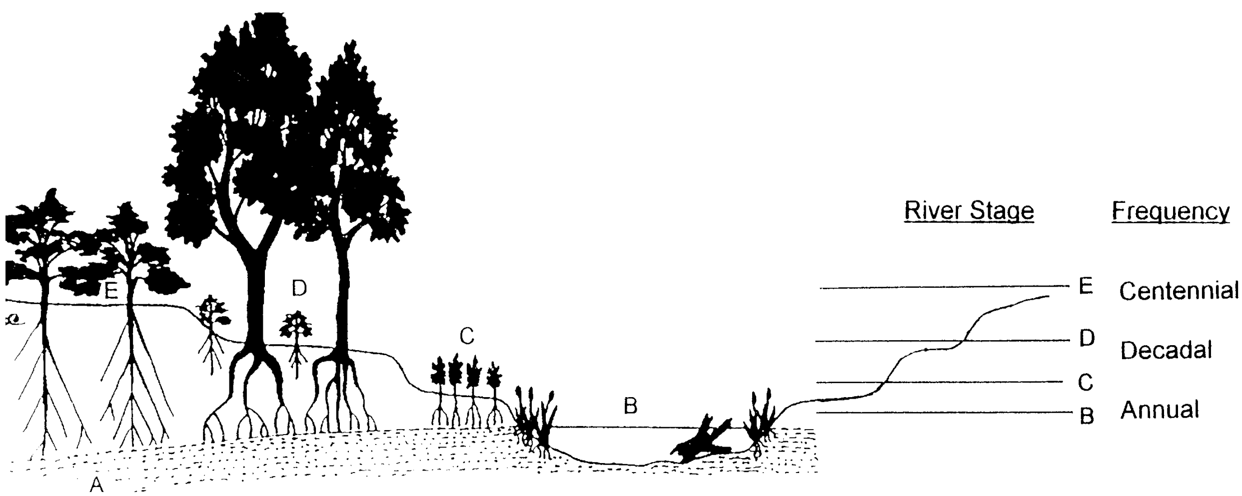


Figure 2-17 Geomorphic and ecological functions provided by different levels of flow. Water tables that sustain riparian vegetation and that delineate in-channel baseflow habitat are maintained by ground water inflow and flood recharge (A). Floods of varying size and timing are needed to maintain a diversity 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.

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).

2.1.3.2 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 supply of water for meeting human needs, including for 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. 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.

Ground water recharge generally occurs in the higher portions of the watershed, on hill slopes, and on valley floors. Spatial and temporal distribution of 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 primary 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. In watersheds of moderate to large size and significant relief, there are typically multiple ground water flow systems of different scales (Figure 2-18). Flow system boundaries are controlled by topography, type and distribution of geomorphic land forms within the watershed, and the underlying geology. Ground water discharge occurs at a variety of locations within a watershed including springs and seeps, streams, wetlands, and lakes. Ground water discharge is dynamic. Discharge from local and intermediate ground water flow systems is likely to fluctuate over an annual hydrograph while discharge from deeper, more 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.

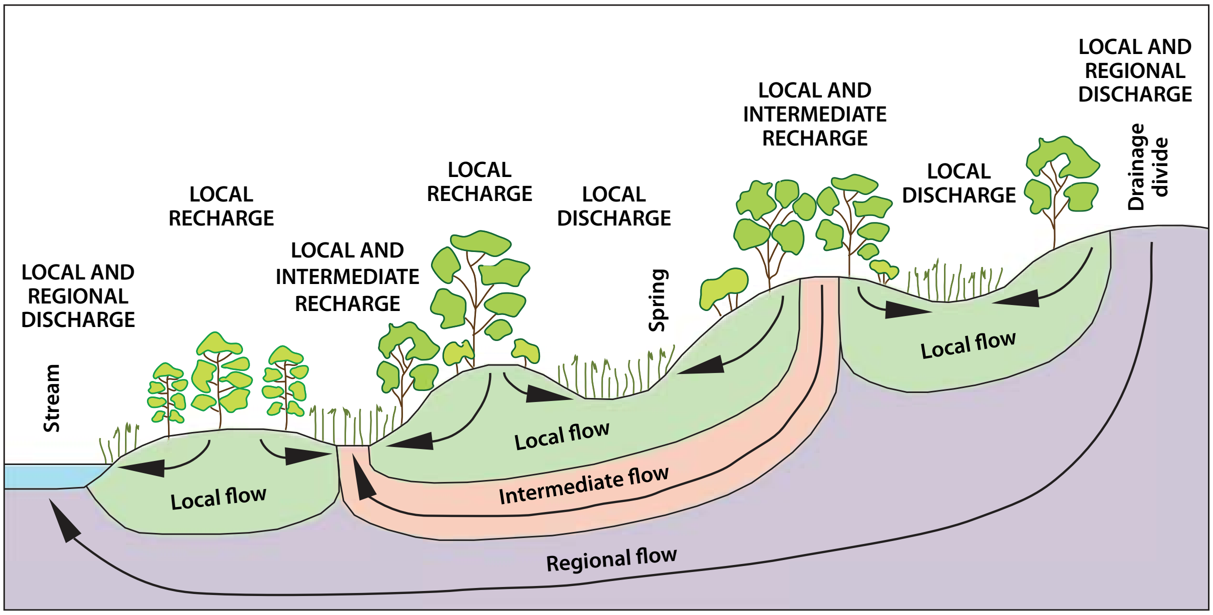


Figure 2-18 Different scales of ground water flow systems (modified from U.S. Geological Survey, 1999).

2.1.3.2.1 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.

2.1.3.2.2 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 baseflow 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 2-19). 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, 3) water from the open channel can flow downward though the bed sediment and infiltrate into the underlying aquifer.

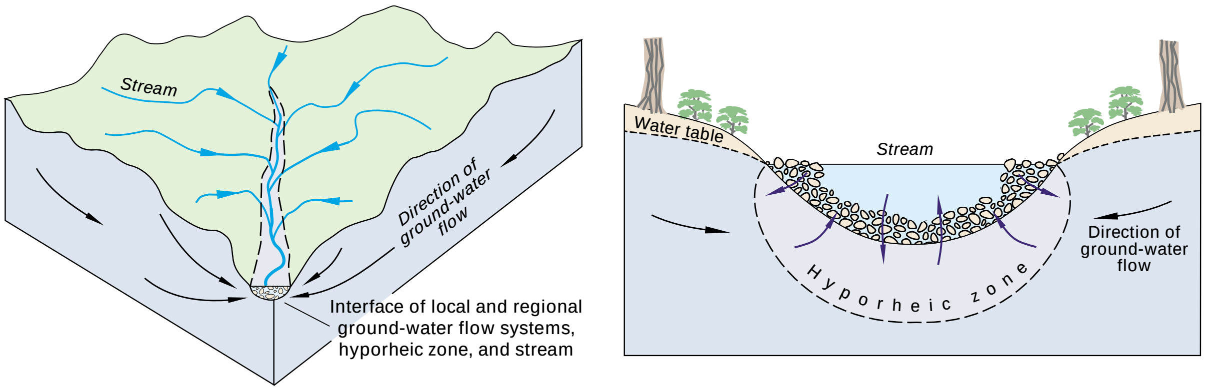


Figure 2-19 Streambeds and banks are unique environments because they are found where ground water that drains much of the subsurface of landscapes interacts with surface water that drains much of the surface of landscapes (Winter, Harvey, Franke, & Alley, 1998).

2.1.3.2.3 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. When ground water is the primary source of water to a wetland, the wetland is known as a fen. In some cases, the flow rate and chemistry of ground water discharging to a fen is relatively constant.

2.1.3.2.4 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 many watersheds, lakes play an important role in catchment water balances. 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. In arid areas it is important to consider water loss to evaporation, which in some cases can account for all discharge from a lake.

2.1.3.2.5 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 provide many values that are important in healthy watersheds. GDEs often harbor high species richness for their overall size. Thus, they often contribute significantly to the ecological diversity of a region. Many endangered, threatened or rare plants and animals are found within GDEs. In addition, GDEs can act as natural reservoirs for storing water during wet times 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 depend on ground water wherever they occur, and 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). In general, wetlands are 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). There are some types of wetlands that 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 also facultatively ground water dependent. However, perennial rivers and streams are often obligately dependent on ground water to maintain late-season baseflow, 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 2-20).

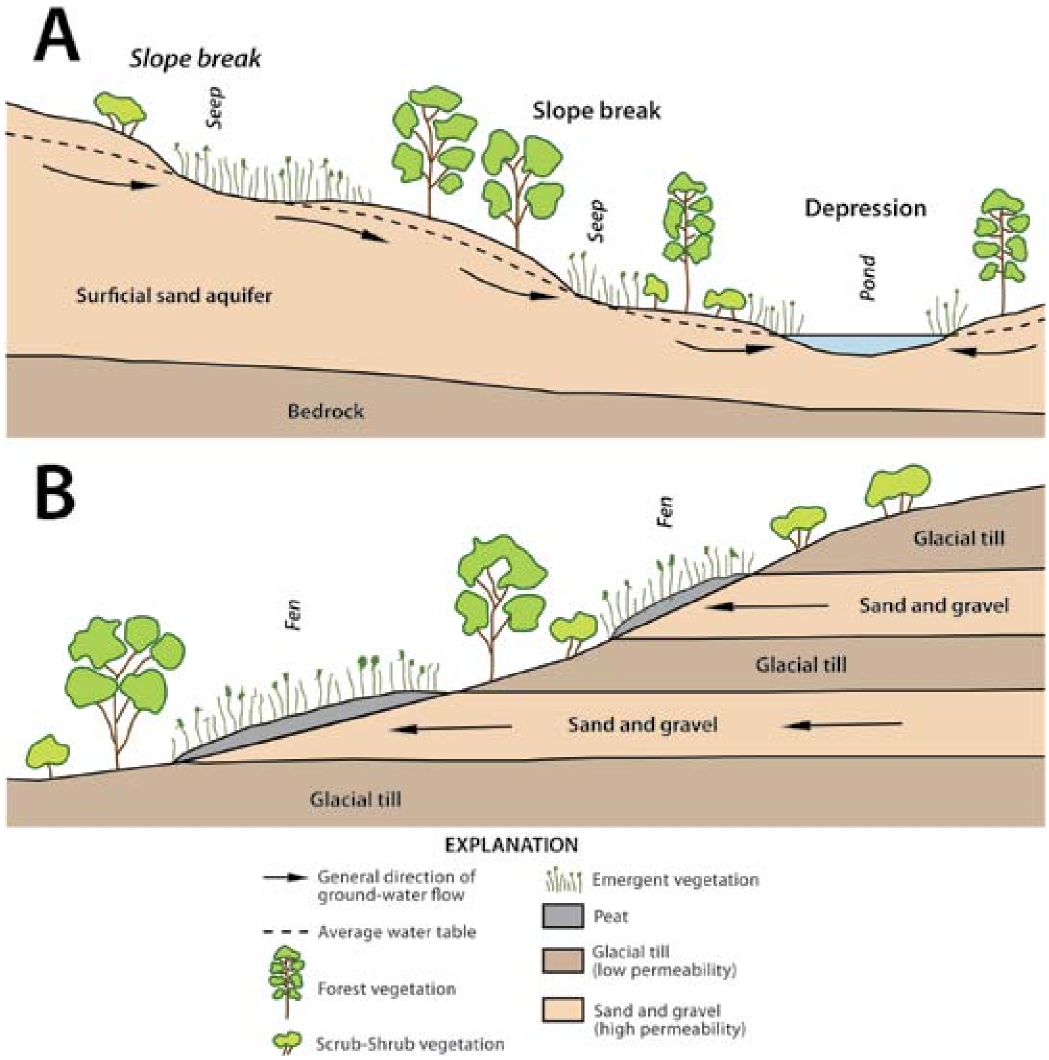


Figure 2-20 Some common locations for ground water dependent ecosystems to occur are landscape depressions, breaks in slope, and areas of stratigraphic change (modified from U.S. Geological Survey, 1999).

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 baseflow 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.
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).

2.1.4 Geomorphology

Although the field of geomorphology is centuries old, modern fluvial geomorphology evolved alongside the rapid growth in the science and methods of hydrology during the 20th century. Fluvial geomorphology seeks to explain river form and process and thus integrates hydrology and geomorphology in a riverine context. The concepts introduced in *Fluvial Processes in Geomorphology* (Leopold, Wolman, & Miller, 1964) are considered some of the most influential in the development of this field.

Fluvial geomorphology as an applied science has been advancing rapidly in recent decades. It seeks to explain river forms and processes through an understanding of landscape characteristics, water movement, and sediment transport. 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 balanced in natural systems. This natural balance is termed "dynamic equilibrium" and is illustrated by Lane's Balance (Figure 2-21). Sediment size and volume 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. These periodic disturbances, of natural intensity and frequency, can increase aquatic biodiversity by creating opportunities for some species and scaling back the prevalence of others.

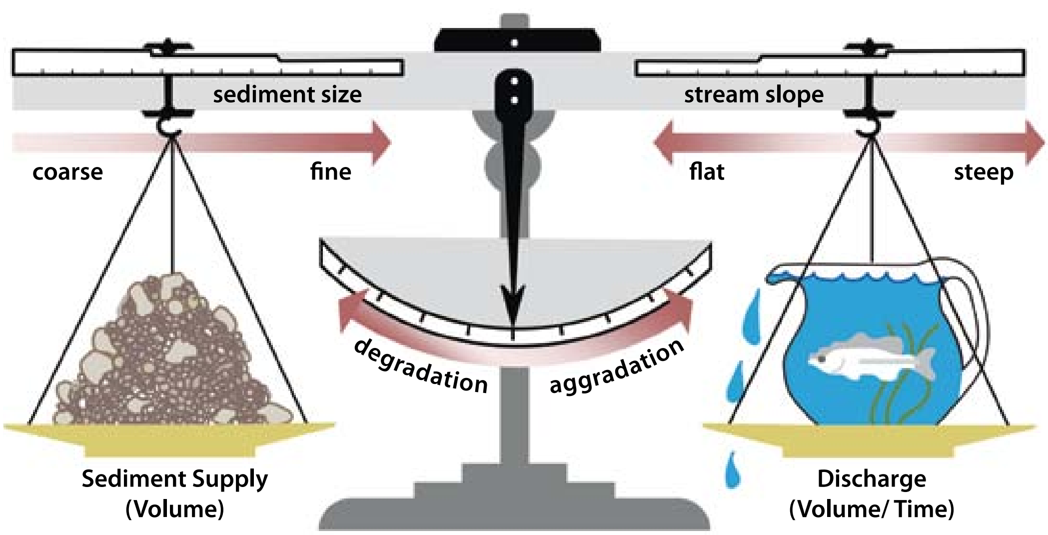


Figure 2-21 Lane's Balance (1955). Modified from Rosgen (1996). Reprinted with permission of American Society of Civil Engineers.

As a result of its watershed inputs and valley characteristics, a stream will 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 2-22). 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).

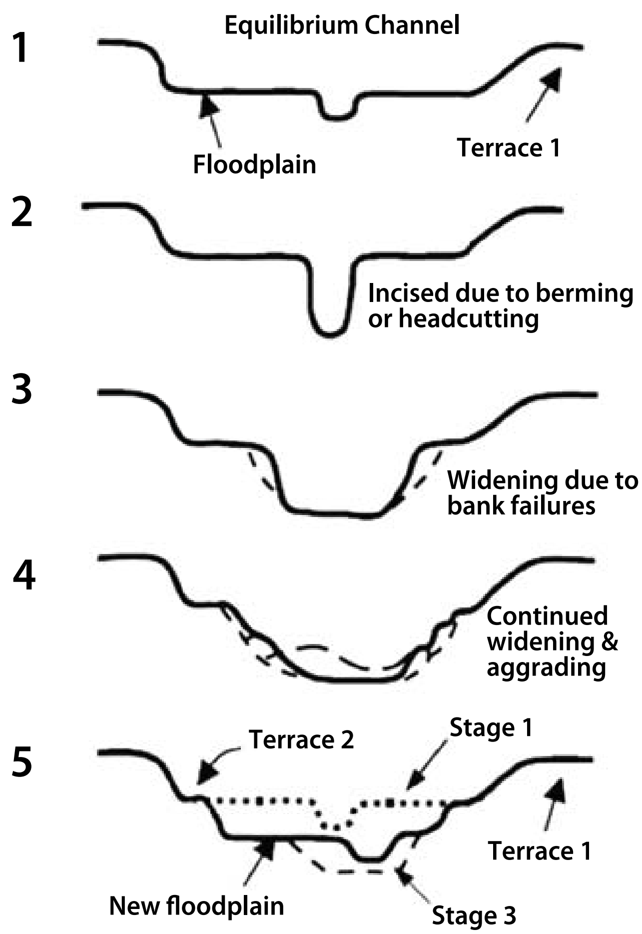


Figure 2-22 This Channel Evolution Model shows the stages of channel adjustment due to a disturbance (modified from Schumm, 1977).

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. His approach for restoring river channels, though somewhat controversial, has become the standard method used and promoted by federal agencies and has been modified by a number of states for use in their own river protection programs. The following are 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. L., 1994) (Figure 2-23). 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 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., 2005).

Fluvial geomorphic assessment approaches are currently exploding in their conceptual and practical development. Some states are beginning to embrace geomorphic assessments and a variety of tools are being developed to assess the geomorphic condition necessary for ecological integrity. It is expected that this trend will play a large role in the evolution of watershed ecosystem protection.

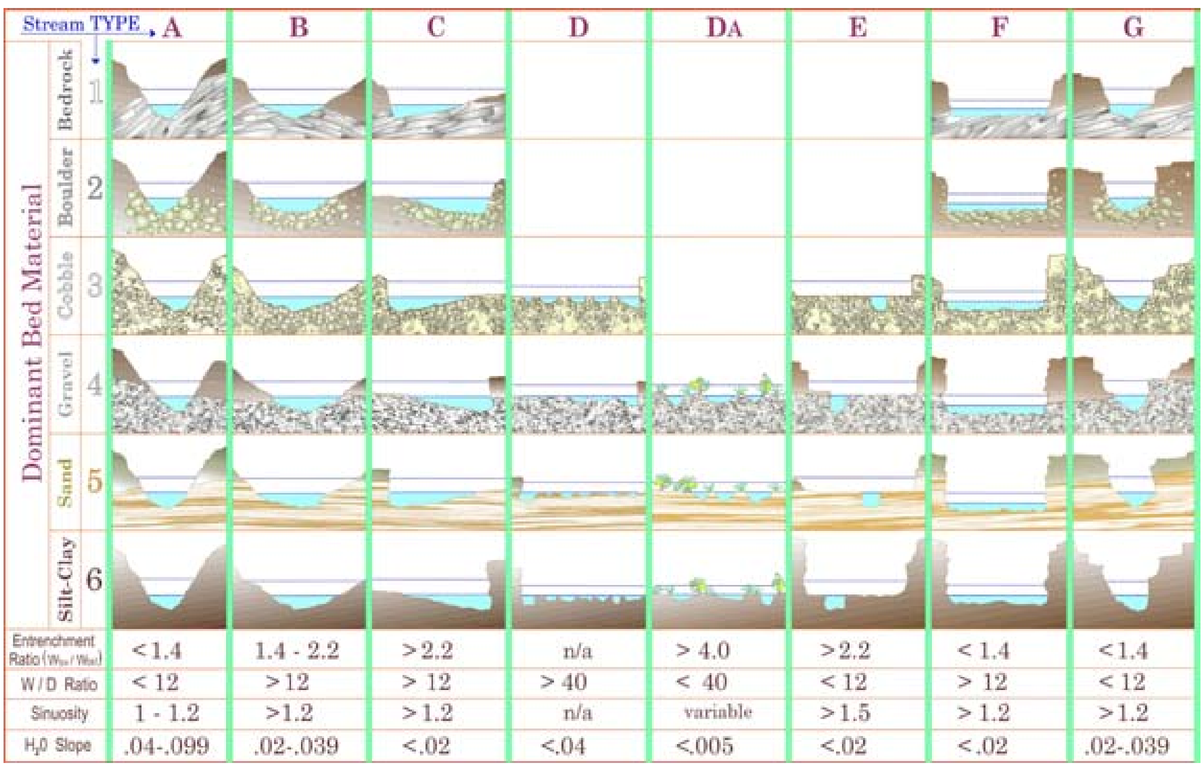


Figure 2-23 Rosgen stream types (Rosgen D., 1996).

2.1.5 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).

Results of water quality assessments are typically compared to state water quality standards (WQS) as a method for evaluating attainment of the designated uses established for a water body (e.g., the concentration of dissolved oxygen in a water body classified as a cold water trout stream). The U.S. Geological Survey (USGS) and EPA have both implemented a number of different national water quality monitoring programs that collect chemical, physical, as well as biological data as part of efforts to assess the quality of our waters.

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 (U.S. Geological Survey, 2009). Through the NAWQA Program, USGS scientists collect and interpret data about surface water and ground water chemistry, as well as hydrology, land use, stream habitat, and aquatic life using a nationally consistent study design and uniform methods of sampling and analysis. The current focus of the NAWQA Program is on regional and national scale assessments of status and trends in streams and rivers across the nation. NAWQA has identified eight large geographical regions (referred to as “major river basins”) as the basis for its status and trends assessments. The primary goals of the NAWQA Program are to: 1) characterize the status of surface and ground water quality (aquatic chemistry and ecology), 2) determine trends at those sites that have been consistently monitored for more than a decade, and 3) build an understanding of how natural features and human activities affect water quality.

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 integrity, hydrology, geomorphology, and the importance of vegetative cover.

2.1.6 Biological Integrity

Biological integrity, defined 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), is often a reflection of the surrounding environment. Habitat variables such as substrate, vegetative cover, and water quality all 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.

Ecosystem protection efforts are typically driven by concerns over biotic condition. This 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, sufficient instream flow, and otherwise unaltered conditions.

Biological assessments typically rely on bioindicators. 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. A stressor that may be missed by chemical or physical water quality monitoring can often be identified through an assessment of bioindicator organisms. 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 are 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 integrity assessment component of a Healthy Watersheds assessment.

A variety of biological assessment methods have been developed over the past 150 years, including: 1) "percent EPT" index, which assesses the relative numbers of organisms in the pollution-sensitive Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) orders, 2) diversity indices, which do not place importance on individual species, but only on the diversity of the species present, and 3) invertebrate tolerance scores, which integrates the indicator species approach with the diversity index approach (Perry & Vanderklein, 1996). Predictive modeling techniques, such as the River Invertebrate Prediction and Classification System (RIVPACS), compare the observed taxa (O) at a site to the expected taxa (E) based on reference conditions. The O/E ratio is then used as a measurement of "taxonomic completeness".

Community health is commonly summarized with statistical metrics for particular geographic areas, such as the IBI. The multi-metric IBI is a scientifically-validated tool that uses biological attributes (or metrics) that are sensitive to changes in biological integrity (Karr, 1981). The IBI approach involves the comparison of what is found at the monitored site to what is expected using a regional baseline that reflects minimally impacted conditions (i.e., a reference site) (Karr, 1981). It is these conditions which can help to identify healthy watersheds. Measures of community structure and dynamics, such as biological indices, are information rich. The individual metrics that an index comprises can be analyzed for the next level of detail.

In the late 1990s, EPA began developing guidance on the use of bioassessment information and biological criteria in state and tribal water quality management programs (U.S. Environmental Protection Agency, 1990). Virtually all of the states and some tribes currently have biological assessment programs and use this information in their water quality management programs. Some states have formally adopted biological criteria into their water quality standards (U.S. Environmental Protection Agency, 2002). States use the information primarily to assess condition and determine impairment. For example, Ohio EPA uses a minimum IBI score of 40 as the numeric criterion that a warm water stream must meet in order to attain its aquatic life use in the Erie/Ontario Lake Plain Ecoregion (State of Ohio Environmental Protection Agency, 2009).

Biotic indices are also an important component of national assessments of aquatic resources (e.g., National Aquatic Resource Assessments) (U.S. Environmental Protection Agency, 2008b). 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, 2006d). 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 establishes 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 2-24). The National Lakes Assessment (NLA) found that 22% of the nation's lakes are in poor biological condition, 21% are in fair condition, and 56% are in good condition (U.S. Environmental Protection Agency, 2009). Data from the WSA and NLA can be used in conjunction with data from a state's existing water quality monitoring program to identify reference sites. Identification of these reference sites is important in identifying healthy watersheds as part of an integrated assessment approach and for conserving these sites so that they remain in reference condition. The National Rivers and Streams Assessment (NRSA) is currently underway, with the report planned for release in 2012. The NRSA is evaluating the condition of both wadable streams and larger rivers at over 2,300 sites across the nation.

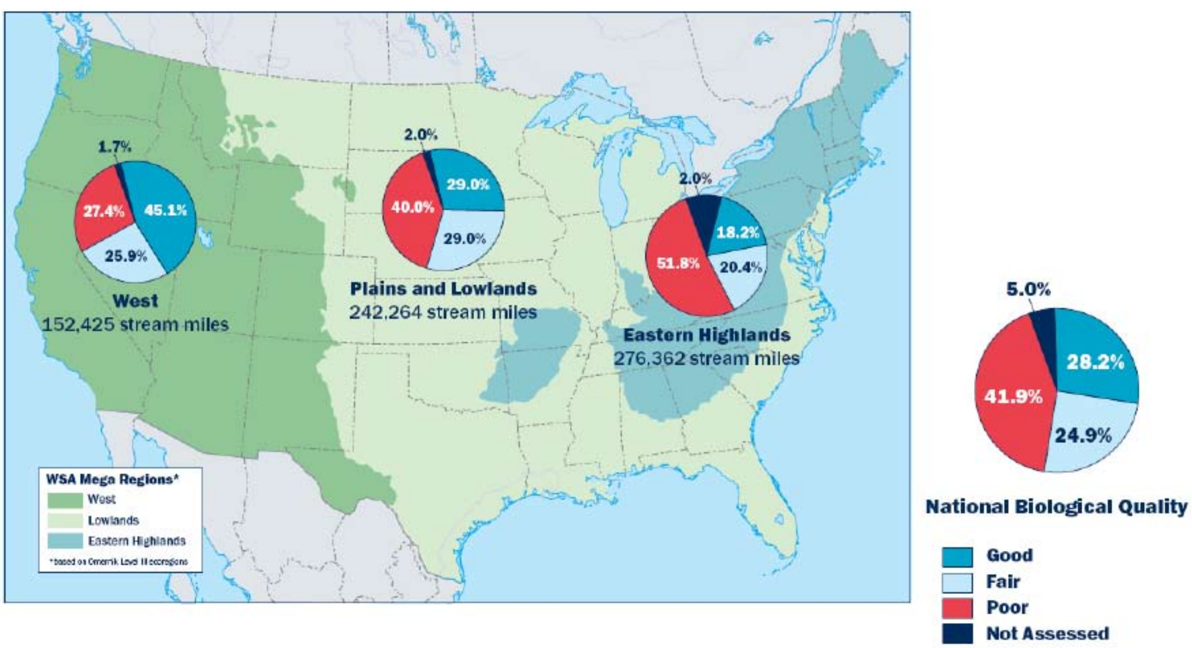


Figure 2-24 Biological quality results of EPA's Wadeable Streams Assessment (U.S. Environmental Protection Agency, 2008e).

EPA, the states, and some tribes are also beginning work on the first-ever national survey of the condition of the nation's wetlands (report planned for 2013). EPA is collaborating with the U.S. Fish and Wildlife Service (FWS) to design the wetland assessment to ensure that it effectively complements the FWS Status and Trends reports, which focus on the distribution of wetlands rather than their condition. The survey will be designed to provide regional and national estimates of the ecological integrity and biological condition of wetlands.

Biological integrity can also be conceived as a function of the relative diversity of living things present in a community or ecosystem. However, biological integrity and biodiversity are not the same thing. For example, there are some healthy aquatic systems where diversity may be naturally low. The field of biodiversity conservation is relatively new, emerging only in the past three decades. As the scientific and resource management community began to understand the importance of diversity at the genetic, species, and ecosystem levels, biological conservation began to focus on the maintenance of ecological relationships between species and with the physical components of their environment. The evolution of this new field has coincided with the recognition that more and more species and their habitats are becoming threatened and endangered. The Endangered Species Act of 1973, accompanied by a number of other environmental statutes, spurred the rapid development of assessment methods and conservation programs that specifically address the maintenance of biodiversity and habitat conservation.

Projects such as the state Natural Heritage Programs inventory the nation's biodiversity and identify rare and endangered species. These programs began in 1974 when The Nature Conservancy helped to establish the first state program in South Carolina. These programs have spread throughout all 50 states, Canada, and Latin America and are part of the NatureServe network (http://www.natureserve.org/) that strives to use the highest quality science and technology to collect and distribute biological information for conservation planning purposes.

While the Natural Heritage Network traditionally focused on rare and endangered species, the USGS Gap Analysis Program (GAP) seeks to ensure that common species remain common by identifying the degree to which the current network of conservation lands protects all native plant and animal species. The program began in 1989 with a focus on terrestrial species and has since expanded to include an Aquatic GAP. The Nature Conservancy and the World Wildlife Fund (WWF) advocate for an ecoregional approach to assessing and planning for biodiversity conservation. Freshwater ecoregions are delineated based on hydrologic boundaries and the distributions of aquatic organisms. Freshwater ecoregion conservation is similar to watershed management in many ways, but is primarily focused on the goals of biological conservation, including identification of areas of biodiversity significance. Ecoregional assessments identify the suite of places that collectively best represent the biodiversity and environmental processes of a river basin. These assessments include evaluations of landscape conditions. The Active River Area, Indices of Biotic Integrity, and other tools, in conjunction with ecoregional assessments and State Wildlife Action Plans, can help to identify the specific processes and the places that, through conservation and rehabilitation, would best contribute to healthy watersheds.

Biological integrity assessments allow for the identification of reference condition sites in watersheds across a state. Many states are already using a variety of biological integrity assessment approaches (see Chapter 3) that are well-suited to integration with other assessment approaches for evaluating watershed health. Some states, such as Ohio and Virginia, have begun to integrate their biological integrity assessments with chemical and physical assessments or landscape condition assessments. This kind of integration is the next step for states and other organizations to take in their development of holistic watershed assessments.

2.2 Vulnerability

Vulnerability can be defined as a function of the exposure and sensitivity of a system to specific stressors and the capacity of the system to cope, adapt, or recover from the effects of those stressors (Smit & Wandel, 2006). Stress from human activities can cause ecosystem declines due to degradation of ecological structure, function, or composition (Chicago Wilderness, 2009). Anthropogenic impacts may take years to be recognized and can persist for decades or centuries (Committee on Hydrologic Impacts of Forest Management, National Research Council, 2008). Landscape changes are persistent and have a cumulative impact downstream in a watershed. Ecosystem restoration is a difficult and costly endeavor. It is far cheaper to conserve and protect ecosystems than it is to restore them after they have been damaged.

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 very difficult to reverse (Noss, LaRoe III, & Scott, 1995). Pollutants that can disrupt ecosystem function can be physical (e.g., sediment from construction sites), chemical (e.g., pesticides), or biological (e.g., invasive species). Salt Cedar, for example, is a non-native 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.

A Healthy Watersheds Vulnerability Assessment should involve an identification of the specific threats to watershed health and an evaluation of the likely locations and intensities of these threats. This assessment will allow for the efficient targeting of protection and restoration actions to minimize effects of the threats.

2.3 Climate Change and Adaptation

The impact of climate change on different ecosystems and regions of the United States will depend on the vulnerability of those systems to the effects of climate change 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. Increasing a system's resilience to such 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 of state because riparian areas and floodplains would help to absorb some of the disturbance. Identifying and protecting healthy watersheds is therefore critical to maintaining the adaptive capacity of natural systems, which helps to ensure resiliency in the face of climate change.

Climate change adaptation strategies are designed to promote resistance and resilience of plant and animal populations and their associated ecosystems. 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. Although some ecosystems can rely on their size for resistance to climate change, other ecosystems will need to rely on resilient *processes*. Optimal adaptation strategies work in concert with ecosystem restoration and greenhouse gas emissions reduction efforts. BioMap2, for example, is a tool designed by the Massachusetts Division of Fisheries and Wildlife to identify and prioritize land protection and stewardship actions needed for long-term conservation of the state's biodiversity, and for climate adaptation. Four central concepts guide the decision-making process of BioMap2 (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.

2.4 Characteristics of a Healthy Watershed

A healthy watershed is one in which natural land cover maintains 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. Part of the definition of a healthy watershed is resilience to disturbances. 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.

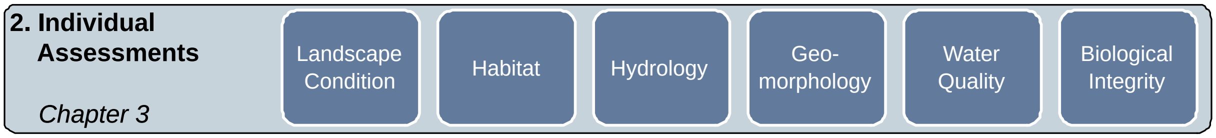
2.5 The Healthy Watersheds Concept

The Healthy Watersheds concept is based on a holistic systems approach to watershed assessment and protection that views watersheds as integral systems. This approach represents a shift from some traditional protection approaches that are concentrated on individual natural areas, and from traditional regulatory frameworks based solely on water quality and biological criteria. Although much progress has been made, and theoretical understanding of watershed ecosystems has been advancing rapidly, a concerted effort by all levels of stakeholder interest is necessary to make integrated assessments of watershed ecosystems a reality. Integration of the EPA SAB's essential ecological attributes is necessary for a holistic systems approach to identifying and assessing healthy watersheds or intact components of other watersheds. Only through an understanding of these dynamic linkages can proactive, comprehensive management and protection of healthy watersheds be achieved.

A number of assessment programs have sought to integrate various measures of ecosystem health into a holistic framework. EPA's Environmental Monitoring and Assessment Program (EMAP) and Mid-Atlantic Integrated Assessment (MAIA) program contributed to an integrated approach by developing tools and the scientific understanding necessary to monitor and assess the nation's ecological resources. EMAP integrated ecologically relevant chemical and physical parameters and landscape indicators with biotic condition assessments. EMAP methods formed the foundation of the WSA. EPA's Index of Watershed Indicators (IWI) evaluated water quality across the nation based on seven indicators of watershed condition and eight indicators of watershed vulnerability (U.S. Environmental Protection Agency, 1997). Although some landscape elements and biotic condition indicators, such as wetland extent and wetland species at risk, were included in the approach, these 15 indicators were primarily based upon physical/chemical water quality characteristics and watershed elements that affect these characteristics (U.S. Environmental Protection Agency, 1997). The Heinz Center's State of the Nation's Ecosystems (2008) and EPA's Report on the Environment (2008d) have replaced the IWI to some degree and assess a larger list of ecological indicators, including extent and fragmentation of habitat patches on the landscape, patterns of biodiversity, and stream flow modification. These are national-level assessments meant to communicate information to the public and to guide policy and decision making. Similarly, under the National Fish Habitat Action Plan (NFHAP), the National Fish Habitat Board has formed a number of partnerships with regional and local initiatives seeking to implement strategies for protecting fish habitat and has conducted a national assessment of fish habitat. A landscape disturbance approach was used to assess fish habitat. The approach included habitat variables such as connectivity, hydrology, circulation, bottom form complexity, material recruitment, water quality, food webs, and biological energy flow along with a nationwide ecological classification system.

The Healthy Watersheds Initiative contributes to this body of work by providing an integrated assessment framework for comprehensive protection of watersheds (see Chapter 4). This framework can be seen as a platform for the practical application of the concepts presented in this chapter. A sound understanding of these concepts is necessary for the appropriate application of the methods described in the following chapters. Select examples of assessment approaches for Healthy Watersheds components are provided in Chapter 3. The Healthy Watersheds Integrated Assessment Framework outlined in Chapter 4 builds on previous efforts to integrate assessments of watershed health and includes examples of assessments that approximate integrated assessments. Chapter 5 describes some management approaches available for protecting and restoring watersheds. Finally, Appendix A contains key assessment tools and Appendix B identifies sources of data.

3. Examples of Assessment Approaches



This chapter summarizes a range of assessment approaches currently being used to assess the health of watershed ecosystems in the United States; this is not meant to be an exhaustive list of all possible approaches. The example assessments are organized into two sections. Section 3.1 provides summaries and case studies of assessments that are considered primarily desktop-based analyses, while Section 3.2 summarizes assessment approaches and case studies that are considered primarily field-based assessments. This is not to say that the desktop assessments do not have elements that require data collection in the field. Virtually all assessments require field data collection at some point. Even remote sensing data (e.g., those collected by satellites) must be ground truthed at some point. Placement in the desktop or field sections of this chapter merely serves to organize the range of approaches available and to provide ideas on the selection of an approach.

3.1 Desktop Assessments

Maryland Green Infrastructure Assessment

Author(s) or Lead Agency: Maryland Department of Natural Resources (DNR)
More Information: http://www.greenprint.maryland.gov/

The Maryland Green Infrastructure Assessment (GIA) 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 is also mapping the state's "blue infrastructure". By combining the GIA 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 technology to identify the ecologically important hubs and connecting corridors in the state. Hubs are defined by 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 which 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 3-1). Each hub or corridors' 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 3-1 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 (POS), operating since 1969, funds land conservation through the real estate transfer tax. Since the completion of the GIA, POS 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 POS 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 brings together different resources to implement the protection strategies identified by the GIA. 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 GIA (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 GIA information.

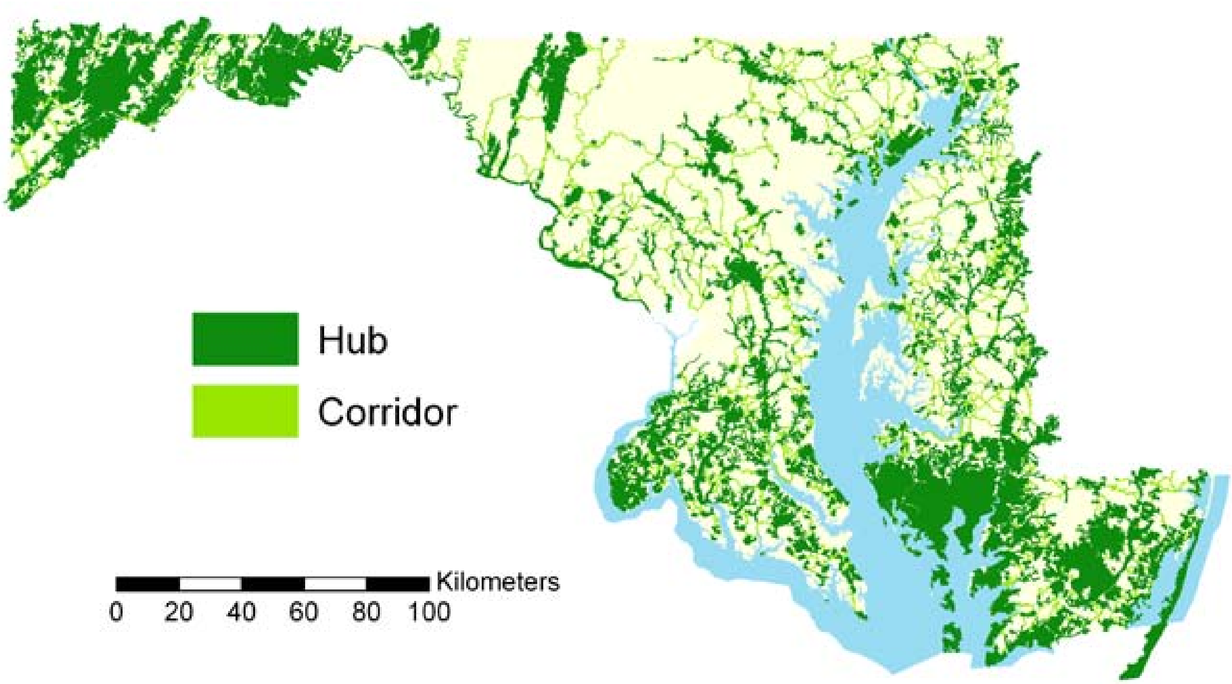


Figure 3-1 Green infrastructure in Maryland (Maryland Department of Natural Resources, 2003b).

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 GIA. 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 help identify the "best" lands for inclusion in the greenways system. These species were chosen because their habitat requirements were 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 GIA 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.

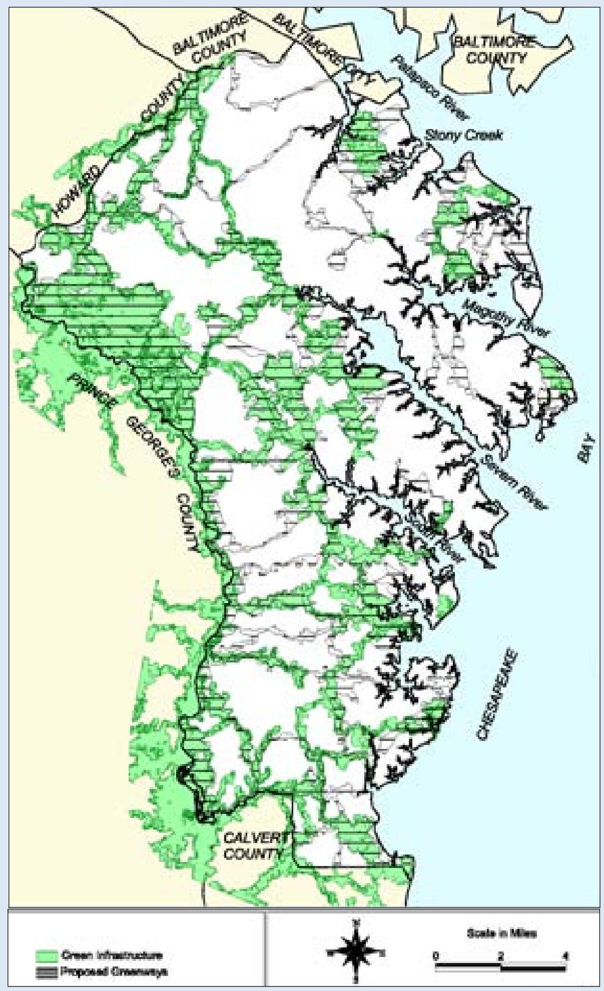


Figure 3-2 Comparison of proposed greenways and green infrastructure in Anne Arundel County, MD (modified from Anne Arundel County, 2002).

Virginia Natural Landscape Assessment

Author(s) 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 detail 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).

