United States
Environmental Protection
Agency

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

Identifying and Protecting Healthy Watersheds

Chapter 3. Examples of Assessment Approaches

February 2012

3. Examples of Assessment Approaches

Introduction

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

Overview of Key Concepts

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

Examples of Assessment Approaches

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

Healthy Watersheds Integrated Assessments

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

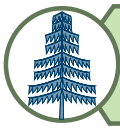
Management Approaches

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

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

3.1 Landscape Condition

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

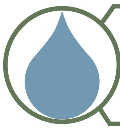


Landscape Condition
Patterns of natural land cover, natural disturbance regimes, lateral and longitudinal connectivity of the aquatic environment, and continuity of landscape processes.

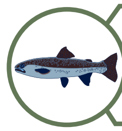
Geomorphology
Stream channels with natural geomorphic dynamics.

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

Water Quality
Chemical and physical characteristics of water.



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



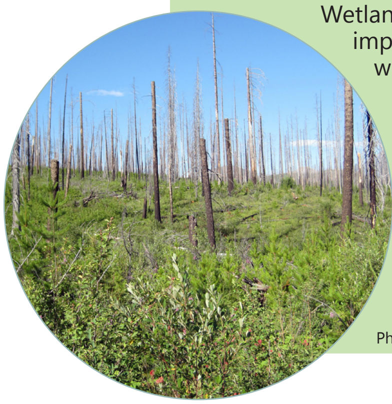
Biological Condition
Biological community diversity, composition, relative abundance, trophic structure, condition, and sensitive species.

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

Photo: BLM.

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

Photo: BLM.



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

Photo: Jane Hawkey, IAN.

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

Photo: USFWS.

Maryland Green Infrastructure Assessment

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

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

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

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

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

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

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

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

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

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

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

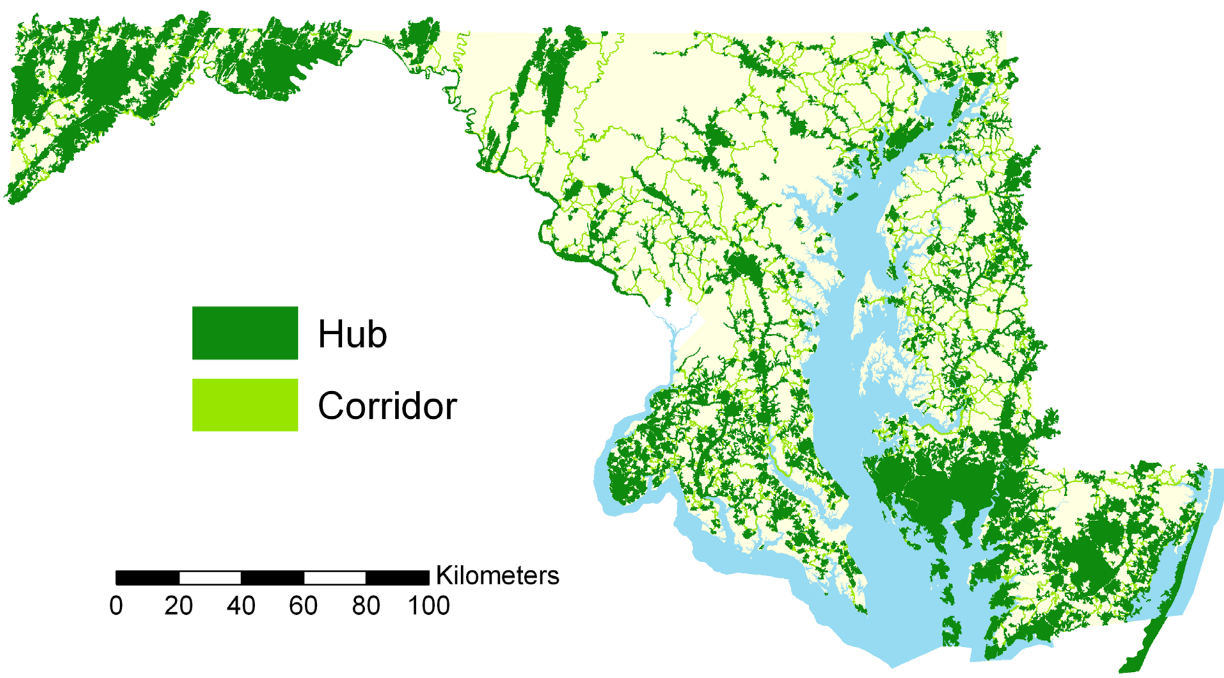


Figure 3-1 Green infrastructure in Maryland (Maryland Department of Natural Resources, 2011).

Case Study

Anne Arundel County Greenways Master Plan

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

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

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

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

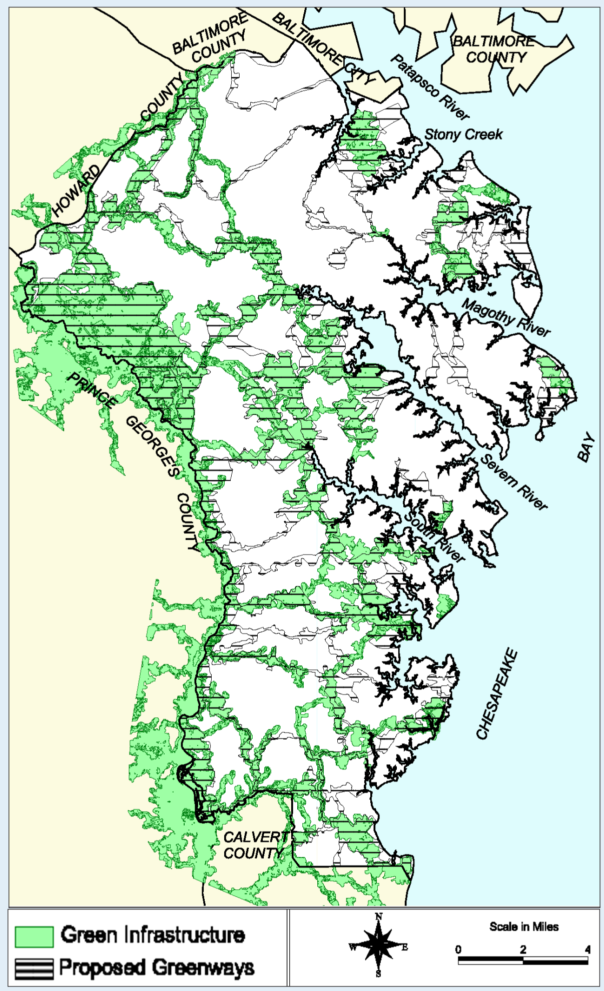


Figure 3-2 Comparison of proposed greenways and green infrastructure in Anne Arundel County, MD (modified from Anne Arundel County, 2002).

Virginia Natural Landscape Assessment

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

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

The Virginia Conservation Lands Needs Assessment (VCLNA) is a flexible GIS tool for integrated and coordinated modeling and mapping of land conservation priorities and actions in Virginia. The VCLNA is currently composed of seven separate, but interrelated models: 1) Natural Landscape Assessment Model, 2) Cultural Model, 3) Vulnerability Assessment Model, 4) Forest Economics Model, 5) Agricultural Model, 6) Recreation Model, and 7) Watershed Integrity Model. Together, these models are used to identify and assess the condition of Virginia's green infrastructure. The Natural Landscape Assessment Model is described here. The Watershed Integrity Model is described in Chapter 4. All VCLNA models, along with Virginia's Conservation Lands and a variety of reference layers, can be viewed on an interactive mapping site called the Virginia Land Conservation Data Explorer at www.vaconservedlands.org.

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

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

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

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

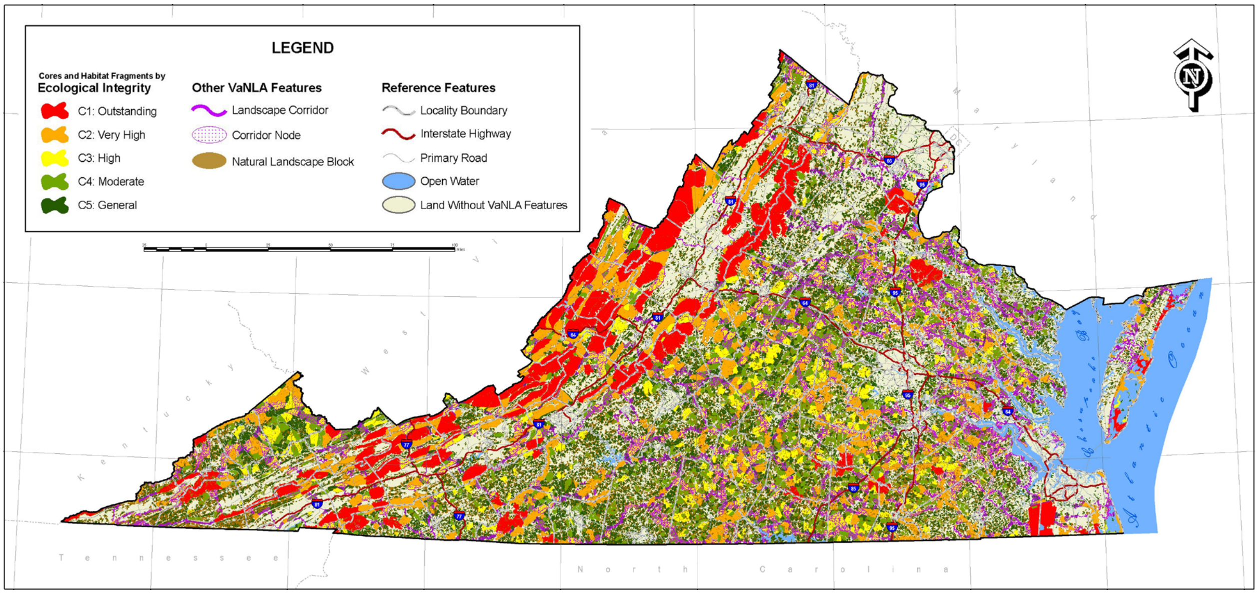


Figure 3-3 Map of results from the Virginia Natural Landscape Assessment Model (Virginia Department of Conservation and Recreation, 2008).

Case Study

Green Infrastructure in Hampton Roads

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

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

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

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

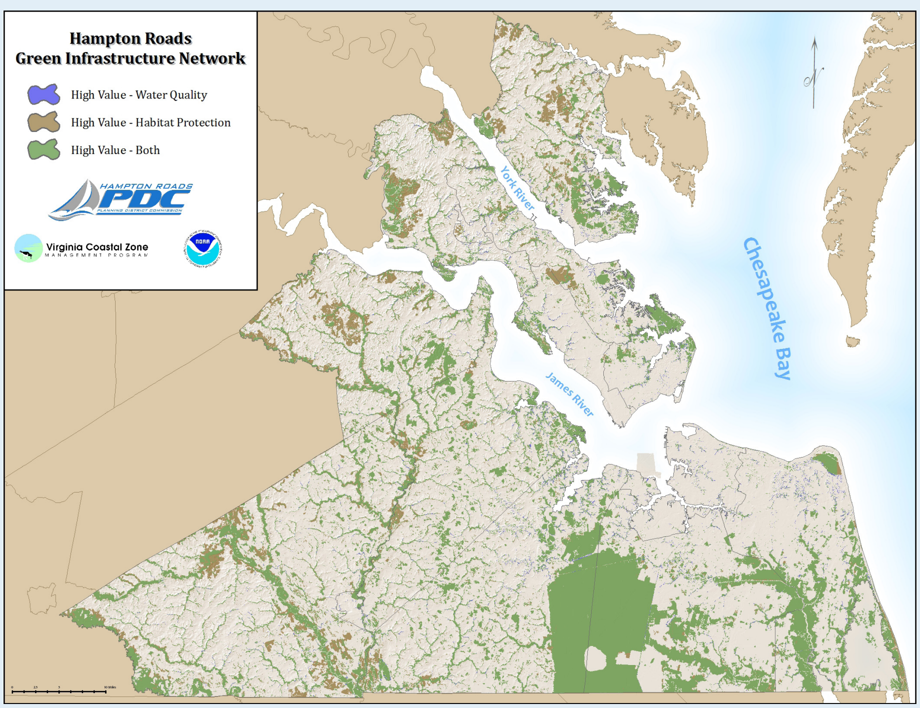


Figure 3-4 Green infrastructure in the Hampton Roads region (Kidd, McFarlane, & Walberg, 2010).