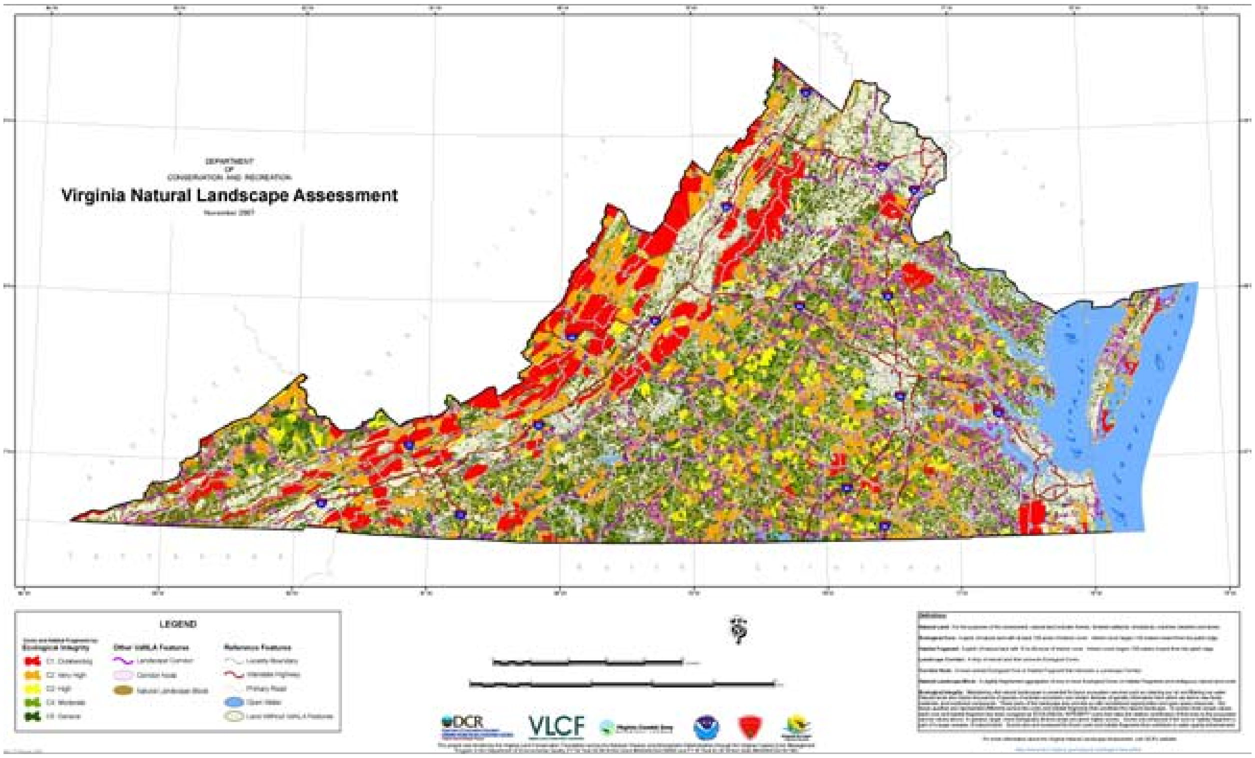


Figure 3-3 Map of results from the Virginia Natural Landscape Assessment Model (Virginia Department of Conservation and Recreation, 2008).

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.

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 (SWAMP) Conservation Corridor System previously developed as a collaborative state, federal, and local effort. The corridor system identified in the SWAMP 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.

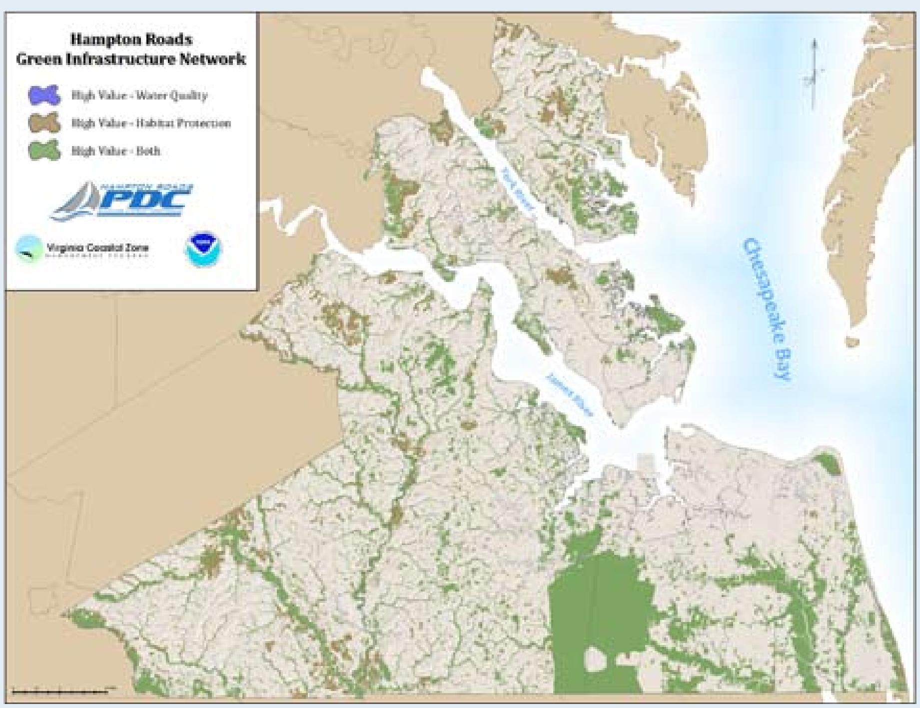


Figure 3-4 Green infrastructure in the Hampton Roads region (Kidd, McFarlane, & Walberg, 2010).

Beaver Creek Green Infrastructure Plan

Author(s) 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. Wide swaths that could link these areas with ground water protection corridors, stream protection corridors, and ridge protection corridors while creating community boundaries were then identified. The composite of the stream protection, ridge protection, and heritage protection corridors gives 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 which 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.

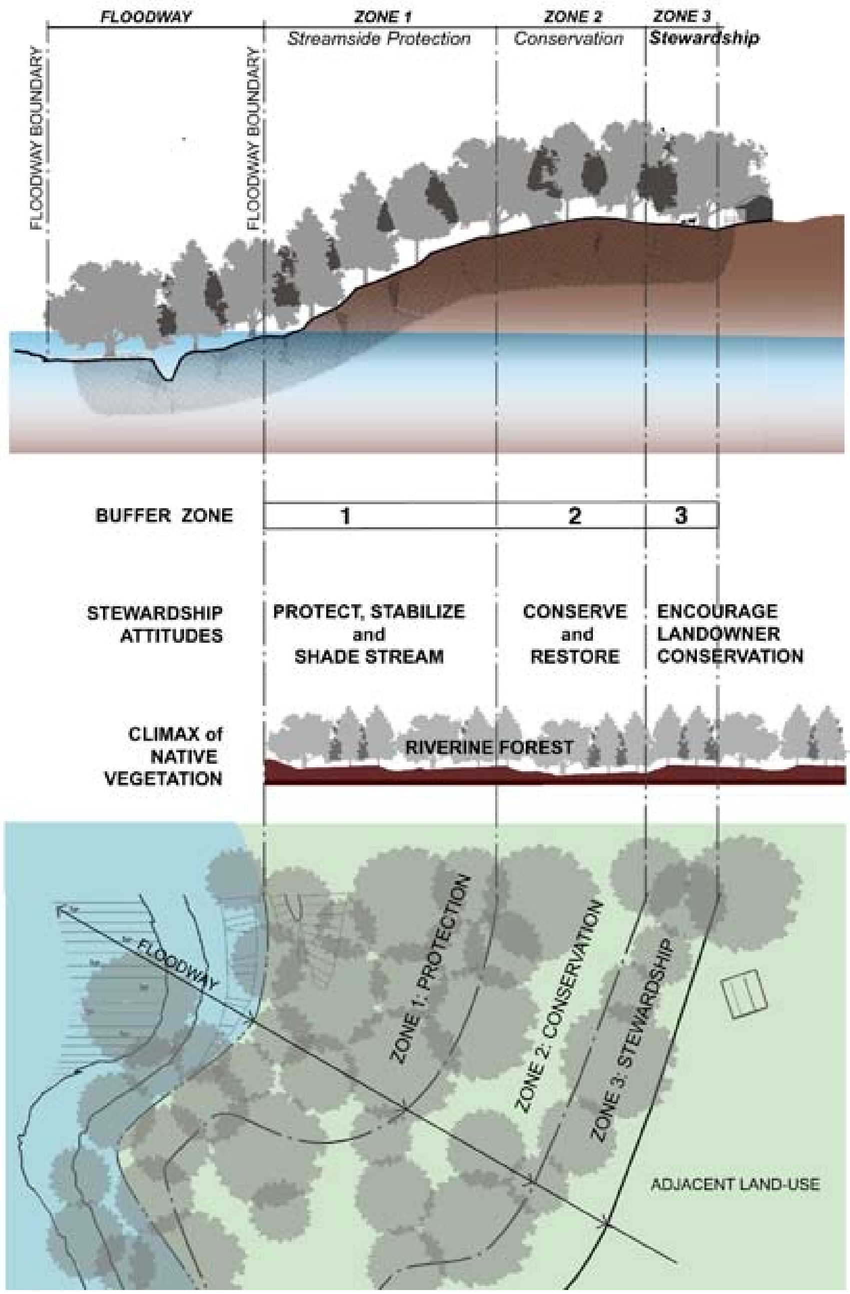


Figure 3-5 Three-zone buffer showing the protection, conservation, and stewardship zones (Moir-McClean & DeKay, 2006).

The Active River Area

Author(s) 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 the PATHDISTANCE GIS technique. This technique calculates the area within which the river is expected to interact dynamically with the land surface. It is based on both the lateral

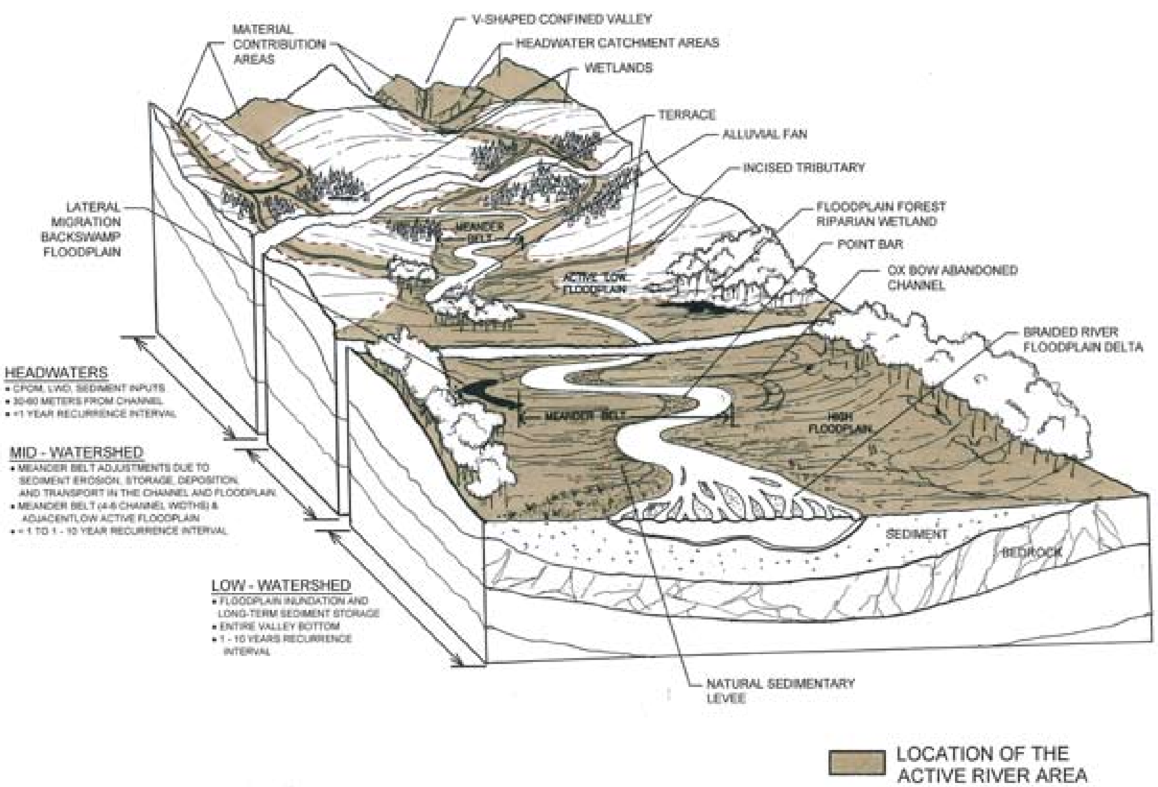


Figure 3-6 Components and dominant processes of the Active River Area (Smith et al., 2008).

and vertical distance (elevation) from the stream and user-supplied cutoff distances that are determined based on stream size (Strager, Yuill, & Wood, 2000). By considering stream size, this simple technique accounts for the dominant physical processes occurring in each zone of the watershed. 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 necessary for identifying these areas. A flow accumulation model uses a DEM 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 be identified using the SLICE technique in GIS. The SLICE technique divides the DEM data layer for a watershed 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 three 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. 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 NLCD 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 watershed 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.

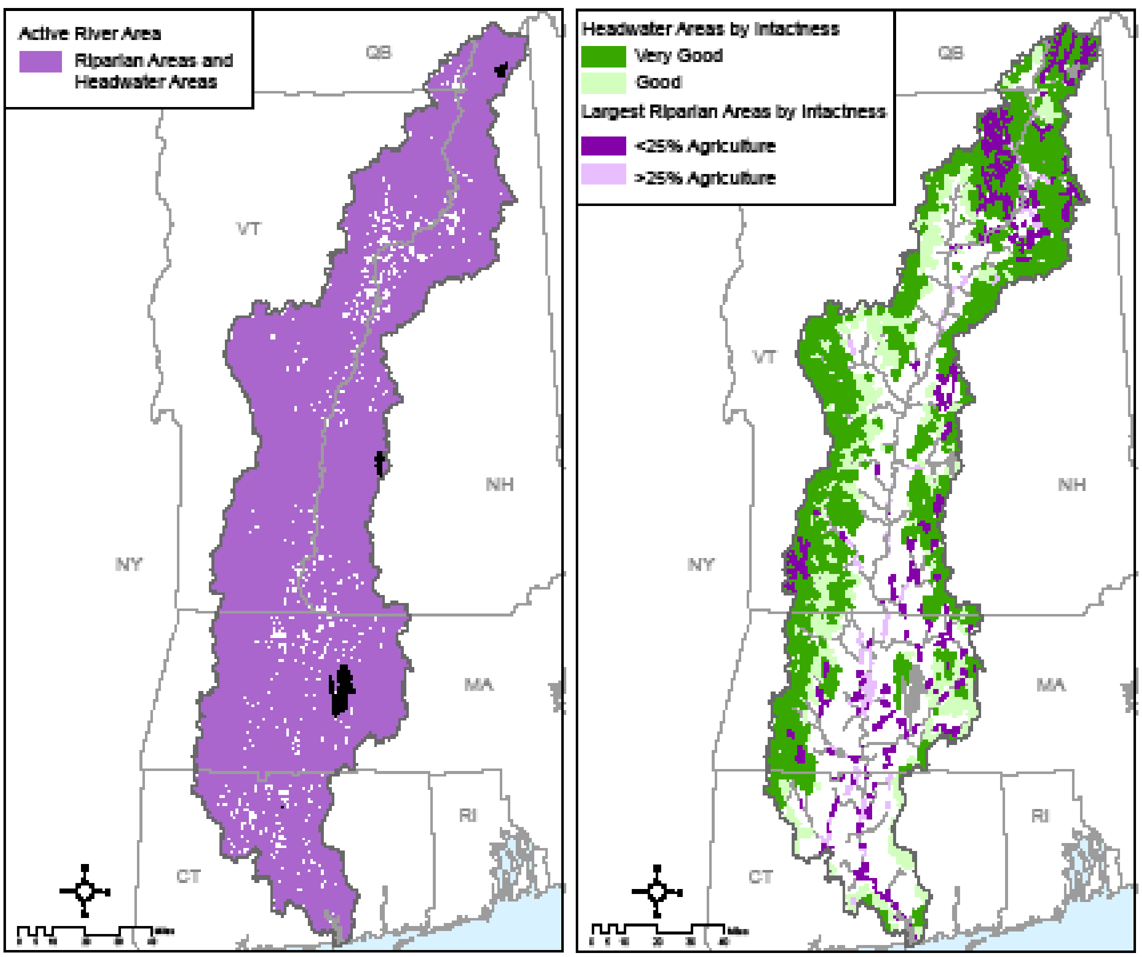


Figure 3-7 The Active River Area in the Connecticut River Basin (Smith et al., 2008).

Interagency Fire Regime Condition Class

Author(s) 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 3-2). 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 3-2 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 3-3 shows the percent coverage of each succession stage (columns A-E) within the biophysical setting. The FRG 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 3-3 Example reference condition table (Hann et al., 2008).

Biophysical Setting	A	B	C	D	E	FRG
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 3-4). 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 3-4 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 3-3). Five natural fire regimes are classified based on frequency and severity, which reflect the replacement of overstory vegetation (Table 3-2). 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). 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 thus 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.

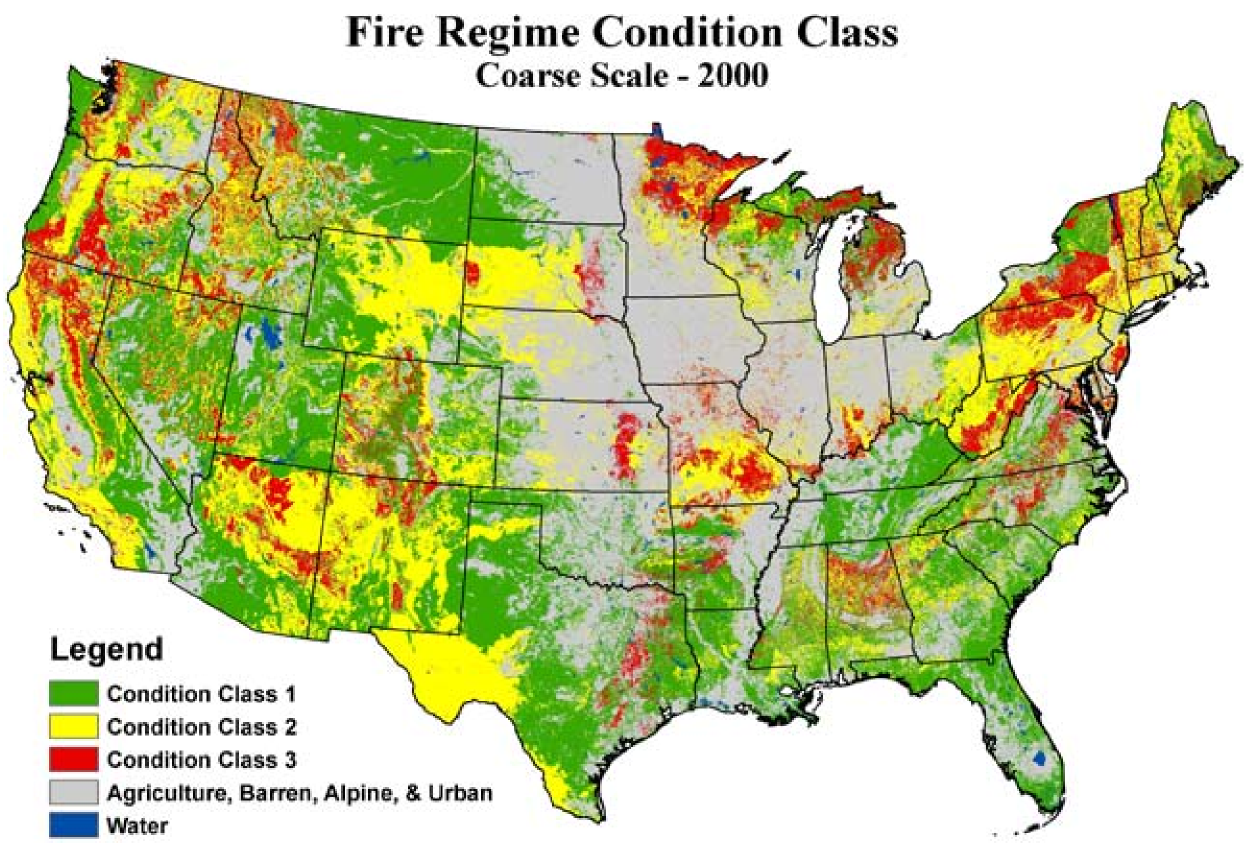


Figure 3-8 National landscape-scale output of the Fire Regime Condition Class Mapping Method. (Hann et al., 2008).

Wyoming Wetland Complex Inventory and Assessment

Author(s) 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 3-9. 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 3-10).

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.

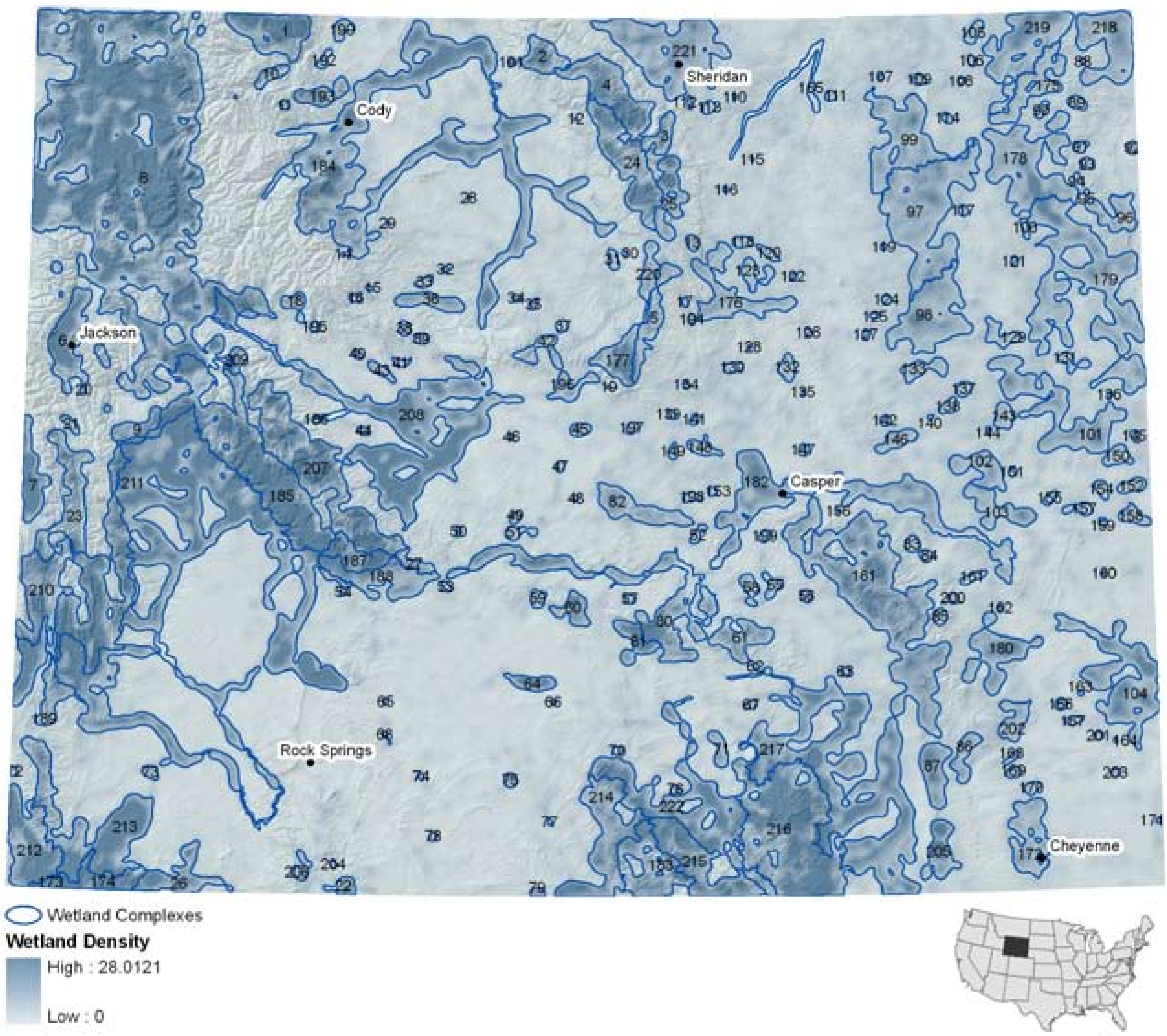


Figure 3-9 Map of focal wetland complexes shown by wetland density. Density is defined as the unit area of wetlands divided by the area of the wetland focal complex. The labels are unique wetland IDs (Copeland et al., 2010). Reprinted with permission of Elsevier.

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 (PET) 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.

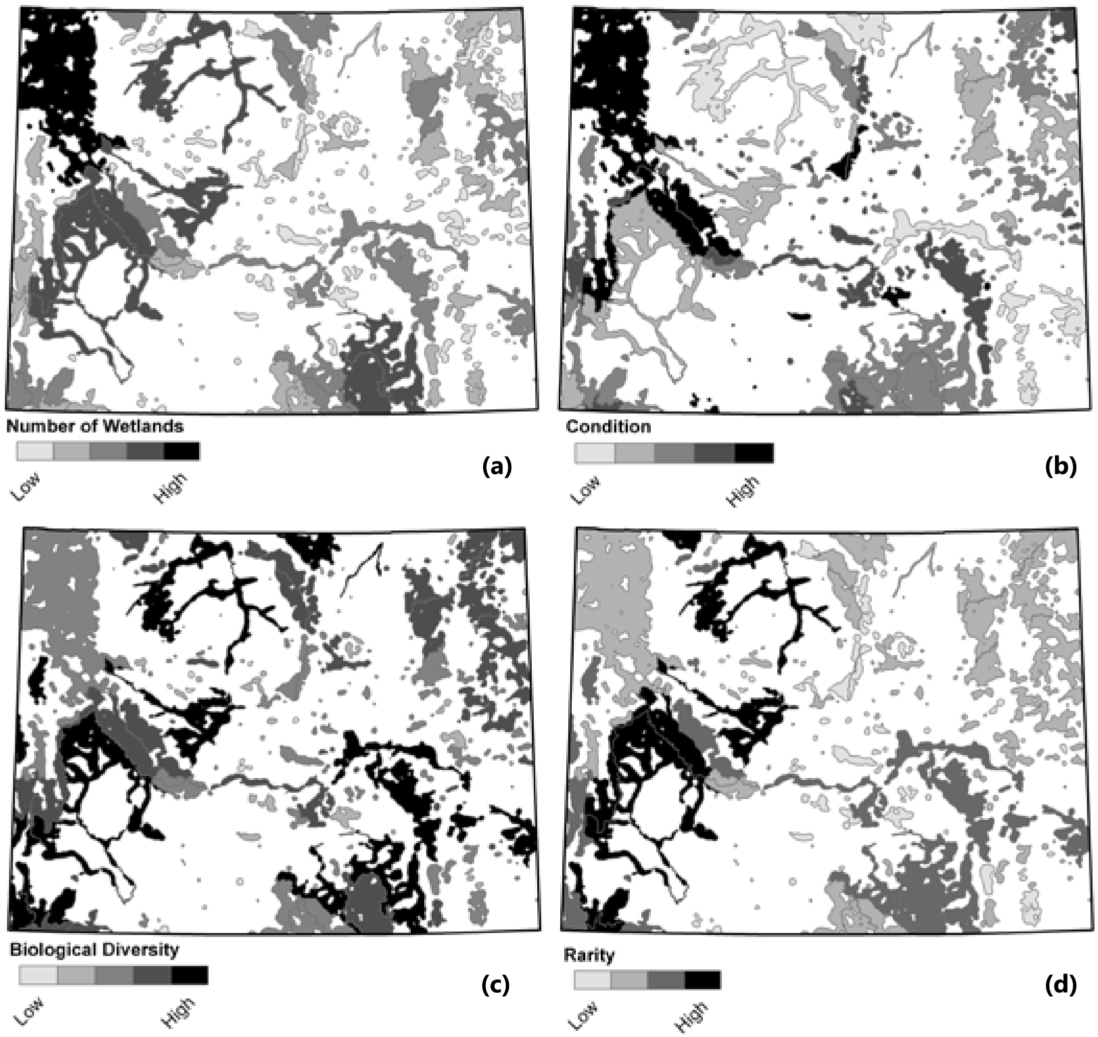


Figure 3-10 Wyoming's wetlands ranked by number (a), condition (b), Shannon diversity (c), and rarity (d). All rankings are presented using the Jenks natural breaks method (Copeland et al., 2010). Reprinted with permission of Elsevier.

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.

Ground Water Dependent Ecosystems Assessment

Author(s) 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) 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 HUC6 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 HUC6 units that contain relatively high densities of GDEs (Table 3-5). The specific rule sets may need to be modified for other landscapes, depending on the relative distribution of GDEs. Once each HUC6 was coded as containing GDEs, the data were further aggregated by number of GDE types within the HUC (Figure 3-11). For example, a green HUC6 has three types of GDEs, and could include springs, a wetland, and a river that are all ground water-dependent.

Table 3-5 Criteria used to identify HUC6 units 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 HUC6 area
Rivers	Contains ground water dependent river
Lakes	Contains a lake
Species and communities	Contains an obligately ground water dependent species or community

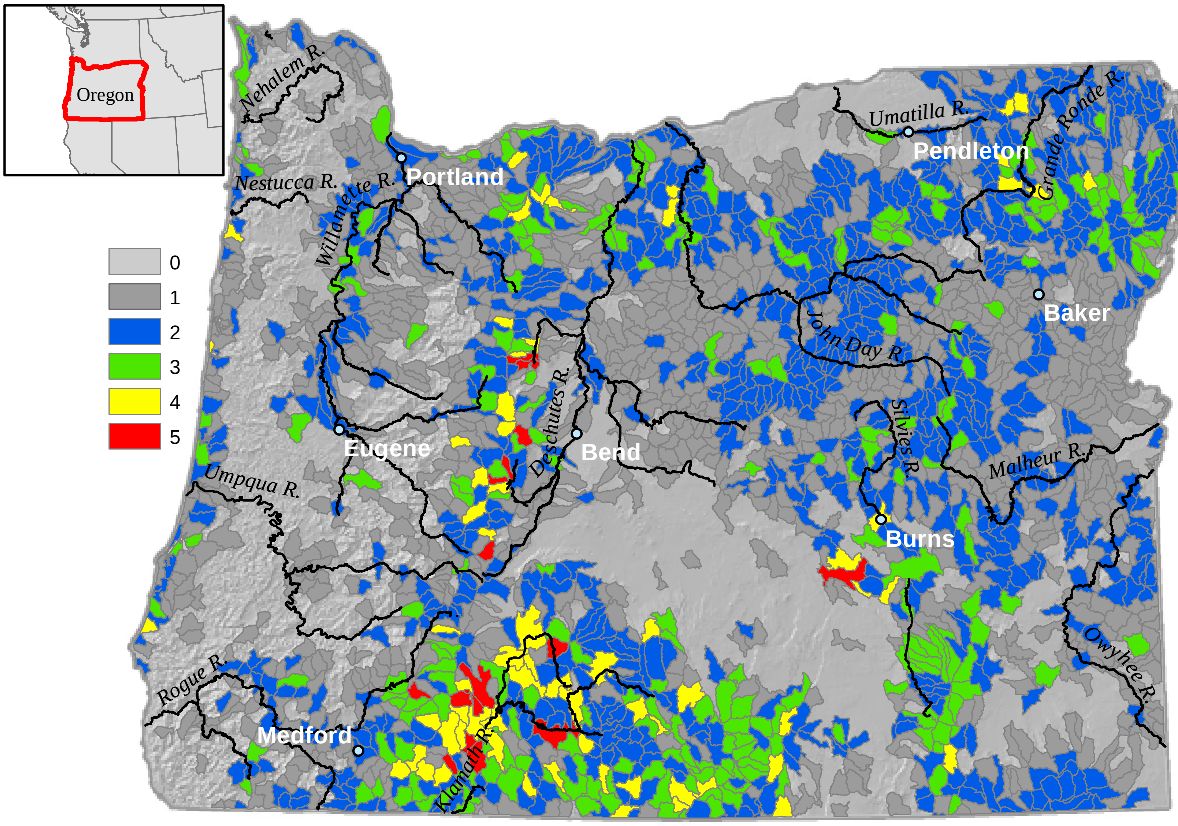


Figure 3-11 Ground water dependent ecosystem clusters (blue through red). Number of ground water dependent ecosystems present in each HUC6, per criteria in Table 3-5 (Brown et al., 2009a).

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. HUC6 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, HUC6 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 3-12). 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, in general there are two categories of EEAs 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 3-6 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 3-6 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.

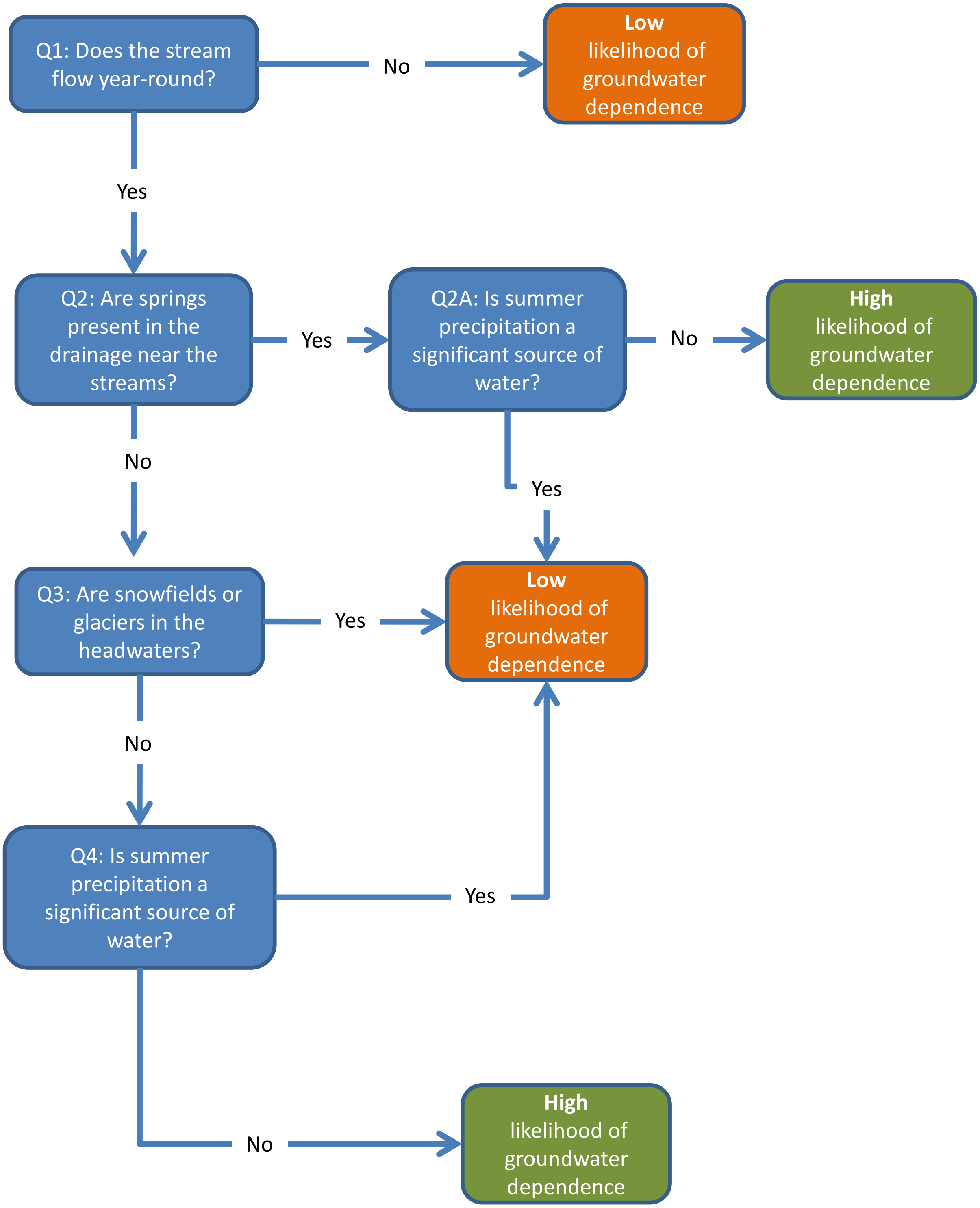


Figure 3-12 Decision tree for identifying ground water dependent river ecosystems (Brown et al., 2009a).

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 baseflow 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 (FLIR) 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 which 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. This recharge, discharge, flow path, and GDE distribution data is now available to inform conservation priorities for the Whychus Creek Watershed.

Ecological Limits of Hydrologic Alteration

Author(s) 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 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 3-13). 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.

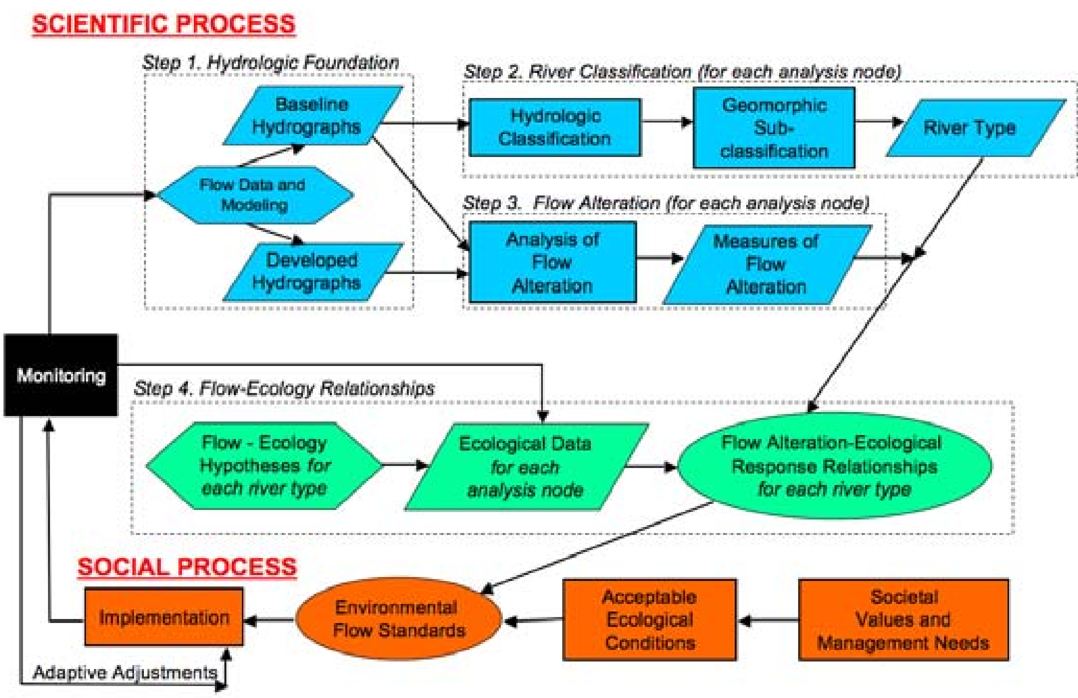


Figure 3-13 Framework for the Ecological Limits of Hydrologic Alteration Process (Poff et al., 2010). Reprinted with permission of John Wiley and Sons.

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 this database 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 ungauged sites.
2. **Classifying river segments** involves grouping rivers according to their similar flow regimes and geomorphic characteristics. A nationwide classification of streamflow 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 Texas Water Availability Model and Colorado River Decision Support System (CRDSS); and regression models such as the Massachusetts Sustainable Yield Estimator (SYE) (The Nature Conservancy, 2011). 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, gauged or ungauged. Basin characteristics were related to the flow duration curves in gauged streams in order to estimate the flow duration curve in ungauged 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 ungauged locations (Archfield, 2009).

A variety of tools are available for assessing the degree of flow alteration including the 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 HIT and HAT 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, the NJHAT, has been created in New Jersey and could 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, or NATHAT, 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 most importantly, 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 3-14).

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 baseflow for each river type. The flow alteration-ecological response curves (Figure 3-15) developed from this modeling analysis were used as a basis for determining, for each river type, the level of flow reduction that would cause 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 streamflow (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.

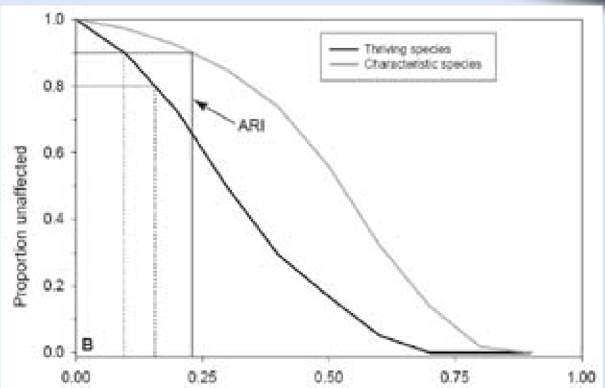


Figure 3-15 Example flow alteration-ecological response curves from Michigan (Zorn et al., 2008). For this river type, an Adverse Resource Impact (10% decline in the fish community metric) occurs when the index flow declines by about 23%.

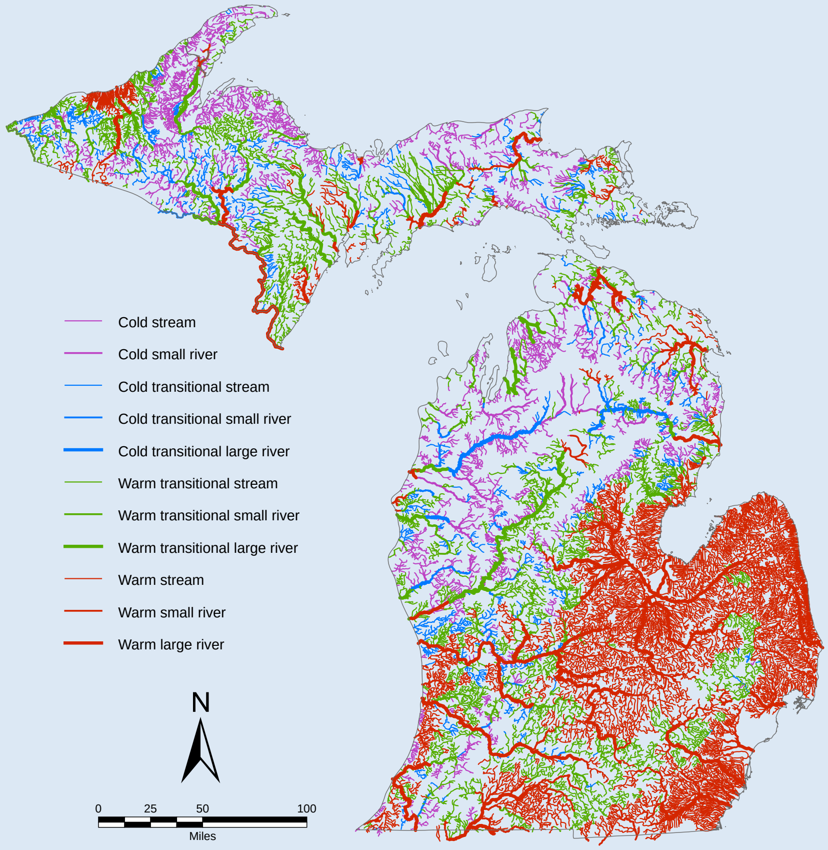


Figure 3-14 Thermal and fish assemblage based classification of streams, small rivers, and large rivers in Michigan (Zorn et al., 2008).

Oregon Water Quality Index

Author(s) 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 (OWQI) 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 OWQI is to provide a simple and concise method for expressing the ambient water quality of Oregon's streams. The OWQI 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 OWQI is not, however, suited for site-specific questions that should be based on the analysis of the original water quality data. The OWQI 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 OWQI 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 OWQI, when used appropriately, can be powerful tools for comparing aquatic health conditions in different water bodies and in communicating information to the general public. 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.

The Biological Condition Gradient and Tiered Aquatic Life Uses

Author(s) or Lead Agency: Susan P. Davies (Maine DEP) and Susan K. Jackson (U.S. EPA)
More Information: http://www.epa.gov/bioindicators/html/bcg.html

The Biological Condition Gradient (BCG) is a conceptual 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 3-16). There are six 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 waterbody 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 Tiers can be made by individual states and tribes if desired (e.g., the use of only three Tiers, as opposed to six).

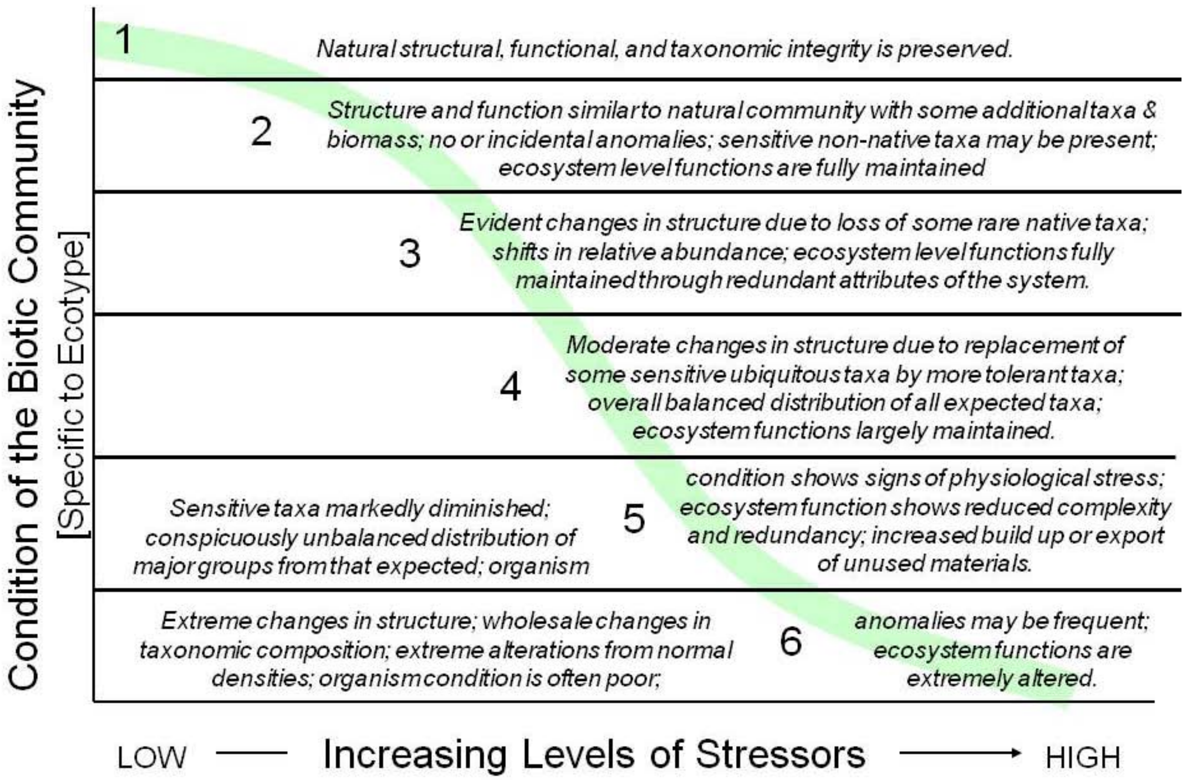


Figure 3-16 Conceptual model of the Biological Condition Gradient (U.S. Environmental Protection Agency, 2006c).

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 Tiers, as described in Figure 3-16, 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 Tier 1 category will be based. Calibration of the model has sometmes resulted in combining BCG Tier 1 and Tier 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 six (or fewer) Tiers of biological condition. It is often possible to calibrate existing indices of biotic integrity, such as the IBI, to the Tiers of biological condition, which will facilitate the application of the BCG model to future monitoring endeavors. If an existing biotic index system does not exist or if it is not possible to calibrate it to the BCG Tiers, an index that corresponds to the newly established Tiers 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. A number of statistical methods are available for relating specific watershed and riparian stressors to biological condition (U.S. Environmental Protection Agency, 2006c).

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 better 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. 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, providing quantitative measures of ecosystem health.

Case Study

Maine Tiered Aquatic Life Use Implementation

More Information: U.S. Environmental Protection Agency, 2006c (http://www.epa.gov/bioindicators/html/biointeg.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 3-17).

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.

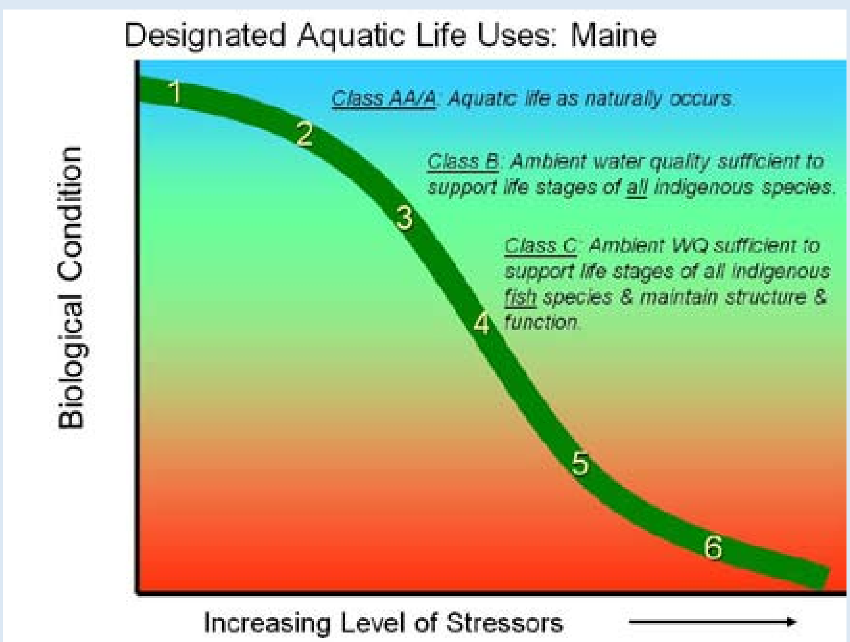


Figure 3-17 Maine Tiered Aquatic Life Uses in relation to Biological Condition Gradient Tiers (U.S. Environmental Protection Agency, 2006c).

Natural Heritage Program Biodiversity Assessments

Author(s) 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.

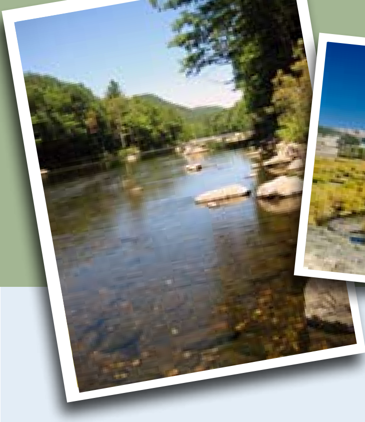
The Natural Heritage Methodology gathers, analyzes, organizes, and manages information on biodiversity through a network of professional biologists in partner agencies who keep pace with the growth in scientific understanding while maintaining an underlying continuity in the methodology. NatureServe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

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.



Case Study

Oregon Natural Heritage Information Center

More Information: Oregon Natural Heritage Program, 2009 (http://orbic.pdx.edu/)

The Oregon Natural Heritage Information Center (ORNHIC) 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. ORNHIC is also heavily involved in the state Gap Analysis Program and other conservation assessment and planning efforts in the state.

ORNHIC 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. ORNHIC 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.

ORNHIC 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. ORNHIC 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.

Aquatic Gap Analysis Program

Author(s) or Lead Agency: U.S. Geological Survey (USGS)
More Information: http://www.gap.uidaho.edu/projects/aquatic/default.htm

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 would 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 3-18). 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 3-7) and AESs and VSTs were prioritized for conservation (Table 3-8).

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 integrity and landscape condition assessment approaches and provide a greater level of protection to healthy ecosystems and their components.

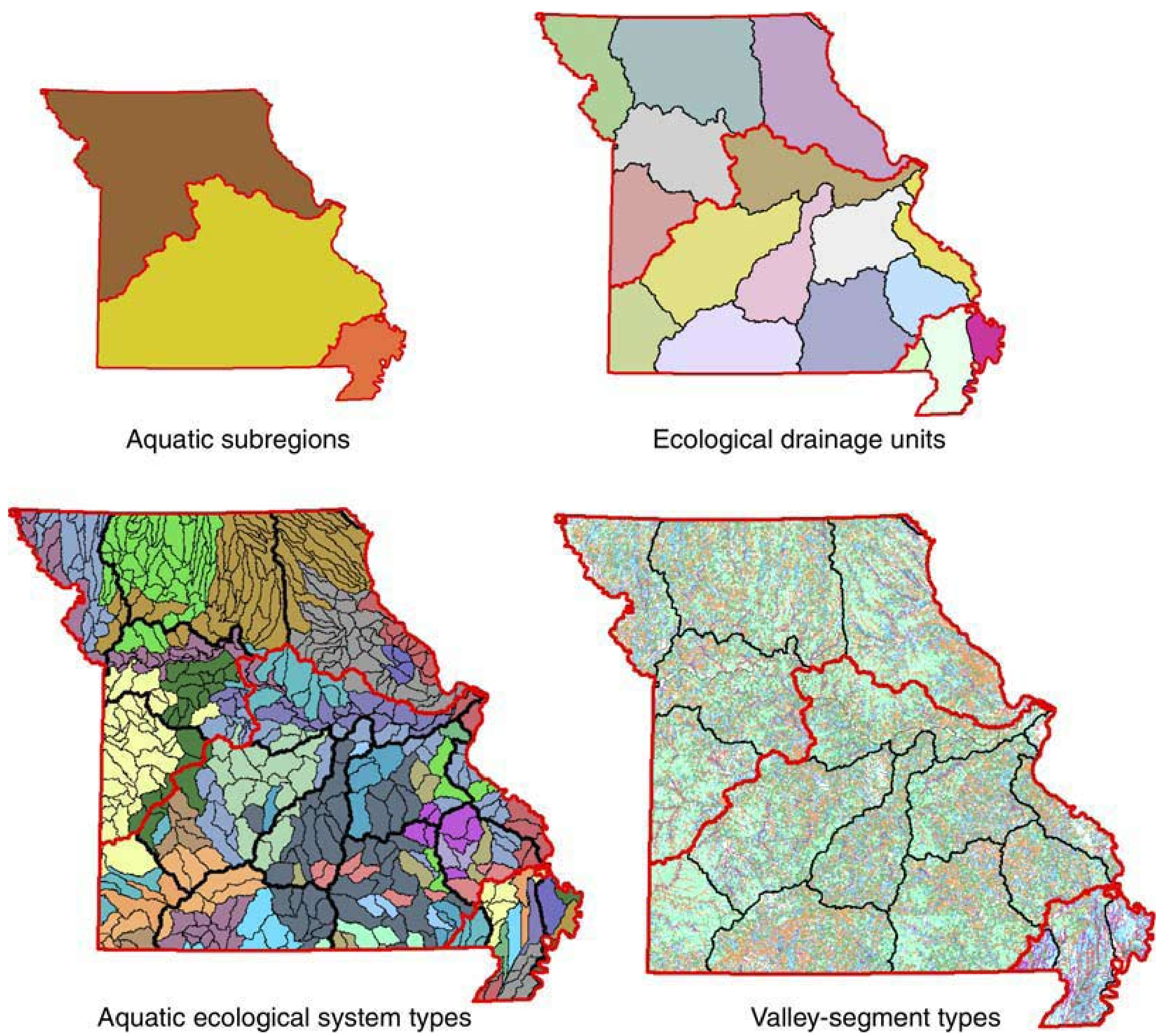


Figure 3-18 Maps of Missouri showing levels four through seven of the aquatic ecological classification hierarchy (Sowa et al., 2007). Reprinted with permission of Ecological Society of America.

Table 3-7 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	.20
Percentage agriculture	0 - 25	26 - 50	51 - 75	.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	.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	.20
Density of coal mines (no./km^2)	0	0.1 - 2	2.1 - 8	.8
Density of lead mines (no./km^2)	0	0.1 - 2	2.1 - 8	.8
Density of permitted discharges (no./km^2)	0	0.1 - 2	2.1 - 8	.8
Density of confined animal feeding operations (no./km^2)	0	0.1 - 2	2.1 - 4	.4

Table 3-8 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 ***Select the AES polygon that:***	VST-level Criteria ***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 (HTI) 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 3-19).

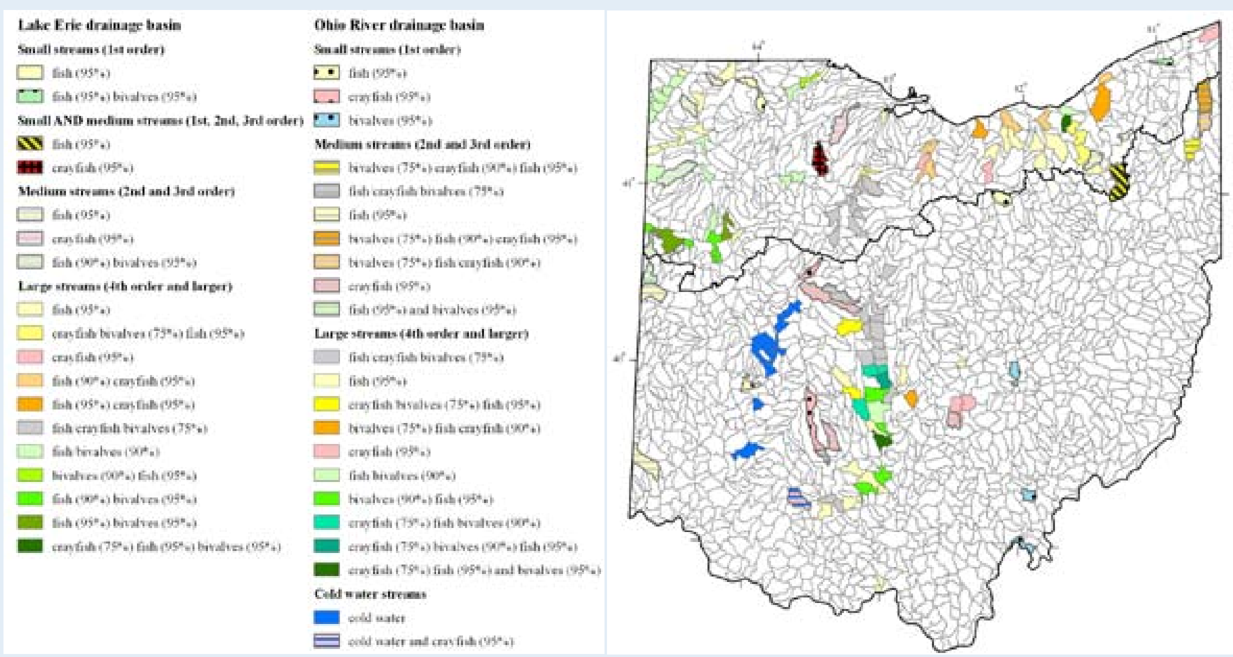


Figure 3-19 HUC12 watersheds in Ohio. The different color watersheds represent high predicted aquatic species richness for various taxa (U.S. Geological Survey, 2006).

3.2 Field Assessments

Ohio's Primary Headwaters Habitat Assessment

Author(s) 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 baseflow 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(s) 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 (MBSS) 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 integrity.

Based on the understanding that physical habitat degradation is one of the leading causes of stream impairment, MBSS 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 3-9. The final PHI for a stream is calculated by averaging the individual metric scores.

Table 3-9 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 3-20). 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.

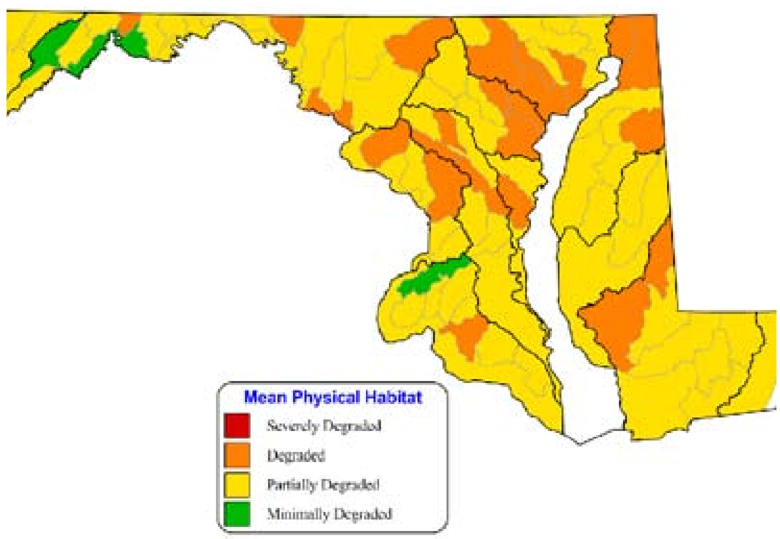


Figure 3-20 Map of stream habitat condition in Maryland, as determined with the Physical Habitat Index (Maryland Biological Stream Survey, 2005)

Proper Functioning Condition

Author(s) 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, 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" (PNC). 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 3-10 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 3-10 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)

Vermont's Stream Geomorphic and Reach Habitat Assessment Protocols

Author(s) 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. The purpose of Vermont's Stream Geomorphic Assessment Protocols (Kline, Alexander, Pytlik, Jaquith, & Pomeroy, 2009) is to provide a method that allows resource managers 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. 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.

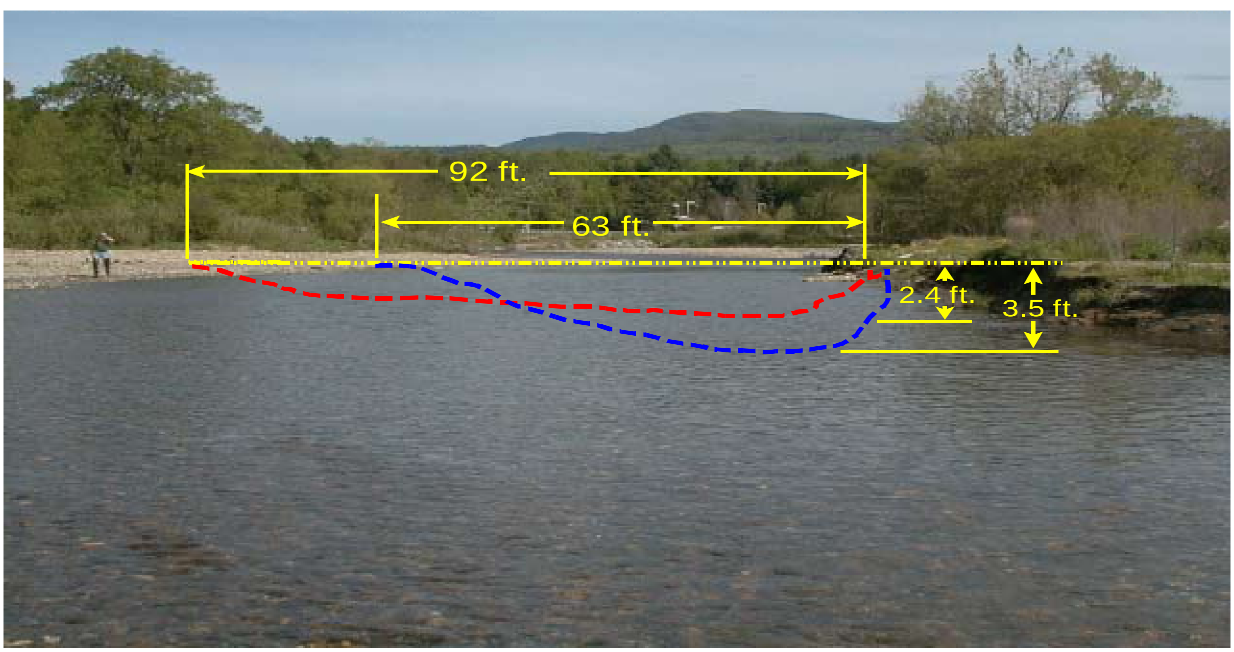


Figure 3-21 Phase 3 data gathering (Vermont Department of Environmental Conservation, 2007).

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.

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.

Regional and National Monitoring and Assessments of Streams and Rivers

Author(s) or Lead Agency: U.S. Geological Survey
More Information: http://water.usgs.gov/nawqa/studies/mrb/

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
- Sulfate
- Specific conductance
- Dissolved oxygen
- pH
- Chloride
- Carbonate
- Bicarbonate
- Alkalinity
- Suspended sediment
- Nutrients (total and dissolved nitrogen and 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 3-22). 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 3-22). 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

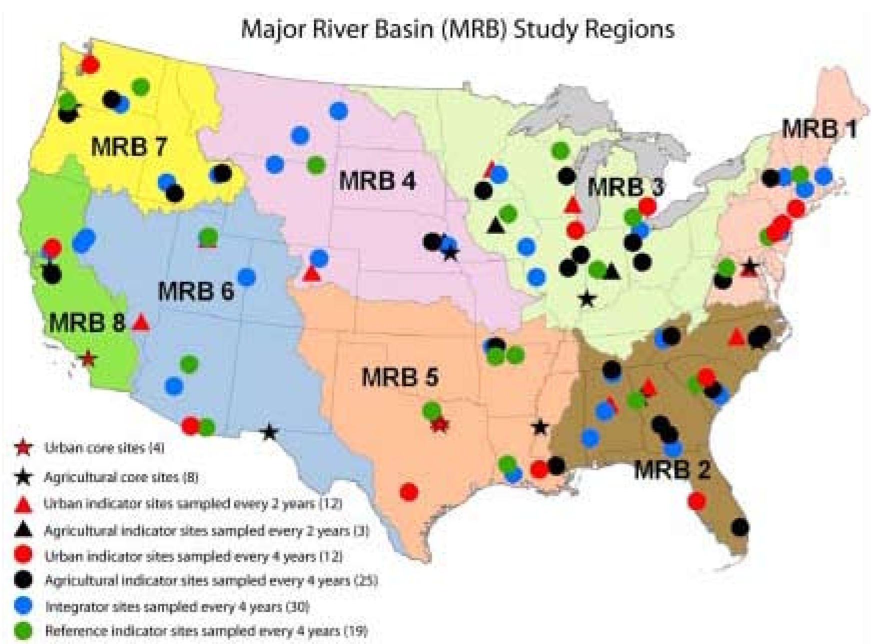


Figure 3-22 Sites for Regional and National Monitoring and Assessments of Streams and Rivers within Major River Basins (MRB) (U.S. Geological Survey, 2009c).

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).

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 a picture of national watershed health.

Index of Biotic Integrity

Author(s) 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 subsequently been modified for use in virtually every state and aquatic ecosystem type in the United States, as well as a number of 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 integrated over time and 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. While chemical monitoring programs might miss some of these, such as habitat alteration and flow modification impacts, biological assessments provide a mechanism for evaluating the effects of these factors on ecosystem health. Additionally, biological communities integrate the effects of pollutants and other disturbances over time. Chemical monitoring programs, for example, might miss episodic discharges of untreated wastewater while the resident biota will 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.

After assessing the chosen metrics, a score is given to each and then summed to arrive at the IBI for the site. The IBI for the site is relative to undisturbed, reference conditions for the region. 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 3-23).

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, enforcing National Pollutant Discharge Elimination System (NPDES) permits, 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 grid 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 integrity of a watershed's streams, lakes, and rivers allows for the identification of the healthiest sites that should be prioritized for protection.

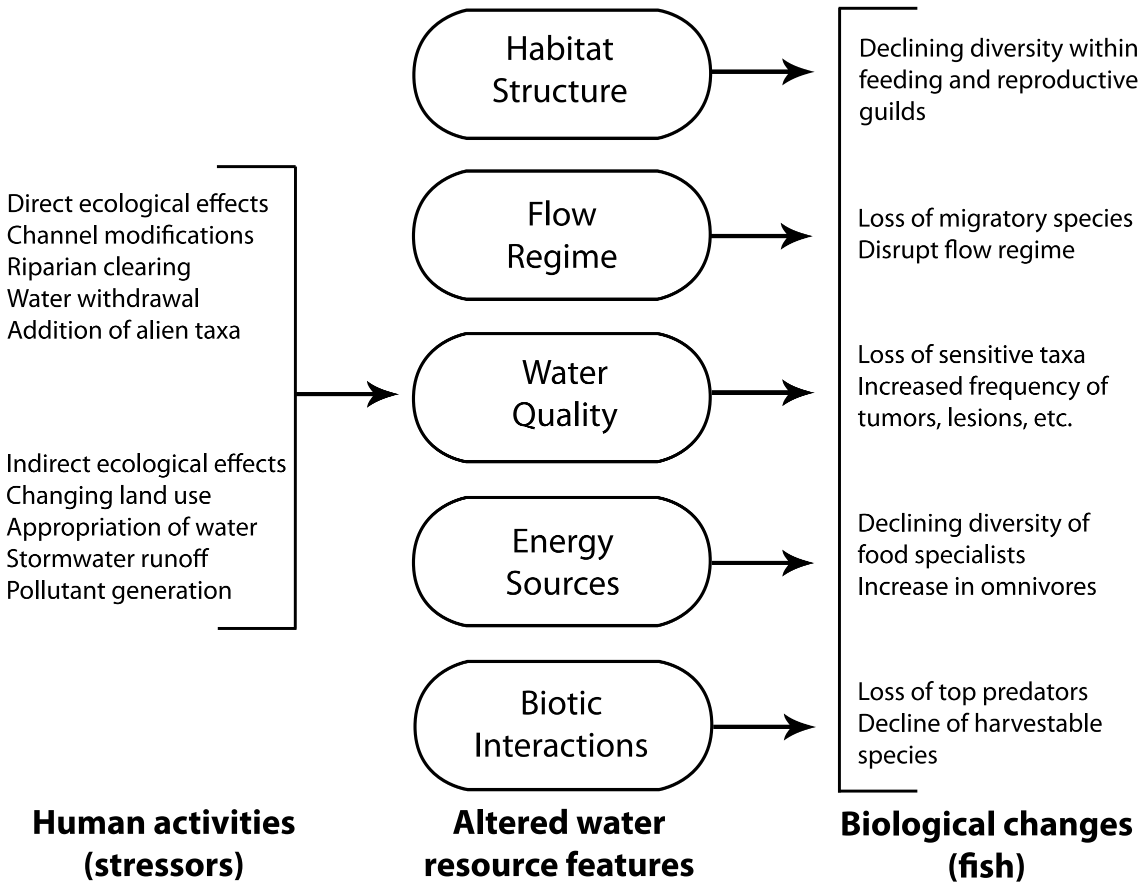
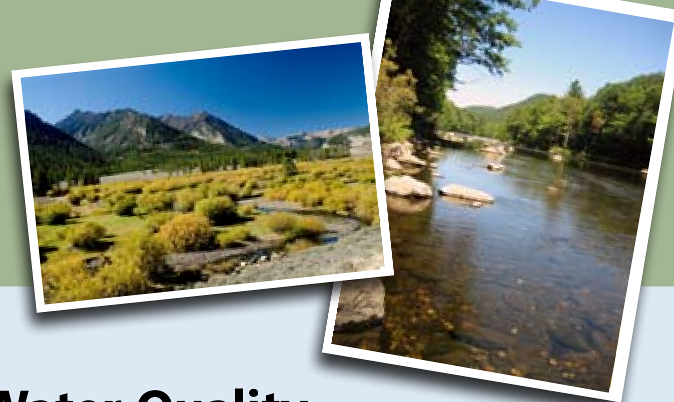


Figure 3-23 Human activities alter five water resource features, resulting in alteration of fish communities (Modified from Karr & Yoder, 2004).



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 (ICI) and a Modified Index of Wellbeing (MIwb). These are conceptually similar to the IBI. The IBI and MIwb are based on assessments of stream fish assemblages while the ICI is based on macroinvertebrate assemblages.

Ohio uses the IBI, ICI, and MIwb 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.

Virginia Interactive Stream Assessment Resource and Healthy Waters Program

Author(s) 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 3-24). 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 3-25).

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.

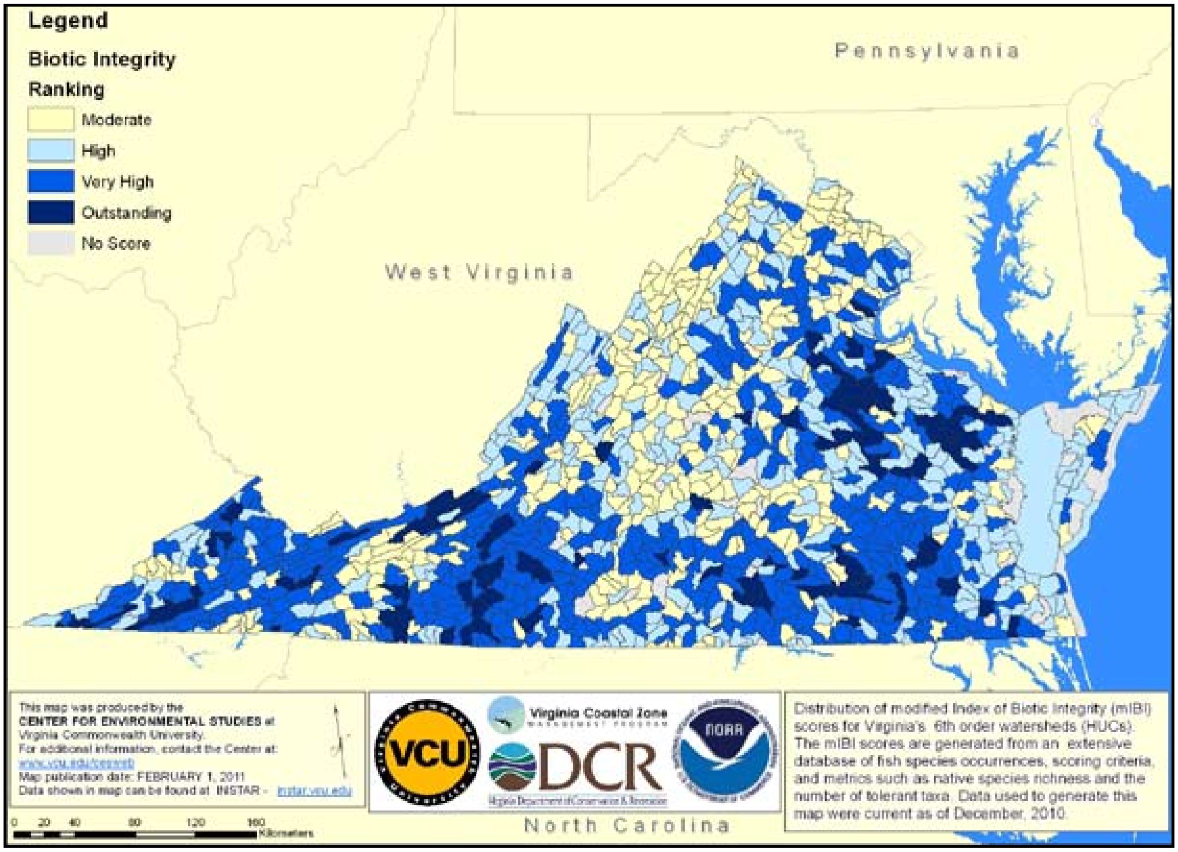


Figure 3-24 Map of watershed integrity in Virginia based on modified Index of Biotic Integrity scores (Greg Garman, Personal Communication).

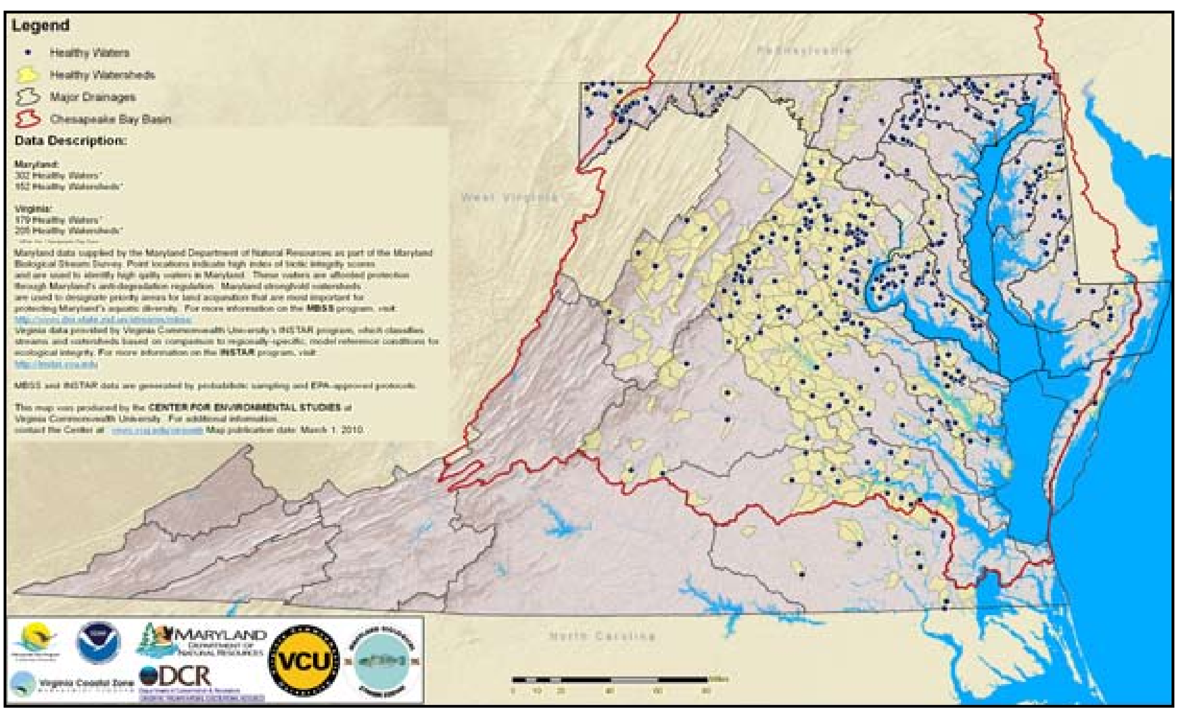


Figure 3-25 Status of healthy waters and watersheds in Maryland and Virginia (Greg Garman, Personal Communication).

National Rivers and Streams Assessment

Author(s) or Lead Agency: U.S. EPA
More Information: http://water.epa.gov/type/rsl/monitoring/riverssurvey/riverssurvey_index.cfm

The National Rivers and Streams Assessment (NRSA) is one of a series of national-scale statistical water surveys being conducted by EPA, states, tribes, and other partners. The purpose of these surveys is to generate statistically valid and environmentally relevant data on the condition of the nation's water resources. 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 2004 Wadeable Streams Assessment.

The sampling design for the NRSA survey is a probability-based network that will provide 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, 900 in each of two categories of waters: wadeable and non-wadeable (Figure 3-26). 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 2011. 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 3-26 National Rivers and Streams Assessment sample sites (U.S. Environmental Protection Agency, 2008c)

National Lakes Assessment

Author(s) or Lead Agency: U.S. EPA
More Information: http://water.epa.gov/type/lakes/lakessurvey_index.cfm

EPA is required to report on the condition of the nation's water resources using reports provided by states, which have historically been difficult to integrate into a cohesive summary. The National Aquatic Resource Surveys were initiated to begin the development of comparable national water quality datasets using consistent methods for data collection from populations of water bodies, rather than individual water bodies, across the nation. Lakes are an important water resource to monitor, because they provide, among other things, drinking water, fish and waterfowl used as food resources, habitat for 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 (Figure 3-27). 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 the Lake Diatom Condition Index, observed versus expected (O/E) phytoplankton and zooplankton, 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 pathogen *(enterococci)* counts, algal toxin concentrations (microcystins), and cyanobacteria counts.

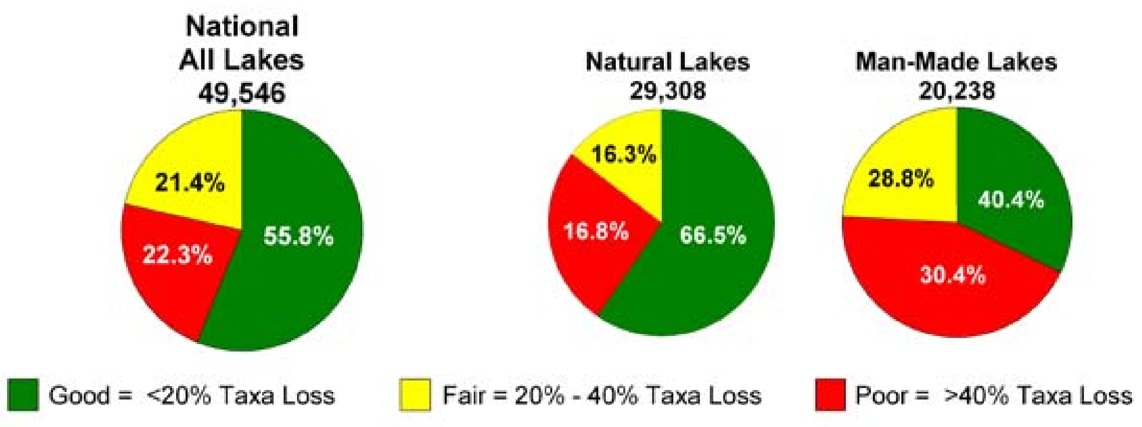


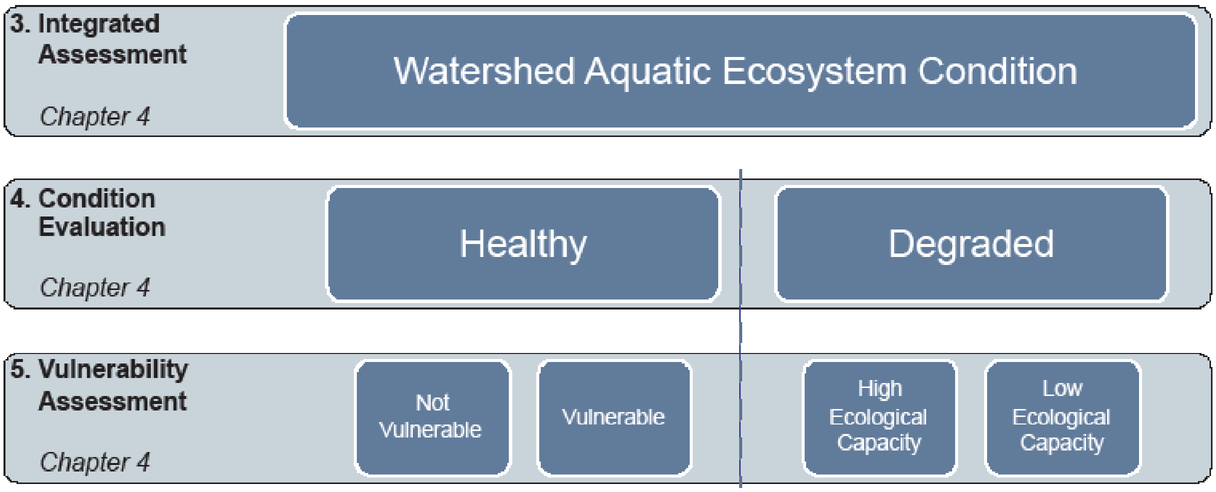
Figure 3-27 Biological condition of lakes nationally and based on lake origin (U.S. Environmental Protection Agency, 2009a).

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"; those which had results between the fifth and 25^{th} percentiles were considered "fair"; and lakes which had results below the fifth percentile of the reference range values were considered "poor."

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.

4. Healthy Watersheds Integrated Assessment Framework



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 outlines the Healthy Watersheds Integrated Assessment Framework. In Steps 1 through 7, each of the six Healthy Watersheds attributes is assessed; the results of the individual assessments are then integrated (in Step 8) in order to evaluate the aquatic ecosystem as a whole. The specific techniques listed in Steps 1 through 7 can be interchanged with other techniques at the discretion of the user. However, it is important that each of the Healthy Watersheds attributes discussed in Chapter 2 is assessed. Only then can the results be integrated to evaluate watershed aquatic ecosystem condition.

Numerous approaches are available for evaluating each Healthy Watersheds attribute, ranging from screening level analyses and desktop assessments to field assessments. This chapter outlines one example of a primarily GIS-based methodology for identifying healthy watersheds and also identifies other suggested techniques for more in-depth analyses. This methodology is based on a combination of methods summarized in Chapter 3 and at the end of this chapter. Users are encouraged to expand and modify it to suit their needs.

1. Delineate Watershed and Active River Area

2. Evaluate Landscape Condition
   - Calculate % natural land cover in watershed and active river area
   - Calculate % core area in watershed
   - Calculate % watershed with FRCC 1

3. Evaluate Habitat Condition
   - Calculate relative bed stability at each sample site
   - Calculate % areal cover at each sample site
   - Calculate % of stream reaches in good or reference condition

4. Evaluate Hydrologic Condition
   - Calculate total seasonal ecochange

5. Evaluate Geomorphic Condition
   - Delineate stream reaches and identify reference types
   - Assign stream impact rating for each reach
   - Calculate % stream reaches in good or reference condition

6. Evaluate Water Quality
   - Calculate water quality index
   - Calculate % steam miles with good or reference water quality index score

7. Evaluate Biological Integrity
   - Calculate macroinvertebrate index of biotic integrity at each sample site
   - Calculate % stream miles with good or reference index of biotic integrity score

8. Evaluate Watershed Condition
   - Normalize indicator scores
   - Combine into index

9. Assess Vulnerability
   - Calculate % watershed unprotected by zoning, parks, conservation lands, etc.

Figure 4-1 Healthy Watersheds Integrated Assessment Framework.

4.1 Integrated Assessment

This methodology identifies healthy watersheds and intact components of watersheds based primarily on remote sensing data and existing information derived from field assessments. Other field level monitoring data (such as biological and geomorphic data) and analysis results (such as detailed hydrologic assessments) can be incorporated into this approach to refine the assessment. The following datasets are needed for this analysis:

- Digital Elevation Model (DEM).
- Land cover (such as NLCD).
- Stream network (such as NHD).
- Built infrastructure locations, including bridges, culverts, dams, roads, etc.
- Long-term flow data, if available (such as USGS stream gage data).
- Water quality data, if available (such as USGS NAWQA and EPA WQX data).
- Biological monitoring data, if available (such as NAWQA or NRSA data).

While the methodology outlined here can be conducted with existing data, further refinements of the analysis may require collection of new data. Opportunities for integration with other monitoring and assessment programs should be sought out in these instances. For example, fluvial geomorphic data are extremely helpful in an integrated assessment of healthy watersheds. These data are also very useful in the development of total maximum daily loads (TMDLs) and restoration plans for impaired watersheds. However, collection of field-level fluvial geomorphic data is resource-intensive. If these data are lacking, opportunities may be sought by leveraging other water quality programs and their field efforts. This approach can improve efficiency across programs.

This assessment methodology uses both an index approach and co-occurrence approach for identifying healthy watersheds and healthy components of watersheds. 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. Co-occurrence models are overlay techniques in GIS that identify areas where multiple attributes coincide, indicating areas with potentially higher protection value. An example dataset is used throughout the description of this methodology to illustrate the real-world application of the techniques.

4.1.1 Determine the Appropriate Scale and Delineate Watersheds

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). If the assessment is to be conducted statewide to identify the healthiest watersheds in the state, then larger drainage basins may be the appropriate scale. If conducted for a county or town, subwatersheds or even smaller catchments may be more appropriate. In this example, a large drainage basin was delineated and used as the basis for the initial Healthy Watersheds assessment (Figure 4-2). The subwatersheds within it were later evaluated to help prioritize protection and restoration actions within the larger basin.