Beaver Creek Green Infrastructure Plan

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

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

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

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

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

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

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

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

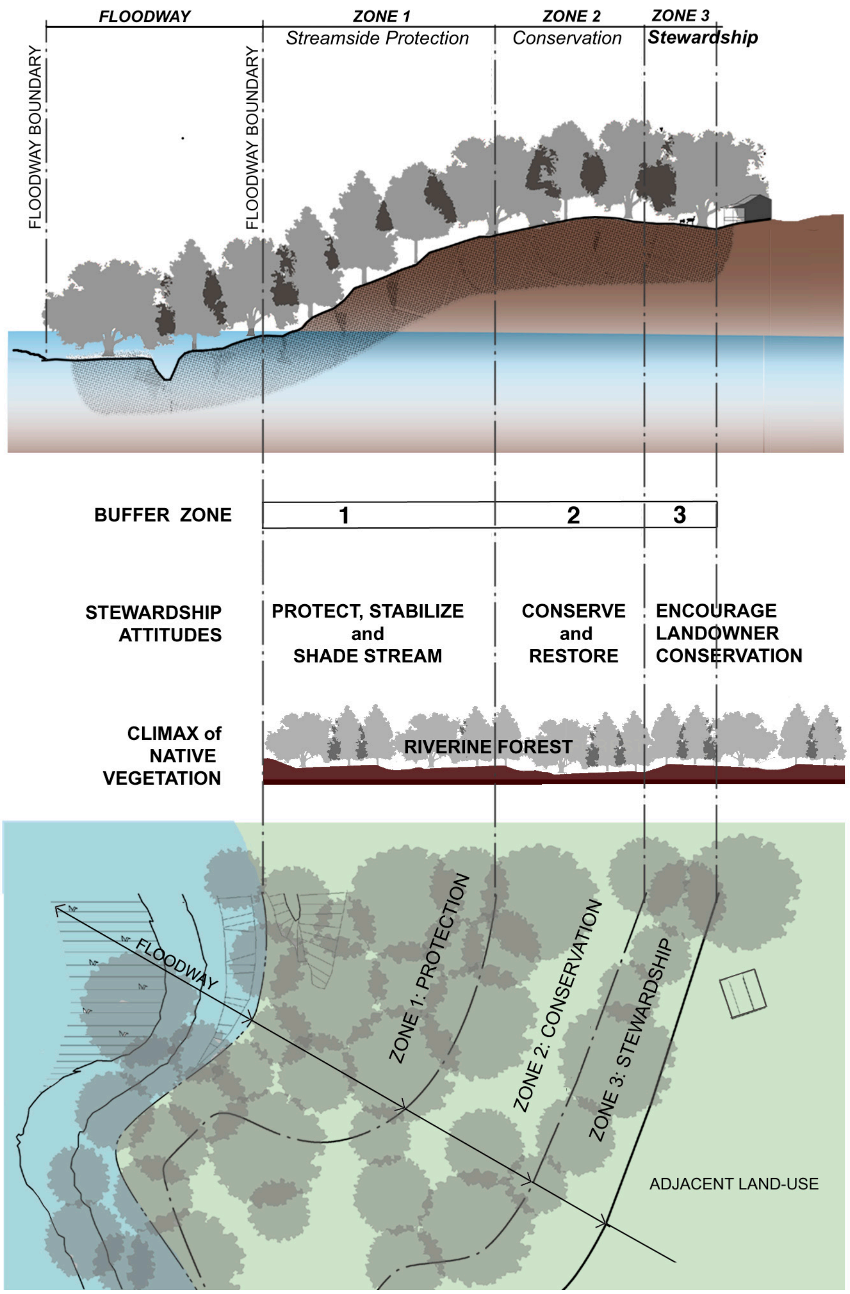


Figure 3-5 Three-zone buffer showing the protection, conservation, and stewardship zones (Moir-McClean & DeKay, 2006).

The Active River Area

Author or Lead Agency: The Nature Conservancy

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

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

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

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

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

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

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

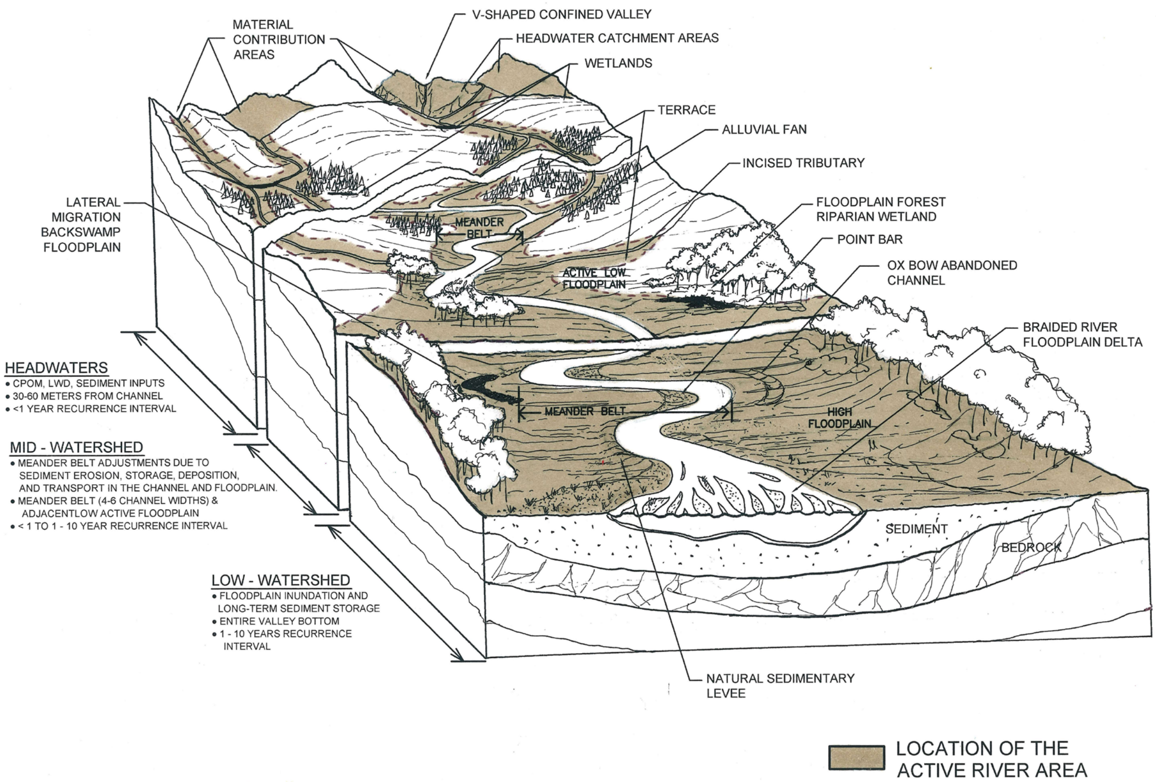


Figure 3-6 Components and dominant processes of the Active River Area (Smith et al., 2008).

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

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

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

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

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

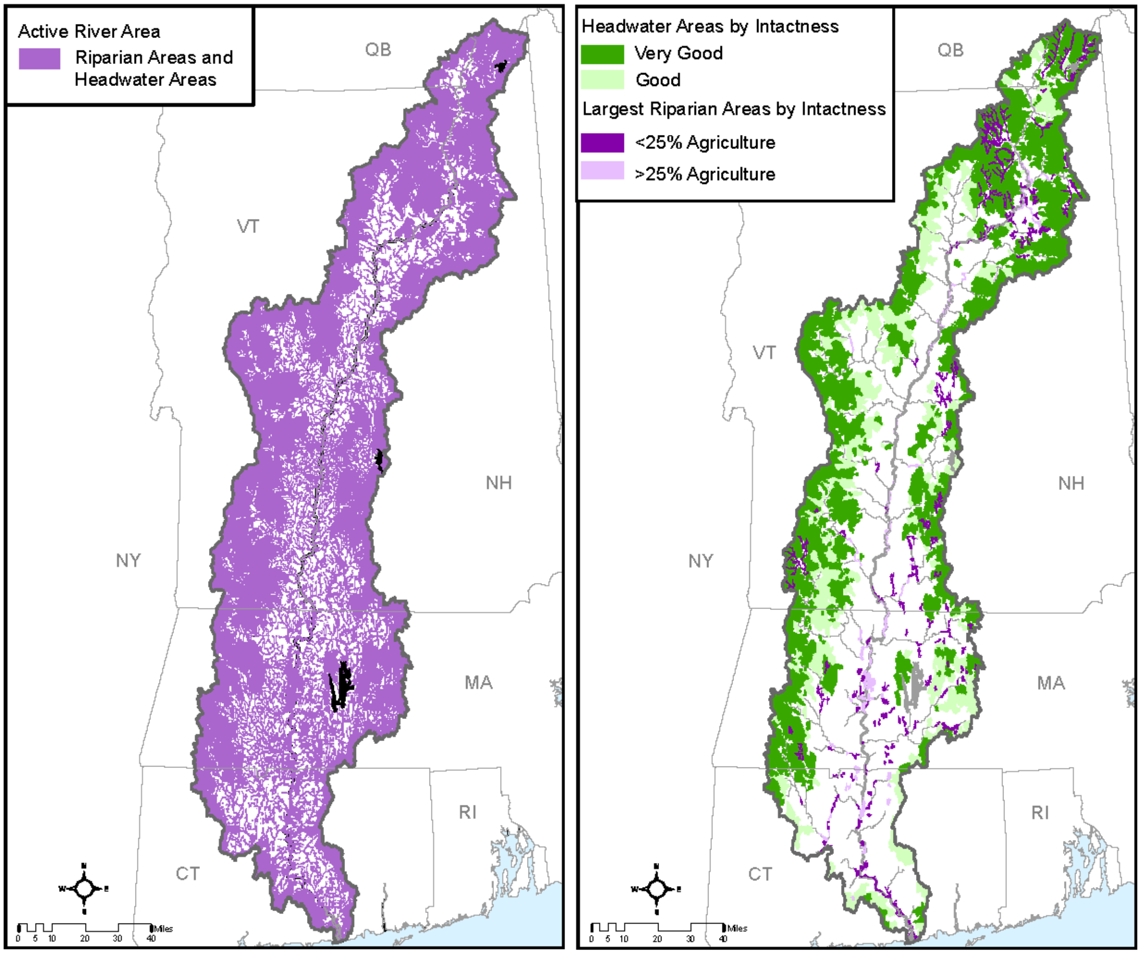


Figure 3-7 The Active River Area in the Connecticut River Basin (Smith et al., 2008).

Interagency Fire Regime Condition Class

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

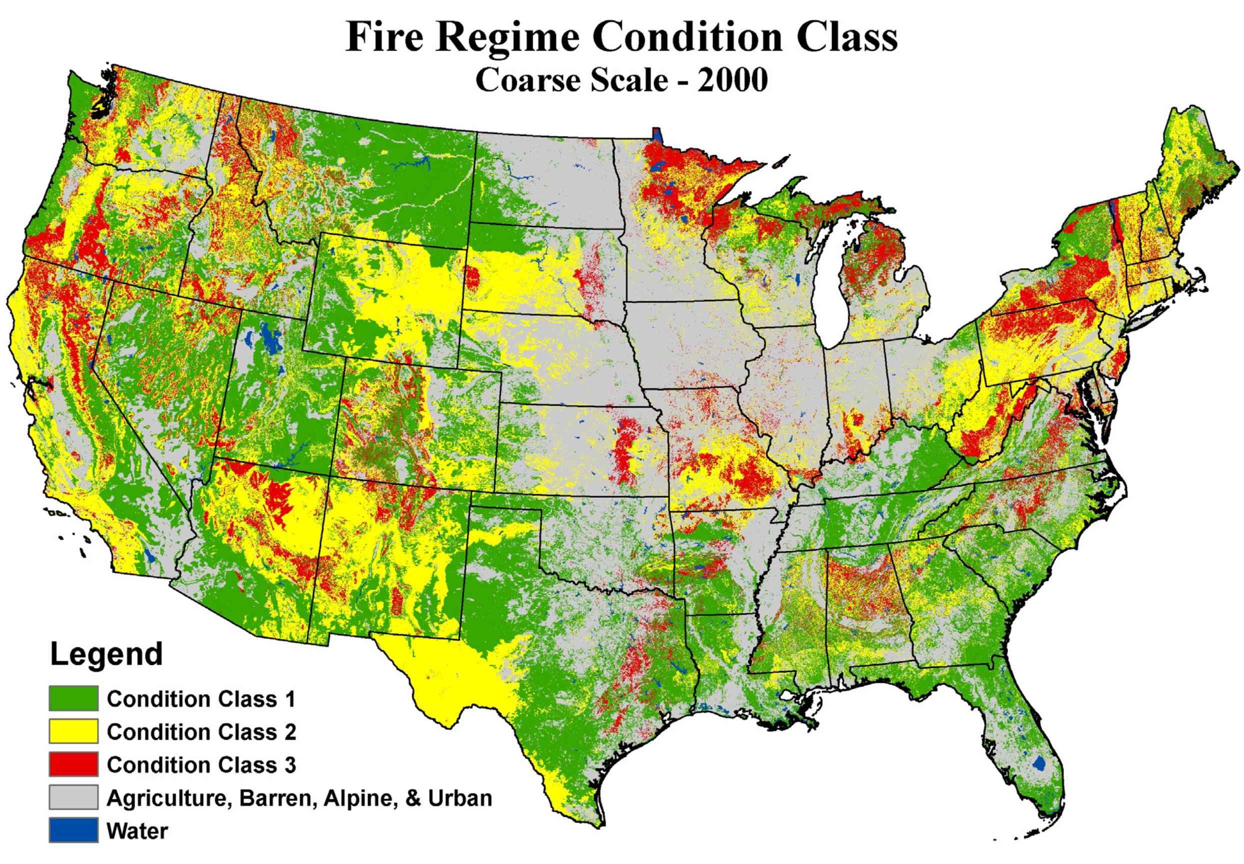
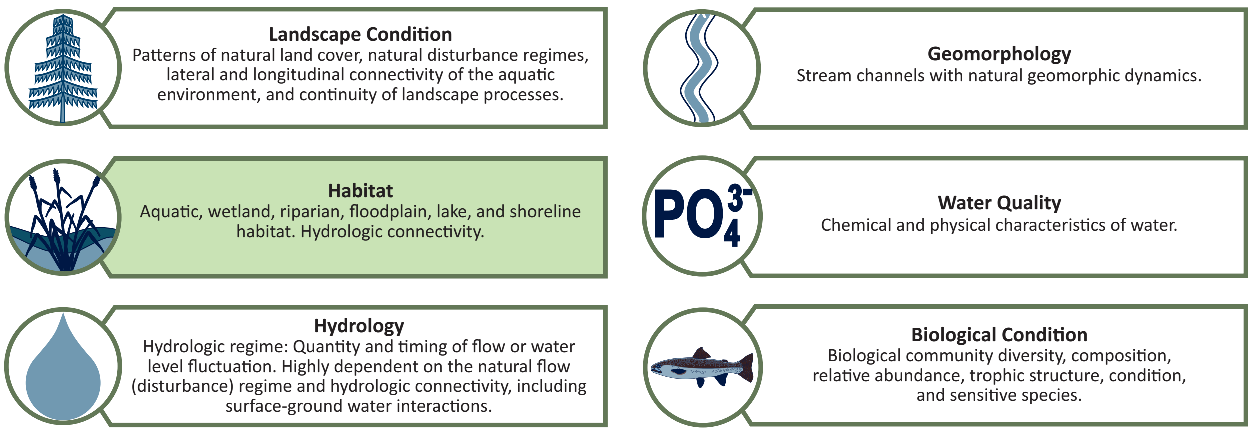