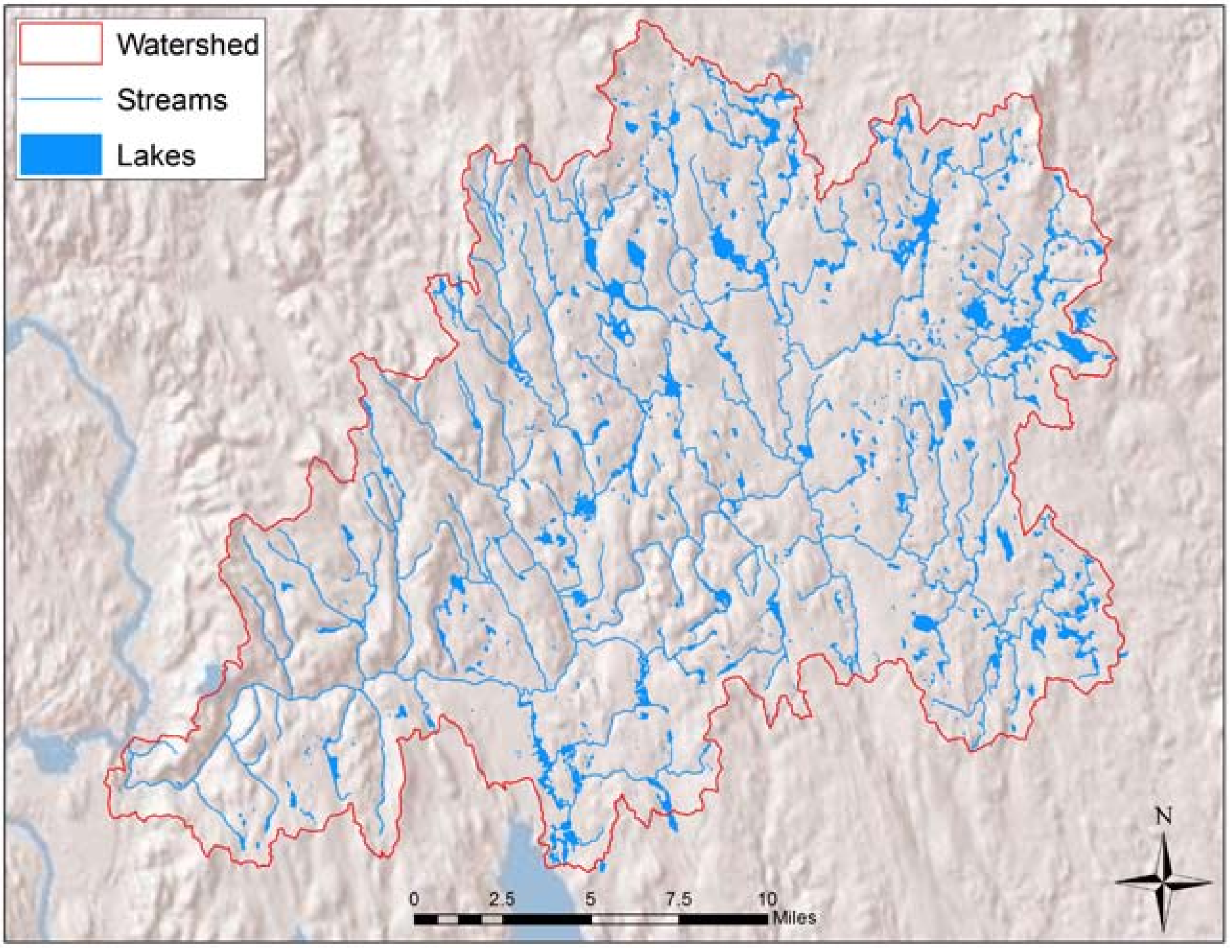


Figure 4-2 Delineation of the example watershed conducted with GIS techniques.

4.1.2 Delineate the Active River Area

Once the scale of assessment has been decided upon and watersheds have been delineated, the Active River Area can be delineated. The Active River Area framework and the delineation method described here were developed by The Nature Conservancy (see Chapter 3). 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. This area is formed and maintained by disturbance events and regular variations in flow 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 five primary components of the Active River Area are:

- Material contribution areas.
- Meander belts.
- Floodplains.
- Terraces.
- 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 (Smith et al., 2008). Material contribution areas provide food and energy (e.g., falling leaves) to aquatic organisms that is then transported downstream through ecological processes. Material contribution areas can be identified using the SLICE technique in GIS. The SLICE technique divides the DEM data layer for a watershed 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, headwater catchments falling within the top 40% of elevation bands were identified as headwater material contribution areas in this example assessment. Streamside material contribution areas were delineated by buffering streams with a width of 50 meters.

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 (Smith et al., 2008).

The meander belt/floodplain/riparian wetland/terrace area can be identified using a DEM and the PATHDISTANCE GIS technique. This technique 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 the stream and cutoff distances that are determined based on stream size (Strager, Yuill, & Wood, 2000). By considering stream size, this simple technique accounts for the dominant physical processes occurring in each zone of the watershed. 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 necessary for identifying these areas. A flow accumulation model uses a DEM to determine those areas expected to be wet based on slope and a flow moisture index. Riparian-associated wetlands can be identified by combining these areas with the known occurrence of wetlands from NLCD and NWI data and a distance cutoff based on stream size (Smith et al., 2008). Distinguishing between the meander belt, floodplains, and terraces requires more detailed field assessments such as the Vermont Stream Geomorphic Assessment Protocols (see Chapter 3). However, these simple GIS techniques alone are enough to delineate the Active River Area and begin to prioritize lands for conservation. Figure 4-3 shows the delineation of the Active River Area, including riparian and headwater areas, in the example watershed.

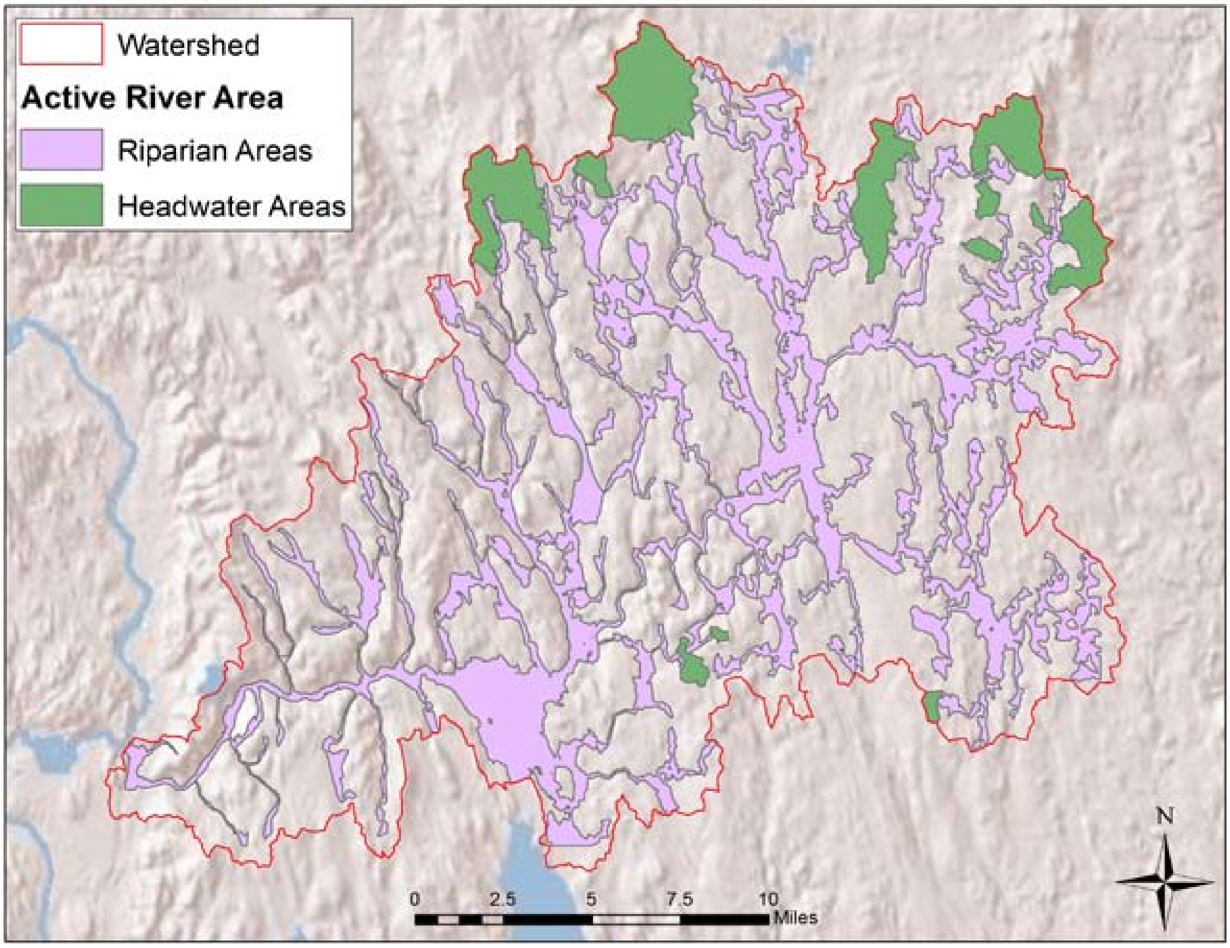


Figure 4-3 Delineation of the Active River Area for the example watershed. The Active River Area includes hydrologically connected riparian areas and headwater areas.

4.1.3 Evaluate Landscape Condition

Once the watershed and Active River Area have been delineated, some basic landscape calculations can be conducted to begin identifying potentially healthy subwatersheds. 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.epa.gov/mrlc/). This dataset contains land cover data, as well as percent impervious data for the entire United States. Impervious surfaces are associated with roads, 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). 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. Using the ZONAL STATISTICS function in GIS, the percent natural land cover can be calculated for the watershed as a whole and the Active River Area specifically. By setting a threshold for natural land cover (e.g., 80%) that defines a healthy watershed, the analyst accounts for impervious surfaces, agricultural, and other developed land uses that can pose threats to aquatic ecosystems. Figure 4-4 shows land cover in one of the example subwatersheds and the Active River Area.

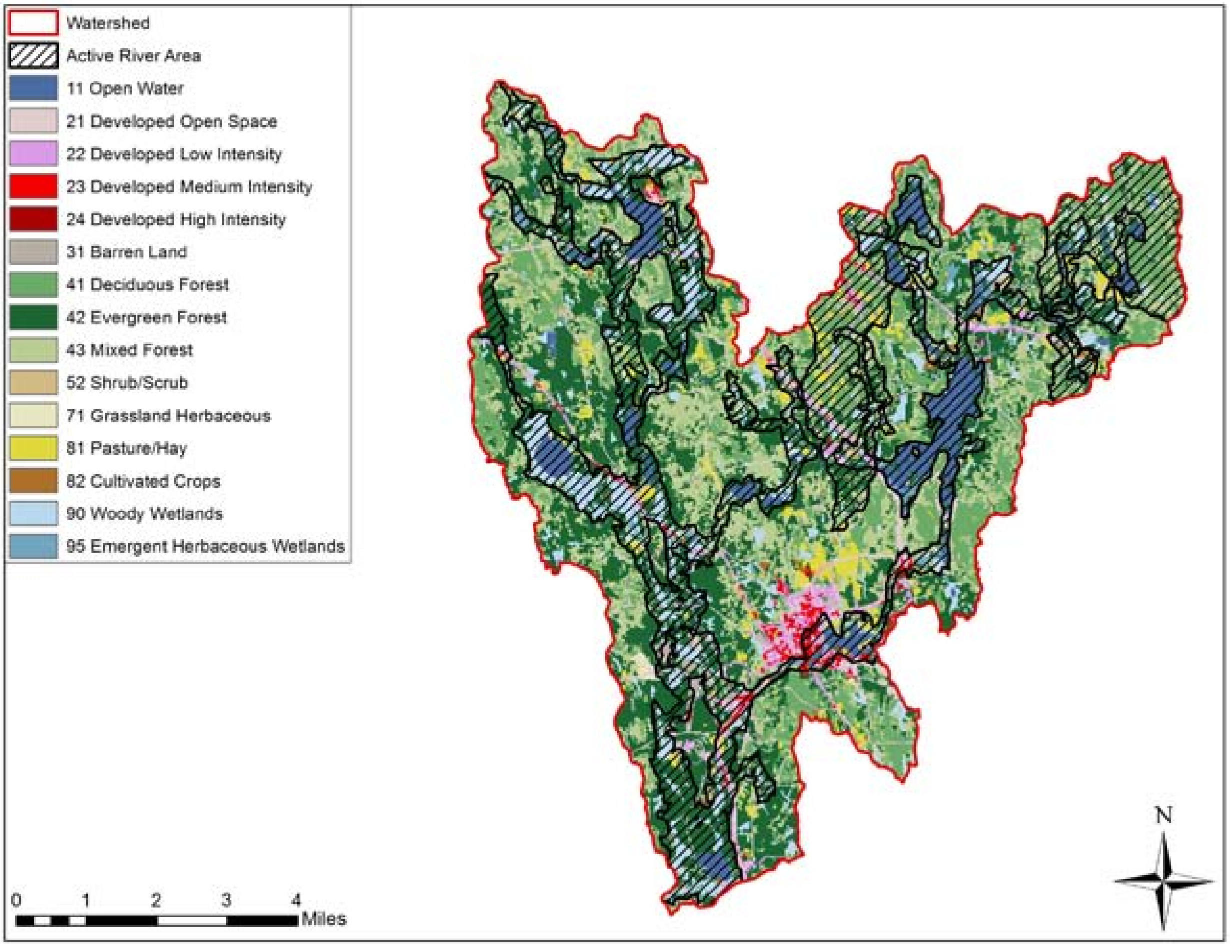


Figure 4-4 Land cover within a subwatershed and Active River Area.

The Fire Regime Condition Class (FRCC) is an assessment of the degree of vegetation departure from reference conditions due to alteration of the natural fire regime. This assessment has been conducted for the entire United States and a GIS layer of the results can be obtained from the LANDFIRE program. This layer represents the departure of current vegetation conditions from simulated historical reference conditions. The three condition classes represent low, moderate, and high departure from reference conditions. Low departure is preferred in healthy watersheds. Inclusion of these data in an integrated assessment allows for a landscape scale evaluation of the natural disturbance regime. The natural fire regime has been severely altered in many regions of the United States. Therefore, it may be appropriate to give this Healthy Watersheds indicator less importance in the overall assessment through the use of a weighting scheme in regions where reference conditions no longer exist. For the example watershed, only 1% of the area remains in FRCC 1, or reference conditions.

The extent of natural land cover within a watershed and an Active River Area is very important for ecological integrity. However, the connectivity of this natural vegetation is also important. Assessing the connectivity of large core areas of natural vegetation involves a green infrastructure assessment such as those conducted by Virginia, Florida, or Maryland (see Chapter 3). These 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 (Figure 4-5). Typically, green infrastructure assessments then use a GIS technique called "least cost path" to identify corridors that represent the easiest migration routes for wildlife to move from one core area to another. In this example, the Active River Area was used to identify corridors that connect all of the core areas (Figure 4-5). The intact Active River Area was then identified through an

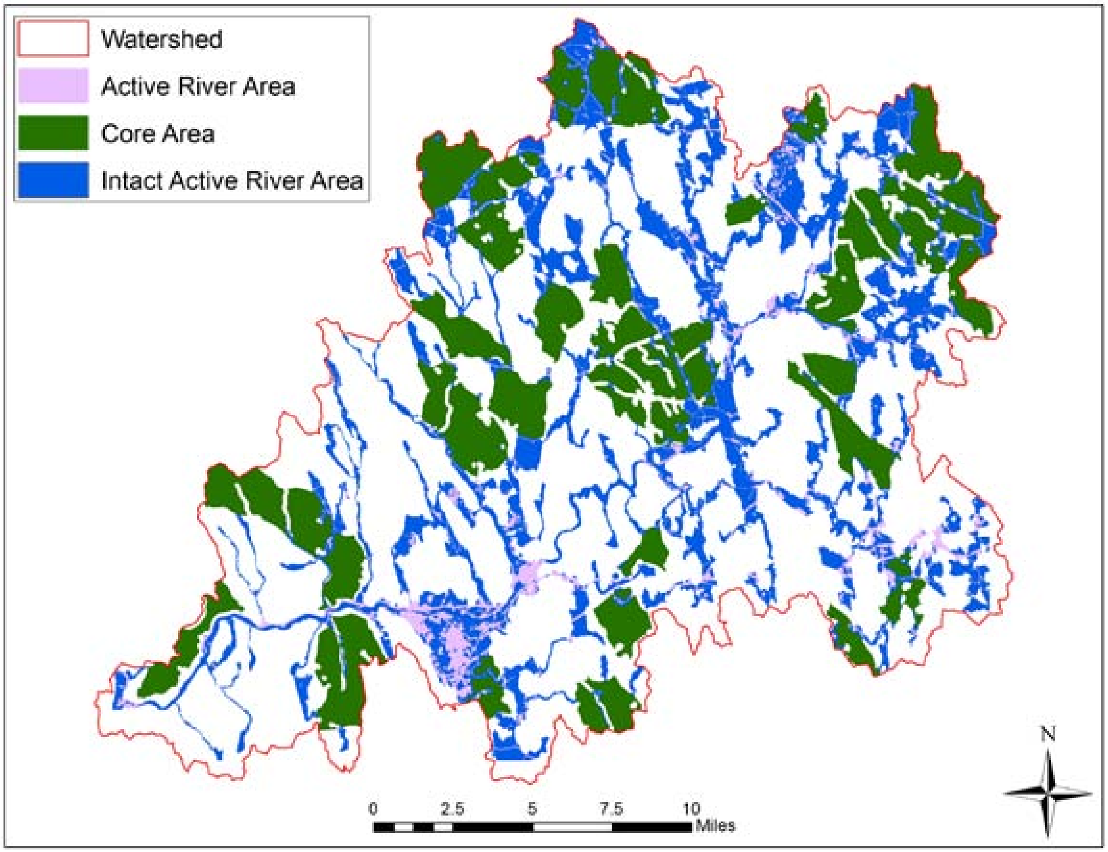


Figure 4-5 Green infrastructure in the example watershed. The intact Active River Area serves the links connecting the ecological hubs, or core areas. Note that virtually all of the headwater areas and much of the riparian areas are covered by intact Active River Area and core forest areas. These are excellent protection opportunities.

evaluation of natural land cover within the riparian areas and headwater catchments (the blue area in Figure 4-5). This is the area that is most capable of providing the geomorphic, hydrologic, and habitat functions of the Active River Area and should be prioritized for protection along with the core areas. The riparian and headwater areas that are not covered by the blue, intact Active River Area in Figure 4-5 are those portions of the Active River Area that overlap with developed land uses; further, site-specific, assessments can be conducted to determine the recovery potential of these areas.

4.1.4 Evaluate Geomorphic and Physical Habitat Condition

Built infrastructure can fragment both terrestrial and aquatic habitat throughout a watershed and can modify natural stream geomorphology. Identification of these features is important for identifying potentially healthy watersheds. GIS data layers containing the locations of roads, railways, bridges, dams, culverts, and other built infrastructure can be overlain on a map displaying the watershed boundary and streams (Figure 4-6).

Simple geomorphic and physical habitat indicators, such as the number of stream crossings, can be calculated in a GIS and divided by the total length of streams. This is an indicator of potential disruption to connectivity. Stream crossings, such as bridges and culverts under roads, are commonly undersized, leading to deposition above and scour below the structure, resulting in a loss of aquatic habitat connectivity. Dams can also be identified using the National Inventory of Dams data layer and/or local information on the locations of smaller dams. Dividing the number of dams by the total length of streams and rivers in the watershed can serve as an index of aquatic habitat fragmentation (Tiner, 2004). In addition to impacts on aquatic habitat connectivity, dams also affect the flow and sediment regimes and hydrologic condition of a river.

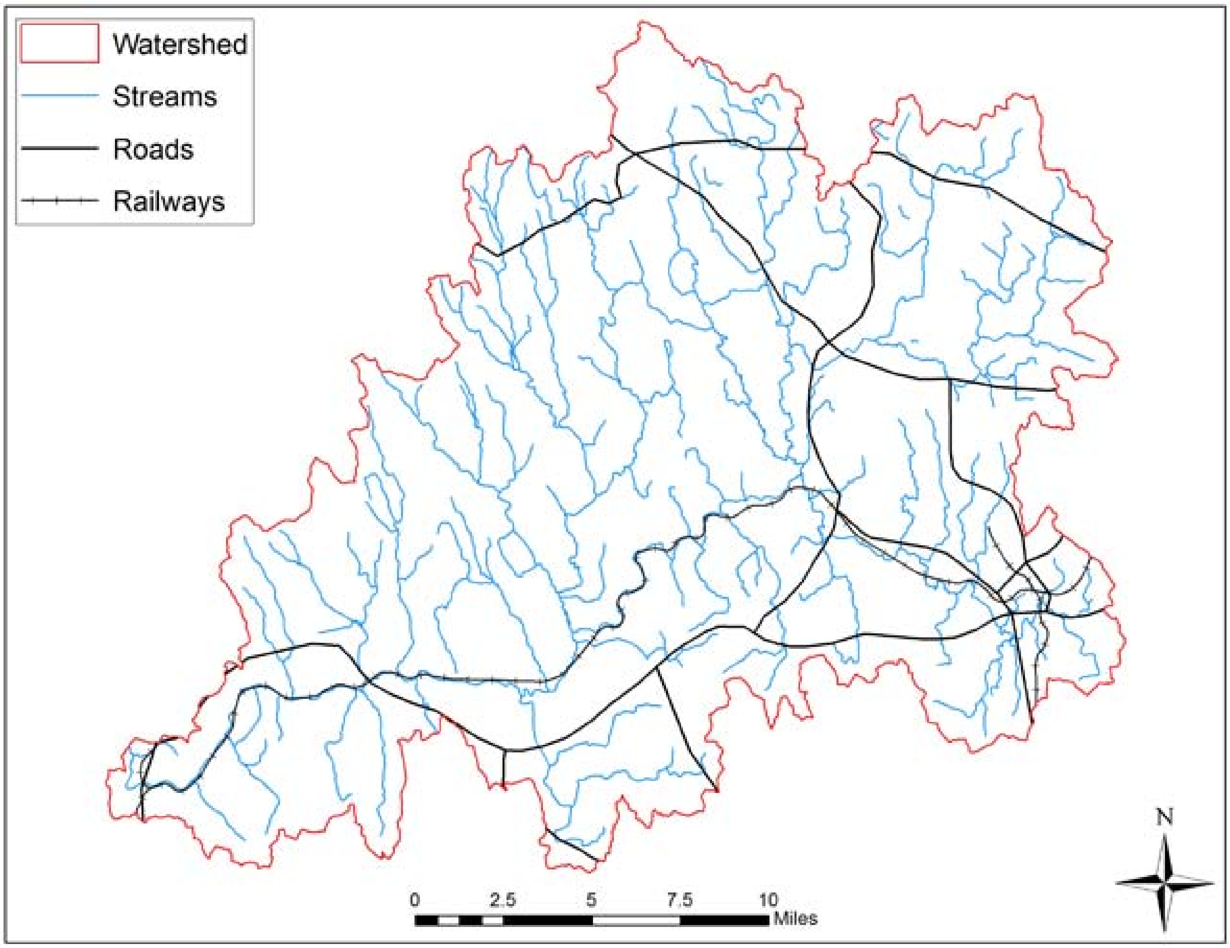


Figure 4-6 There are a total of 95 stream crossings by road and railway in this watershed. Note how the railway follows the length of the mainstem river.

More detailed assessments of stream geomorphic condition can be conducted using procedures such as the Massachusetts River and Stream Continuity Project protocols (Massachusetts Department of Fish & Game, 2011) or Vermont's Stream Geomorphic Assessment protocols (Kline, Alexander, Pytlik, Jaquith, & Pomeroy, 2009) or similar, region-specific tools. These protocols begin with a desktop based analysis (Phase 1) of geomorphic condition and can be followed through to detailed field assessments.

A Phase 1 stream geomorphic assessment was conducted for the example watershed using techniques described by the Vermont River Management Program (see Chapter 3) (Kline et al., 2009). 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.

Each reach of the mainstem and major tributaries was first classified by reference stream type (Table 4-1). The Vermont Stream Geomorphic Assessment (SGA) protocols recommend defining reaches based on stream size, geology, valley confinement and valley slope. Reach breaks are placed at the confluence of major tributaries, changes in the erodibility of soils, significant changes in the width of the valley, and significant changes in valley slope.

Table 4-1 Reference stream types (Kline et al., 2009). Note that valley slope ranges will differ among physiographic regions.

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.

Different stream types are associated with different bed forms and substrates, flow velocities, and valley characteristics, which help to determine the reference equilibrium conditions and specific physical habitat available for aquatic biota. For example, brook trout might be found in "A" stream types due to the fast-moving, well-oxygenated cold water found there, while bass would be expected to occur in "C or E" stream types due to the slow moving, warmer water found in these rivers. The quality of the physical habitat will be affected by the geomorphic condition. 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. Table 4-2 lists the parameters that were evaluated to determine the impact rating for each reach in the example watershed. The specific methods used to evaluate each of these parameters 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 (based on evaluation of the parameters in Table 4-2). Figure 4-7 shows the distribution of stream geomorphic conditions in the example watershed. The green and blue streams in Figure 4-7 are the healthy streams, while the yellow and red streams are the degraded streams. Overall, the watershed is mostly in good to reference condition. However, there are some reaches that deserve a more detailed, field-level assessment to determine the potential need for restoration actions.

Table 4-2 Parameters evaluated for the stream impact rating.

Parameter
Watershed Land Cover
Corridor Land Cover
Riparian Buffer Width
Flow Regulations and Water Withdrawals
Depositional Features
Meander Migration/Channel Avulsion
Meander Width Ratio
Wavelength Ratio
Dominant Bed Form/Material
Bank Erosion
Bridges & Culverts
Bank Armoring
Channel Modifications
Dredging and Gravel Mining History
Berms and Roads
River Corridor Development

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

Reference Stream Type	Confinement (Valley Type)	Valley Slope
A	Narrowly confined (NC)	Very Steep > 6.5 %
A	Confined (NC)	Very Steep 4.0 - 6.5 %
B	Confined or Semi-confined (NC, SC)	Steep 3.0 - 4.0 %
B	Confined or Semi-confined or Narrow (NC, SC, NW)	Mod.- Steep 2.0 – 3.0 %
C or E	Unconfined (NW, BD, VB)	Mod.- Gentle < 2.0 %
D	Unconfined (NW, BD, VB)	Mod.- Gentle < 4.0 %

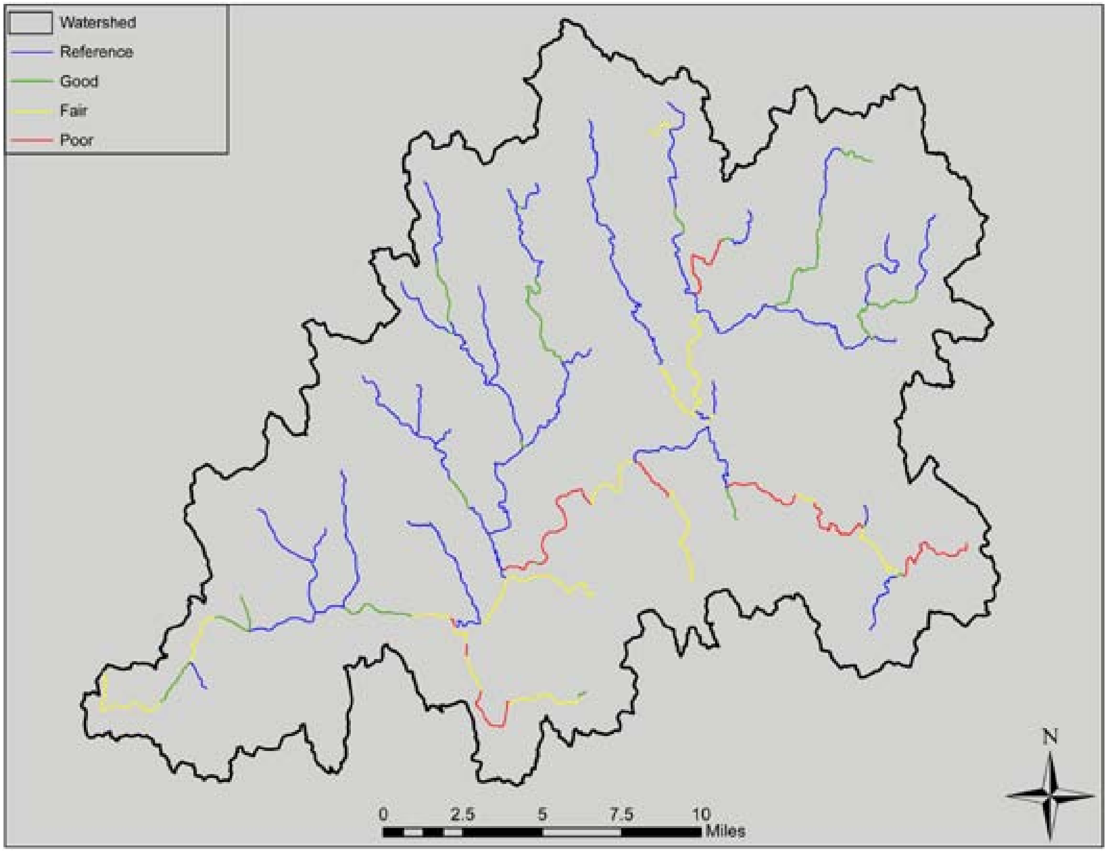


Figure 4-7 Map of stream geomorphic condition in the example watershed.

Physical habitat condition assessments typically require field methods similar to geomorphic condition assessments. Phases 2 and 3 of Vermont's SGA protocols integrate Reach Habitat Assessment Protocols (Schiff, Kline, & Clark, 2008) with field collection of detailed geomorphic measurements. Additionally, physical habitat data are often collected in state bioassessment and water quality monitoring programs. Where resources are available, these data can be extremely valuable in a Healthy Watersheds assessment.

Information from existing aquatic habitat assessments can also be used for evaluating habitat condition. Aquatic GAP analyses have been completed in some areas of the United States (Chapter 3), and a National Fish Habitat Assessment is currently underway to identify and evaluate the condition of aquatic habitat across the nation (Association of Fish and Wildlife Agencies, 2006). Once completed, the results of the National Fish Habitat Assessment will be available to help identify healthy watersheds. This information can be useful for providing additional aquatic habitat information. See Appendix B for information on where to obtain these data.

For the example watershed, physical habitat condition was evaluated following part of the methodology used in EPA's Wadeable Streams Assessment (U.S. Environmental Protection Agency, 2006d). Pebble count data collected in the field as part of the state biomonitoring program were used to calculate the median substrate diameter. Relative Bed Stability (RBS) is determined by comparing the observed median substrate diameter to the expected substrate diameter based on a calculation of the "critical bed particle diameter," which is based on stream size, power, and landscape setting. A value of one represents reference conditions, while values above one can indicate anthropogenic coarsening of substrates or bank armoring, and values below one can indicate excess fine sediments from soil erosion. Either of these conditions can reduce the quality of habitat for macroinvertebrates, periphyton, and fish assemblages.

Visual assessments of instream fish habitat were also conducted during the state's routine biomonitoring. The percent areal cover of fish concealment features, including undercut banks, overhanging vegetation, large woody debris, and boulders was estimated by field crews and used as an indicator of fish habitat. Table 4-4 describes the percent areal cover and RBS criteria for inclusion in one of the four habitat categories for the example watershed.

Table 4-4 Habitat categories used in the example assessment based on relative bed stability and % areal cover indicators (U.S. Environmental Protection Agency, 2006d). Note that these criteria will vary among regions and stream types.

	Bed Stability	% Areal Cover
Reference	0.9 – 1.1	>40%
Good	0.8 – 0.9 or 1.1 – 1.2	25 – 40%
Fair	0.7 – 0.8 or 1.2 – 1.3	15 – 25%
Poor	<0.7 or >1.3	<15%

4.1.5 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 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, 2009).

More than 170 hydrologic indicators have been identified for use in assessments of hydrologic alteration (Gao, Vogel, Kroll, Poff, & Olden, 2009). Methods such as The Nature Conservancy's Indicators of Hydrologic Alteration (IHA) or the USGS' Hydroecological Integrity Assessment Process (HIP) can be used to calculate a variety of these flow statistics for determining hydrologic alteration. Current research seeks to identify redundancy in these indicators so that hydrologic alteration can be represented by just one or a few measures. The concepts of ecosurplus and ecodeficit have recently been proposed as general indicators of ecologically relevant hydrologic alteration (Vogel, Sieber, Archfield, Smith, & Huber-Lee, 2007). Using a flow duration curve (FDC) for the period relatively free of human impacts (or a simulated natural FDC) and a FDC for the current period, ecosurplus is the area below the current FDC, but above the historical (or simulated natural) FDC (Figure 4-8). Similarly, ecodeficit is the area below the historical (or simulated natural) FDC, but above the current FDC (Figure 4-8). Therefore, the ecodeficit represents the amount of flow lost while the ecosurplus represents the amount of additional flow available. The concept of total seasonal ecochange has been proposed as an overall index of hydrologic alteration that combines the values calculated for ecosurplus and ecodeficit across the three

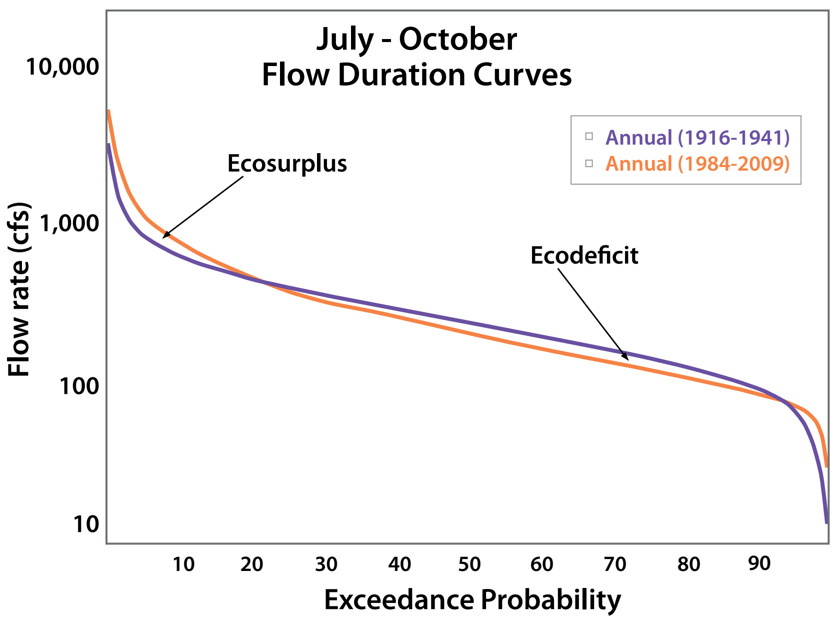


Figure 4-8 Flow duration curves for historical and current conditions for the summer months. Note that the highest flows (low exceedance probability) and lowest flows (high exceedance probability) are higher now than they were historically, yet the intermediate flows are lower. Historic and current flow duration curves were also created for the winter and spring months to obtain ecosurplus and ecodeficit values for all three seasons (winter, spring, and summer).

seasons of spring, winter, and summer (Gao et al., 2009). That is, ecosurplus and ecodeficit are calculated for each of the three seasons and all of the absolute values are summed to obtain the total seasonal ecochange. While total seasonal ecochange does not directly consider all aspects of the natural flow regime, statistical analysis has shown it to explain more than 80% of the variability that is explained by the IHA statistics (Gao et al., 2009). This provides strong statistical support for the use of a single index value in evaluating hydrologic condition when resources preclude a full IHA, HIP, or ELOHA analysis.

Total seasonal ecochange was calculated for the example watershed by comparing historical and current flow duration curves for the winter, spring, and summer seasons. All of the ecosurpluses and ecodeficits were summed to obtain a total seasonal ecochange value of 3.07. This number is unitless and can range from zero (signifying no change) to infinity (theoretically). Therefore, a threshold that represents healthy hydrologic conditions must be decided upon for this number to have meaning. This is typically accomplished through an evaluation of regional flow-ecological response curves. ELOHA is a framework for applying indicators of hydrologic alteration (individual or composite indicators, such as total seasonal ecochange) to the development of regional environmental flow rules in the context of ecological responses to hydrologic alteration (see Chapter 3 for further discussion). One must be careful when comparing ecochange statistics, as the choice of number and extent of seasons will impact the result. Comparisons should only be made when the same seasons were used in the analysis. For the example watershed, total seasonal ecochange was compared to the value obtained from a nearby reference site.

4.1.6 Evaluate Available Water Quality Data

Every state collects water quality data. However, not all states use water quality indices (WQIs). Where WQIs do not exist, they can be constructed (Oram, 2009). For the example watershed, the National Sanitation Foundation's WQI approach was used to create an index based on state monitoring data. Table 4-5 displays the water quality parameters evaluated in the WQI for a representative site in the example watershed.

The National Sanitation Foundation's WQI approach uses non-linear functions for each parameter to derive indicator scores (see http://www.water-research.net/watrqualindex/index.htm). The indicator scores are then averaged to arrive at the final WQI score. For the dataset in Table 4-5, the WQI is 91. Table 4-6 summarizes the interpretation of the WQI for the example watershed, which was calculated from data collected at 40 monitoring locations spread across the 10 subwatersheds.

Table 4-5 Water quality parameters used in the construction of the water quality index. Values for a representative reference site in the example watershed are given.

Factor	Value
Dissolved oxygen (%sat)	90
Fecal coliform (colonies/100 mL)	2
pH	6.8
Biochemical oxygen demand (ppm)	0.9
Temperature change from reference site	1.3
Total phosphate (ppm)	0.2
Nitrates (ppm)	1.8
Turbidity (ntu)	4
Total solids (ppm)	48

Table 4-6 Water quality index interpretation.

Range	Quality
90-100	Reference
70-90	Good
50-70	Fair
0-50	Poor

4.1.7 Evaluate Available Biological Integrity Data

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, the raw biological data can be used to create them. Examples of approaches for developing IBIs are summarized in Chapter 3. If biological data are not collected as part of routine monitoring programs, efforts can be made to begin collecting such data (see http://www.epa.gov/bioiweb1/).

For the example watershed, a modified Macroinvertebrate IBI was constructed based on raw data that were available from the state monitoring program. Table 4-7 displays a dataset from one of the sample sites. The number of individuals in each taxon is multiplied by a weighting factor and then summed and divided by the total number of individuals collected to arrive at the Macroinvertebrate IBI. Streams were then categorized according to the criteria in Table 4-8.

Table 4-7 Biomonitoring dataset from one of the sample sites. Weighting factors will differ among regions based on regional taxonomic differerences.

Indicator Taxa	N	Weighting Factor	Weighted N
Dragonfly	11	4	44
Mayfly	45	3.5	157.5
Stonefly	10	1	10
Caddisfly	16	4.5	72
Midge	5	5.5	27.5
Total	89	X	311

Table 4-8 Macroinvertebrate Index of Biotic Integrity categories.

Category	Macroinvertebrate IBI Score
Reference	<5
Good	5-10
Fair	10-15
Poor	>15

4.2 Evaluate Watershed Condition

The integrated assessment methodology summarized in this chapter will provide a number of indicator scores, addressing all of the Healthy Watersheds attributes. Many of these indicator scores represent the condition of multiple attributes (Table 4-9). The last four indicators in Table 4-9 are some of the most important, but can only be assessed when data are available. All other indicators can be assessed with GIS data layers that are available nationwide.

Table 4-9 Healthy Watersheds assessment indicators and the attributes they address.

Indicator	Attributes Addressed
Percent natural land cover in watershed	Landscape Condition
Percent natural land cover in the Active River Area (intact Active River Area)	Landscape Condition Habitat Geomorphology
Percent core area in watershed	Landscape Condition Habitat
Percent of watershed with Fire Regime Condition Class 1	Landscape Condition
Percent stream miles in good or reference geomorphic condition	Geomorphology Habitat
Percent stream miles in good or reference habitat condition	Habitat
Total seasonal ecochange	Hydrology
Percent stream miles with good or reference water quality index scores	Water Quality
Percent stream miles with good or reference index of biotic integrity scores	Biological Integrity

Normalization of these indicator scores can help to integrate multiple ecological attributes into a composite score or graphical representation of watershed health. Normalization converts the raw data of each variable 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. Alternatively, the values obtained from each ecological attribute assessment may be scaled to a value between zero and one by dividing the observed value by the reference value, essentially representing the condition as a percentage.

A composite index of watershed health can be most simply constructed by summing or calculating the average of the normalized indicator scores for each attribute. However, 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 much more subjective and a logical decision framework, such as the Analytical Hierarchy Process (AHP) should be used. This approach is a systematic process for soliciting and documenting expert opinion (see Smith, Tran, & O'Neill (2003) for an in-depth discussion of the AHP and other statistical data integration methods for environmental assessment). For the example watershed, criteria (or thresholds) were identified for each indicator and the scores normalized to a value of either zero or one (Table 4-10). The composite index is then the average of these individual indicator scores.

Table 4-10 Scoring system for the example Healthy Watersheds integrated assessment.

Indicator	Raw Score	Healthy Criteria	Normalized Score
Percent natural land cover in watershed	0.86	>0.8	1
Percent natural land cover in the Active River Area	0.86	>0.8	1
Percent core area in watershed	0.21	>0.1	1
Percent of watershed with FRCC 1	0.01	>0.5	0
Percent stream miles in good or reference geomorphic condition	0.82	>0.8	1
Percent stream miles in good or reference habitat condition	0.91	>0.9	1
Total seasonal ecochange	3.07	<1	0
Percent stream miles with good or reference WQI scores	0.91	>0.9	1
Percent stream miles with good or reference IBI scores	0.95	>0.9	1
Total			**7**
Total possible			**9**
Score		**>70%**	**78%**

A minimum score can be chosen to represent healthy watersheds (e.g., 70%). This would rate a watershed as either healthy or degraded. Figure 4-9 shows the results of the example watershed assessment results grouped as either healthy or degraded. Watershed health does not have to be reported in an either or manner (e.g., healthy or degraded). The full range of scores can be used (e.g., all of the scores between 0-100%). The example watershed was further delineated into subwatersheds and the above assessment methodology repeated on each subwatershed. Figure 4-10 shows the results of this assessment grouped into four levels of watershed health.

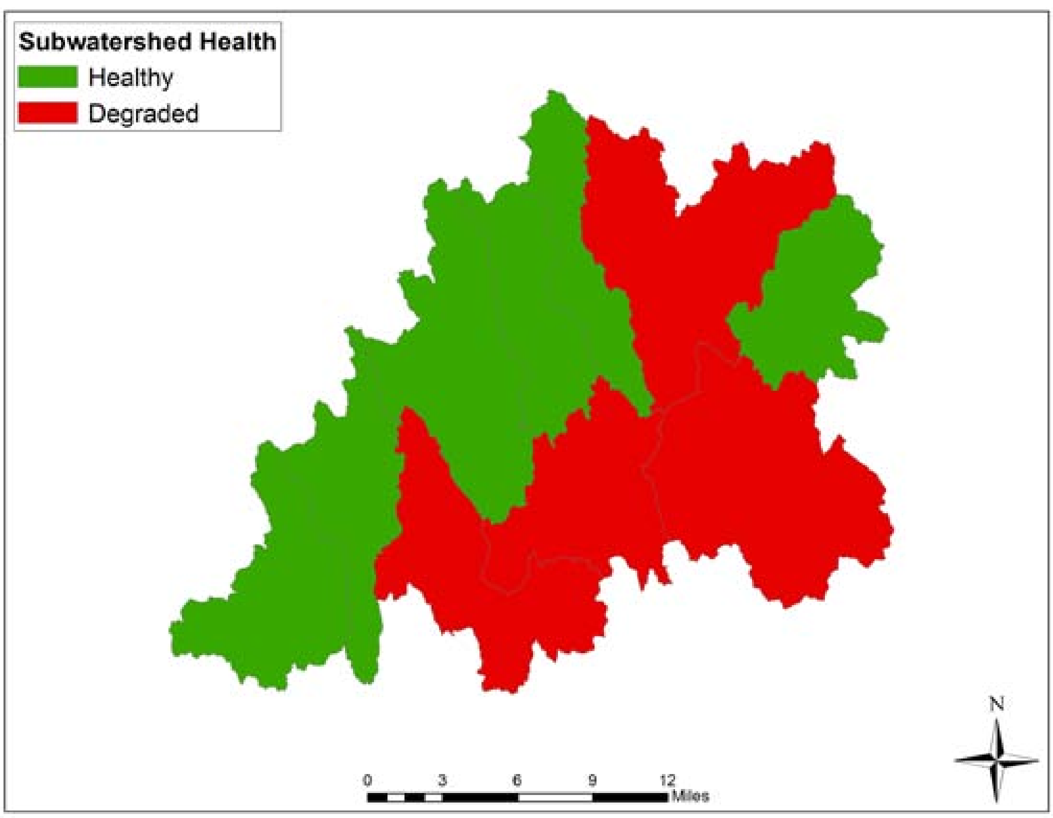


Figure 4-9 A map classifying watersheds as either healthy or degraded.

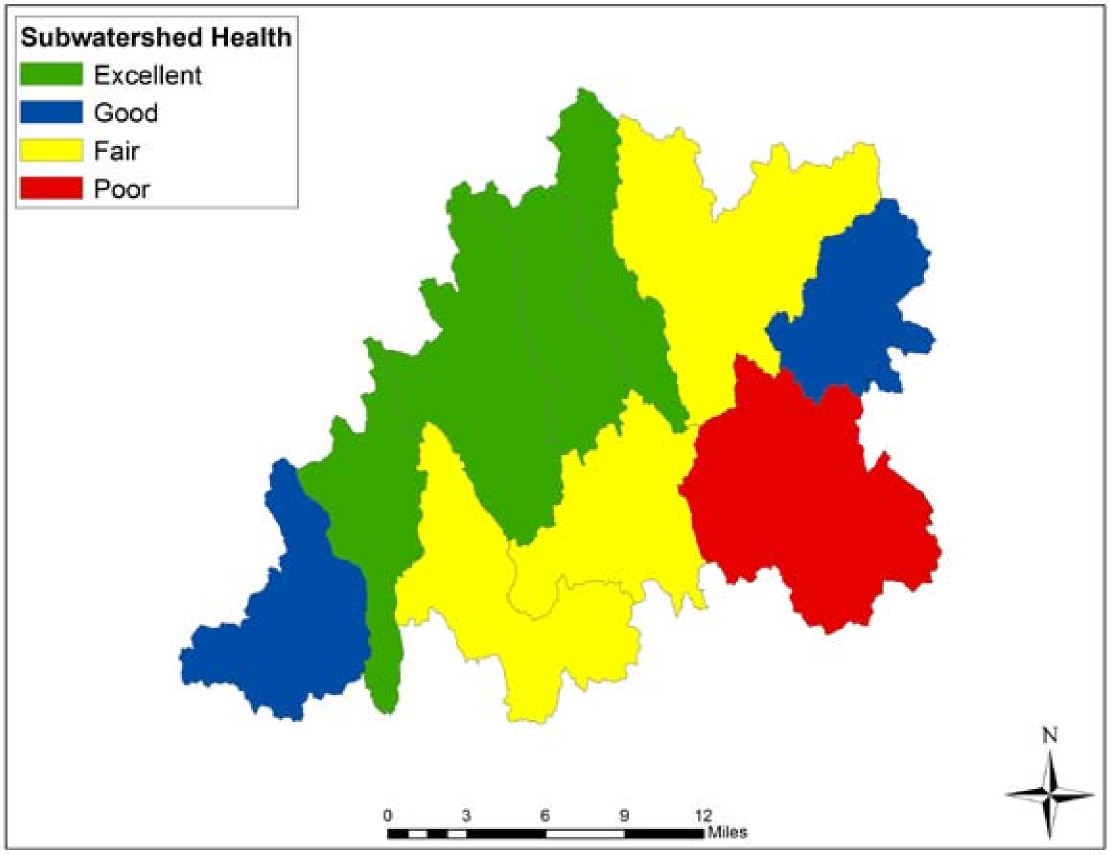


Figure 4-10 A map using a color ramp to represent a range of scores for watershed condition.

4.3 Assess Vulnerability

A vulnerability assessment, though not essential to identifying healthy watersheds and their intact components, facilitates the prioritization of protection and restoration strategies. Vulnerability can be defined as a function of the exposure and sensitivity of a system to specific threats and the capacity of the system to cope, adapt, or recover from the effects of those threats (Smit & Wandel, 2006). 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 a combination of urban growth models, climate change predictive models, water use forecasts, invasive species threats, and best professional judgment.

Areas of vulnerability can be identified on a map, and the healthy areas that fall within those "vulnerable boundaries" can be prioritized for protection. 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 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 a reclassification technique in GIS to reflect these potential future land uses. Projections of future urban and exurban development have been generated for the United States and are available for download (Bierwagen, Theobald, Pyke, Choate, & Groth, 2010).

The rate at which urban growth will occur can be estimated based on population growth estimates for a region. These estimates are available from the U.S. Census Bureau and various state agencies. Future water use can also be estimated based on these population projections. Coastal watersheds are often vulnerable to different threats than interior watersheds. Coastal areas are subject to rising sea levels and larger storm surges as a consequence of climate change. These effects can destroy wetlands and other valuable habitats. Climate change is also expected to change water availability and quality through increased surface runoff in some areas, which will also affect geomorphic stability and the natural disturbance regime of riverine and floodplain ecosystems. Some vegetation distributions will also likely change as a result of changing weather patterns. Downscaled climate projections are available in GIS format from climatewizard.org (Zganjar, Girvetz, & G., 2009) and other sources. These data can be used along with a build-out analysis, population, and future water use projections to identify vulnerable areas and potential strategies for addressing these threats.

For the example watershed, a data layer representing current zoning in the watershed was combined with a data layer representing permanently protected areas (e.g., conservation easements, wildlife reserves, parks) to identify all land that is vulnerable to future development. This simple technique allows subwatersheds to be targeted for protection based on their future development potential (Figure 4-11). A more spatially explicit evaluation would identify specific areas that are protection priorities. Figure 4-12 identifies specific areas that are protection priorities based on co-occurrence of green infrastructure (i.e., the intact Active River Area and ecological cores) and vulnerable areas, as determined by current zoning. Protection of these areas will help to protect this healthy watershed by ensuring that the most ecologically valuable lands are not developed. 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.

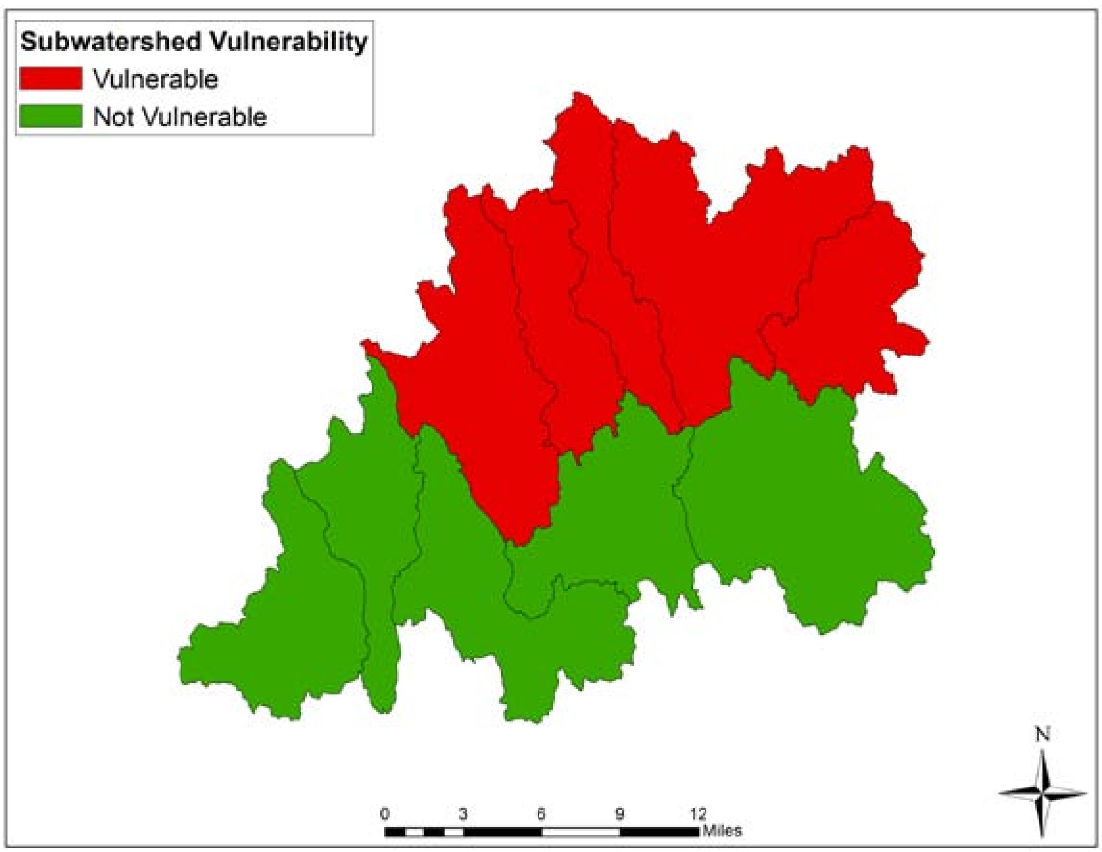


Figure 4-11 Subwatershed vulnerability assessment for the example watershed based on current zoning and protected areas.

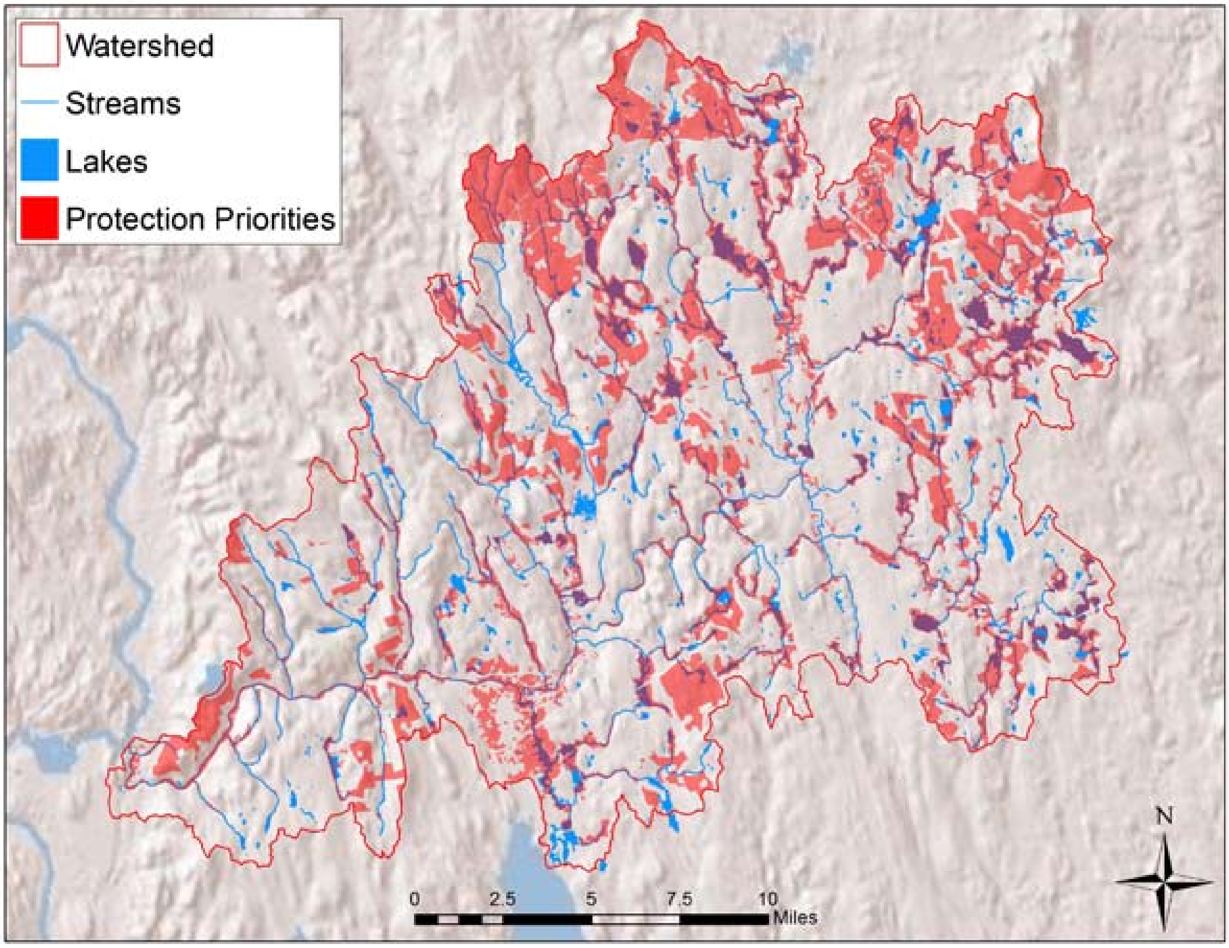


Figure 4-12 Protection priorities in the example watershed based on co-occurrence of green infrastructure (i.e., the intact Active River Area and ecological cores) and vulnerable areas, as determined through current zoning.


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 VCLNA Vulnerability Assessment Model provides guidance to the Virginia Conservation Lands Needs Assessment by identifying those areas most at risk from development pressures and other factors. The Vulnerability Assessment 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 Assessment used Rural Area Community Codes (U.S. Department of Agriculture Economic Research Service, 2005) to distinguish between urban, urban fringe, and suburban areas. The analysis 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 Assessment Model provide an opportunity for local communities to proactively plan for growth. The results of the assessment can be used to help 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 Assessment Model's results in the Commonwealth of Virginia and can be combined with other data or analyses. The Vulnerability Assessment Model can be used for targeting and prioritizing of conservation sites, guiding local planning and growth assessment, land management, and public education. Figure 4-13 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.

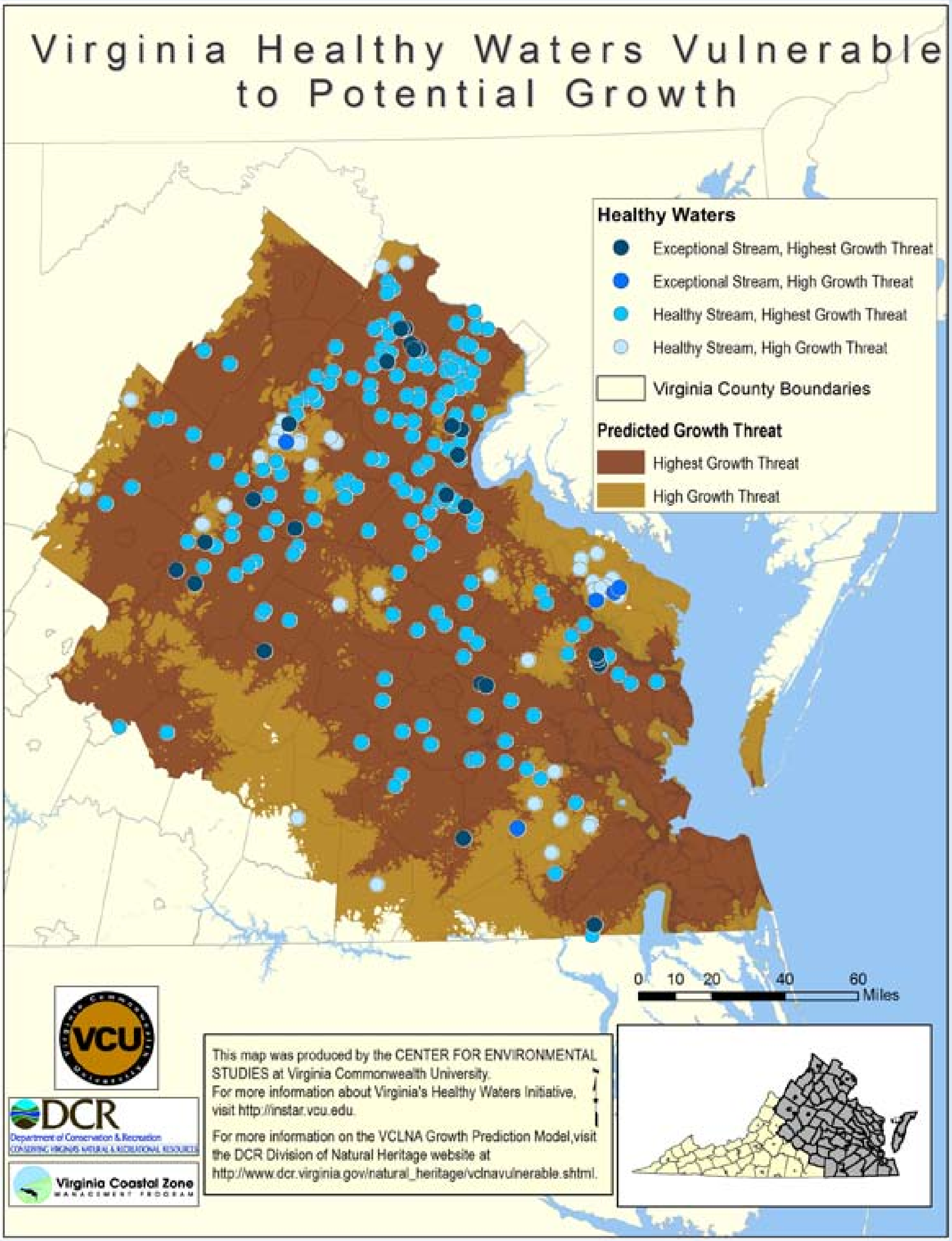
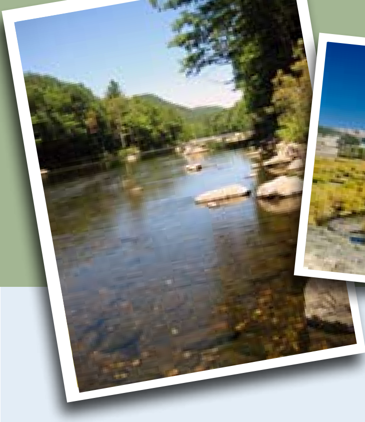


Figure 4-13 Regional results of the Virginia Vulnerability Assessment Model overlain with results from Virginia's Healthy Waters program (Greg Garman, Personal Communication).




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 (discharge pipes such as municipal waste water treatment facilities), nonpoint sources (pollution generated by activities such as agriculture or urban areas), 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., popluation 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. ReVA's approach is represented by the diagram in Figure 4-14.

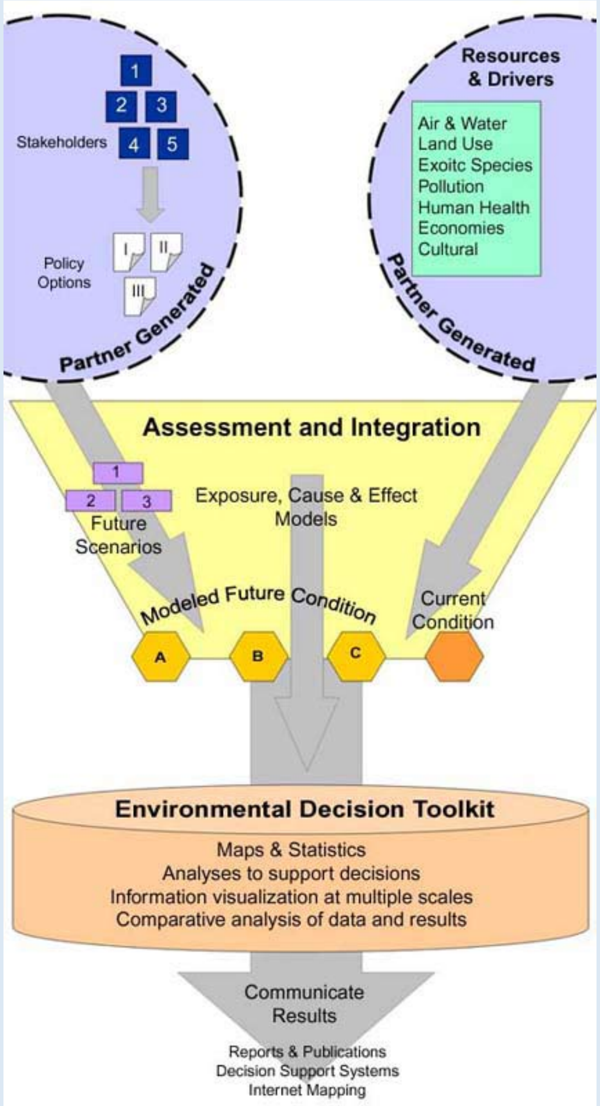
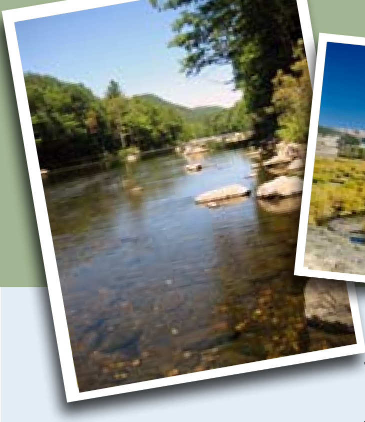


Figure 4-14 ReVA Approach (U.S. Environmental Protection Agency, 2011).



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. Land uses that include the 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 the EPA, completed a statewide assessment of aquifer sensitivity and ground water vulnerability for the shallow aquifers that occur across the state. 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. 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 at the local level and management of agricultural chemicals. Aquifer sensitivity and ground water vulnerability maps could be used to assess the vulnerability of groundwater dependent ecosystems.

4.4 Moving Towards Integrated Assessments

The following assessment approaches represent state and EPA efforts to move towards integrated evaluations of watershed health. A detailed summary of each approach is provided in the subsequent pages. Pages 4-50 through 4-60 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 could 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

This approach 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

This 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

This manual presents an organizational framework for integrated assessments of California watersheds. It 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

This 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

This approach identified the least disturbed watersheds across the State of Connecticut based on an impervious surface and natural land cover analysis, an IBI approach, water quality, flow modifications and 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 Approach

This approach identified the least disturbed watersheds across the State of 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 sources 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 or restore watersheds with highest ecological capacity for recovery.

Virginia Watershed Integrity Model

Author(s) 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 Model is described in Chapter 3 and the Vulnerability Assessment 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 increased erosion and resultant sediment loading from decreased forest cover in a watershed, increased nutrient loading as a result of intensive agriculture, and overall 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 very 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 4-15). 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 potential general 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.

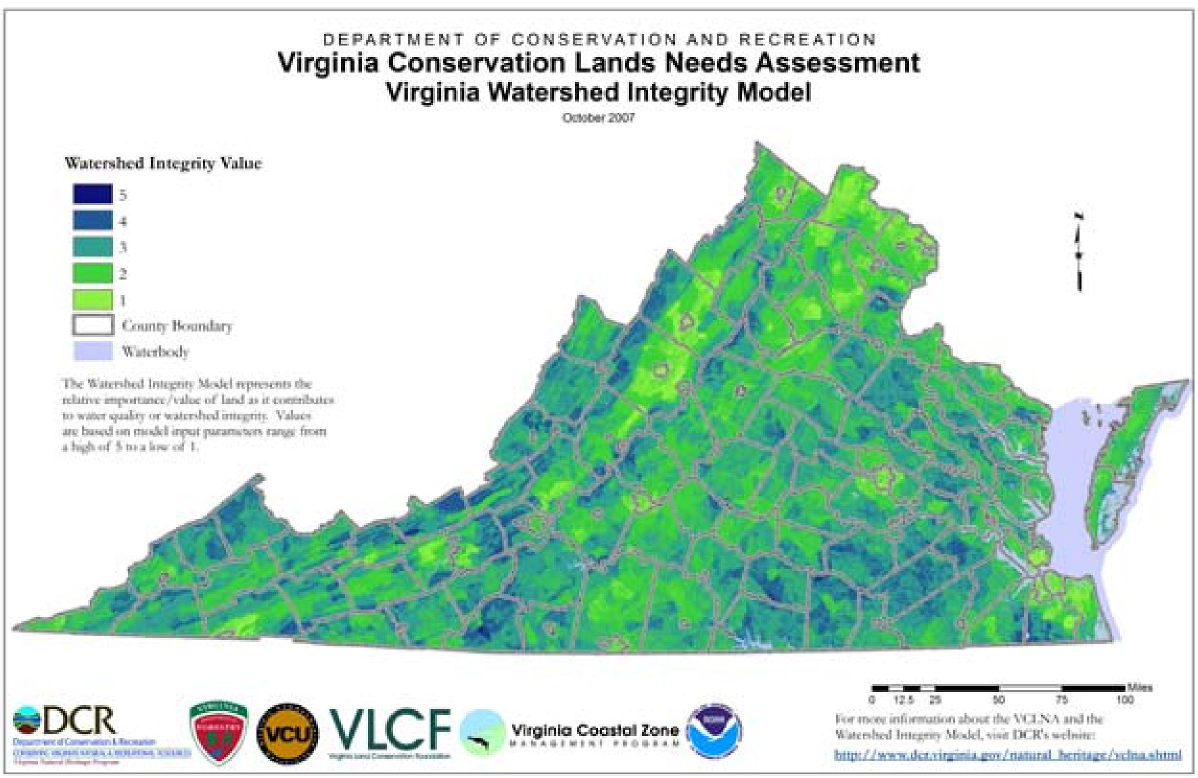


Figure 4-15 Virginia Conservation Lands Needs Assessment Watershed Integrity Model final output (Virginia Department of Conservation and Recreation, 2008).

Minnesota Watershed Assessment Tool

Author(s) 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 4-11 lists the data layers available for viewing with this tool.

Table 4-11 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 1990's
% Change in Population	Karst Features	Roads	2001 National Land Cover
Depth to Bedrock		2003 Air photos	USGS Topo Map 250K
		Shaded Relief	

Although the online WAT is simply a viewer for these various data layers, providing this information in such a user-friendly way allows for a much more holistic understanding of watershed ecosystems in the State of Minnesota (Figure 4-16). Patterns among watershed components and different data layers that may have not been apparent before using the tool become obvious when viewed as overlays in the WAT. Additionally, each layer is also available for download and can be used in a user's GIS to perform original analyses at a variety of scales and for a variety of purposes.

The WAT provides state agencies, counties and municipalities, and local and regional nongovernmental organizations with the capacity to perform a variety of assessments of watershed health and ecosystem integrity. From simple overlay analyses using an online viewer to complex modeling of water quality, habitat fragmentation, or hydrology, such a tool has great utility. For example, the WAT has 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 indicators used to develop the statewide index are listed in Figure 4-17. Figure 4-18 displays the draft results for each of Minnesota's major 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.

A new map interface that will display the index values and compiled scores is planned for the WAT web site. The data and calculations used for generating these values will be accessible along with a database of scientific articles and supporting information.

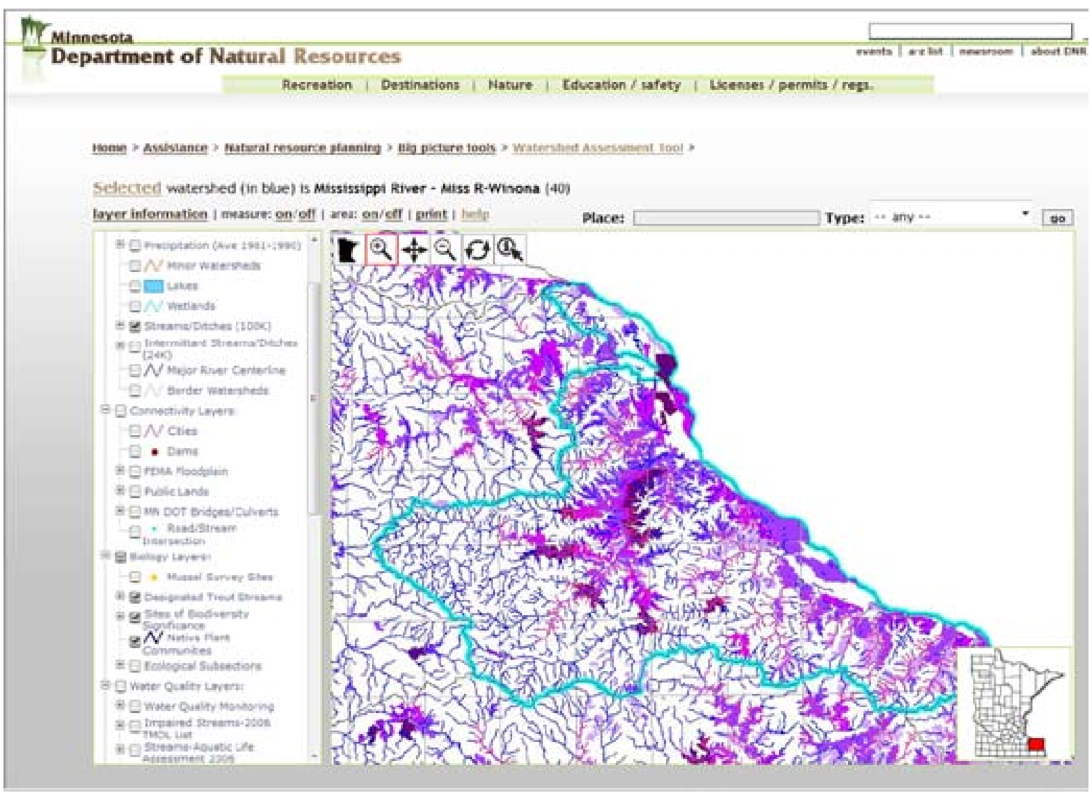


Figure 4-16 Screenshot of Watershed Assessment Tool (Minnesota Department of Natural Resources, 2009).

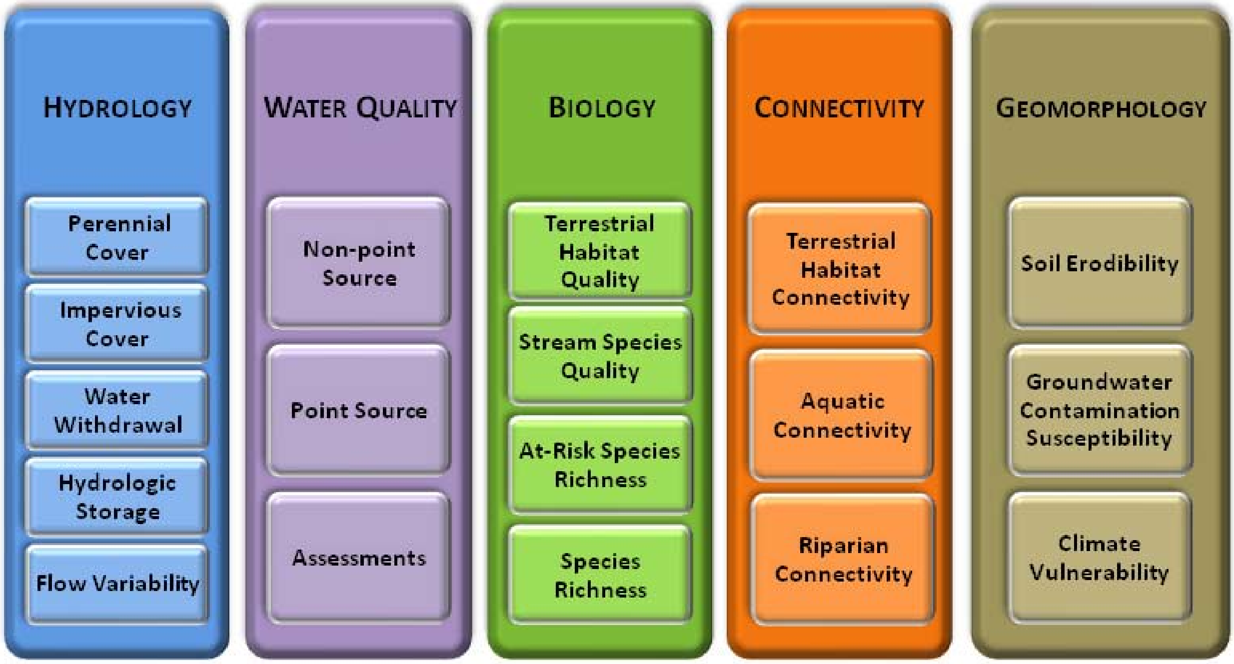


Figure 4-17 Indicators used by the Watershed Assessment Tool for calculating watershed health scores (Beth Knudsen, Personal Communication, 2011).

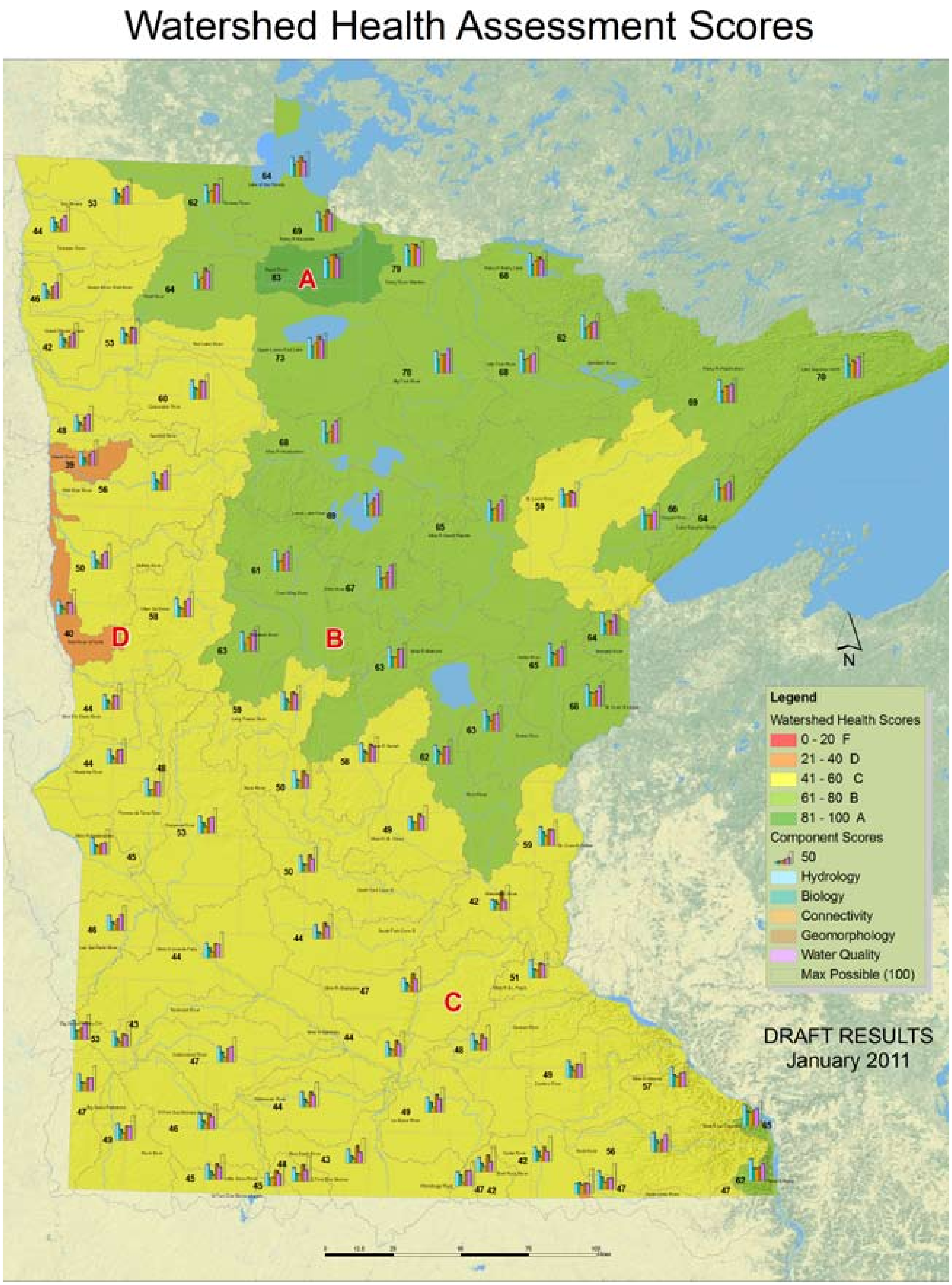


Figure 4-18 Draft results of the statewide watershed health assessment conducted with the Watershed Assessment Tool (Beth Knudsen, Personal Communication, 2011).

Oregon Watershed Assessment Manual

Author(s) 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 by different team members (Figure 4-19). 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.

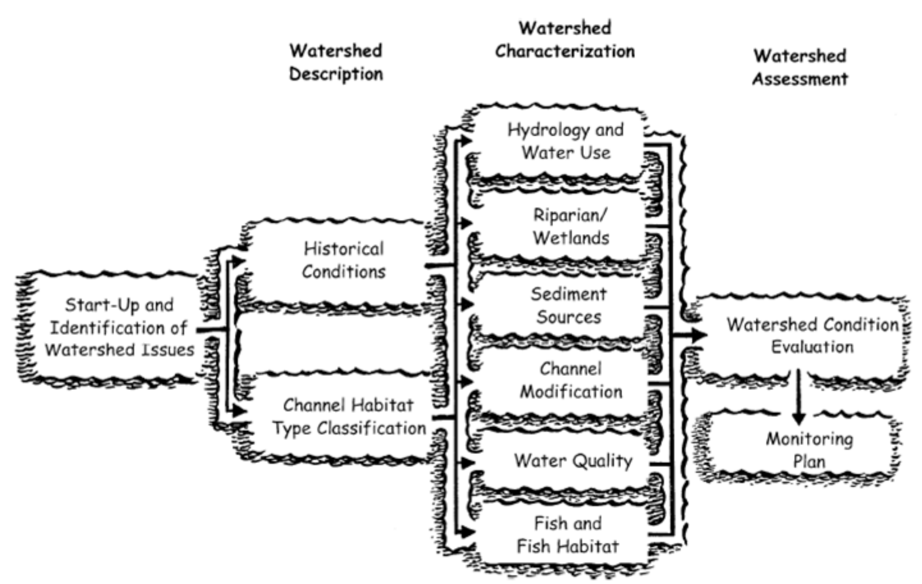


Figure 4-19 The Watershed Assessment Manual methodology is divided into components. Different people can work on different components at the same time (Watershed Professionals Network, 1999).

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 identifies areas representing 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(s) or Lead Agency: University of California, Davis
More Information: http://cwam.ucdavis.edu/

The *California Watershed Assessment Manual* (CWAM) was written primarily 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 Manual, the CWAM was designed to meet the very 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 4-20. 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 assessing all of the components of a watershed ecosystem. 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 in the near future.

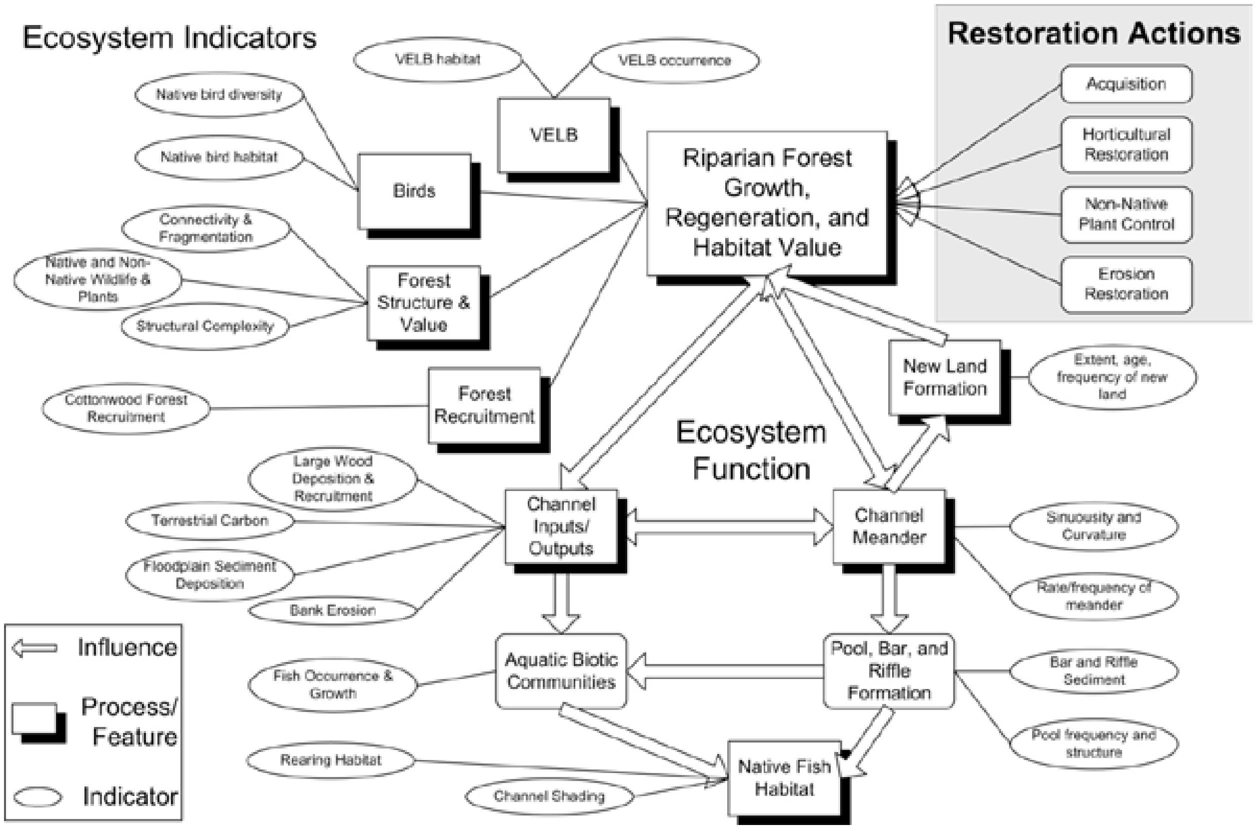


Figure 4-20 Example conceptual model for riparian forest indicator selection (Shilling, 2007).

Pennsylvania Aquatic Community Classification and Watershed Conservation Prioritization

Author(s) or Lead Agency: Pennsylvania Natural Heritage Program
More Information: http://www.naturalheritage.state.pa.us/aquaticsIntro.aspx

The Pennsylvania Aquatic Community Classification was conducted across 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 Action Plan 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 4-21), while community habitat and quality metrics were used to set restoration priorities for other watersheds. The results are being used across Pennsylvania in a variety of conservation and watershed management projects.