Figure 3-8 National landscape-scale output of the Fire Regime Condition Class Mapping Method. (Hann et al., 2008).

3.2 Habitat

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



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

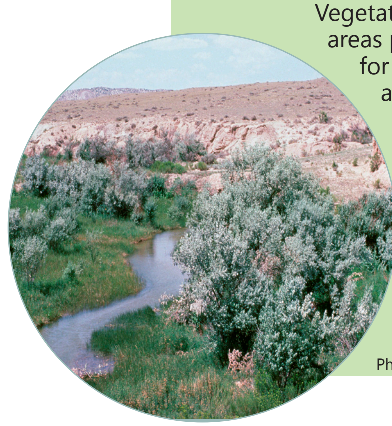
Photo: Adrian Jones, IAN.

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

Photo: USFS.

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

Photo: USFWS.



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

Photo: USFWS.

Ohio's Primary Headwaters Habitat Assessment

Author or Lead Agency: Ohio Environmental Protection Agency

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

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

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

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

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

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

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

A Physical Habitat Index for Freshwater Wadeable Streams in Maryland

Author or Lead Agency: Maryland Department of Natural Resources

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

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

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

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

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

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

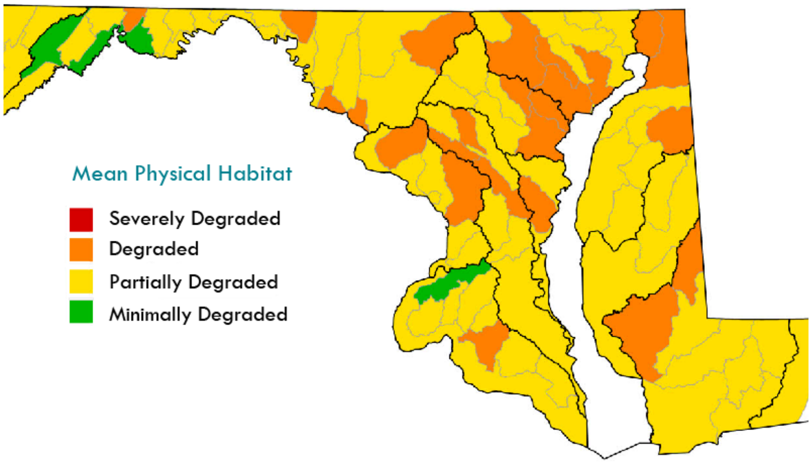


Figure 3-9 Map of stream habitat condition in Maryland, as determined with the Physical Habitat Index (Maryland Biological Stream Survey, 2005).

Proper Functioning Condition

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

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

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

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

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

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

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

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

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

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

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

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

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

Rapid Stream-Riparian Assessment

Author or Lead Agency: Wild Utah Project

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

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

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

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

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

Examples of RSRA Variables

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

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

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

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

Ohio Rapid Assessment Method

Author or Lead Agency: Ohio EPA Division of Surface Water

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

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

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

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

Metrics assessed in the quantitative rating process include:

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

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

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

California Rapid Assessment Method

Author or Lead Agency: California Wetland Monitoring Group

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

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

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

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

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

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

Wyoming Wetland Complex Inventory and Assessment

Author or Lead Agency: The Nature Conservancy

More Information: Copeland et al., 2010

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

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

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

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

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

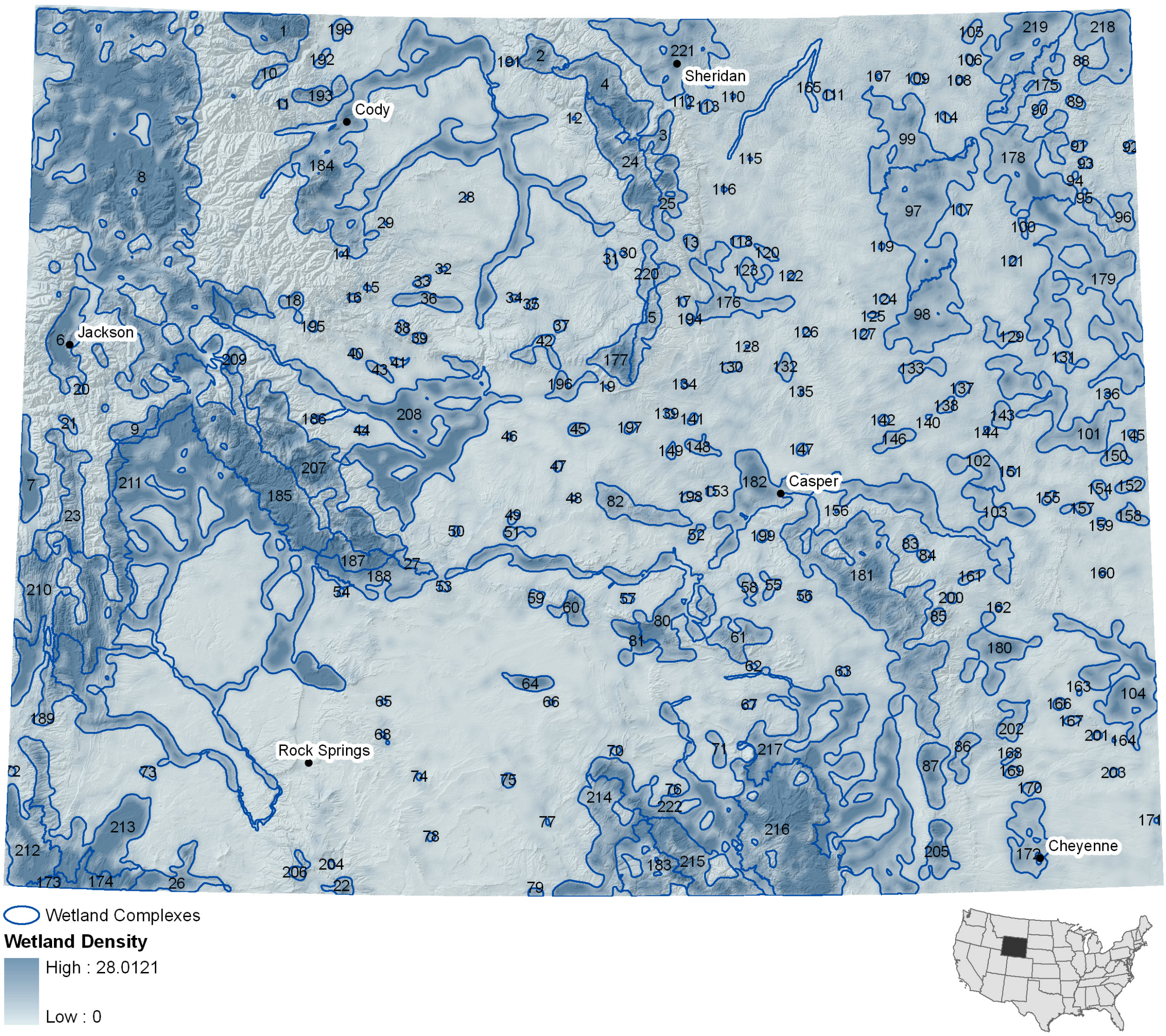


Figure 3-10 Map of focal wetland complexes shown by wetland density. Density is defined as the unit area of wetlands divided by the area of the wetland focal complex. The labels are unique wetland IDs (Copeland et al., 2010). Reprinted with permission of Elsevier.

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

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

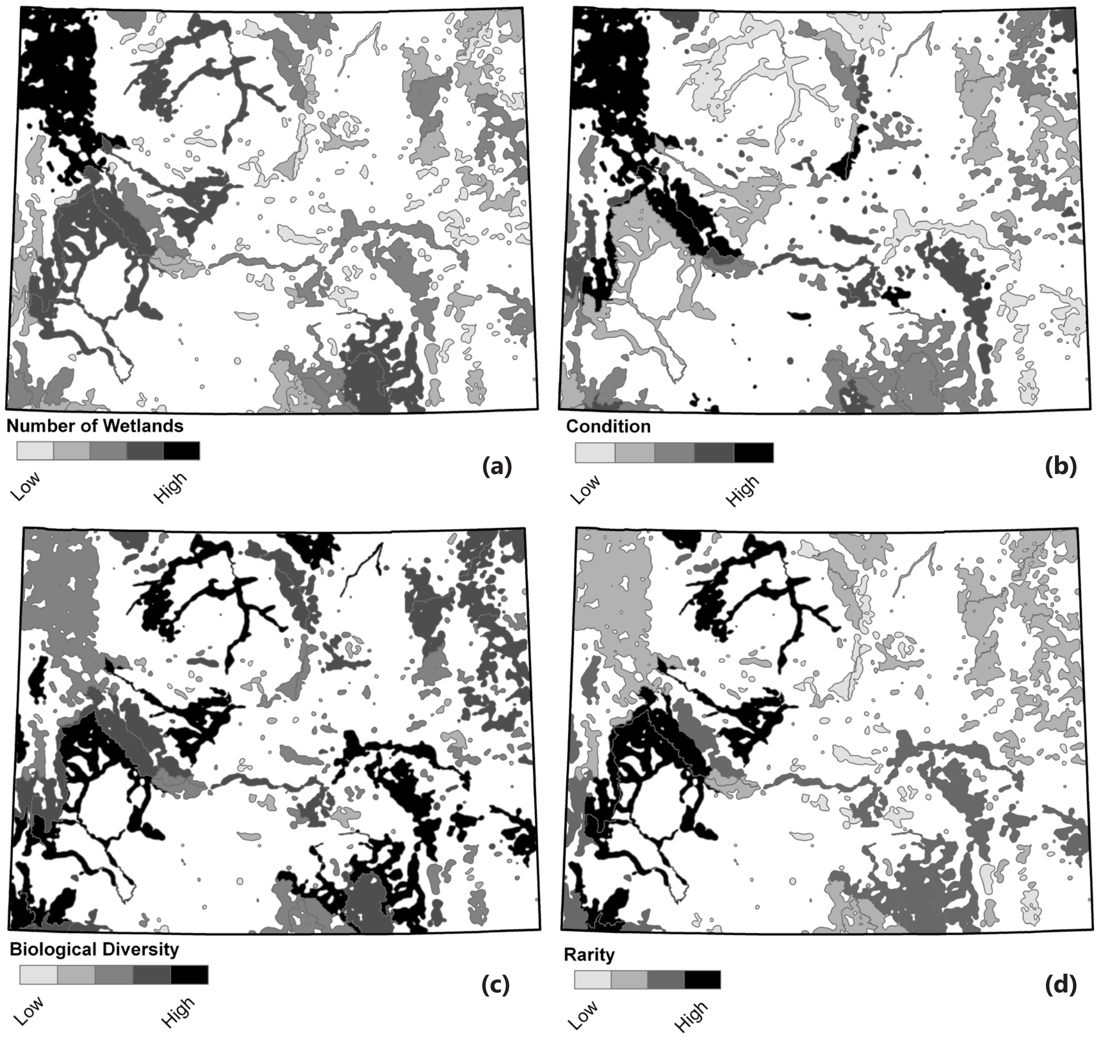


Figure 3-11 Wyoming's wetlands ranked by number (a), condition (b), Shannon diversity (c), and rarity (d). All rankings are presented using the Jenks natural breaks method (Copeland et al., 2010). Reprinted with permission of Elsevier.