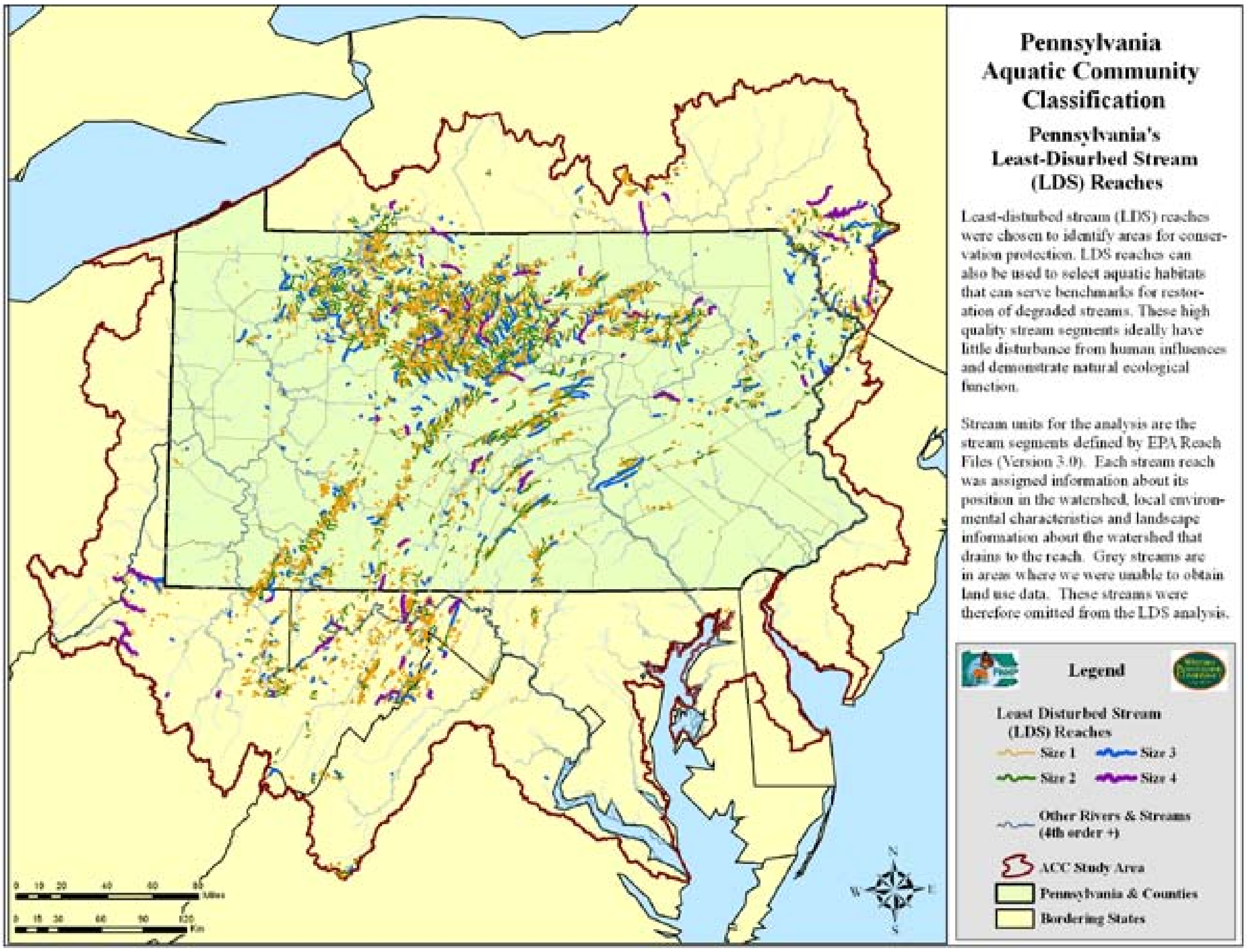


Figure 4-21 Map of Pennsylvania's Least Disturbed Streams (Walsh, Deeds, & Nightingale, 2007).

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, while 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 4-22 shows the watershed conservation priorities in Pennsylvania.

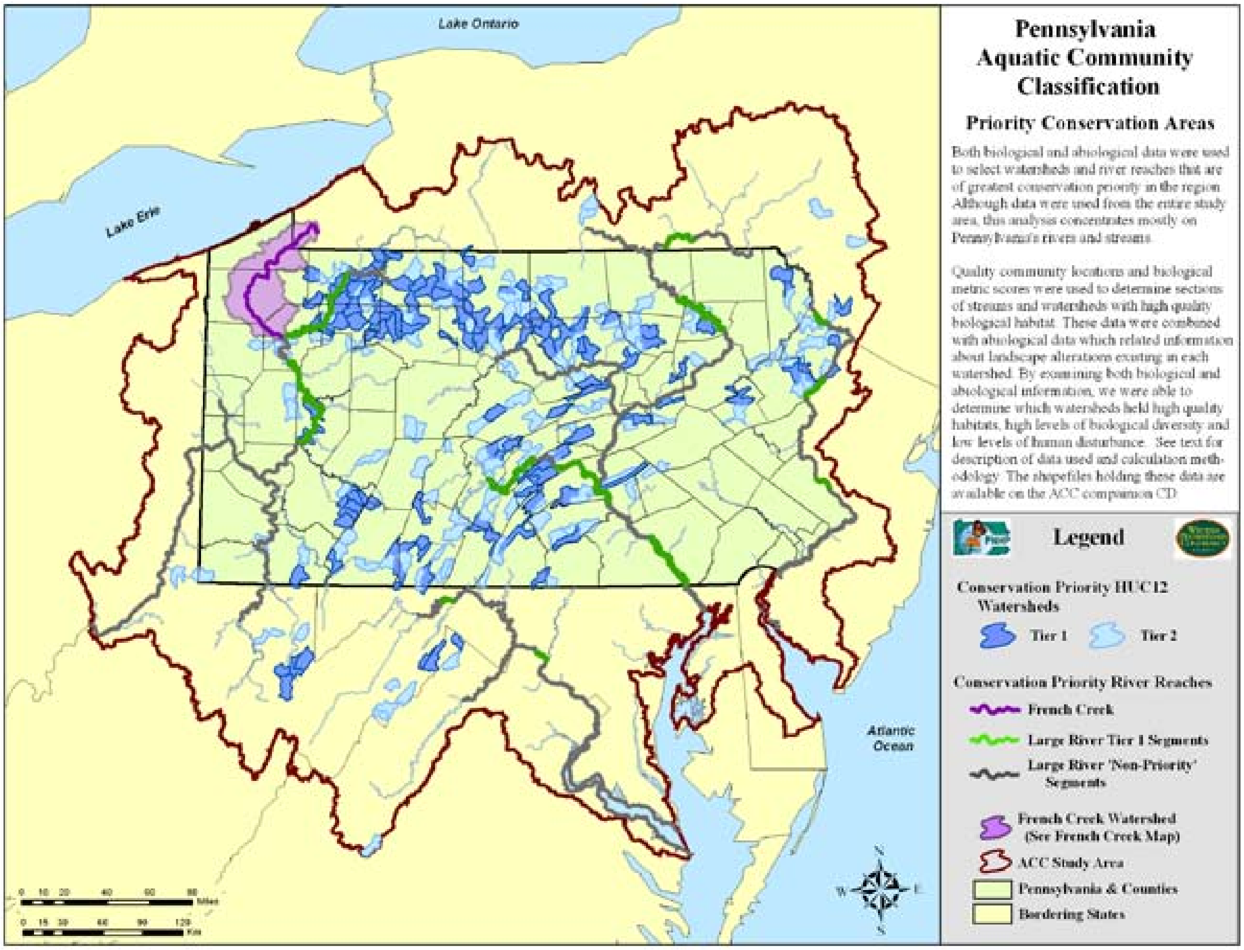


Figure 4-22 Watershed conservation priorities in Pennsylvania (Walsh, Deeds, & Nightingale, 2007).

Connecticut Least Disturbed Watersheds

Author(s) 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 across the State of Connecticut, the Department of Environmental Protection selected 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 4-23). 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 would fall in to 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 4-12 describes these parameters and the thresholds used.

Table 4-12 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.
- 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 4-24 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.

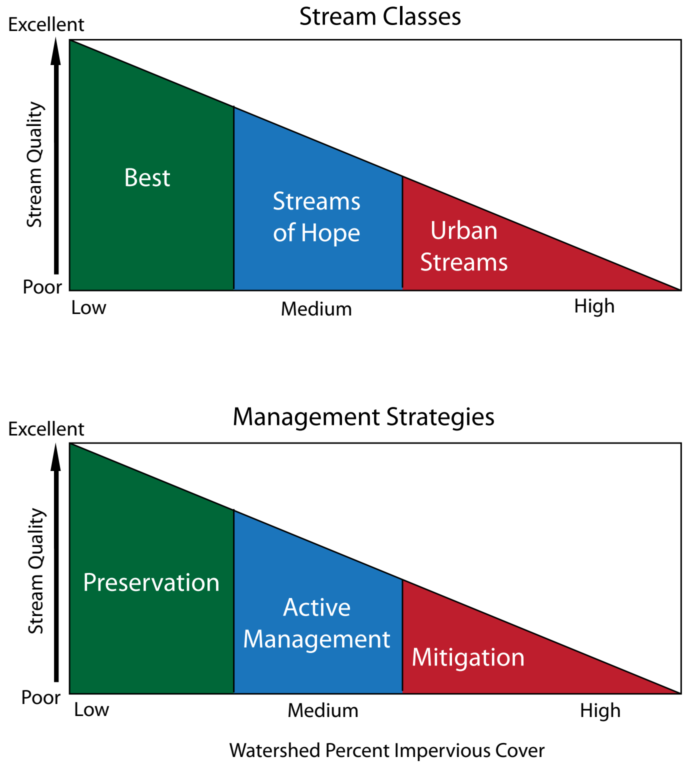


Figure 4-23 Conceptual model of the effect of impervious cover on stream quality. Watershed percent impervious cover is used to identify stream classes (top) and potential management strategies (bottom) (Bellucci, Beauchene, & Becker, 2009).

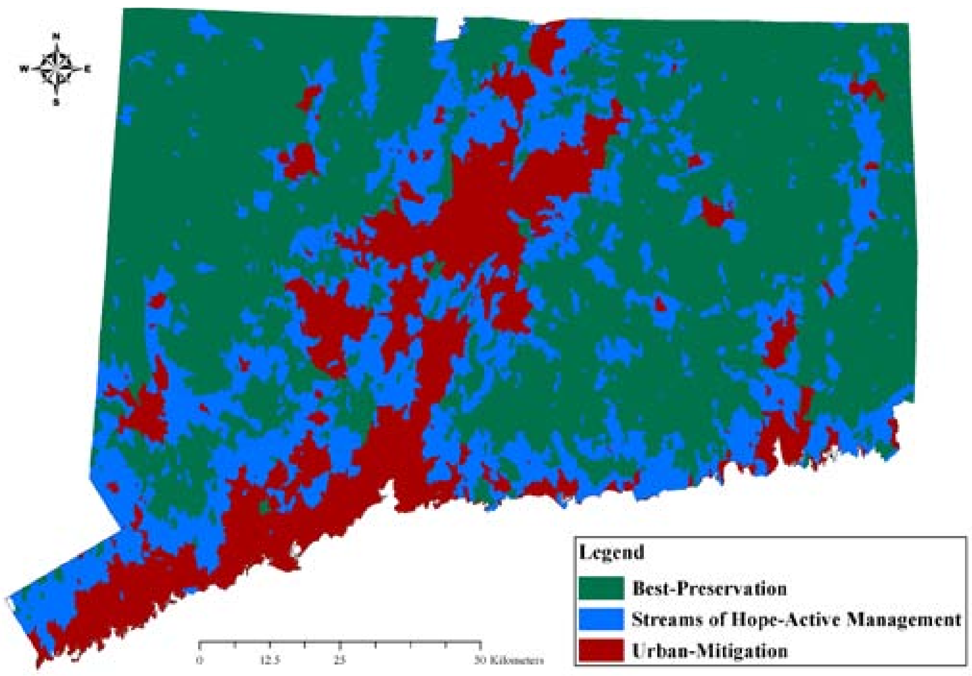


Figure 4-24 Map of Connecticut showing stream classes and management classes based on the conceptual model in Figure 4-23 (Bellucci, Beauchene, & Becker, 2009).

Kansas Least Disturbed Watersheds Approach

Author(s) 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 critically needed context 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 could 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 4-25). 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 4-13). 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.

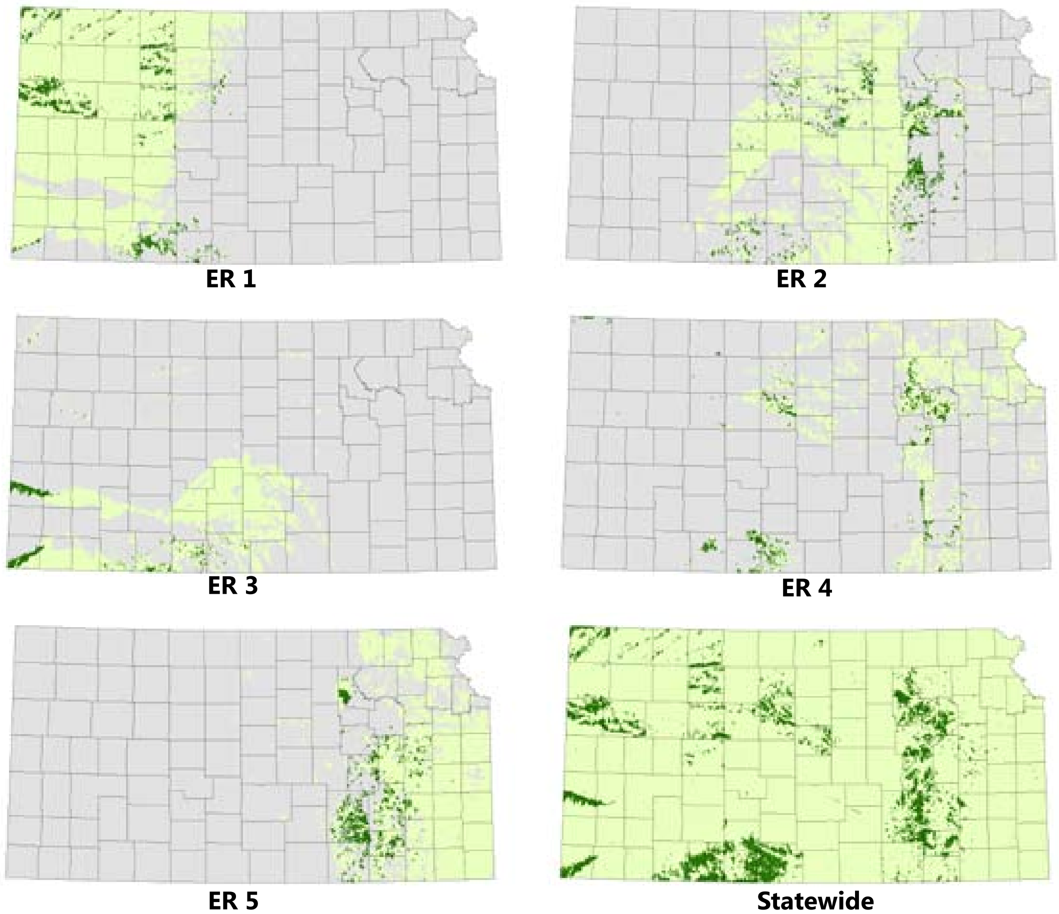


Figure 4-25 Location of least disturbed watersheds within individual quantitative ecoregions (ER) (k = 5) (Angelo, Knight, Olson, & Stiles, 2010). Rankings are based on the disturbance index derived via principal components analysis. Highlighted watersheds rank in the lowest (best) 10th percentile within their respective ecoregions. The statewide (10th percentile) map is shown for comparison.

Table 4-13 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 Action Plan Landscape Disturbance Index

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 NFHAP have also assessed landscape disturbance for stream catchments using NHDPlus (Figure 4-26). The NFHAP cumulative disturbance index uses five natural environmental variables and 17 human disturbance variables quantified at local and network catchment levels to assess landscape disturbance. The NFHAP's 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.

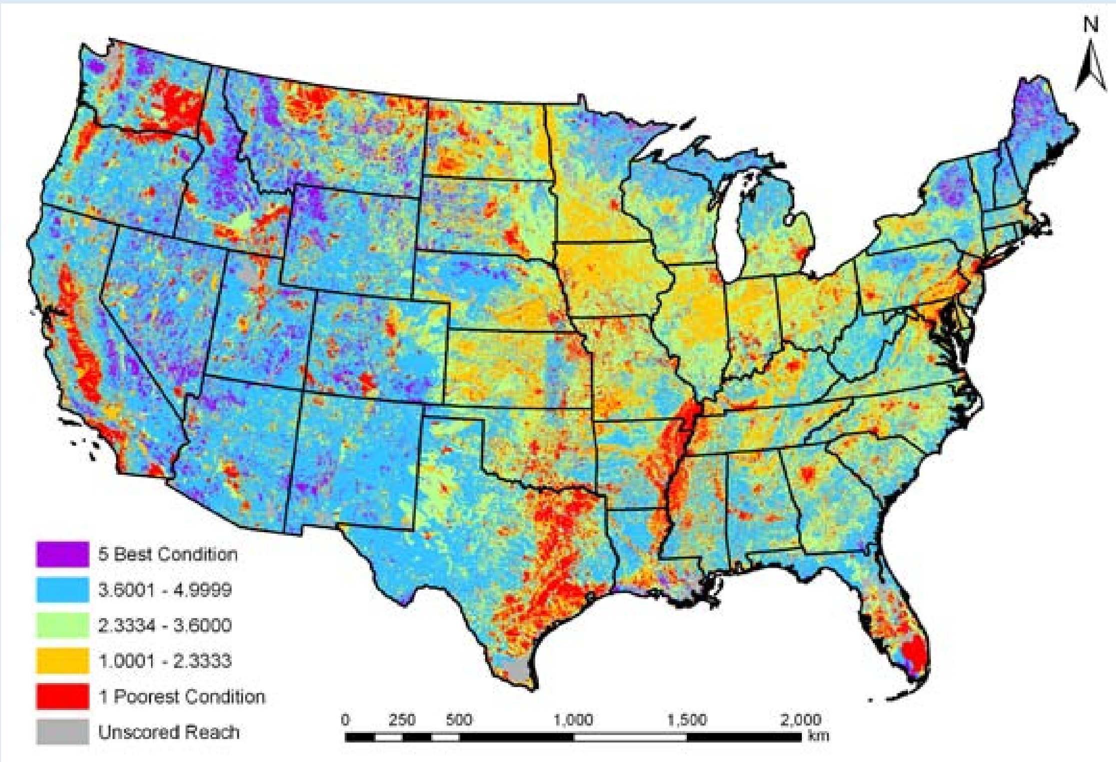


Figure 4-26 Reach cumulative landscape disturbance scores summarized by local catchments for the entire United States. Scores are presented in five percentile categories, each containing 20% of the reaches (Esselman et al., 2011).

Continued from previous page

Using PCA, 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 NFHAP's 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 NFHAP 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.

Recovery Potential Screening

Author(s) or Lead Agency: U.S. Environmental Protection Agency, Office of Water
More Information: Doug Norton or James Wickham, EPA

This screening and priority-setting method is based on recovery potential, defined as the likelihood of an impaired water to re-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 4-14. Five to eight metrics in each of three different classes are chosen for an individual assessment. Metric selection is specific to each assessment's location and purpose. 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:

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

A second method for integrating the three summary scores uses three-dimensional "bubble-plotting" (Figure 4-27). 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 4-14 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

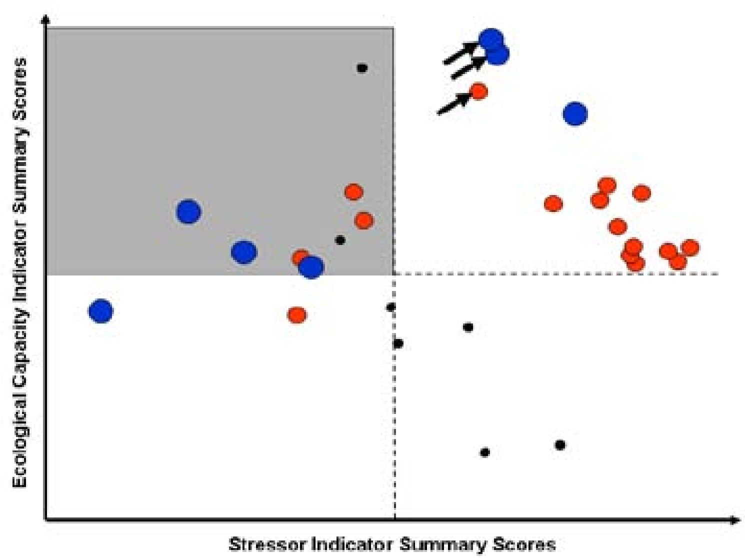


Figure 4-27 Three-dimensional bubble plot comparing recovery potential among subwatersheds. Dots represent subwatersheds plotted by summary score relative to the ecological and stressor axes. Social context scores (higher = better) are incorporated as dot size and color. Median values for ecological 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. Often large (e.g., statewide) datasets can be re-assessed in a matter of hours. The "R" script used for bubble plotting (Figure 4-28) also allows for varying color assignment based on any attribute in the spreadsheet.

Recovery potential screening in Maryland demonstrates how a restoration-oriented screening could easily be adapted for protection screening purposes. The goal was to identify which impaired watersheds were the strongest prospects for successful restoration, but all of the state's healthy watersheds were also screened with the same indicators (Table 4-15). 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 bio-assessment 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 4-28) may be strong prospects for protection in time. Assessing watersheds specifically for protection purposes is feasible given the many protection-relevant metrics that could be considered (Table 4-14) or developed.

Table 4-15 Recovery potential indicators used to screen Maryland watersheds statewide.

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

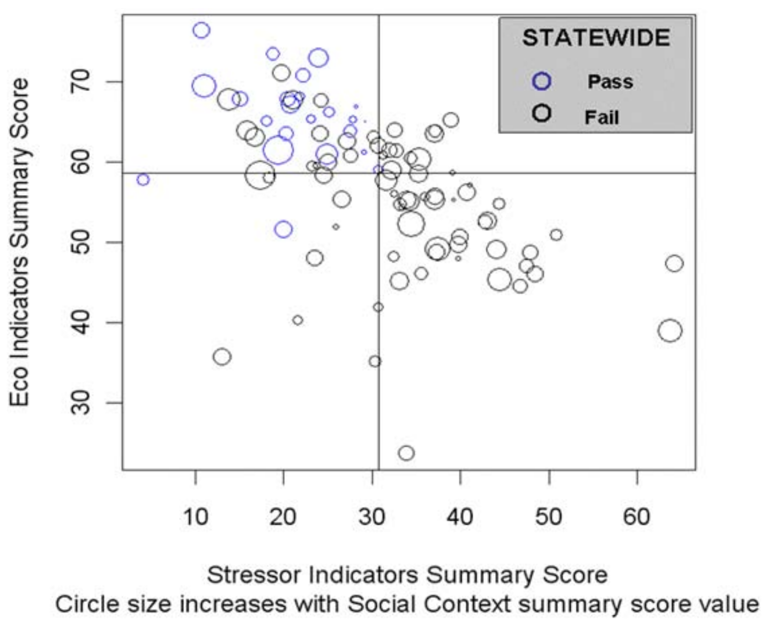


Figure 4-28 Bubble plot of recovery potential screening of 94 Maryland non-tidal watersheds. Colors signify whether watersheds passed the state's watershed bio-assessment. Although indicators were selected to compare recovery potential of impaired waters, the output also contrasts healthy watershed differences (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
HUC-12	✓	✓			✓			✓
Ecoregions							✓	
Channel Habitat Types			✓					
Landscape Position			✓					
Channel Slope			✓					
Confinement			✓					
Size			✓					
Physical Habitat Types					✓		✓	
Geology					✓			
Stream Gradient					✓			
Mean Stream Flow							✓	
Watershed Size					✓			
>1 mi^2					✓	✓		
>2,000 mi^2					✓			
Biological Communities					✓	✓	✓	
Mussels					✓		✓	
Fish					✓	✓	✓	
Macroinvertebrates					✓	✓	✓	
Ecological Classification System Subsections		✓						
Climate		✓					✓	
Geology		✓						
Topography		✓					✓	
Soils		✓					✓	
Hydrology		✓					✓	
Vegetation		✓						

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

Landscape Indicators Used in Integrated Assessments

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

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

Landscape Indicators Used in Integrated Assessments (Cont.)

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

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

Habitat Indicators Used in Integrated Assessments

Indicator	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Designated Trout Streams		✓						
Karst Features		✓						
Springs		✓						
Stream Sink		✓						
Sinkhole		✓						
Species Range Factor				✓				
Domestic Predators				✓				
Habitat Diversity				✓				
RTE Species Habitat				✓				
Stream Crossing Density		✓					✓	
Recolonization Access				✓				✓
Migration Barriers			✓		✓			
Culverts Passable			✓					
Water Velocity ≤2 fps			✓					
Outlet perching ≤6 in.			✓					
Flow Depth ≥12 in.			✓					
Outlet Drop less than 6 in.			✓					
Slope <0.5%			✓					
Diameter >0.5 X bankful channel width			✓					
Length <100 feet			✓					
Substrate Complexity and Embeddedness			✓					

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 Approach
EPA RPST: EPA Recovery Potential Screening Tool

Habitat Indicators Used in Integrated Assessments (Cont.)

Indicator	VA WIM	MN WAT	OR WAM	CA WAM	PA ACC	CT LDW	KS LDW	EPA RPST
Riffles with ≥35% Gravel			✔					
Riffles with <8% Silt, Sand, Organics			✔					
Ratio of Fine Sediment Volume In Pools To Total Pool Volume				✔				
Large Woody Debris Recruitment Potential			✔					
>20 Pieces of Large Woody Debris per 100 Meters			✔					
Expected Riparian Vegetation by Ecoregion			✔					
Stream Shading by Riparian Vegetation			✔					
Shade >70% of reach			✔					
Pool Area > 35% of stream area			✔					
Pool Frequency (every 5-8 channel widths)			✔					
>300 Conifers within 30 M of Stream per 1,000 ft			✔					
Corridor % Woody Vegetation				✔				✔

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

Hydrologic Indicators Used in Integrated Assessments

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

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

Geomorphology Indicators Used in Integrated Assessments

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

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

Water Quality Indicators Used in Integrated Assessments

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

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

Biological Indicators Used in Integrated Assessments

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

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

Biological Indicators Used in Integrated Assessments (Cont.)

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

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

Vulnerability Indicators Used in Integrated Assessments

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

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

5. Management Approaches

6. Management Actions

Chapter 5

Protection Priorities | Restoration Priority | Low Priority

A watershed-based assessment approach examines all of the processes occurring on the landscape to evaluate their cumulative effect on aquatic ecosystem health. With effective implementation, this approach can aid in the holistic management of ecological integrity. The restoration of impaired water bodies has been the primary focus of most watershed management 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). As important as restoration of these water bodies is, success in restoring ecological integrity will largely depend on protection of the remaining healthy aquatic ecosystems, which provide the ecological infrastructure that supports restoration.

EPA's Healthy Watersheds Web Page

http://www.epa.gov/healthywatersheds

Visit EPA's Healthy Watersheds web page to read about examples of innovative management approaches being used to protect healthy watersheds across the nation. The web page is periodically updated to provide the latest information on the Healthy Watersheds Initiative, assessment approaches, outreach tools, management approaches, sources of data, etc.

This document places heavy emphasis on assessments of the ecological condition of watersheds. Assessment results should guide decisions on protection strategies and inform priorities for restoration. Also, assessments, identification of healthy watersheds, and management actions are not usually implemented in a stepwise, linear fashion. This chapter focuses on specific management strategies to protect and restore priority watersheds identified through the integrated assessment.

Most every protection or restoration project is guided by goals and objectives, and implemented using strategies for reaching those objectives. In the context of Healthy Watersheds, the goal can be thought of as maintaining the health of the watershed ecosystem; the specific objectives may be to maintain each ecological attribute in good condition; and the strategic management approaches are the actions taken to reach the objectives. Each strategic management approach should be (The Nature Conservancy, 2003):

- Linked – directly related to a specific objective(s).
- Strategic – maximizes leverage and efficiency.
- Focused – outlines specific steps for implementing the action.
- Feasible – accomplishable in light of the project's resources and constraints.
- Appropriate – acceptable to and fitting within project-specific cultural, social, and ecological norms.

Implementation is often more difficult than the assessment and design phase of conservation planning. In order to ensure effectiveness, a monitoring and evaluation plan should be developed and implemented alongside the conservation action(s). Without monitoring and evaluation, it is difficult to determine the effectiveness

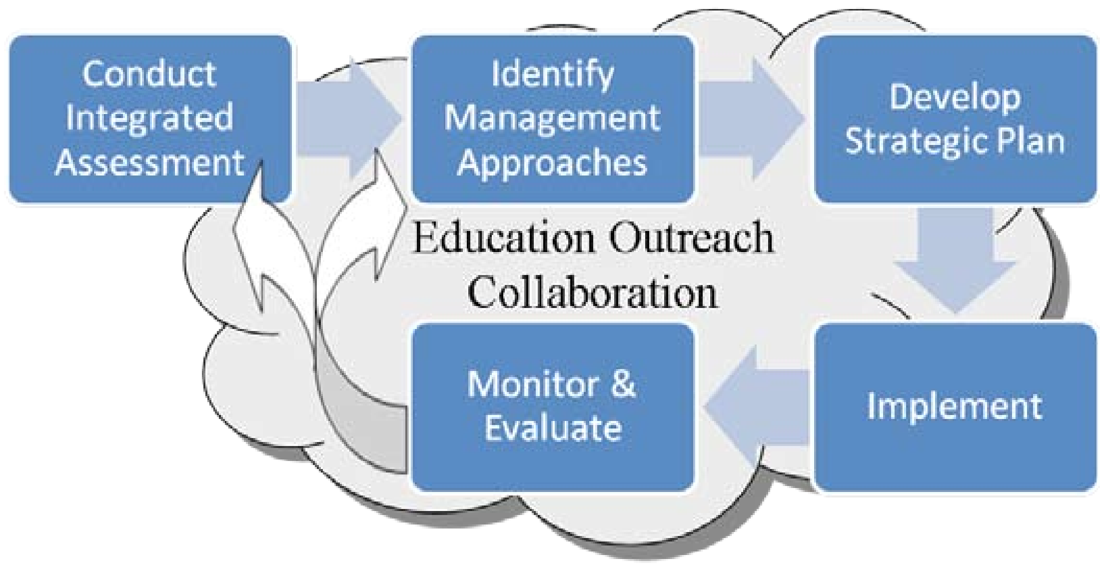


Figure 5-1 Healthy Watersheds Management Framework. Education, outreach, and collaboration are essential components at all stages of the Healthy Watersheds Management Framework. This Framework is meant to be iterative in nature. New data may warrant revisiting the integrated assessment or effectiveness monitoring results may indicate that additional management measures need to be implemented.

of the approach. Using an adaptive management approach, the chosen management strategies can be altered or even replaced if they are not resulting in the desired effect (ecosystem protection). Fortunately, data and information from many existing monitoring programs can be used to assess the effectiveness of Healthy Watersheds protection actions. Ambient water quality monitoring, biomonitoring, remote sensing of landcover, wildlife habitat assessments, and other data can be used in the evaluation of program effectiveness. If, through monitoring and evaluation, it is discovered that watershed condition is declining, other approaches should be chosen for implementation. However, alternatives should be chosen strategically, relying on assessments of watershed health and vulnerability, as well as lessons learned from implementation of previous management approaches.

A variety of management approaches are presented in this chapter. Protection strategies are appropriate for healthy areas and should consider the degree of watershed health, opportunities for protection, and vulnerability. Restoration strategies are only briefly covered here, but should be targeted towards degraded systems that have high ecological capacity for recovery, are important for providing ecological services, or are important for biodiversity. The strategies presented in this section are identified as national, state, or local scale approaches. These categories should not be considered rigid or constraining. They merely serve to organize the diversity of innovative techniques that can be used to maintain and improve watershed health at different geographic scales.

5.1 Education, Outreach, and Collaboration

Outreach and education are two conservation strategies whose importance cannot be overstated. Efforts to conserve and protect are more likely to succeed if understood and supported by the local community. Communicating the results of the integrated assessment using plain language and graphical elements, such as a watershed report card 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. 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.

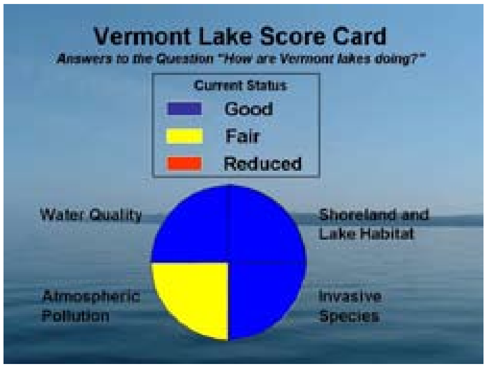
Examples of actions that communities can take to protect healthy watersheds include integrating green infrastructure and habitat protection into comprehensive plans, protecting the Active River Area from future development through rezoning, preventing landscape fragmentation through the use of conservation 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. Examples of outreach and education activities include:

- Presentations to local governments and the public in general.
- 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 with a script that stakeholders can use to present to others.
- Field trips (e.g., fishing, hiking, canoeing) that enable the public to see and appreciate examples of healthy watersheds firsthand.

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 5-2). 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 could be used to rate watersheds across a state, county, or region. This type of approach encourages a competitive spirit that can result in improvement of watershed health.

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.

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 (The Conservation Campaign, 2009) provides a free online space for communities and citizen groups to organize their campaign to protect land and water resources.



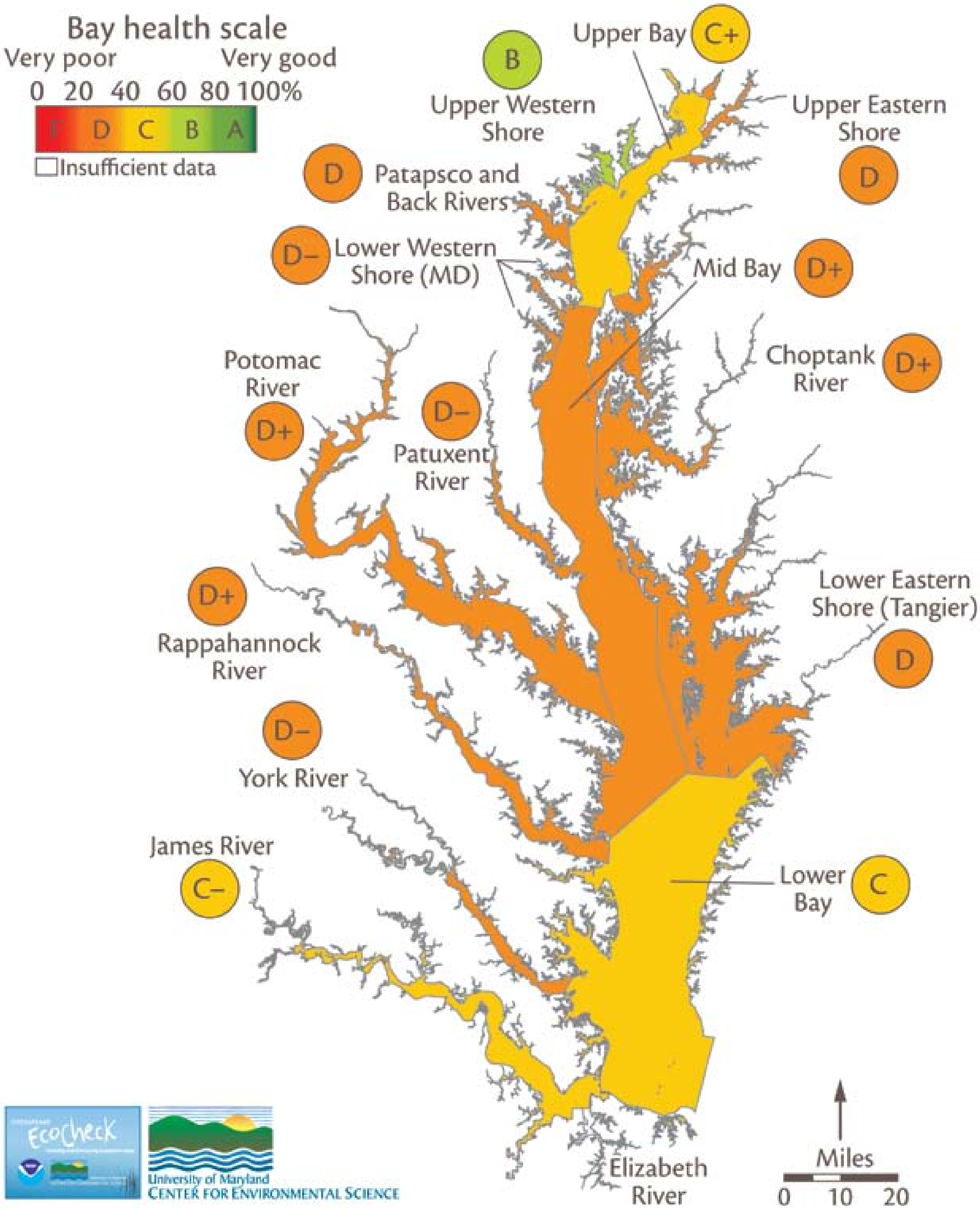


Figure 5-2 Chesapeake Bay Report Card results for 2007 (University of Maryland Center for Environmental Science; National Oceanic and Atmospheric Administration, 2009).

Millions of Americans are outdoor enthusiasts, and many belong to organizations that provide substantial protection to natural resources. 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. Collaboration with outdoor recreation organizations has been shown to increase support for conservation time and time again.

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.

5.2 Protection Strategies

5.2.1 National

Freshwater Conservation Priorities

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). All freshwater assessments for the United States are being organized and will be made available soon on the web link above.

The purpose of creating a set of freshwater conservation priorities is 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.

TNC 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 in the process 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, a suite of 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 Analie R. Barnett at The Nature Conservancy for further information and access to programs and tools). 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, TNC and its partners have developed regional freshwater conservation plans that cover the majority of the United States. There are many GIS tools 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).

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 5-3). 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.

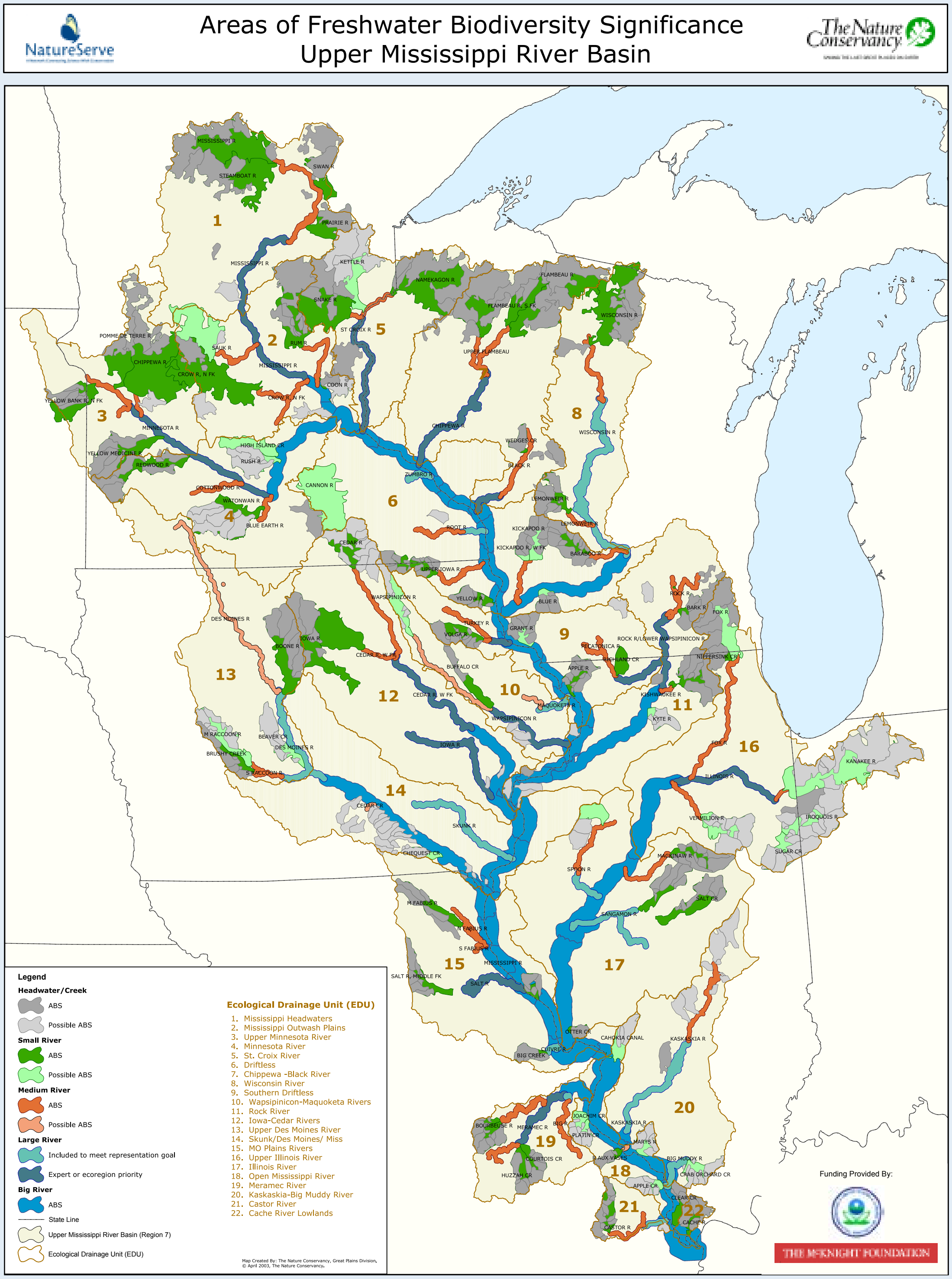


Figure 5-3 Areas of Freshwater Biodiversity Significance in the Upper Mississippi River Basin (Weitzell et al., 2003).

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" (ORV). ORVs 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.

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. 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 (CRS), 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 (NAI) approach promoted by the Association of State Floodplain Mangers qualify for credit under the CRS. 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 NAI 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, the NAI approach 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 CRS 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. The program is administered in cooperation with state partners. 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.

The Nature Conservancy's Freshwater Initiative

The Nature Conservancy's Freshwater Initiative works to protect aquatic ecosystems across the nation and the world through protection of watershed lands and floodplains, instream flow protection using an ELOHA approach, and ecologically sustainable water management policies (Richter, Mathews, Harrison, & Wigington, 2003). TNC has conducted more than 28,000 conservation transactions and protected over 119 million acres around the world.