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

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

3.3 Hydrology

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

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

Geomorphology
Stream channels with natural geomorphic dynamics.

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

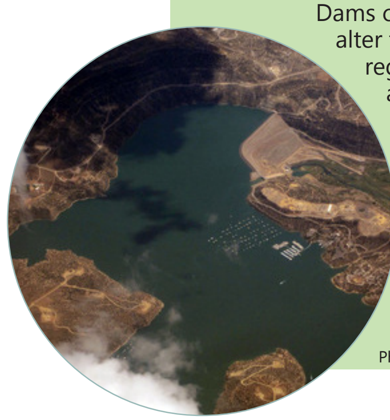
Water Quality
Chemical and physical characteristics of water.

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

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

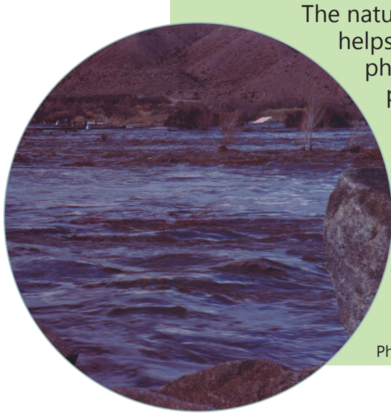
Springs are a type of ground water dependent ecosystem that are characterized by relatively stable ground water discharge, temperature, and chemistry.

Photo: USFWS.



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

Photo: Jane Hawkey, IAN.



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

Photo: BLM.

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

Photo: Melissa Andreycheck, IAN.

Ecological Limits of Hydrologic Alteration

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

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

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

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

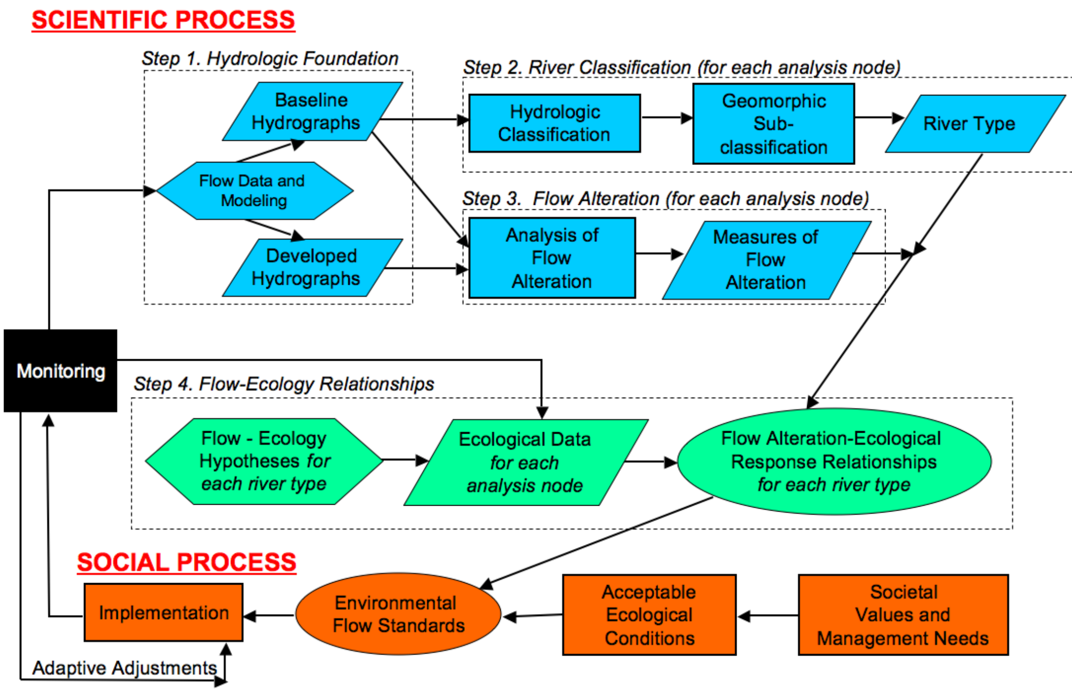


Figure 3-12 Framework for the Ecological Limits of Hydrologic Alteration Process (Poff et al., 2010). Reprinted with permission of John Wiley and Sons.

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

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

The social component of ELOHA involves three steps:

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

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

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

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

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

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

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

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

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

Case Study

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

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

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

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

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

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

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

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

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

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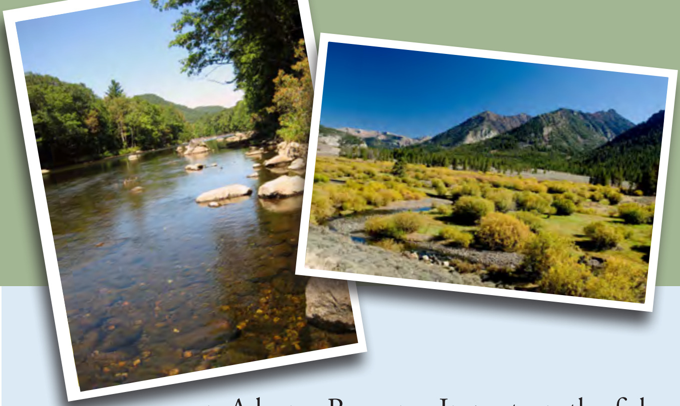

an Adverse Resource Impact on the fish community. The river-type specific, flow reduction limits were linked to a database with flow predictions for rivers statewide and a model that predicts effects of ground water pumping on stream flow (the hydrologic foundation) to develop a water withdrawal assessment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

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

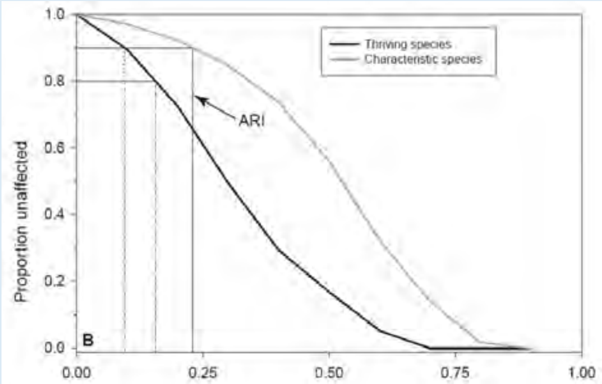

Figure 3-14 Example flow alteration-ecological response curves from Michigan (Zorn et al., 2008). For this river type, an Adverse Resource Impact (10% decline in the fish community metric) occurs when the index flow declines by about 23%.

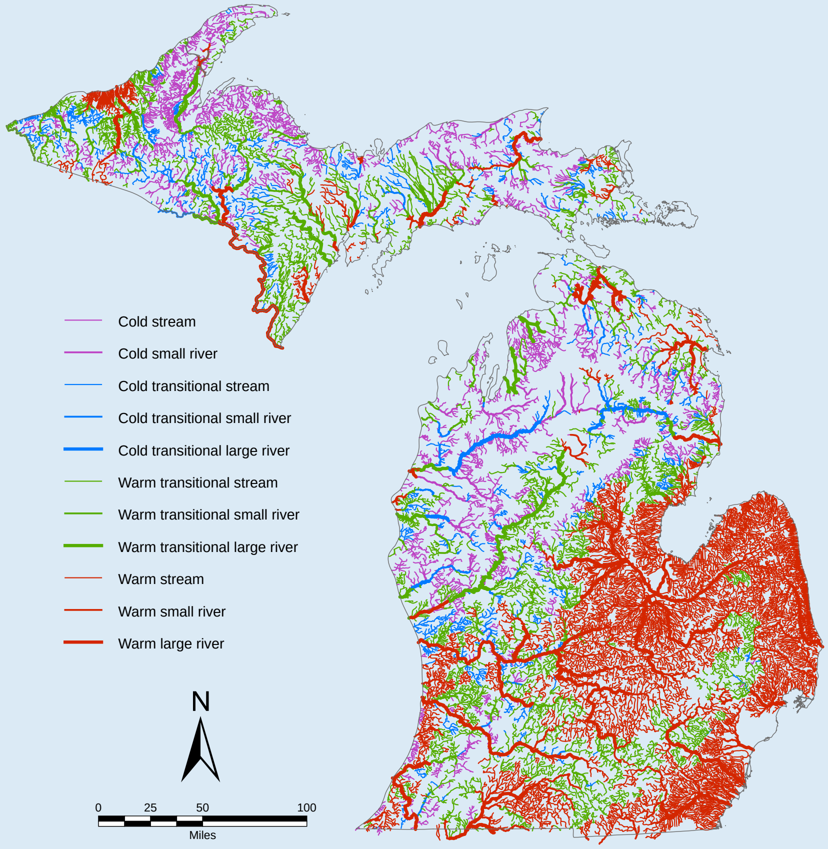

Figure 3-13 Thermal and fish assemblage based classification of streams, small rivers, and large rivers in Michigan (Zorn et al., 2008).

Texas Instream Flow Program

Author or Lead Agency: Texas Water Development Board

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

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

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

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

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

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

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

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

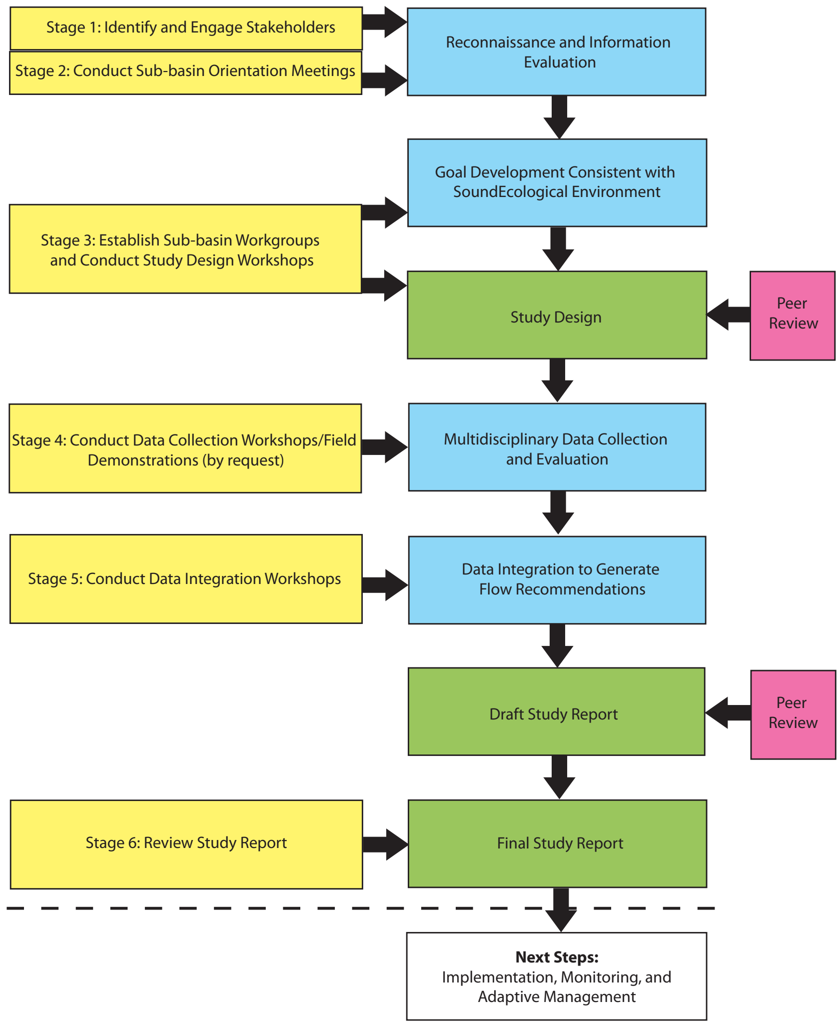

Figure 3-15. Diagram of the Texas Instream Flows Program process. Blue boxes represent the four primary steps, green boxes represent deliverables, yellow boxes represent public outreach components, and pink boxes represent peer review steps (Texas Commission on Environmental Quality; Texas Parks and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

Case Study

San Antonio River Basin

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

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

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

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

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

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

Continued on page 3-42

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

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

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

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

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

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

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

Hydrogeomorphic Classification of Washington State Rivers

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

More Information: Reidy Liermann et al., 2011

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

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

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

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

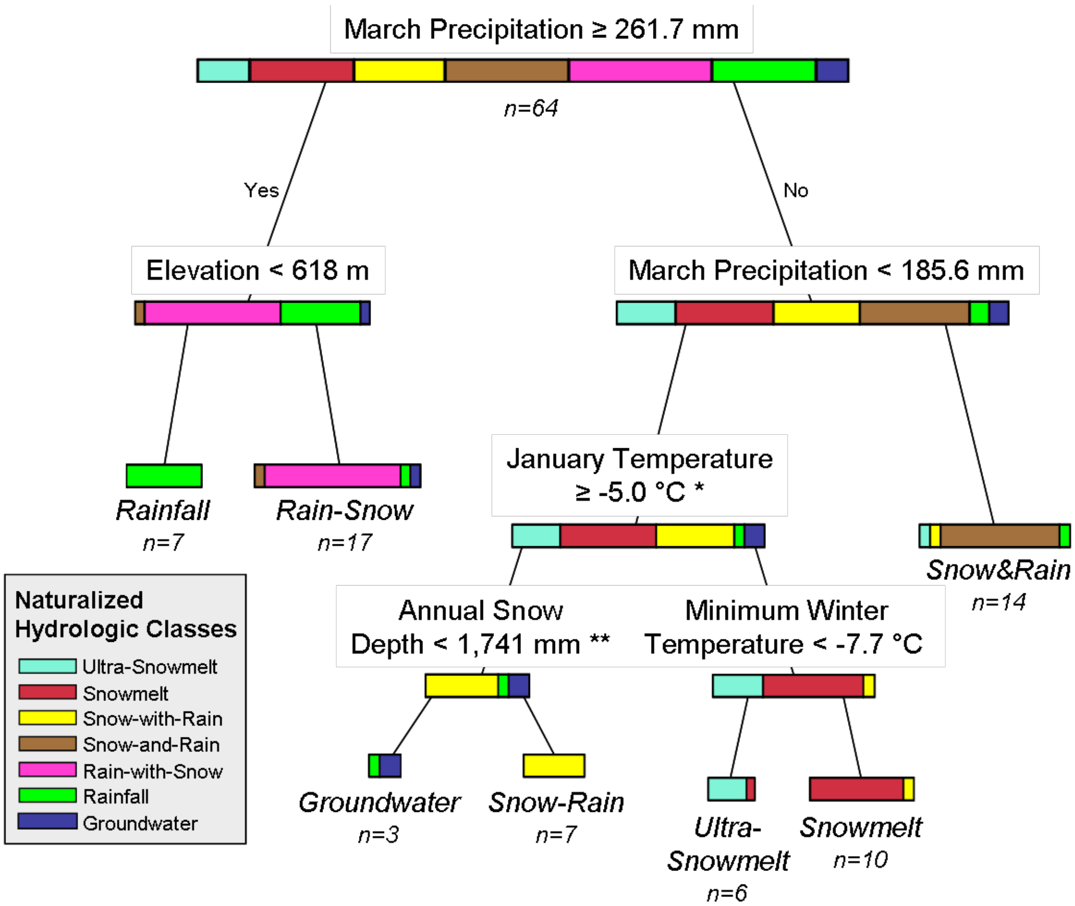

Figure 3-17 Classification tree showing the seven naturalized hydrologic classes. Combined with the geomorphic classification distinguishing between migrating and non-migrating channels, the number of stream classes doubles (Reidy Liermann et al., 2011).

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

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

Ground Water Dependent Ecosystems Assessment

Author or Lead Agency: The Nature Conservancy

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

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

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

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

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

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

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

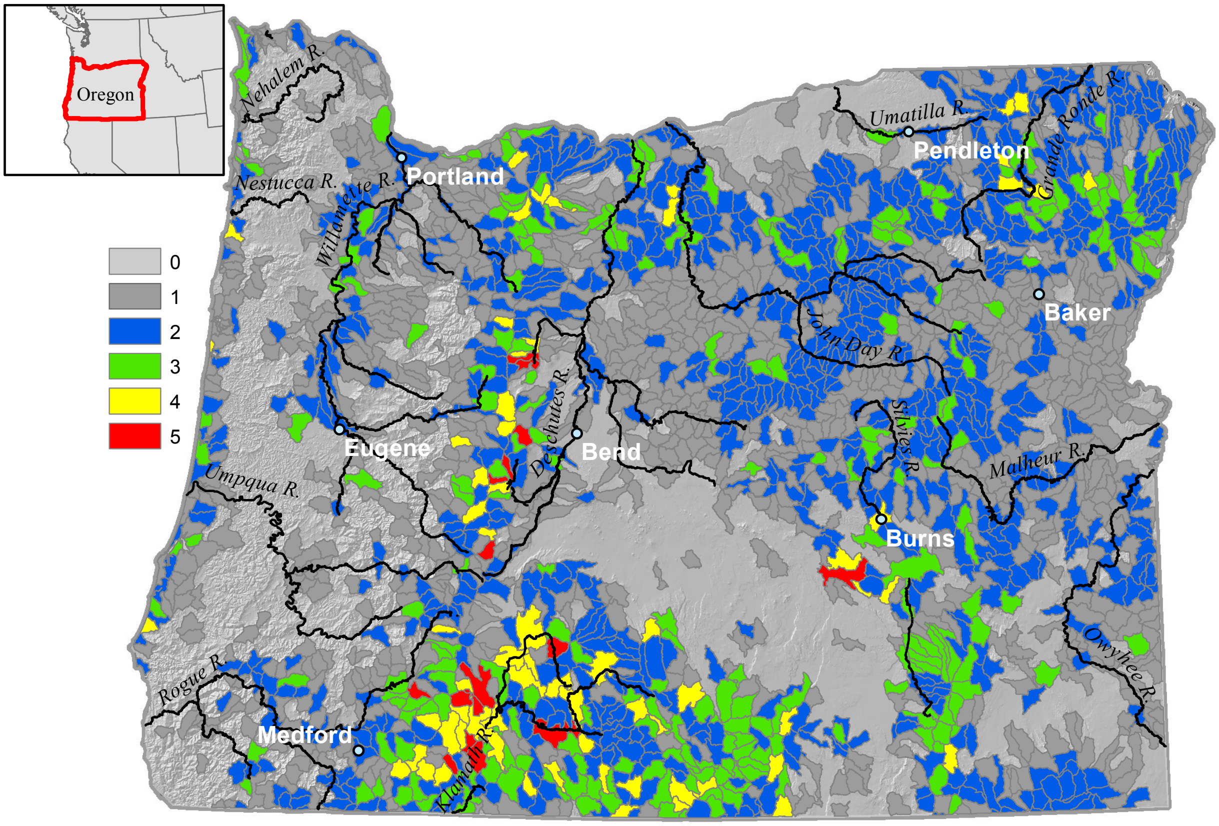

Figure 3-18 Ground water dependent ecosystem clusters (blue through red). Number of ground water dependent ecosystems present in each HUC12, per criteria in Table 3-9 (Brown et al., 2009a).

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

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

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

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

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

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

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

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

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

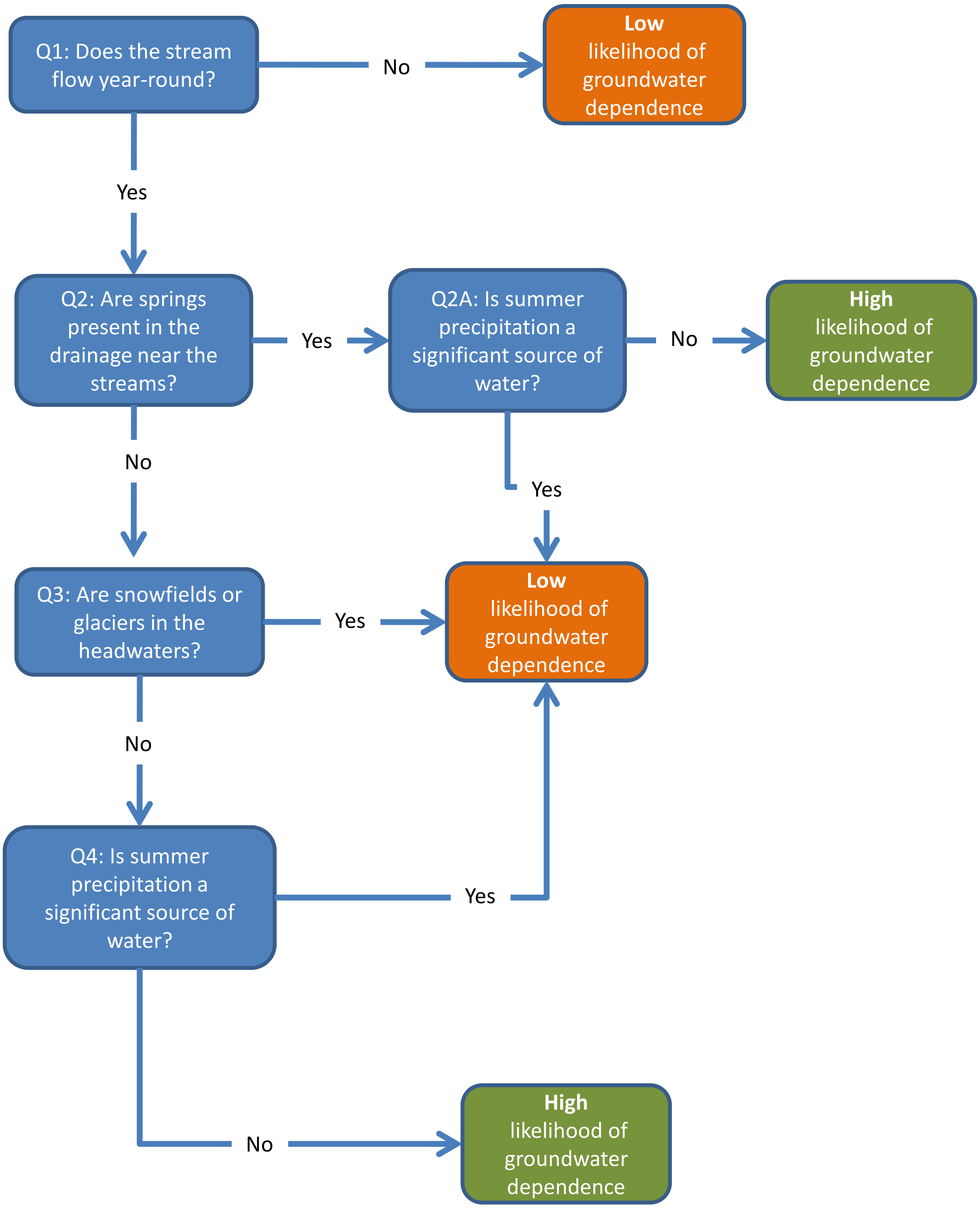

Figure 3-19 Decision tree for identifying ground water dependent river ecosystems (Brown et al., 2009a).