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

Antidegradation

In addition to defining designated uses and identifying water quality criteria, the states and tribes are required to develop and adopt statewide antidegradation policies to protect existing instream uses, high quality waters, and outstanding national resource waters (ONRW), as designated by the state or tribe. States are also required to develop implementation methods as part of the antidegradation policy. These implementation methods define how the high quality waters will be identified, what activities will trigger the antidegradation review process, and the components of a review process. All waters of a state must be placed into one of the three Tiers: 1) existing uses, 2) high quality waters, or 3) ONRWs. Tier 1 is the minimum baseline of protection afforded to all waters. Tier 2, high quality waters, 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 to any activity that 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. Although it applies to any activity that has the potential to lower water quality, regulatory authority is lacking to fully implement antidegradation in most states. This is yet another reason why stakeholder involvement and outreach is an important component of the Healthy Watersheds Initiative. When community members understand the value of healthy aquatic systems and the activities that affect them, they will be more likely to implement voluntary measures to reduce their impact on the system.

Instream Flow Protection

With the ever increasing demands that humans place on freshwater resources for drinking water, electric 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, 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 (gpd) 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.

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.

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 more 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.

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 (RMPP) is administered by the New Hampshire Department of Environmental Services (NH DES) and a statewide River Management Advisory Committee (RMAC). 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 NH DES, 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 (LAC) consisting of representatives from all riverfront municipalities develops and implements a management plan for the designated river with assistance from NH DES. LACs also comment on activities requiring state or federal permits that may impact the river. The intent of the RMPP is to balance competing demands for river resources for the benefit of present and future generations.

The Massachusetts Rivers Protection Act (RPA) takes a somewhat different approach to river protection. The RPA 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 RPA 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 (WCA) 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, destruction of any state-threatened plants occurring on a calcareous fen is regulated under Minnesota's endangered species law.

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 State 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://www.michigan.gov/documents/deq/Ground water_report_206809_7.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 5-4). The stream types are defined based on habitat characteristics such as catchment size, baseflow 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

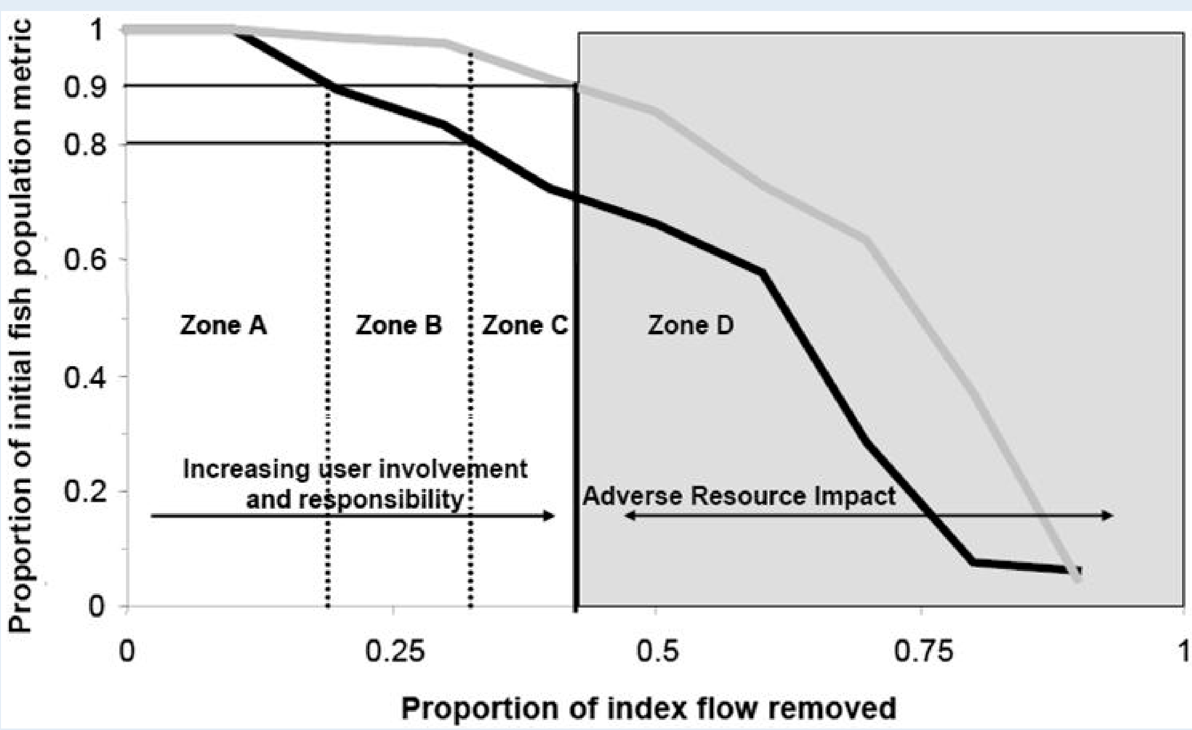


Figure 5-4 Example fish response curves. The dark curve represents "thriving species still thriving" at incremental reductions in index flow. The light curve represents "characteristic species still present and abundant." (Troy Zorn, Personal Communication).

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 5-5.

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 (WWAP). The council ensures that the process is inclusive and collaborative and that it is based on the best available science.

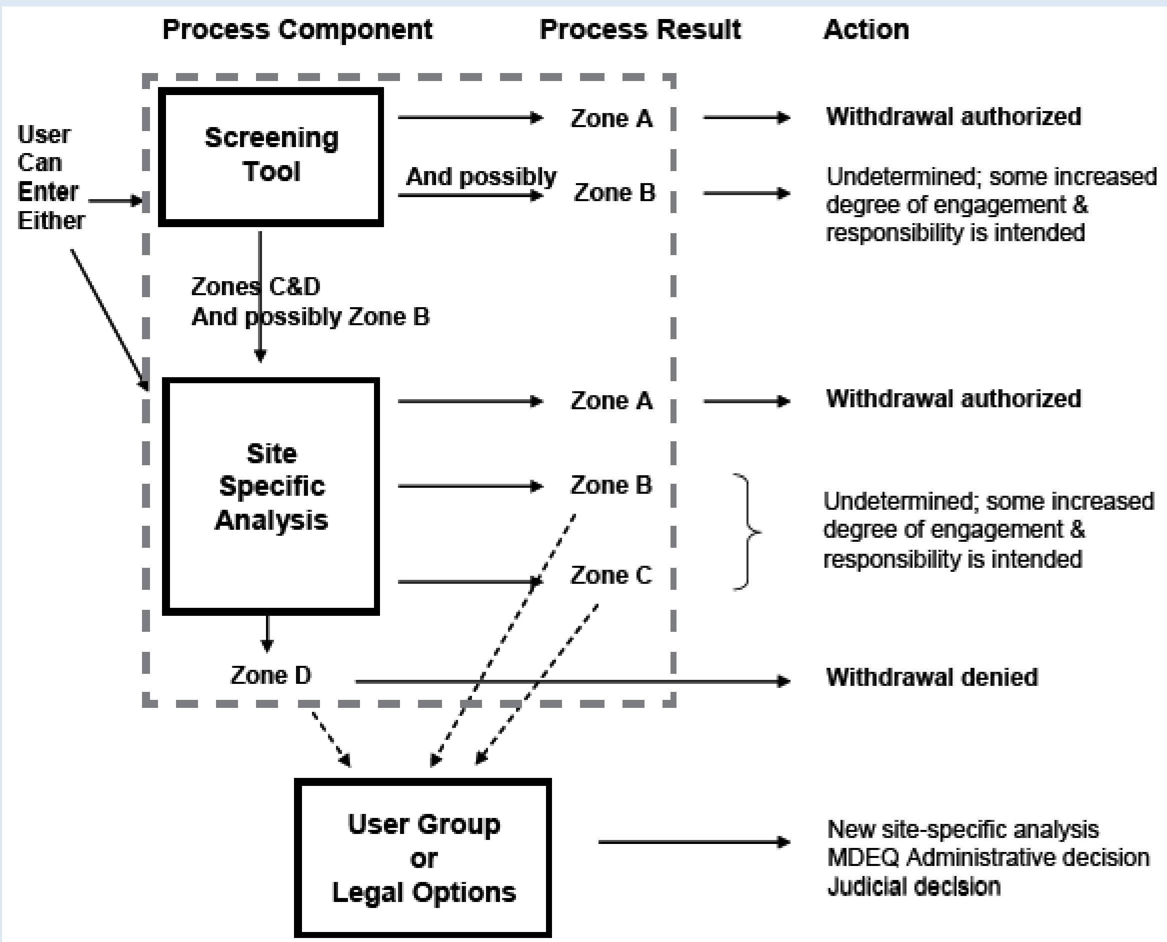
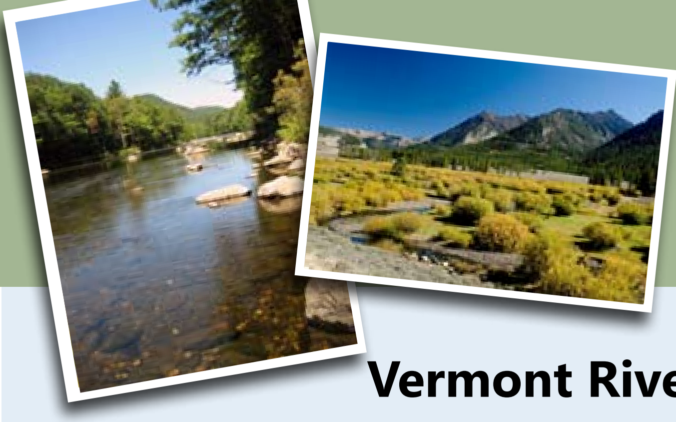


Figure 5-5 Illustration of the water withdrawal assessment process and resulting actions. (Troy Zorn, Personal communication).



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 following 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 5-6). 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.

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.

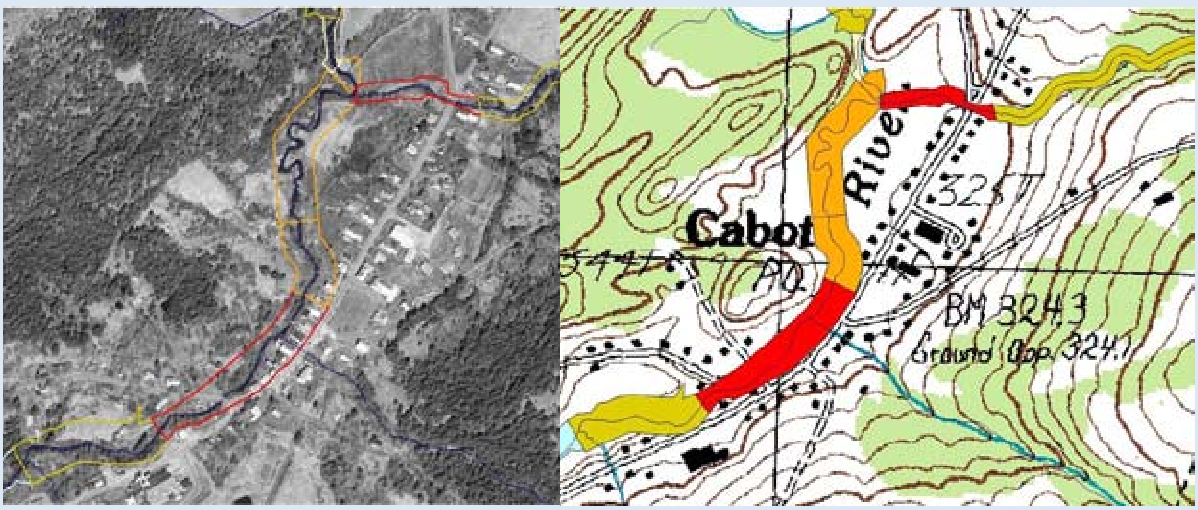


Figure 5-6 Map and orthophoto depicting the meander belt width-based river corridor being considered for protection in the town of Cabot, Vermont to help restore water quality, aquatic habitat, and natural channel stability of the Winooski River. The belt width corridor is designed to accommodate the geomorphology and fluvial processes associated with the river's dynamic equilibrium condition (Mike Kline, 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 could 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 5-7) 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 5-8). Areas that are conservation priorities for several of these purposes are then designated as targeted ecological areas (TEA). It is likely that there would 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.

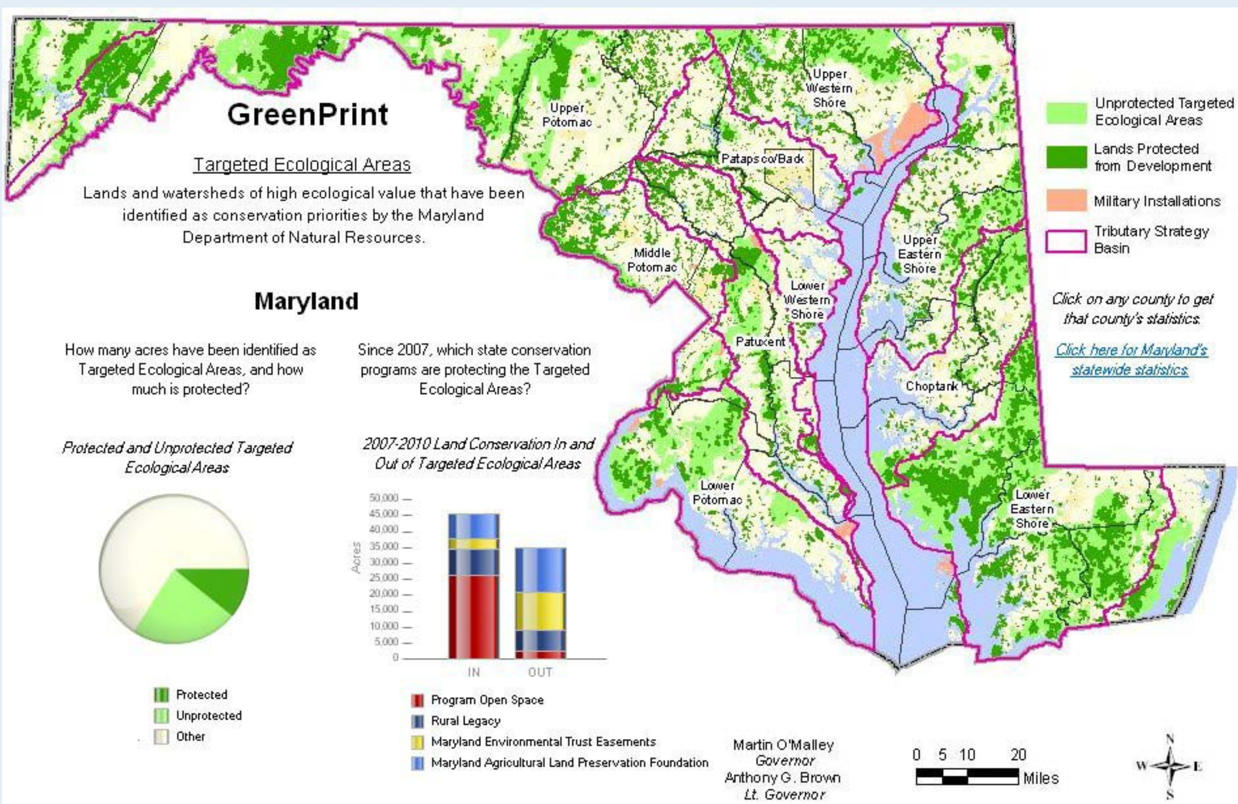


Figure 5-7 Maryland's GreenPrint map of Targeted Ecological Areas (Maryland Department of Natural Resources, 2011).

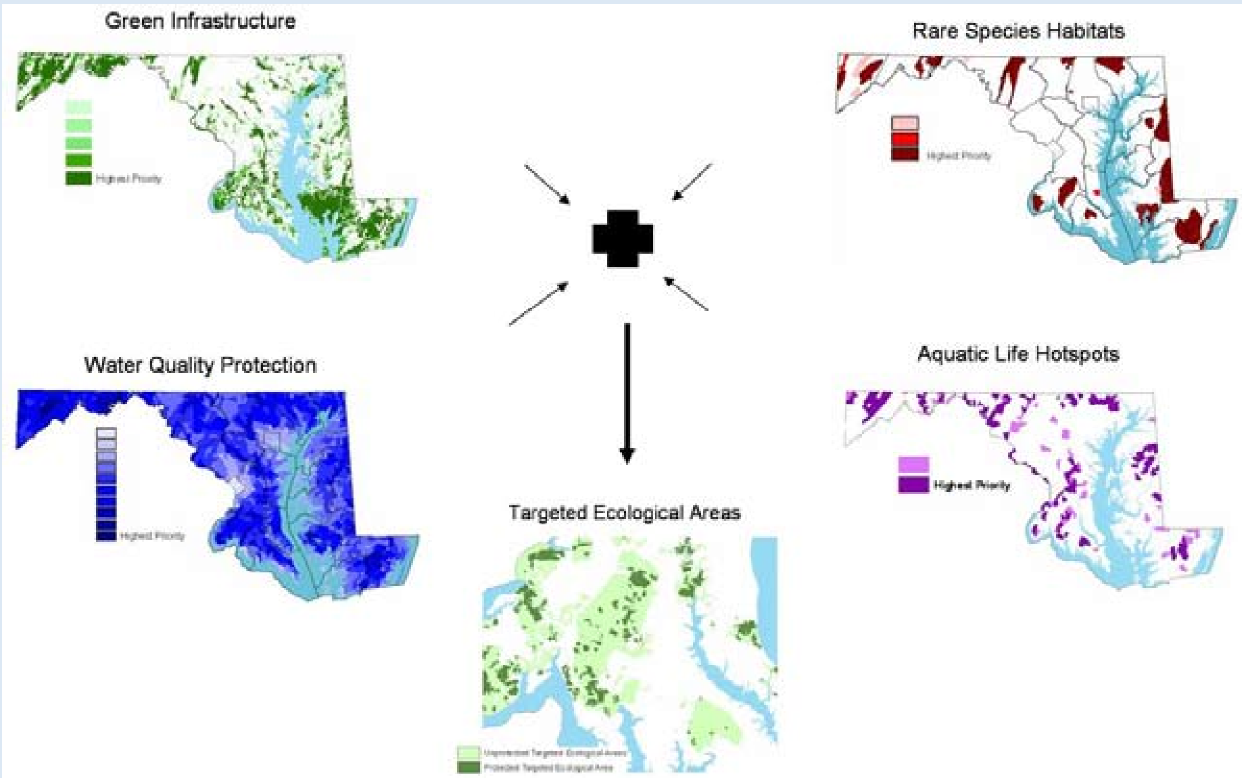


Figure 5-8 Identification of Targeted Ecological Areas (Maryland Department of Natural Resources, 2011).

Maryland's Board of Public Works now 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.

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 who will frequently 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 could be sold on the private market and be developed, or they could 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.

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

http://www.tpl.org/tier3_cd.cfm?content_item_id=23183&folder_id=264

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 most endangered 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.

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 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 trusts and local governments have also taken advantage of both the Clean Water State Revolving Fund (CWSRF) and Drinking Water State Revolving Fund (DWSRF) for land acquisition through either fee simple purchase or conservation easements. These two EPA programs are administered by each of the states and provide financing to projects that protect, enhance, or restore water quality. The interest rates on these loan programs are typically well below market rates and have flexible repayment terms that can be extended up to 20 years.

Land Protection and Climate Change

Land protection and stewardship are critical components of the Healthy Watersheds approach. 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 focused 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.

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 states' 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).

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.

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.

BLM

Smart Growth is a land use planning concept that could 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.

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 would have the least negative impact, this strategy can protect watersheds with especially 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 (TDR) are usually necessary in implementing watershed based zoning. TDR 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 conveyance systems (U.S. Environmental Protection Agency, 2007b). LID practices help to reduce stormwater runoff from urban areas, which improves water quality, ground water recharge, and the biological integrity of stream habitats.

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 TDR, 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.

River Corridor, Headwaters, and Source Water 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), they 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).

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 baseflow 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 Communtiy Viz (www.communityviz.com), the community mapped the green infrastructure that is important for protecting each of these values (Figure 5-9). 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.

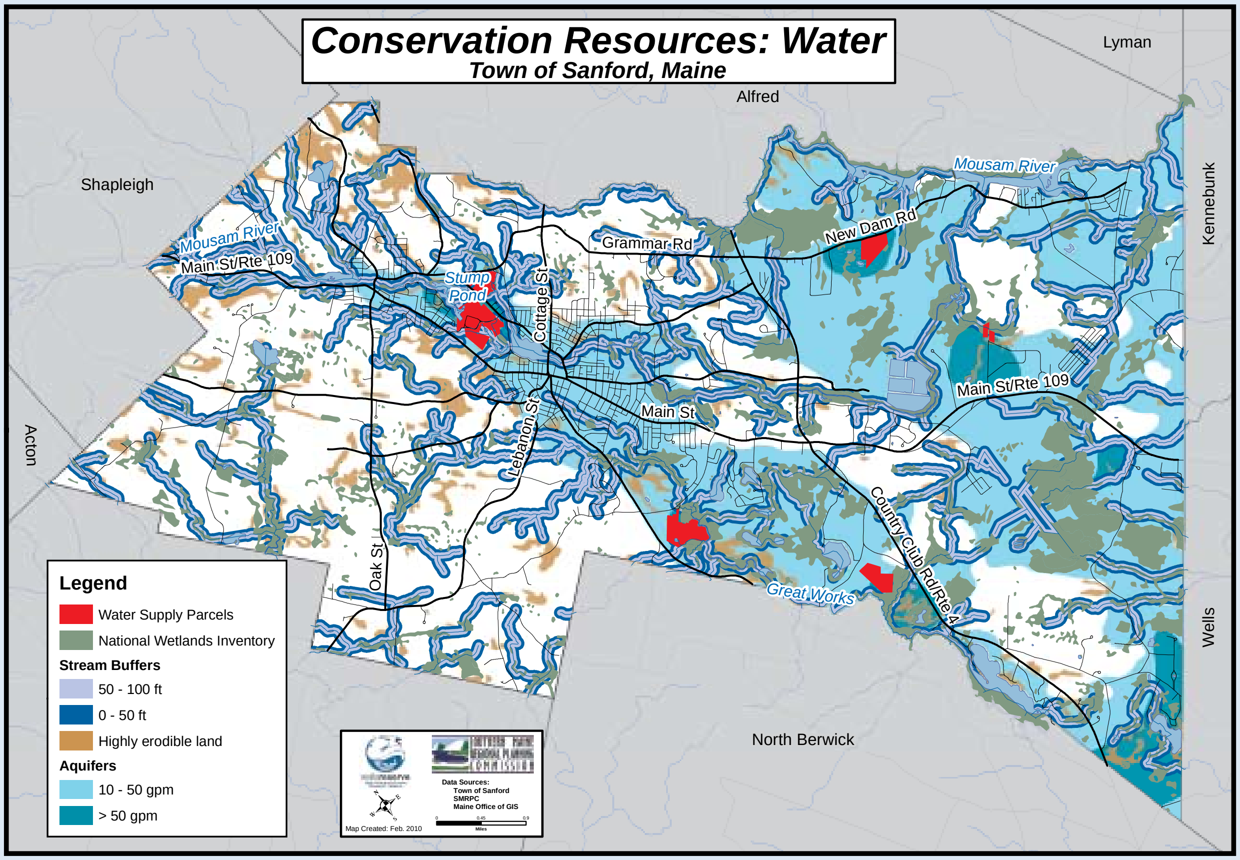
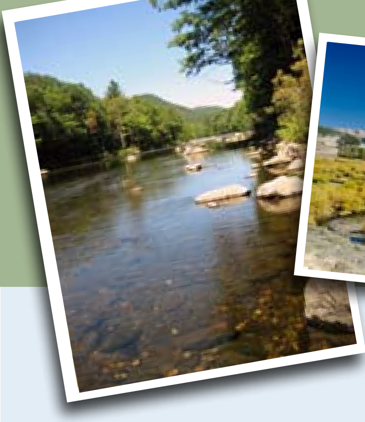


Figure 5-9 Green infrastructure identified for water quality protection (Wells National Estuarine Research Reserve; Southern Maine Regional Planning Commission, 2009)

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.



Case Study

Lower Meramec Drinking Water Source Protection Project

More Information: http://www.tpl.org/tier3_cd.cfm?content_item_id=23278&folder_id=1885

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 (MRTA), 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 MRTA 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 5-10) 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 MRTA 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 would 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 MRTA member groups have individually set out to protect.

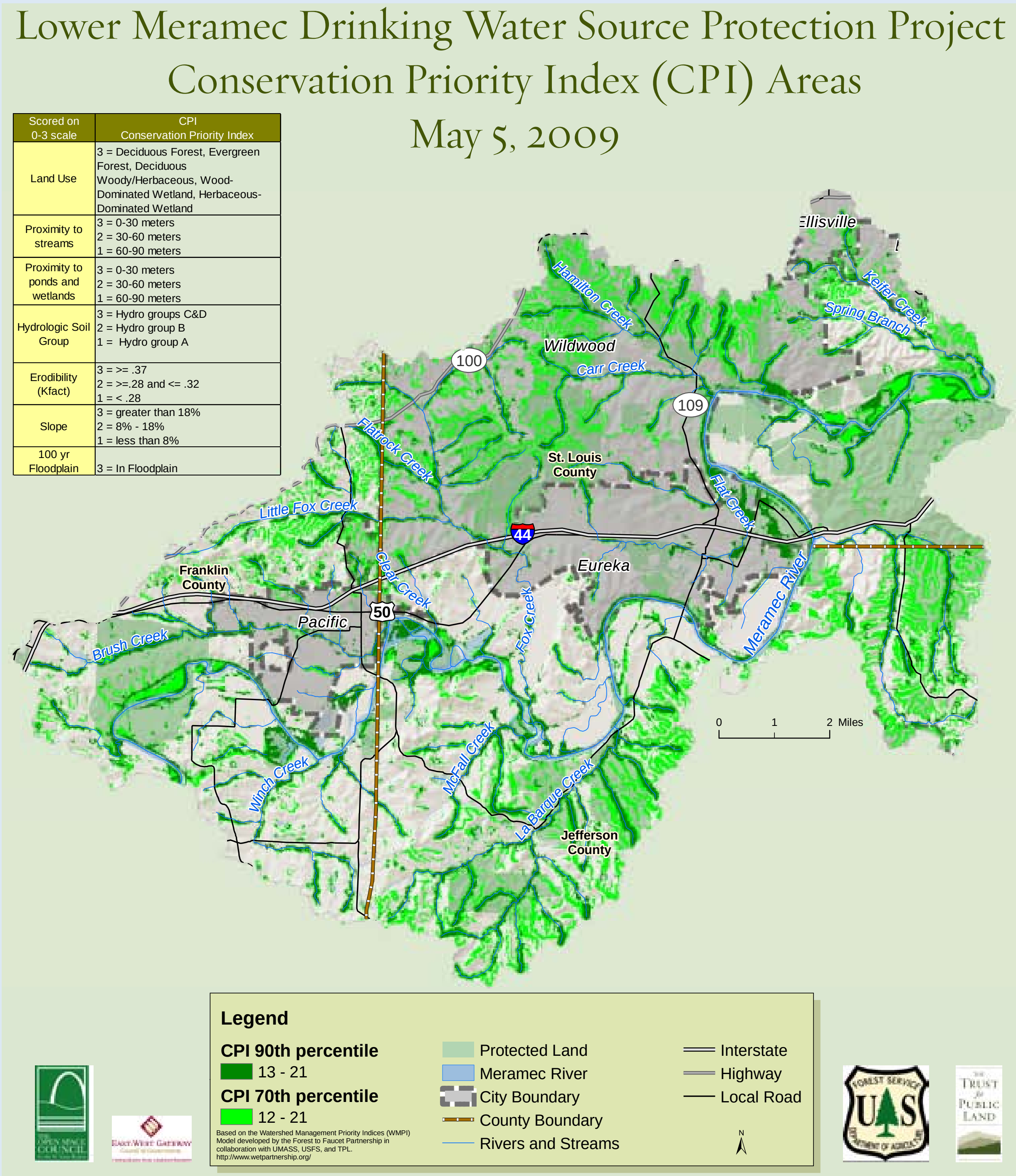


Figure 5-10 Map of Lower Meramec Drinking Water Source Protection Project Conservation Priority Index Areas (Trust for Public Land, 2010).

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 5-11). 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 (TDR) and Purchase of Development Rights (PDR) 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.

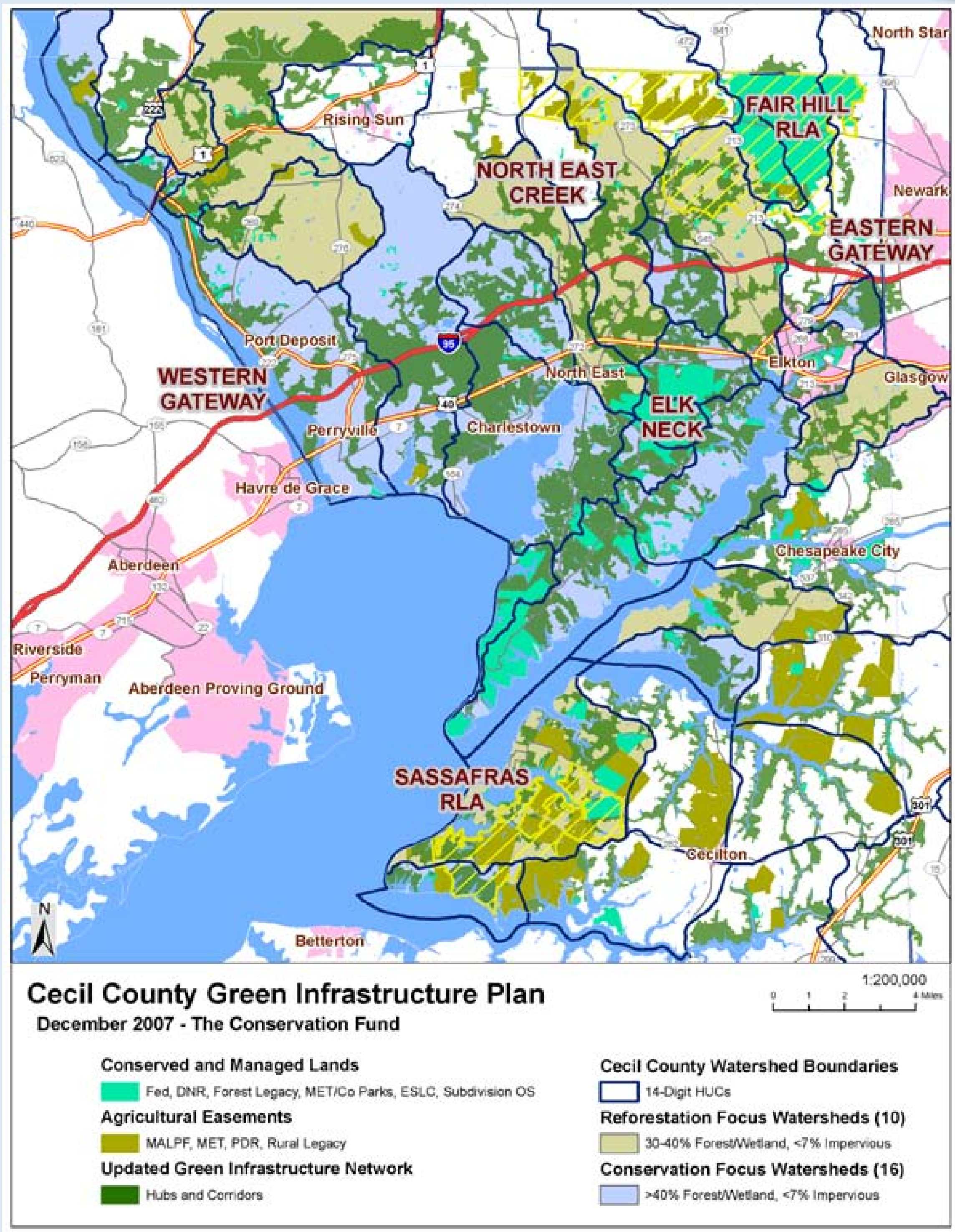


Figure 5-11 Map of Cecil County Green Infrastructure Plan (Will Allen, Personal Communication).

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 (EQIP), Conservation Reserve Program (CRP), Wetlands Reserve Program (WRP), Wildlife Habitat Incentives Program (WHIP), Conservation Security Program (CSP), and Grassland Reserve Program (GRP), all of which are described under Section 5.3.

Sustainable Forestry

Forestry is also 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 (SFI) 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 SFI 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 introduced suddenly (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 GDEs 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 Strategies

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 helpful to consider the "protect the best first" strategy. This strategy prioritizes first restoring 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, and the restoration of upstream reaches before downstream reaches. 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.

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 (NFPP) was initiated by the USFWS to reconnect aquatic species with their historic habitats. Through the NFPP, USFWS leverages federal funds to secure donations from partners and provides technical assistance to remove or bypass artificial barriers to fish movement.

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 (CREP) 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 (WRP), 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 (WHIP) assists private landowners in creating and improving wildlife habitat through cost-share assistance up to 75% of project costs.

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

The USDA Conservation Security Program (CSP) 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 (GRP) 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

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 a variety of 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.

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.

Meeting Urban Water Demands While Protecting Rivers: Rivanna River, Virginia (Richter B. , 2007)

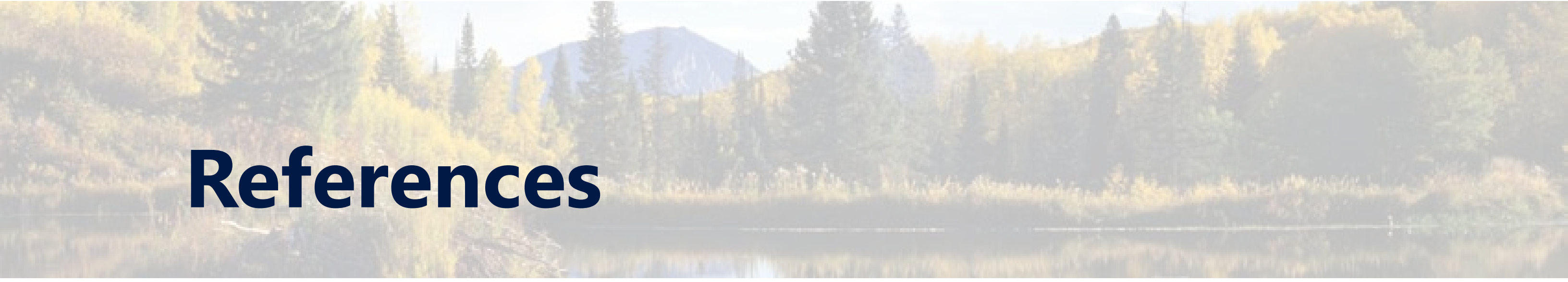
The Rivanna Water and Sewer Authority, working with The Nature Conservancy, has developed a new water supply plan that meets growing water demands and improves river ecosystem health. The new plan mimics natural flow regimes through controlled dam releases while ensuring adequate water supplies during drought. The releases are calculated as varying percentages of the inflow to the reservoir.

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).



References

Abell, R., Theime, M. L., Revenga, C., Bryer, M., Kottelat, M., Bogutskaya, N., et al. (2008). Freshwater Ecoregions of the World: A New Map of Biogeographic Units for Freshwater Biodiversity Conservation. BioScience, 403-414.

Aber, J., Christensen, N., Fernandez, I., Franklin, J., Hidinger, L., Hunter, M., et al. (2000). Applying Ecological Principles to Management of the U.S. National Forests. Issues in Ecology, Number 6.

Alachua County. (2008). Alachua County Green Infrastructure Investment Program. Retrieved October 7, 2009, from http://www.alachuacounty.us/Depts/EPD/Documents/LandConservation/Pages/LandConservation.aspx

Alley, W., Reilly, T., & Franke, O. (1999). Sustainability of Ground Water Resources, USGS Circular 1186. U.S. Government Printing Office.

Almendinger, J., & Leete, J. (1998). Regional and local hydrogeology of calcareous fens in the Minnesota River basin. Wetlands, 184-202.

American Rivers. (2009a). Dams and Dam Removal. Retrieved December 3, 2009, from Restoring Rivers: http://www.americanrivers.org/our-work/restoring-rivers/dams/

American Rivers. (2009b). What Does it Mean to be a Wild and Scenic River? Retrieved October 6, 2009, from American Rivers: http://www.americanrivers.org/our-work/protecting-rivers/wild-and-scenic/

American Trails. (2009). Greenways and Community Trails. Retrieved December 3, 2009, from Resources: http://www.americantrails.org/resources/greenways/index.html

Angelo, R., Knight, G., Olson, K., & Stiles, T. (2010). Kansas Reference Streams. Kansas Department of Health and the Environment.

Anne Arundel County. (2002). Anne Arundel County Greenways Master Plan. Anne Arundel County.

Annear, T., Chisholm, I., Beecher, H., Locke, A., Aarrestad, P., Coomer, C., et al. (2004). Instream Flows for Riverine Resource Stewardship. Instream Flow Council.

Archfield, S. (2009, January 20). ELOHA Case Studies. Retrieved June 5, 2009, from Conserve Online: http://conserveonline.org/workspaces/eloha/documents/template-kyle

Arendt, R. (1999). Growing Greener: Putting Conservation into Local Plans and Ordinances. Island Press.

Arthington, A. H., Bunn, S. E., Poff, N. L., & Naiman, R. J. (2006). The Challenge of Providing Environmental Flow Rules to Sustain River Ecosystems. Ecological Applications, 1311-1318.

Association of Fish and Wildlife Agencies. (2006). The National Fish Habitat Action Plan. Washington D.C.: Association of Fish and Wildlife Agencies.

Barneycastle, C. (2001). The Sustainable Forestry Initiative of the American Forest & Paper Association. U.S. Department of Agriculture, Forest Service.

Baron, J. S., Poff, N. L., Angermeier, P. L., Dahm, C. N., Gleick, P. H., Hairston, N. G., et al. (1997). Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems. Issues in Ecology, Number 2.

Bayley, P. B. (1995). Understanding Large River: Floodplain Ecosystems. BioScience, 153-158.

Bedford, B. (1999). Cumulative effects on wetland landscapes: links to wetland restoration in the United States and southern Canada. Wetlands, 775-788.

Bedford, B., & Godwin, K. (2003). Fens of the United States: distribution, characteristics, and scientific connection versus legal isolation. Wetlands, 608-629.

Beechie, T., Sear, D., Olden, J., Pess, G., Buffington, J., Moir, H., et al. (2010). Process-based Principles for Restoring River Ecosystems. BioScience, 209-222.

Bellucci, C., Beauchene, M., & Becker, M. (2009). Physical, Chemical, and Biological Attributes of Least Disturbed Watersheds in Connecticut. Connecticut Department of Environmental Protection.

Benedict, M. A., & McMahon, E. T. (2002). Green Infrastructure: Smart Conservation for the 21st Century. Washington, D.C.: Sprawl Watch Clearinghouse.

Benedict, M. A., & McMahon, E. T. (2006). Green Infrastructure: Linking Landscapes and Communities. Washington D.C.: Island Press.

Bierwagen, B., Theobald, D., Pyke, C., Choate, A., & Groth, P. (2010). National housing and impervious surface scenarios for integrated climate impact assessments. Proceedings of the National Academy of Sciences of the United States of America.

Brooks, J., Meinzer, F., Coulombe, R., & Gregg, J. (2002). Hydraulic redistribution of soil water during summer drought in two contrasting Pacific Northwest coniferous forests. Tree Physiology, 1107-1117.

Brown, J., Wyers, A., Aldous, A., & Bach, L. (2007). Groundwater and Biodiversity Conservation: A methods guide for integrating groundwater needs of ecosystems and species into conservation plans in the Pacific Northwest. The Nature Conservancy.

Brown, J., Wyers, A., Bach, L., & Aldous, A. (2009a). Groundwater-Dependent Biodiversity and Associated Threats: A statewide screening methodology and spatial assessment of Oregon. 2009: The Nature Conservancy.

Brown, J., Wyers, A., Bach, L., & Aldous, A. (2009b). Groundwater-Dependent Biodiversity and Associated Threats: Oregon Atlas. The Nature Conservancy.

Bunn, S., & Arthington, A. H. (2002). Basic principles and consequences of altered hydrological regimes for aquatic biodiversity. Environmental Management, 492-507.

Bureau of Land Management. (1998). Riparian Area Management: Process for Assessing Proper Functioning Condition. Denver, CO: U.S. Department of the Interior.

Carter, V. (1996). Technical Aspects of Wetlands: Wetland Hydrology, Water Quality, and Associated Functions. In National Water Summary on Wetland Resources. U.S. Geological Survey.

Center for Watershed Protection. (2008a). Model Ordinances. Retrieved July 28, 2009, from Center for Watershed Protection: http://www.cwp.org/index.php?option=com_content&view=article&id=128:free-downloads-intro&catid=1&Itemid=116

Center for Watershed Protection; U.S. Forest Service. (2008b). Watershed Forestry Resource Guide. Retrieved December 3, 2009, from Forests for Watersheds: http://www.forestsforwatersheds.org/

Center for Watershed Protection. (2008c). Wetlands and Watersheds. Retrieved January 23, 2009, from Center for Watershed Protection: http://www.cwp.org/index.php?option=com_content&view=article&id=128:free-downloads-intro&catid=1&Itemid=116

Chicago Wilderness. (2009). Chicago Wilderness. Retrieved January 23, 2009, from http://www.chicagowilderness.org/

Cohen, R. (1997). The Importance of Protecting Riparian Areas along Smaller Brooks and Streams. Retrieved January 23, 2011, from Massachusetts Department of Fish and Game: http://www.mass.gov/dfwele/der/riverways/pdf/riparian_factsheet_9.pdf

Committee on Hydrologic Impacts of Forest Management, National Research Council. (2008). Hydrologic Effects of a Changing Forest Landscape. Washington D.C.: National Academies Press.

Copeland, H., Tessman, S., Girvetz, E., Roberts, L., Enquist, C., Orabona, A., et al. (2010). A geospatial assessment on the distribution, condition, and vulnerability of Wyoming's wetlands. Ecological Indicators, 869-879.

Cox, K. M. (2006). Batten Kill Trout Management Plan. Vermont Agency of Natural Resources.

Dingham, S. L. (2002). Physical Hydrology. Prentice Hall.

Doppelt, B., Scurlock, M., Frissell, C., & Karr, J. (1993). Entering the Watershed: A New Approach to Save America's River Ecosystems. Washington D.C.: Island Press.

Dunne, T., & Leopold, L. (1978). Water in Environmental Planning. New York: W.H. Freeman and Company.

Eamus, D. and R. Froend. (2006). Groundwater-Dependent ecosystems: The where, what and why of GDEs. Australian Journal of Botany, 54, 91-96.

Environmental Law Institute; Defenders of Wildlife. (2003). Planning for Biodiversity: Authorities in State Land Use Laws. Washington D.C.: Environmental Law Institute.

Environmental Law Institute. (2007a). Lasting Landscapes: Reflections on the Role of Conservation Science in Land Use Planning. Washington D.C.: The Environmental Law Institute.

Environmental Law Institute. (2007b). State Wildlife Action Plans and Utilities: New Conservation Opportunities for America's Wildlife. Environmental Law Institute.

Ernst, C. (2004). Protecting the Source: Land Conservation and the Future of America's Drinking Water. The Trust for Public Land.

Esselman, P., Infante, D. M., Wang, L., Cooper, A., Taylor, W. W., Tingley, R., et al. (2011). A landscape assessment of fish habitat conditions in United States rivers and their watersheds. Retrieved from www.fishhabitat.org

Federal Interagency Stream Restoration Working Group. (1998). Stream Corridor Restoration: Principles, Processes, and Practices.