Case Study

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

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

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

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

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

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

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

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

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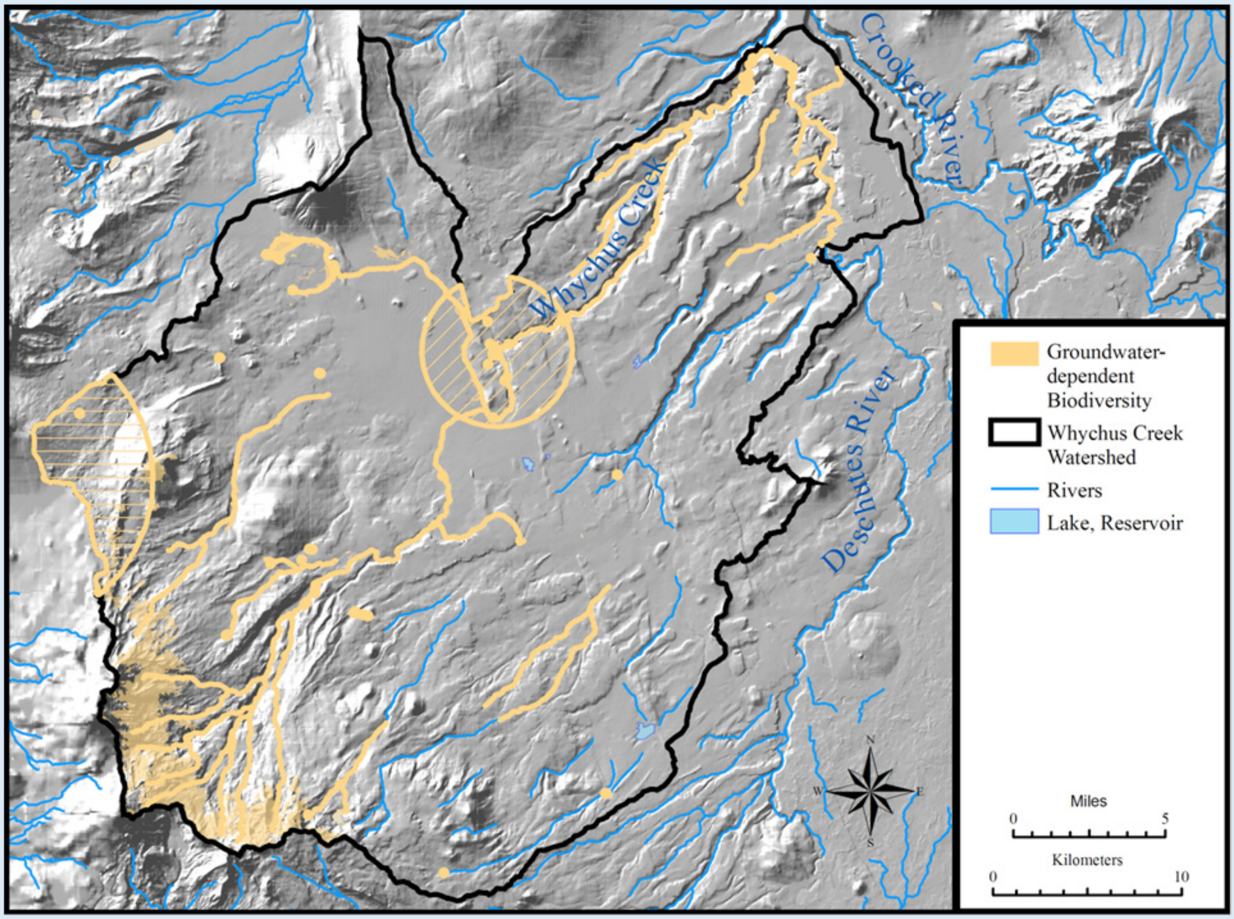


Figure 3-20 Ground water dependent biodiversity in the Whychus Creek Watershed (Brown et al., 2007).

3.4 Geomorphology

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

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

Geomorphology
Stream channels with natural geomorphic dynamics.

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

Water Quality
Chemical and physical characteristics of water.

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

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

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

Photo: BLM.

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

Photo: USFWS.

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

Photo: NRCS.

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

Photo: USFWS.

Vermont's Stream Geomorphic and Reach Habitat Assessment Protocols

Author or Lead Agency: Vermont Agency of Natural Resources

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

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

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

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

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

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

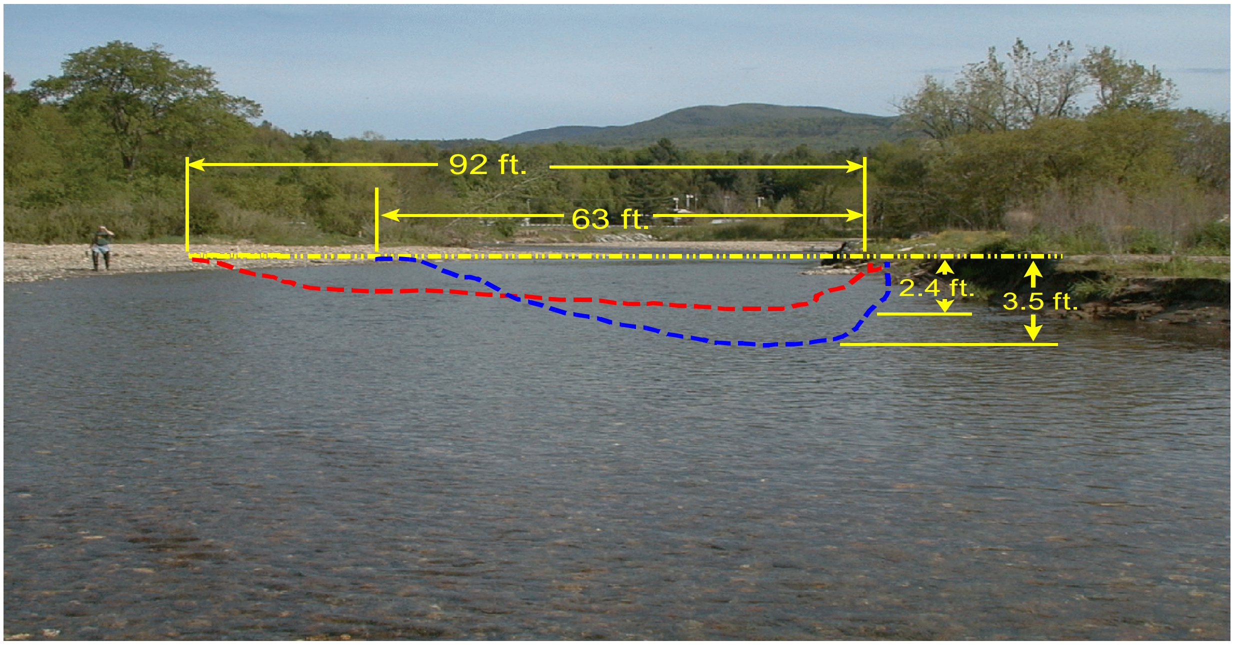


Figure 3-21 Phase 3 data gathering (Vermont Department of Environmental Conservation, 2007).

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

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

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

Case Study

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

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

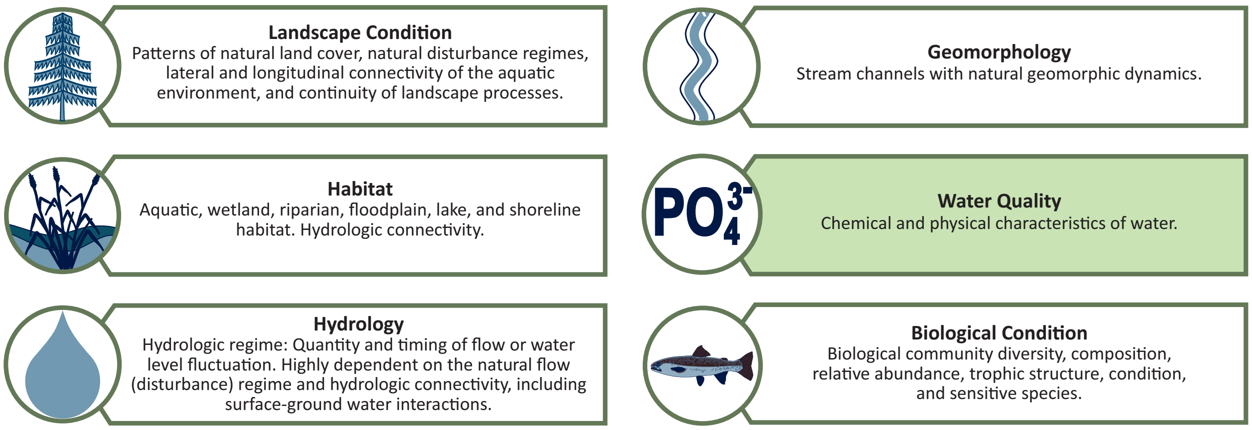
The Batten Kill is considered Vermont's best trout fishing stream and has been rated by Trout Unlimited as one of the 10 best trout streams in the United States (Cox, 2006). However, since the early 1900s the quality of the fishery has been declining (Jaquith, Kline, Field, & Henderson, 2004). Altered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

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

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

3.5 Water Quality

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

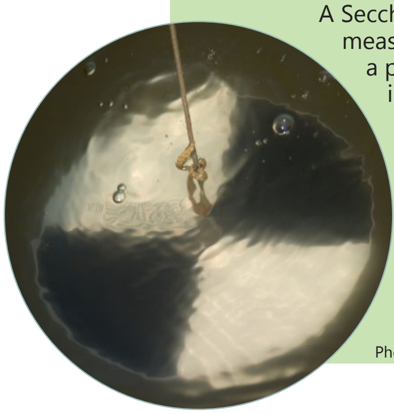


Riparian buffers filter pollutants, regulate water temperature, and help to maintain hydrologic regimes that support water quality.

Photo: NRCS.

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

Photo: NRCS.



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

Photo: Adrian Jones, IAN.

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

Photo: Jane Thomas, IAN.

Oregon Water Quality Index

Author or Lead Agency: Oregon Department of Environmental Quality

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

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

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

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

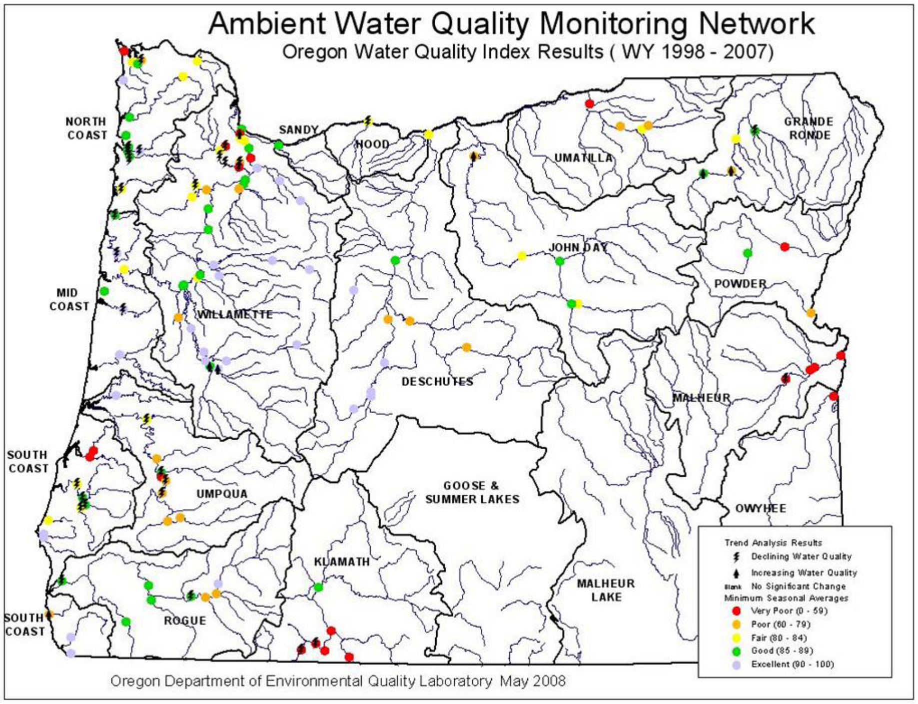


Figure 3-23 Map of Oregon Water Quality Index (WQI) results for water years (WY) 1998-2007 (Oregon Department of Environmental Quality, 2008).

3.6 Biological Condition

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

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

Geomorphology
Stream channels with natural geomorphic dynamics.

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

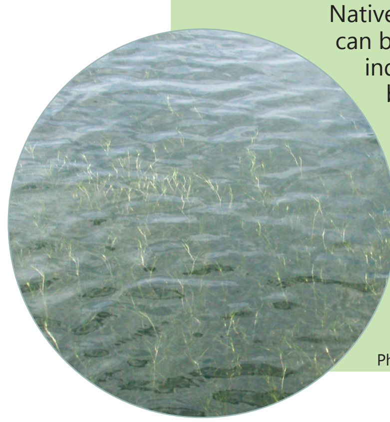
Water Quality
Chemical and physical characteristics of water.

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

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

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

Photo: Jane Hawkey, IAN.



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

Photo: Ben Fertig, IAN.

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

Photo: USFWS.

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

Photo: USFWS.