Frey, D. (1977). Biological Integrity of Water: An Historical Approach. The Integrity of Water. Proceedings of a Symposium, March 10-12, 1975 (pp. 127-140). Washington D.C.: U.S. Environmental Protection Agency.

Frissel, C., Poff, N. L., & Jensen, M. (2001). Assessment of Biotic Patterns in Freshwater Ecosystems. In M. Jensen, & P. Bourgeron, A Guidebook for Integrated Ecological Assessments (pp. 390-403). New York: Springer.

Gao, Y., Vogel, R., Kroll, C., Poff, N., & Olden, J. (2009). Development of Representative Indicators of Hydrologic Alteration. Journal of Hydrology, 136–147.

Gilbert, J. (1996). Do Ground Water Ecosystems Really Matter? Ground Water and Land Use Planning Conference. Perth: CSIRO Division of Water Resources Centre for Ground Water Studies.

Gilbert, J., Danielopol, D., & Stanford, J. (1998). Groundwater Ecology. San Diego, CA: Academic Press.

Goldscheider, N., Hunkeler, D., Pronk, M., Rossi, P., Kozel, R., & Zopfi, J. (2007). Heterogeneous aquifers as habitats for microbial biocenoses. XXXV International Association of Hydrogeologists Congress Groundwater and Ecosystems. Lisbon, Portugal: International Association of Hydrogeologists.

Grimm, N., Gergel, S., McDowell, W., Boyer, E., Dent, C., Groffman, P., et al. (2003). Merging aquatic and terrestrial perspectives of nutrient biogeochemistry. Oecologia, 485-501.

Groves, C., Klein, M., & Breden, T. (1995). Public-Private Partnerships for Biodiversity Conservation. Wildlife Society Bulletin, 784-790.

H. John Heinz III Center for Science, Economics, and the Environment. (2008). The State of the Nations Ecosystems. Washington D.C.: Island Press.

Haas, A., Ahn, G.-C., Rustay, M., & Dittbrenner, B. (2009). Critical Areas Monitoring 2008 Status Report. Snohomish County Public Works.

Habich, E. F. (2001). Ecological Site Inventory. Denver, Colorado: Bureau of Land Management.

Hancock, P., Boulton, A., & Humphreys, W. (2005). Aquifers and hyporheic zones: Towards an ecological understanding of groundwater. Hydrogeology Journal, 98-111.

Hann, W., Shlisky, A., Havlina, D., Schon, K., Barrett, S., DeMeo, T., et al. (2008). Interagency Fire Regime Condition Class Guidebook. National Biological Information Infrastructure.

Hayashi, M., & Rosenberry, D. (2002). Effects of groundwater exchange on the hydrology and ecology of surface water. Ground Water, 309-316.

Heal the Bay. (2009, October 27). Beach Report Card. Retrieved November 4, 2009, from Heal the Bay: http://www.healthebay.org/brcv2/

Healy, R., Winter, T., LaBaugh, J., & Franke, O. (2007). Water Budgets: Foundations for Effective Water Resource and Environmental Management, USGS Circular 1308. U.S. Government Printing Office.

Henriksen, J., Heasley, J., Kennen, J., & Nieswand, S. (2006). Users' Manual for the Hydroecological Integrity Assessment Process Software (including the New Jersey Assessment Tools). Reston, VA: U.S. Geological Survey.

Higgins, J. V. (2003). Maintaining the Ebbs and Flows of the Landscape - Conservation Planning for Freshwater Ecosystems. In C. R. Groves, Drafting a Conservation Blueprint: a Practitioner's Guide to Regional Planning for Biodiversity. Washington D.C.: Island Press.

Higgins, J., Bryer, M., Khoury, M., & Fitzhugh, T. (2005). A Freshwater Classification Approach for Biodiversity Conservation Planning. Conservation Biology, 432-445.

Higgins, V. J., & Esselman, R. (2006). Ecoregional Assessment and Biodiversity Vision Toolbox. Retrieved January 14, 2011, from The Nature Conservancy: http://conserveonline.org/workspaces/cbdgateway/era/index_html

Higgins, J. V., & Duigan, C. (2009). So Much to Do, So Little Time: Identifying Priorities for Freshwater Biodiversity Conservation in the United States and Britain. In P. J. Boon, & C. M. Pringle, Assessing the Conservation Value of Freshwaters (pp. 61-90). New York, NY USA: Cambridge University Press.

Hubert, W. (2004). Ecological processes of riverine wetland habitats. In M. McKinstry, W. Hubert, & S. Anderson, Wetland and Riparian Areas of the Intermountain West (pp. 52–73). Austin, TX: University of Texas Press.

Humphreys, W. (2006). Aquifers: The ultimate groundwater-dependent ecosystems. Australian Journal of Botany, 115-132.

Interagency Wild and Scenic Rivers Council. (2009, October 6). Retrieved October 6, 2009, from National Wild and Scenic Rivers: www.rivers.org

Jaquith, S., Kline, M., Field, J., & Henderson, J. (2004). Phase 1 Geomorphic Assessment of the Batten Kill Main-Stem and Major Tributaries. Vermont Department of Environmental Conservation.

Jelks, H. L., Walsh, S. J., Burkhead, N. M., Contreras-Balderas, S., Díaz-Pardo, E., Hendrickson, D. A., et al. (2008). Conservation Status of Imperiled North American Freshwater and Diadromous Fishes. Fisheries, 33(8): 372-407.

Jennings, M. (2000). Gap Analysis: Concepts, Methods, and Recent Results. Landscape Ecology, 15:5-20.

Junk, W., & Wantzen, K. (2004). The Flood Pulse Concept: New Aspects, Approaches, and Applications. Max-Planck-Institute for Limnology, Working Group Tropical Ecology.

Karr, J. R. (1981). Assessment of Biotic Integrity Using Fish Communities. Fisheries, 6: 21-27.

Karr, J., & Dudley, D. (1981). Ecological Perspectives on Water Quality Goals. Environmental Management , 55-68.

Karr, J. R., Fausch, K. D., Angermeier, P. L., Yant, P. R., & Schlosser, I. J. (1986). Assessment of Biological Integrity in Running Waters: A Method and its Rationale. Champaign, Illinois: Illinois Natural History Survey Special Publication 5.

Karr, J., & Yoder, C. (2004). Biological assessment and criteria improve total maximum daily load decision making. Journal of Environmental Engineering, 594-604.

Khoury, M., Higgins, J., & Weitzell, R. (2010). A Freshwater Conservation Assessment of the Upper Mississippi River Basin Using a Coarse and Fine Filter Approach. Freshwater Biology, 1365-2427.

Kidd, S., McFarlane, B., & Walberg, E. (2010). A Green Infrastructure Plan for the Hampton Roads Region. Chesapeake, VA: Hampton Roads Planning District Commission.

King County Department of Natural Resources. (2000). Literature Review and Recommended Sampling Protocol for Bull Trout in King County . Seattle, WA: King County Department of Natural Resources.

Kline, M., Alexander, C., Pytlik, S., Jaquith, S., & Pomeroy, S. (2009). Vermont Stream Geomorphic Assessment Protocol Handbooks and Appendices. Waterbury, VT: Vermont Agency of Natural Resources.

Kline, M., & Dolan, K. (2009). River Corridor Protection Guide. Waterbury, VT: Vermont Agency of Natural Resources.

Kline, M. (2010). VT ANR River Corridor Planning Guide: to Identify and Develop River Corridor Protection and Restoration Projects. Waterbury, VT: Vermont Agency of Natural Resources.

Kline, M., & Cahoon, B. (2010). Protecting River Corridors in Vermont. Journal of the American Water Resources Association , 227-236.

Komor, S. (1994). Geochemistry and hydrology of a calcareous fen within the Savage fen wetlands complex, Minnesota, U.S.A. Geochimica et Cosmochimica Acta, 3353-3367.

Kraemer, S. R., Schroer, K., Chesney, C., Bonds, J., Ryan, W., & Melgin, W. (2000). Ground Water, Watersheds and Environment. Unpublished US EPA Issue paper.

Leopold, L., Wolman, M., & Miller, J. (1964). Fluvial Processes in Geomorphology. W.H. Freeman. San Francisco, CA.

Leopold, L. (1994). A View of the River. Cambridge, MA: Harvard University Press.

MacDonald, L. H., Smart, A. W., & Wissmar, R. C. (1991). Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska. Seattle: U.S. Environmental Protection Agency Region 10.

Maryland Department of Natural Resources. (2003). A Physical Habitat Index for Freshwater Wadeable Streams in Maryland. Annapolis: Maryland Department of Natural Resources.

Maryland Biological Stream Survey. (2005). Statewide and Basin Conditions 2000-2004. Annapolis: Maryland Department of Natural Resources.

Maryland Department of Natural Resources. (2011). GreenPrint. Retrieved January 23, 2011, from Maryland Department of Natural Resources: http://www.greenprint.maryland.gov/

Massachusetts Department of Fish & Game and The Nature Conservancy. (2010). BioMap2: Conserving the Biodiversity of Massachusetts in a Changing World. MA Department of Fish & Game.

Massachusetts Department of Fish & Game. (2011). River Continuity Data Sheets. Retrieved January 11, 2011, from Division of Ecological Restoration: http://www.mass.gov/dfwele/der/freshwater/rivercontinuity/datasheets.htm

Matthews, R., & Richter, B. (2007). Application of the Indicators of Hydrologic Alteration software in environmental flow-setting. Journal of the American Water Resources Association , 1400-1413.

Meyer, J. L., Wallace, J. B., Eggert, S. L., Helfman, G. S., & Leonard, N. E. (2007). The Contribution of Headwater Streams in Biodiversity Networks. Journal of the American Water Resources Association, 86-103.

Millennium Ecosystem Assessment. (2005). Ecosystems and Human Well-Being. Washington D.C.: Island Press.

Miller, W., Johnson, D., Loupe, T., Sedinger, J., Carroll, E., Murphy, J., et al. (2006). Nutrients Flow From Runoff at Burned Forest Site in Lake Tahoe Basin. Restoring Clarity, 65-71.

Minnesota Department of Natural Resources. (2008, February). What is a Calcareous Seepage Fen? Retrieved January 10, 2011, from Wetlands: http://www.bwsr.state.mn.us/wetlands/Calc_fen-factsheet.pdf

Minnesota Department of Natural Resources. (2009). Watershed Assessment Tool. Retrieved April 27, 2009, from http://www.dnr.state.mn.us/watershed_tool/index.html

Mitsch, W. J., & Gosselink, J. G. (2007). Wetlands. Hoboken, NJ: John Wiley & Sons, Inc.

Moir-McClean, T., & DeKay, M. (2006). Beaver Creek Watershed Green Infrastructure Plan. University of Tennessee College of Architecture and Design.

Montgomery, D. R., & Buffington, J. M. (1998). Channel Processes, Classification, and Response. River Ecology and Management, 13-42.

Murray, B., Hose, G., Eamus, D., & Licari, D. (2006). Valuation of groundwater-dependent ecosystems: a functional methodology incorporating ecosystem services. Australian Journal of Botany , 221-229.

National Fish and Wildlife Foundation; Bonneville Power Administration. (2004). Finding Balance. Retrieved July 24, 2009, from Columbia Basin Water Transactions Program: http://www.cbwtp.org/jsp/cbwtp/index.jsp

NatureServe. (2008). Natural Heritage Methodology. Retrieved May 21, 2009, from Products and Services: http://www.natureserve.org/prodServices/heritagemethodology.jsp

Nel, J. L., Roux, D. J., Cowling, R. M., Abell, R., Thieme, M., Higgins, J. V., et al. (2009). Progress and Challenges in Freshwater Conservation Planning. Aquatic Conservation: Marine and Freshwater Ecosystems, 474-485.

Nicholoff, S. (2003). Wyoming Bird Conservation Plan, Version 2.0. Lander, WY: Wyoming Game and Fish Department.

Norton, D., Wickham, J., Wade, T., Kunert, K., Thomas, J., & Zeph, a. P. (2009). A Method for Comparative Analysis of Recovery Potential in Impaired Waters Restoration Planning. Environmental Management, 356-368.

Noss, R. F., LaRoe III, E. T., & Scott, J. M. (1995). Endangered Ecosystems of the United States: A Preliminary Assessment of Loss and Degradation. Washington D.C.: National Biological Service; U.S. Department of the Interior.

Ohio Watershed Network. (2009). Watershed Toolshed. Retrieved July 28, 2009, from Ohio Watersheds: http://ohiowatersheds.osu.edu/

Oram, B. (2009, October 14). Calculating NSF Water Quality Index. Retrieved December 7, 2009, from Wilkes University Center for Environmental Quality Environmental Engineering and Earth Sciences: http://www.water-research.net/watrqualindex/index.htm

Oregon Natural Heritage Program. (2009). Oregon Natural Heritage Information Center. Retrieved September 24, 2009, from Oregon State: http://orbic.pdx.edu/

Perry, J. A., & Vanderklein, E. (1996). Water Quality: Management of a Natural Resource. Wiley-Blackwell.

Poff, N. L. (1996). A Hydrogeography of Unregulated Streams in the United States and an Examination of Scale Dependence in Some Hydrological Descriptors. Freshwater Biology, 71-91.

Poff, N. L., Allan, D. J., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., et al. (1997). The Natural Flow Regime: A Paradigm for River Conservation and Restoration. BioScience, 47(11) 769-784.

Poff, N. (2009). Managing for Variability to Sustain Freshwater Ecosystems. Journal of Water Resources Planning and Management.

Poff, N. L., Richter, B. D., Arthington, A. H., Bunn, S. E., Naiman, R. J., Kendy, E., et al. (2010). The ecological limits of hydrologic alteration (ELOHA): A new framework for developing regional environmental flow standards. Freshwater Biology, 147-170.

Poiani, K., Richter, B., Anderson, M., & Richter, H. (2000). Biodiversity Conservation at Multiple Scales. BioScience, 133-146.

Postel, S., & Richter, B. (2003). Rivers for Life: Managing Water for People and Nature. Island Press.

Postel, S., & Thompson, B. (2005). Watershed protection: Capturing the benefits of nature's water supply services. Natural Resources Forum, 98-108.

Power, G., Brown, R., & Imhof, J. (1999). Groundwater and fish- insights from northern North America. Hydrologic Processes, 401-422.

Protected Areas Database of the United States Partnership. (2009). Retrieved November 11, 2009, from Protected Lands: http://www.protectedlands.net/padus/

Richter, B. D., Baumgartner, J. V., Powell, J., & Braun, D. P. (1996). A Method for Assessing Hydrologic Alteration Within Ecosystems. Conservation Biology, 10(4) 1163-1174.

Richter, B., Mathews, R., Harrison, D., & Wigington, R. (2003). Ecologically Sustainable Water Management: Managing River Flows for Ecological Integrity. Ecological Applications , 206-224.

Richter, B., Warner, A., Meyer, J., & Lutz, K. (2006). A Collaborative and Adaptive Process for Developing Environmental Flow Recommendations. River Research and Applications, 297-318.

Richter, B. (2007, June). Meeting Urban Water Demands While Protecting Rivers: A Case Study from the Rivanna River in Georgia. Journal of the American Water Works Association, pp. 24-26.

Riera, J., Magnuson, J., Kratz, T., & Webster, K. (2000). A geomorphic template for the analysis of lake districts applied to the Northern Highland Lake District. Freshwater Biology, 301-318.

Rosgen, D. L. (1994). A Classification of Natural Rivers. Catena, 169-199.

Rosgen, D. (1996). Applied River Morphology. Pagosa Springs, CO: Wildland Hydrology Books.

Sada, D., Williams, J., Silvey, J., Halford, A., Ramakka, J., Summers, P., et al. (2001). Riparian Area Management: A guide to managing, restoring, and conserving springs in the Western United States. Technical Reference 1737-17. Denver, Colorado: Bureau of Land Management.

Schiff, R., Kline, M., & Clark, J. (2008). The Vermont Reach Habitat Assessment Protocol. Waterbury, VT: Prepared by Milone and MacBroom, Inc. for the Vermont Agency of Natural Resources.

Schueler, T. (1994). The Importance of Imperviousness. Watershed Protection Techniques, 100-111.

Schueler, T. (2000). The Tools of Watershed Protection. In T. Schueler, & H. Holland, The Practice of Watershed Protection. Ellicott City, MD: Center for Watershed Protection.

Schumm, S. A. (1977). The Fluvial System. New York, NY: John Wiley and Sons.

Shilling, F. (2007). California Watershed Assessment Manual. Retrieved June 13, 2009, from University of California Davis: http://cwam.ucdavis.edu/

Simon, A., Doyle, M., Kondolf, M., Shields, F. J., Rhoads, B., Grant, G., et al. (2005). How Well Do the Rosgen Classification and Associated "Natural Channel Design" Methods Integrate and Quantify Fluvial Processes and Channel Response? Reston, VA: American Society of Civil Engineers Environmental and Water Resources Institute.

Smart Growth Network. (2009). Principles of Smart Growth. Retrieved July 27, 2009, from Smart Growth Online: http://www.smartgrowth.org/engine/index.php/principles/

Smit, B., & Wandel, J. (2006). Adaptation, Adaptive Capacity and Vulnerability. Global Environmental Change-Human and Policy Dimensions, 282-292.

Smith, E., Tran, L., & O'Neill, R. (2003). Regional Vulnerability Assessment for the Mid-Atlantic Region: Evaluation of Integration Methods and Assessments Results. U.S. Environmental Protection Agency.

Smith, M., de Groot, D., Perrot-Maîte, D., & Bergkamp, G. (2006). Pay – Establishing payments for watershed services. Gland, Switzerland: IUCN.

Smith, M. P., Schiff, R., Olivero, A., & MacBroom, J. (2008). The Active River Area: A Conservation Framework for Protecting Rivers and Streams. Boston: The Nature Conservancy.

Sowa, S., Annis, G., Morey, M., & Diamond, D. (2007). A GAP Analysis and Comprehensive Conservation Strategy for Riverine Ecosystems of Missouri. Ecological Monographs, 301-334.

Springer, A., Stevens, L., Anderson, D., Parnell, R., Kreamer, D., & Flora, S. (2008). A comprehensive springs classification system: integrating geomorphic, hydrogeochemical, and ecological criteria. In L. Stevens, & V. Meretsky, Aridland Springs in North America: Ecology and Conservation. Tucson, Arizona: University of Arizona.

Stalnaker, C., Lamb, B., Henriksen, J., Bovee, K., & Bartholow, J. (1995). The Instream Flow Incremental Methodology. Washington D.C.: National Biological Service; U.S. Department of the Interior.

State of Ohio Environmental Protection Agency. (2009). Statewide Biological and Water Quality Monitoring & Assessment. Retrieved September 24, 2009, from Monitoring and Assessment Section; Division of Surface Water: http://www.epa.state.oh.us/dsw/bioassess/ohstrat.aspx

Stoddard, J., Larsen, D., Hawkins, C., Johnson, R., & Norris, R. (2006). Setting Expectations for the Ecological Condition of Streams: The Concept of Reference Condition. Ecological Applications, 1267-1276.

Strager, J., Yuill, C., & Wood, P. (2000). Landscape-based Riparian Habitat Modeling for Amphibians and Reptiles using ARC/INFO GRID and ArcView GIS. 2000 ESRI International User Conference. Redlands, California: Environmental Systems Research Institute (ESRI).

Striegl, R. G., & Michmerhuizen, C. M. (1998). Hydrologic influence on methane and carbon dioxide dynamics at two north-central Minnesota lakes. Limnology and Oceanography, 1519–1529.

Tharme, R. (2003). A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications, 397-441.

The Conservation Campaign. (2009). Retrieved November 12, 2009, from The Conservation Campaign Toolkit: http://www.conservationcampaign.org/wizard/index.cfm?ID=125

The Lumber River Conservancy. (2009). Retrieved November 12, 2009, from http://www.lumberriverconservancy.org/lumber_river.html

The Nature Conservancy. (2003). Guidelines for Designing and Selecting Conservation Strategies. The Nature Conservancy.

The Nature Conservancy. (2011). ELOHA Toolbox. Retrieved January 27, 2011, from ConserveOnline: http://www.conserveonline.org/workspaces/eloha/documents/hydrologic-foundation-0

The Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission. (2005). Pennsylvania Comprehensive Wildlife Conservation Strategy.

The Trust for Public Land. (2009). LandVote. Retrieved July 28, 2009, from LandVote: http://www.tpl.org/tier3_cd.cfm?content_item_id=12010&folder_id=2386

Thorp, J., Thoms, M., & DeLong, M. (2006). The Riverine Ecosystem Synthesis: Biocomplexity in River Networks Across Space and Time. River Research and Applications, 123-147.

Thorp, J., Thoms, M., & Delong, M. (2008). The Riverine Ecosystem Synthesis: Toward Conceptual Cohesiveness in Riverine Science. Elsevier.

Tiner, R. (2004). Remotely Sensed Indicators for Monitoring the General Condition of "Natural Habitat" in Watersheds: An Application for Delaware's Nanticoke River Watershed. Ecological Indicators, 227–243.

Tomlinson, M., & Boulton, A. (2008). Subsurface groundwater dependent ecosystems: A review of their biodiversity, ecological processes and ecosystem services. Waterlines Occasional Paper Number 8.

Trout Unlimited and Northstar Economics. (2008). The Economic Impact of Recreational Trout Angling in the Driftless Area. Trout Unlimited.

Trust for Public Land. (2009). Watershed Cases. Retrieved July 28, 2009, from Center for Land and Water: http://www.tpl.org/tier2_pa.cfm?folder_id=3153

Trust for Public Land. (2010, January). Lower Meramec River Source Water Demonstration Project. Retrieved February 16, 2011, from Center for Land and Water: http://www.tpl.org/tier3_cd.cfm?content_item_id=23278&folder_id=1885

U.S. Department of Agriculture Economic Research Service. (2005, September 2). Rural-Urban Commuting Area Codes. Retrieved December 11, 2009, from Measuring Rurality: http://www.ers.usda.gov/Data/RuralUrbanCommutingAreaCodes/

U.S. Department of Agriculture. (2009, October 27). National Organic Program. Retrieved November 2, 2009, from Agricultural Marketing Service: http://www.ams.usda.gov/AMSv1.0/NOP

U.S. Department of Agriculture; U.S. Department of the Interior. (2009). LandFire. Retrieved May 21, 2009, from LandFire: http://www.landfire.gov

U.S. Environmental Protection Agency. (1987). Handbook: Ground Water. U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. (1990). Biological Criteria: National Program Guidance for Surface Waters. Washington D.C.: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. (1995). America's Wetlands: Our Vital Link Between Land and Water. U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. (1997). The Index of Watershed Indicators. Washington D.C.: Office of Water.

U.S. Environmental Protection Agency. (2002). Summary of Biological Assessment Programs and Biocriteria Development for States, Tribes, Territories, and Interstate Commissions: Streams and Wadeable Rivers. Washington D.C.: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. (2003). Getting in Step: A Guide for Conducting Watershed Outreach Campaigns. Washington D.C.: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. (2006a, November 27). Model Ordinances to Protect Local Resources. Retrieved July 28, 2009, from Nonpoint Source Pollution: http://www.epa.gov/owow/nps/ordinance/

U.S. Environmental Protection Agency. (2006b). Protecting Water Resources with Higher Density Development. Washington D.C.

U.S. Environmental Protection Agency. (2006c). Use of Biological Information to Better Define Designated Aquatic Life Uses in State and Tribal Water Quality Standards: Tiered Aquatic Life Uses. Washington, DC: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. (2006d). Wadeable Streams Assessment. Washington D.C.: Office of Water.

U.S. Environmental Protection Agency. (2007a, August 14). Principles for the Ecological Restoration of Aquatic Resources. Retrieved November 12, 2009, from Office of Wetlands Oceans and Watersheds: http://www.epa.gov/owow/wetlands/restore/principles.html#1

U.S. Environmental Protection Agency. (2007b). Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices. Washington D.C.: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. (2007c, August 14). River Corridor and Wetland Restoration. Retrieved December 3, 2009, from Wetlands, Oceans, and Watersheds: http://www.epa.gov/owow/wetlands/restore/

U.S. Environmental Protection Agency. (2008a). Handbook for Developing Watershed Plans to Restore and Protect Our Waters. Washington, DC: Office of Water.

U.S. Environmental Protection Agency. (2008b, December 19). National Aquatic Resource Surveys. Retrieved January 23, 2009, from Monitoring and Assessing Water Quality: http://water.epa.gov/type/watersheds/monitoring/nationalsurveys.cfm

U.S. Environmental Protection Agency. (2008c, December 10). National Rivers and Streams Assessment. Retrieved April 27, 2009, from Monitoring and Assessing Water Quality: http://water.epa.gov/type/rsl/monitoring/riverssurvey/riverssurvey_index.cfm

U.S. Environmental Protection Agency. (2008d). U.S. EPA's 2008 Report on the Environment. Washington D.C.: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. (2008e, November 17). The Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams. Retrieved January 20, 2010, from Monitoring and Assessing Water Quality: http://water.epa.gov/type/rsl/monitoring/streamsurvey/index.cfm

U.S. Environmental Protection Agency. (2009a). National Lakes Assessment: A Collaborative Survey of the Nation's Lakes. Washington D.C.: Office of Water and Office of Research and Development.

U.S. Environmental Protection Agency. (2009b). State and County Land Protection Programs: Review of Selection Processes. Washington D.C.: Global Change Research Program; National Center for Environmental Assessment.

U.S. Environmental Protection Agency. (2011, February 15). Regional Vulnerability Assessment Program. Retrieved February 15, 2011, from www.epa.gov/reva

U.S. EPA Science Advisory Board. (2002). A Framework for Assessing and Reporting on Ecological Condition. Washington D.C.: U.S. Environmental Protection Agency.

U.S. Fish & Wildlife Service. (2002). Bull Trout (Salvelinus confluentus) Recovery Plan. U.S. Fish & Wildlife Service.

U.S. Fish and Wildlife Service. (2009, September 4). National Fish Passage Program. Retrieved December 3, 2009, from http://www.fws.gov/fisheries/fwco/fishpassage/

U.S. Geological Survey. (1999). National Water Summary on Wetland Resources. U.S. Geological Survey.

U.S. Geological Survey. (2006). Ohio Aquatic Gap Analysis-An Assessment of the Biodiversity and Conservation Status of Native Aquatic Animal Species. Retrieved September 24, 2009, from Publications Warehouse: http://pubs.er.usgs.gov/usgspubs/ofr/ofr20061385

U.S. Geological Survey. (2009a, May 21). National Hydrologic Assessment Tool. Retrieved May 21, 2009, from Fort Collins Science Center: http://www.fort.usgs.gov/products/Software/NATHAT/

U.S. Geological Survey. (2009b, May 21). National Water Information System. Retrieved May 21, 2009, from Water Resources: http://waterdata.usgs.gov/nwis

U.S. Geological Survey. (2009c, April 19). National Water Quality Assessment Program (NAWQA). Retrieved April 26, 2009, from Water Resources of the United States: http://water.usgs.gov/nawqa/about.html

U.S. Geological Survey. (2009d, April 17). SPARROW Surface Water Quality Modeling. Retrieved April 26, 2009, from National Water Quality Assessment Program: http://water.usgs.gov/nawqa/sparrow/

U.S. Geological Survey. (2009e, October 13). StreamStats. Retrieved December 1, 2009, from Office of Surface Water: http://water.usgs.gov/osw/streamstats/

University of Connecticut Center for Land Use Education and Research. (2009). Landscape Fragmentation Tool. Retrieved October 26, 2009, from http://clear.uconn.edu/tools/lft/lft2/index.htm

University of Maryland Center for Environmental Science; National Oceanic and Atmospheric Administration. (2009). EcoCheck. Retrieved October 28, 2009, from http://www.eco-check.org/reportcard/chesapeake/2008/

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., & Cushing, C. E. (1980). The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences, 37: 130-137.

Vermont Department of Environmental Conservation. (2007, July). Geomorphic Assessment. Retrieved April 27, 2009, from Water Quality Division: http://www.vtwaterquality.org/rivers/htm/rv_geoassess.htm

Vermont Law School Land Use Institute. (2009). Preparing for the Next Flood: Vermont Floodplain Management. Vermont Law School.

Virginia Commonwealth University. (2009, May 13). Center for Environmental Studies. Retrieved May 21, 2009, from Virginia Commonwealth University: http://www.vcu.edu/cesweb/

Virginia Department of Conservation and Recreation. (2008, July). Virginia Conservation Lands Needs Assessment. Retrieved April 27, 2009, from Natural Heritage: http://www.dcr.virginia.gov/natural_heritage/vclna.shtml

Virginia Department of Conservation and Recreation. (2009). Land Conservation Data Explorer. Retrieved May 21, 2009, from Virginia Natural Heritage Program: http://www.vaconservedlands.org/gis.aspx

Vogel, R., Sieber, J., Archfield, S., Smith, M. A., & Huber-Lee, A. (2007). Relations Among Storage, Yield and Instream Flow. Water Resources Research, 43.

Walsh, M., Deeds, J., & Nightingale, B. (2007). User's Manual and Data Guide to the Pennsylvania Aquatic Community Classification. Pennsylvania Natural Heritage Program.

Wang, X., & Yin, Z. (1997). Using GIS to Assess the Relationship Between Land Use and Water Quality at a Watershed Level. Environment International, 103-114.

Watershed Professionals Network. (1999). Oregon Watershed Assessment Manual. Salem, Oregon: Governor's Watershed Enhancement Board.

Weber, T. (2003). Maryland's Green Infrastructure Assessment. Annapolis, MD: Maryland Department of Natural Resources.

Weitzell, R. E., Khoury, M., Gagnon, P., Schreurs, B., Grossman, D., & Higgins, J. (2003). Conservation Priorities for Freshwater Biodiversity in the Upper Mississippi River Basin. Nature Serve and The Nature Conservancy.

Wells National Estuarine Research Reserve; Southern Maine Regional Planning Commission. (2009). Headwaters: A Collaborative Conservation Plan for the Town of Sanford.

Wheeler, B., Gowing, D., Shaw, S., Mountford, J., & Money, R. (2004). Ecohydrological guidelines for lowland wetland plant communities. Environment Agency.

Wickham, J., & Norton, D. (2008). Recovery Potential as a Means of Prioritizing Restoration of Waters Identified as Impaired Under the Clean Water Act . Water Practice, 1-11.

Wiens, J. A. (2002). Riverine Landscapes: Taking Landscape Ecology into the Water. Freshwater Biology, 501-515.

Williams, D., & Williams, N. (1998). Invertebrate communities from freshwater springs: What can they contribute to pure and applied ecology? In L.Botosaneanu, Studies in Chrenobiology. Leiden: Backhuys Publishers.

Winter, T. (1978). Ground-water component of lake water and nutrient budgets. Verhandlungen des Internationalen Verein Limnologie, 438-444.

Winter, T., Labaugh, J., & Rosenberry, D. (1988). The design and use of a hydraulic potentiomanometer for direct measurement of differences in hydraulic head between groundwater and surface water. Limnology and Oceanography, 1209-1214.

Winter, T. (1995). Recent advances in understanding the interaction of groundwater and surface water. Reviews of Geophysics Supplement, 985-994.

Winter, T., Harvey, J., Franke, O., & Alley, W. (1998). Ground Water and Surface Water: A Single Resource. U.S. Geological Survey.

Younger, P. (2006). Groundwater in the Environment. Blackwell Publishing.

Zencich, S., & Froend, R. (2001). Guidelines for identification and monitoring of terrestrial vegetation water requirements. Terrestrial Phreatophytic Vegetation Research Review Report Number 2001-16.

Zganjar, C., Girvetz, E., & G., R. (2009). Retrieved October 28, 2009, from Climate Wizard: http://www.climatewizard.org/

Zorn, T. G., Seelbach, P. W., Rutherford, E. S., Willis, T. C., Cheng, S. T., & Wiley, M. J. (2008). A Regional-scale Habitat Suitability Model to Assess the Effects of Flow Reduction on Fish Assemblages in Michigan Streams. Ann Arbor: Michigan Department of Natural Resources; Fisheries Division.

Appendix A. Examples of Assessment Tools

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:

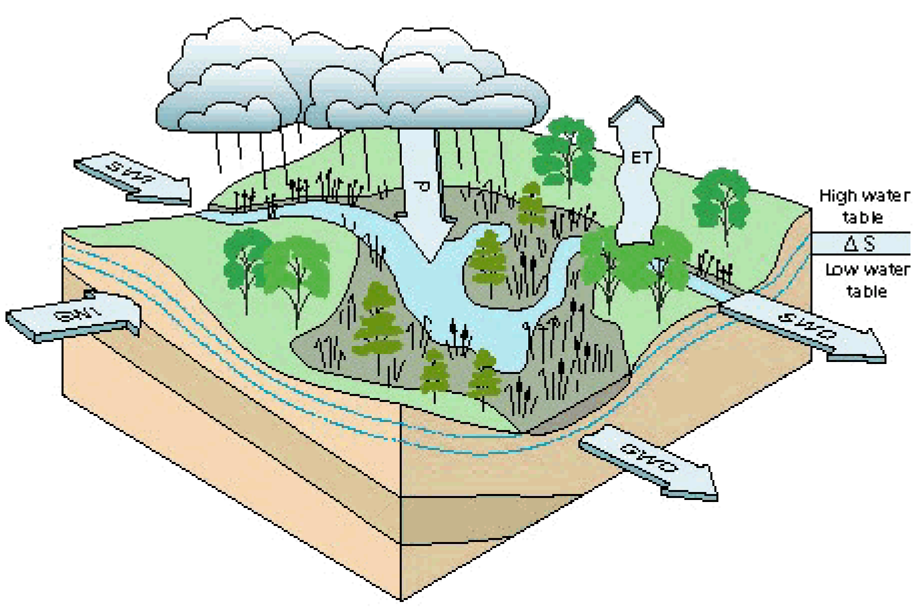
Inputs:

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).

Integrated Land and Water Information System (ILWIS)

Developer: World Institute for Conservation and Environment

More Information: http://52north.org/

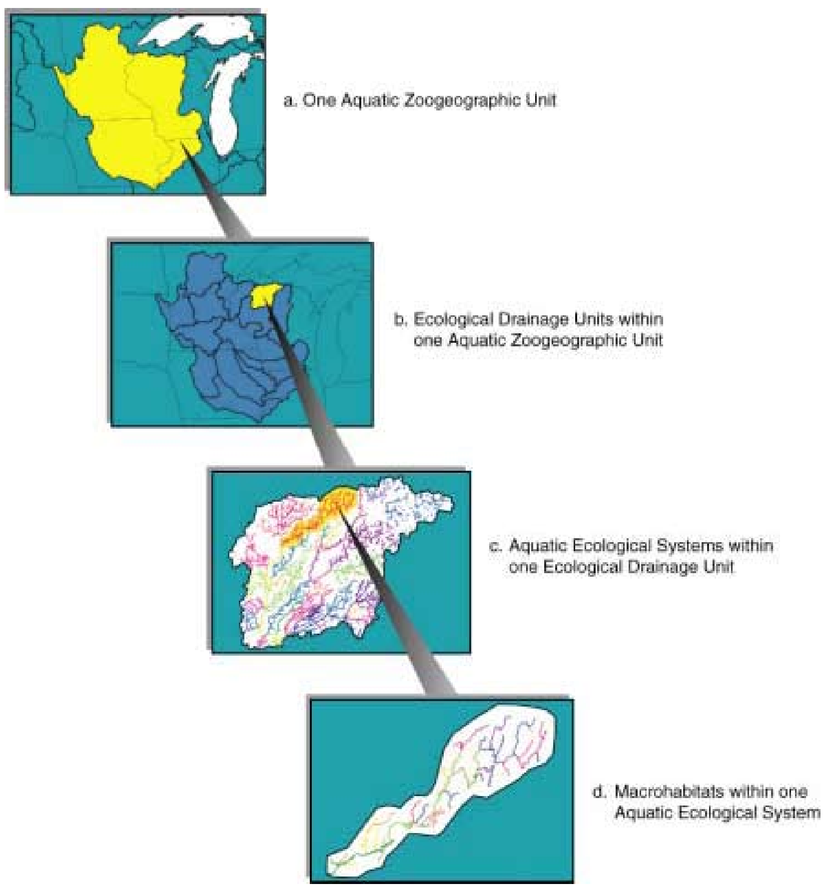
ILWIS is free remote sensing and GIS software, which integrates image, vector, and thematic data in one unique and powerful desktop package. ILWIS delivers a wide range of features including import/export, digitizing, editing, analysis and display of data, as well as production of quality maps. ILWIS software is renowned for its functionality, user-friendliness and low cost, and has established a wide user community over the years of its development.

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)

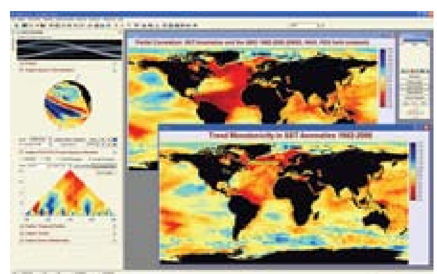
More Information: http://www.esri.com/index.html

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.

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.

Marxan

Developer: University of Queensland

More Information: http://www.uq.edu.au/marxan/

Marxan is used to support the design of marine and terrestrial reserves worldwide. Marxan can assist with the evaluation of existing reserve systems to identify gaps in biodiversity protection, identify areas to include in new reserve systems, and provide decision support by producing a number of different options that meet both socio-economic and conservation objectives. Marxan can also be used to support multiple-use zoning plans that balance the varied interests of stakeholders.

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:

- **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.

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 which 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" you 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

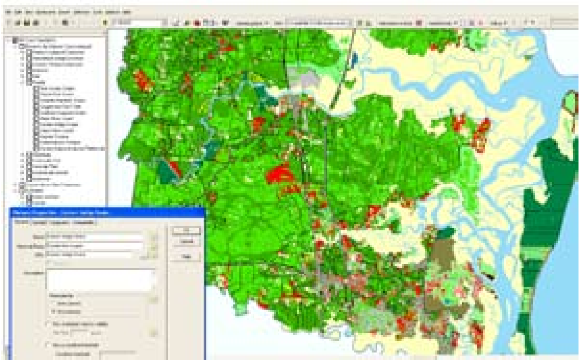
Developer: NatureServe

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 National Oceanic and Atmospheric Administration's (NOAA) 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.

Impervious Surface Analysis Tool (ISAT)

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 ISAT is used to calculate the percentage of impervious surface area of user-selected geographic areas (e.g., watersheds, municipalities, subdivisions). ISAT is available as an ArcView 3.x, ArcGIS 8.x or an ArcGIS 9.x extension.

Miradi

Developer: Conservation Measures Partnership

More Information: http://www.miradi.org

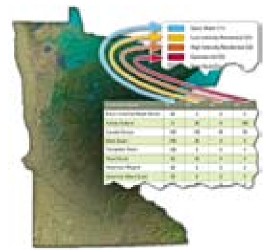
Miradi is a user-friendly program that allows nature conservation practitioners to design, manage, monitor, and learn from their projects to more effectively meet their conservation goals. The program guides users through a series of step-by-step interview wizards, based on the Open Standards for the 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.

LINK

Developer: U.S. Geological Survey

More Information: http://www.umesc.usgs.gov/management/dss/bird_conservation_tools_link.html

LINK is a set of ArcGIS tools designed to analyze habitat patterns across a landscape. LINK is the latest product from a series of decision support systems that uses species habitat matrices to model potential species habitat and habitat diversity. LINK's main purpose is to make comparisons of conservation potential between management units and the surrounding landscape. LINK does this by summarizing potential species richness, habitat diversity, and habitat composition.



Habitat Evaluation Procedures (HEP)

Developer: U.S. Geological Survey

More Information: www.fort.usgs.gov/products/software/hep/hep.asp

The HEP accounting program uses the area of available habitat and Habitat Suitability Index (HSI) to compute the values needed for HEP. This is an important tool for land use managers, as it can be used to quantify the effects of alternative management plans over time, and provide for mitigation and compensation that can allow fair use of the land and maintain healthy habitats for affected species.

Habitat Priority Planner (HPP)

Developer: National Oceanic and Atmospheric Administration (NOAA)

More Information: http://www.csc.noaa.gov/digitalcoast/tools/hpp/

The HPP 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. HPP 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.

Wildlife Habitat Benefits Estimation Toolkit

Developer: Defenders of Wildlife, Colorado State University

More Information: http://www.defenders.org/programs_and_policy/science_and_economics/conservation_economics/valuation/benefits_toolkit.php

The Wildlife Habitat Benefits Estimation Toolkit is a set of easy-to-use spreadsheet-based valuation models, tables, and databases directed at land use and wildlife planners and others interested in estimating the economic benefits associated with wildlife and habitat conservation in specific geographic regions.

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 non-point 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.

Nonpoint Source Pollution and Erosion Comparison Tool (NSPECT)

Developer: National Oceanic and Atmospheric Administration (NOAA)

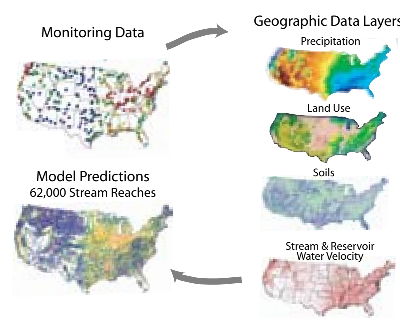
More Information: http://www.csc.noaa.gov/digitalcoast/tools/nspect/

NSPECT helps predict potential water quality impacts to rivers and streams from nonpoint source pollution and erosion. Users first enter information about their 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 get information about potential changes in surface water runoff, nonpoint 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 factor's influencing terrestrial and aquatic transport. SPARROW empirically estimates the origin and fate of contaminants in river networks and quantifies uncertainties in model predictions.

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.

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 (an RDBMS-based GIS System), 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.

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

The 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.

Indicators of Hydrologic Alteration

Developer: The Nature Conservancy

More Information: http://www.nature.org/initiatives/freshwater/conservationtools/art17004.html

The 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, the IHA software 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.

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.

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.

Rapid Assessment of Stream Conditions Along Length (RASCAL)

Developer: Iowa Department of Natural Resources

More Information: http://www.igsb.uiowa.edu/wqm/PPpresentations/Conf08/Kiel.pdf

RASCAL uses a combination of GPS technology and an assessment procedure designed to provide continuous stream condition data at a watershed scale. The assessment procedure is a modified version of the NRCS Stream Visual Assessment Protocol.

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 (SYE) 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 the Commonwealth of Massachusetts, it could potentially be adapted for use in other New England states, but may not be applicable outside this geographic region.

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.

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.

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 Web site 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, National Pollutant Discharge Elimination System stormwater Phase II permits, total maximum daily load permits, Nonpoint Source Program goals, and water quality standards.

Tools for Understanding Ground Water and Biodiversity.
Developer: The Nature Conservancy
More Information: http://nemo.srnr.arizona.edu/nemo/WebDocs/Ground water%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, baseflow as a percentage of annual stream flow, water table data, Forward Looking Infrared Remote Sensing (FLIR), 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.

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/

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.

Subbasin 02070010 covering Washington DC

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 done 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://www.landfire.gov/ra3.php

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 and 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.gap.uidaho.edu:8081/padus/padus2.do#

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 is 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 directly 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 (AFF) 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.

U.S. Environmental Protection Agency
Office of Wetlands, Oceans, and Watersheds
1200 Pennsylvania Avenue, N.W. (4503T)
Washington, D.C. 20460

Healthy Watersheds