Index of Biotic Integrity

Author or Lead Agency: James Karr

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

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

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

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

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

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

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

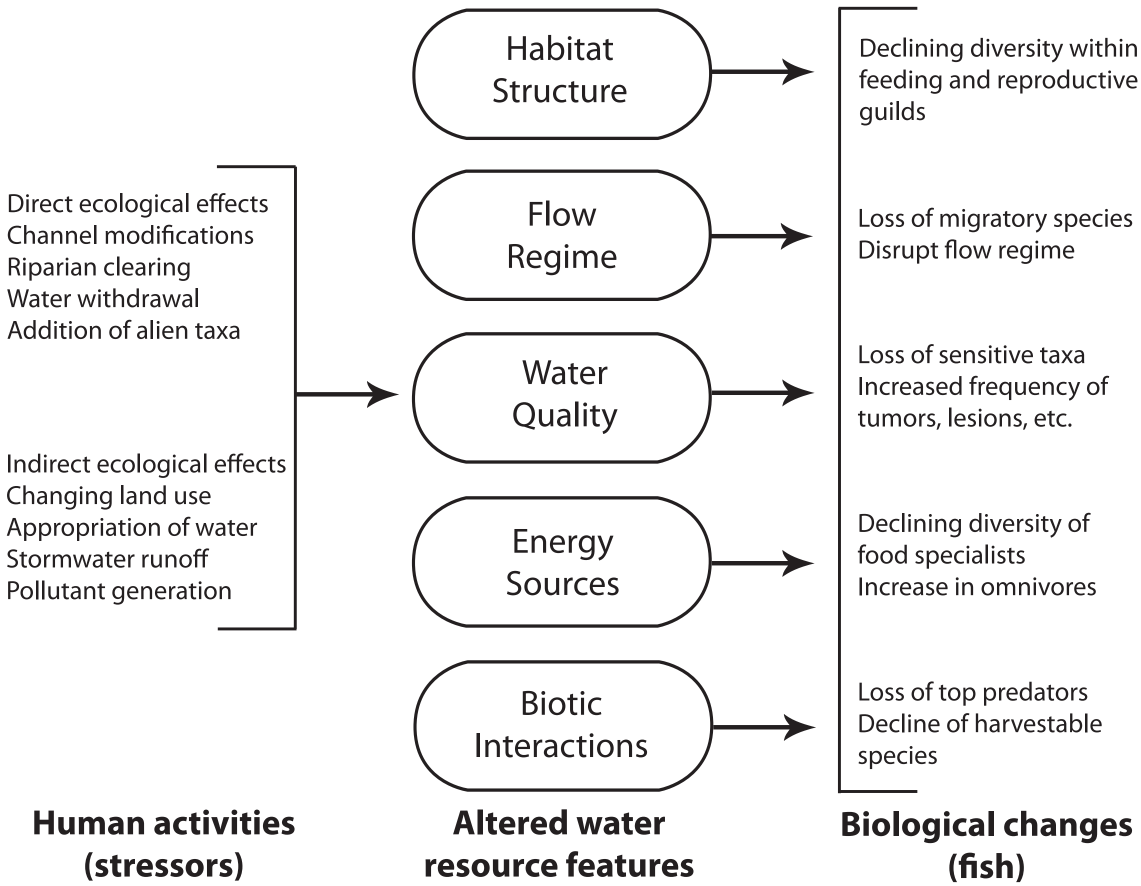


Figure 3-24 Human activities alter five water resource features, resulting in alteration of fish communities (Modified from Karr & Yoder, 2004).

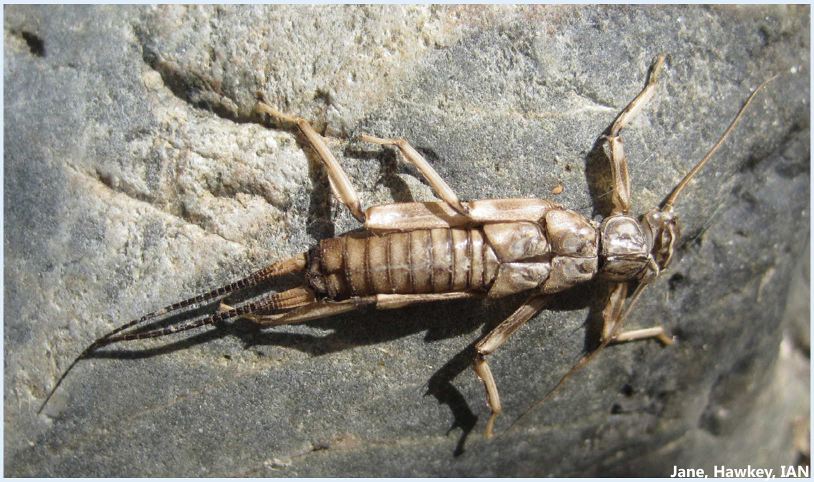
Case Study

Ohio Statewide Biological and Water Quality Monitoring and Assessment

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

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

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



The Biological Condition Gradient and Tiered Aquatic Life Uses

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

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

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

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

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

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

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

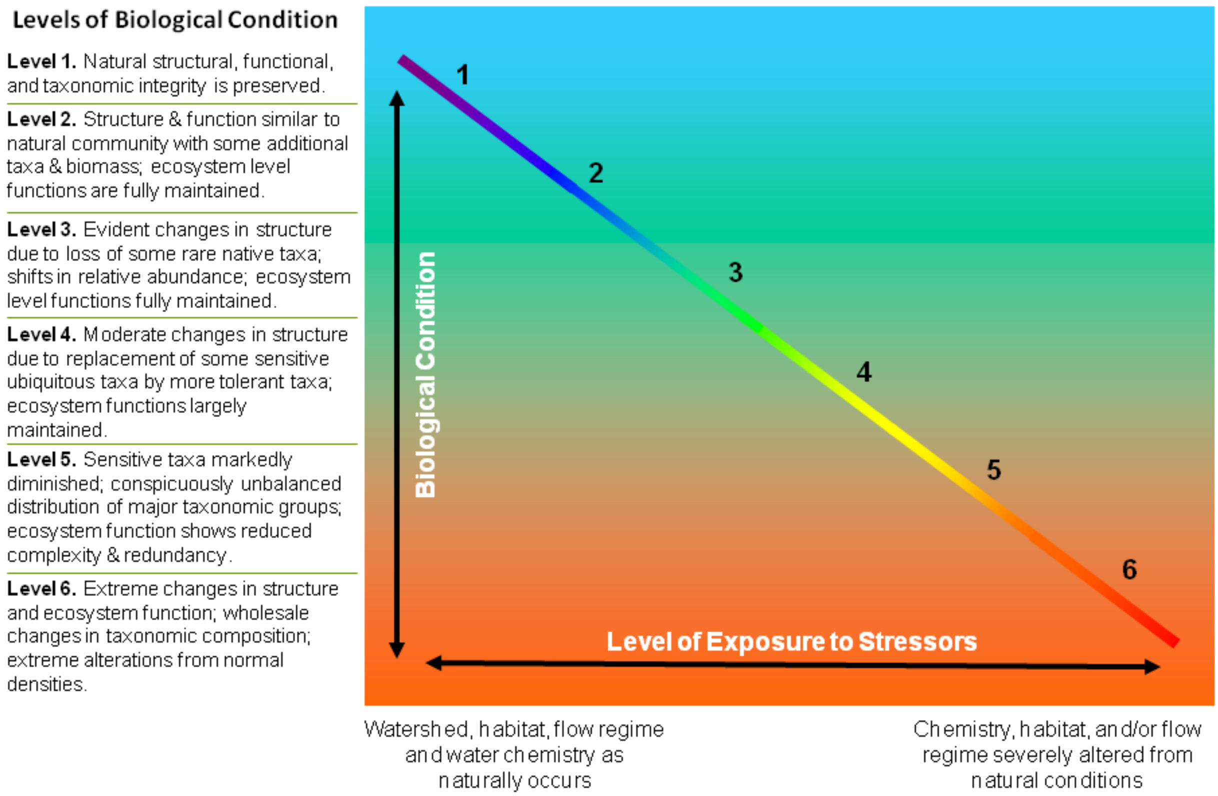


Figure 3-25 Conceptual model of the Biological Condition Gradient (U.S. Environmental Protection Agency, 2011c).

Case Study

Maine Tiered Aquatic Life Use Implementation

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

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

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

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

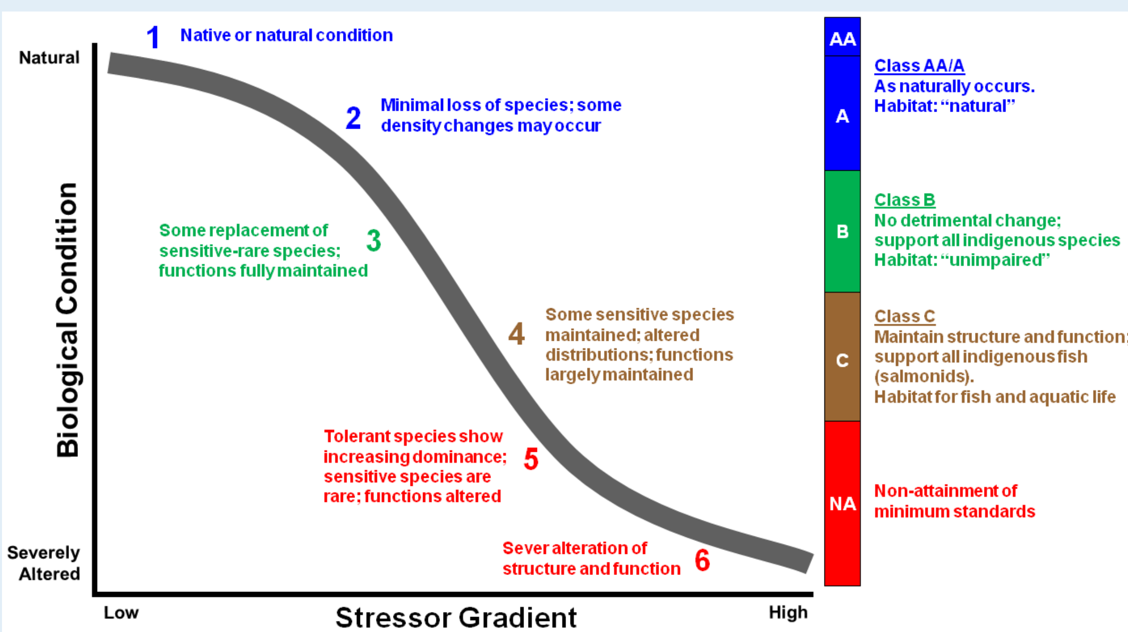


Figure 3-26 Maine Tiered Aquatic Life Uses in relation to Biological Condition Gradient Levels (Davies and Courtemanch, 2012).

Aquatic Gap Analysis Program

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

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

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

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

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

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

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

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

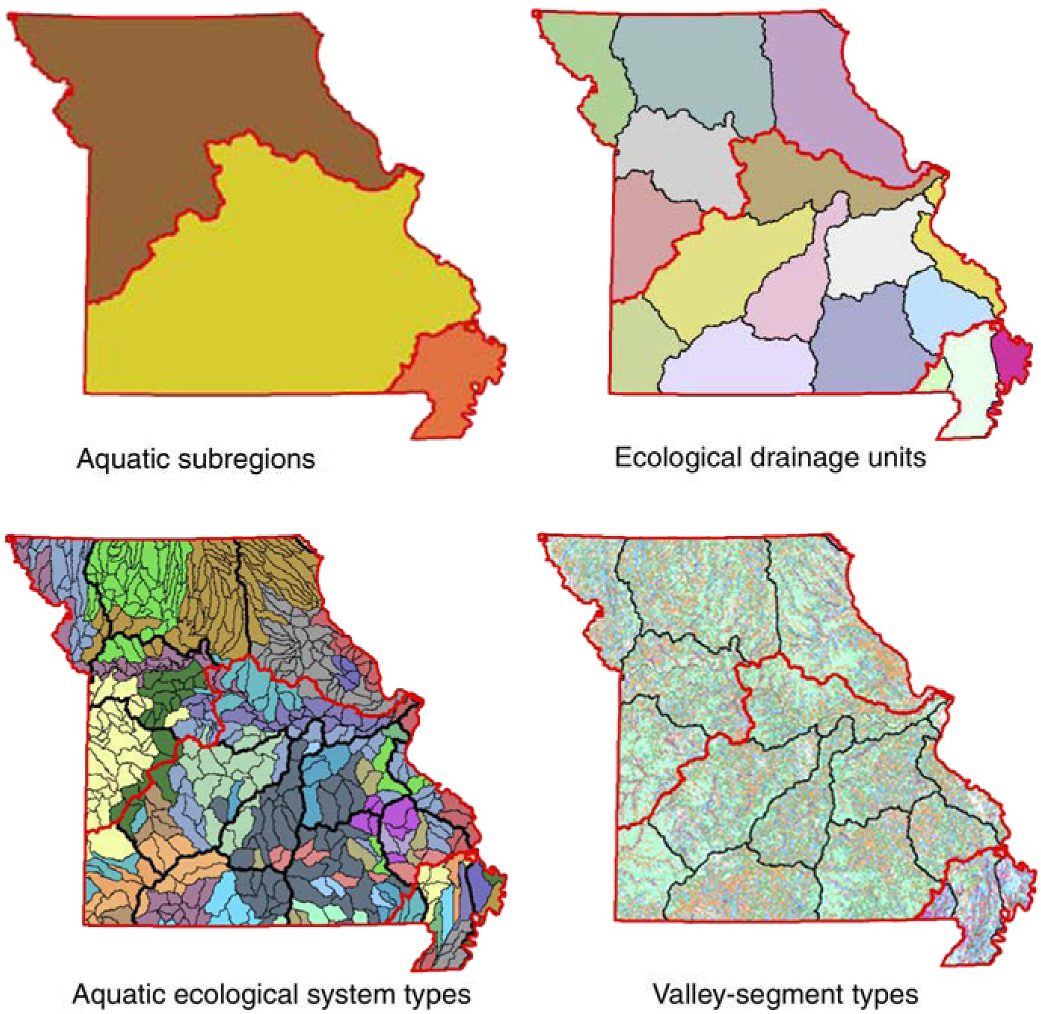


Figure 3-27 Maps of Missouri showing levels four through seven of the aquatic ecological classification hierarchy (Sowa et al., 2007). Reprinted with permission of Ecological Society of America.

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

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

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

AES-level Criteria ***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 value and qualitative evaluation of threats using the full breadth of available human-threats data.	Has the lowest degree of human disturbance based on a qualitative evaluation of relative local and watershed conditions using the full breadth of available human-threats data.
Has the highest percentage of public ownership.	Is already contained within the existing matrix of public lands.
Overlaps with existing conservation initiatives or high public support for conservation.	Overlaps with existing conservation initiatives or high public support for conservation.

Case Study

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

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

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

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

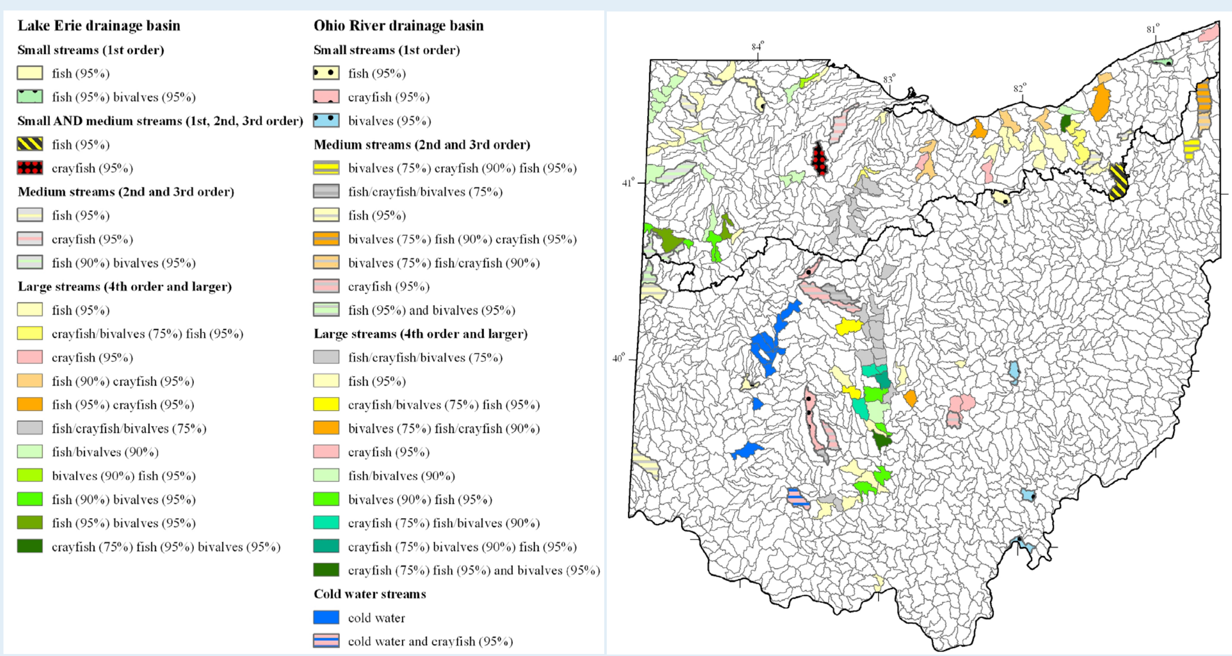


Figure 3-28 HUC12 watersheds in Ohio. The different color watersheds represent high predicted aquatic species richness for various taxa (U.S. Geological Survey, 2006).

Natural Heritage Program Biodiversity Assessments

Author or Lead Agency: NatureServe and state partners

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

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

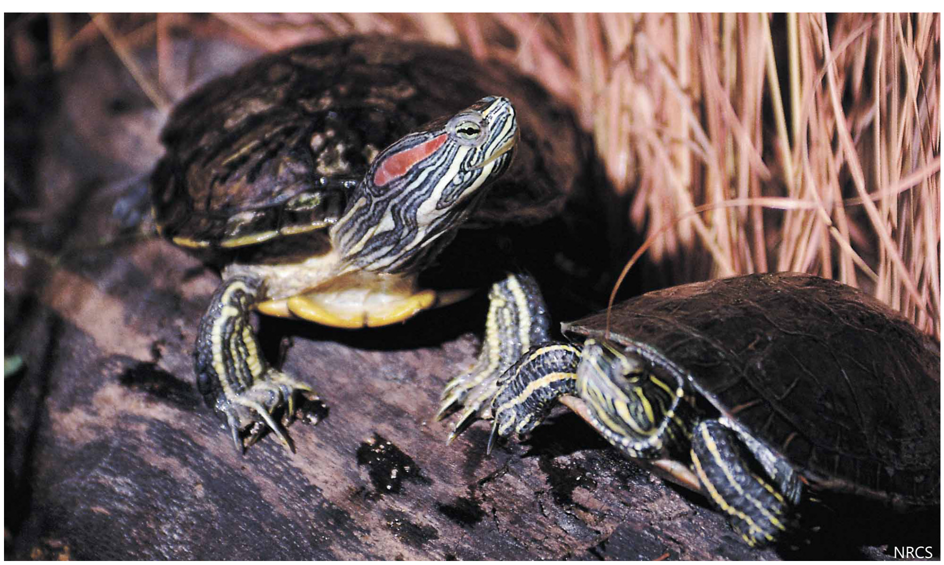
The Natural Heritage Methodology gathers, analyzes, organizes, and manages information on biodiversity through a network of professional biologists in partner agencies who keep pace with the growth in scientific understanding while maintaining an underlying continuity in the methodology. NatureServe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

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

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 Biodiversity Information Center

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

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

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

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

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

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

Virginia Interactive Stream Assessment Resource and Healthy Waters Program

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

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

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

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

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

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

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

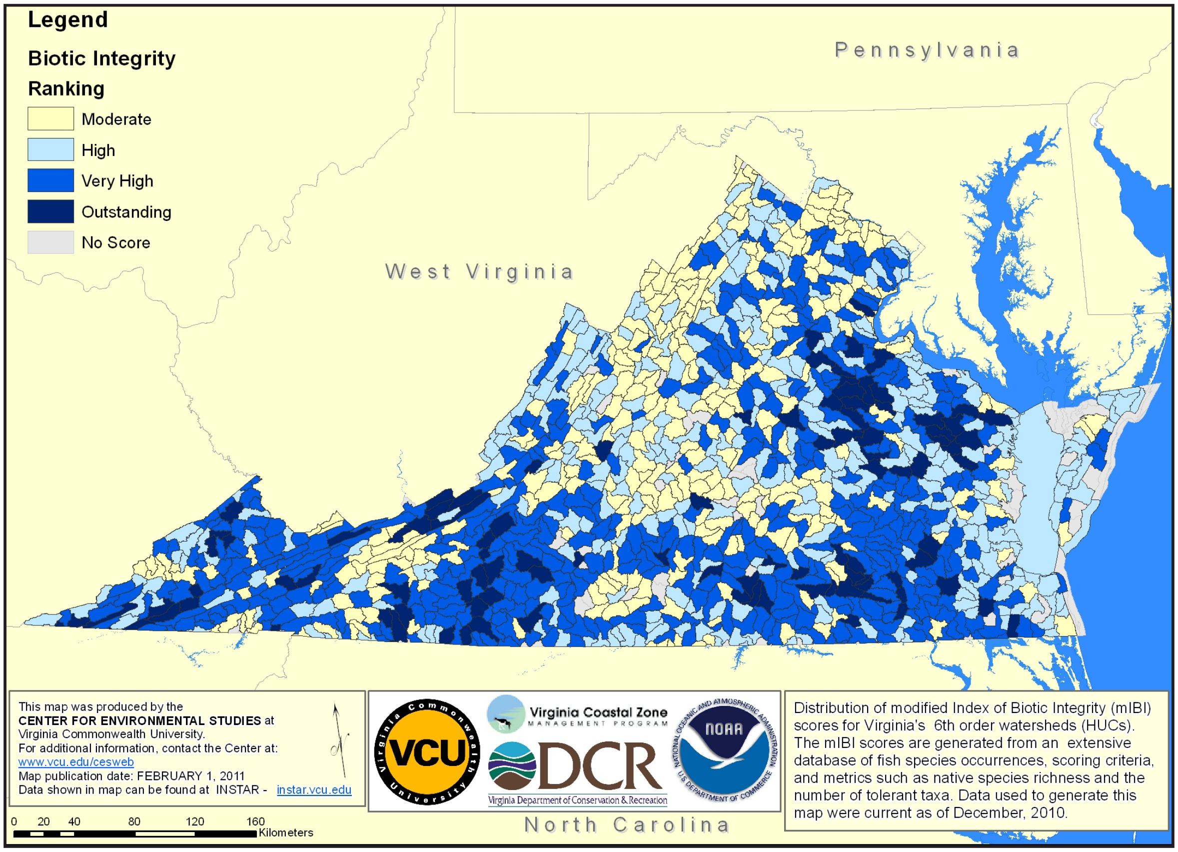


Figure 3-29 Map of watershed integrity in Virginia based on modified Index of Biotic Integrity scores (Greg Garman, Virginia Commonwealth University, Personal Communication).

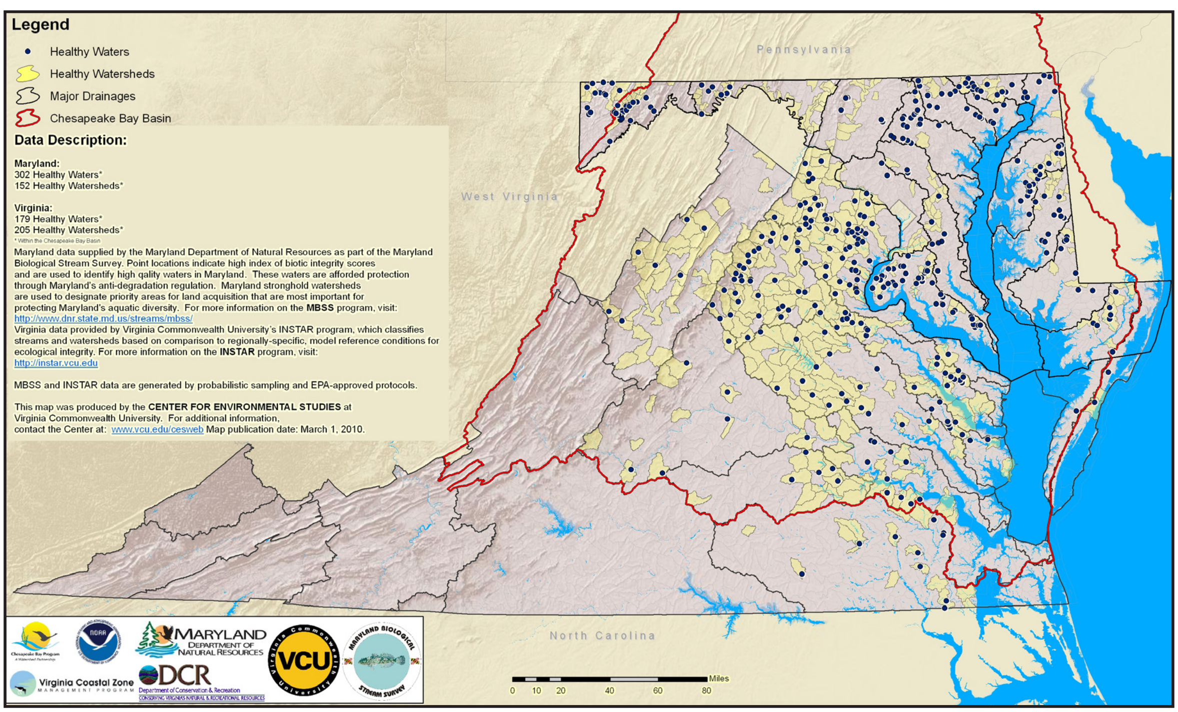
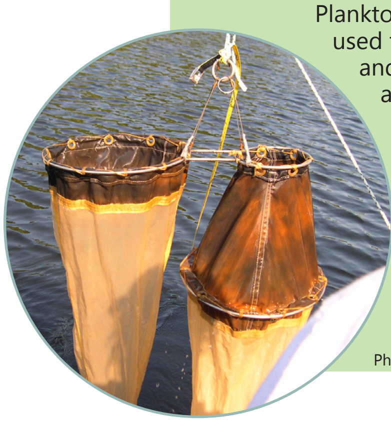


Figure 3-30 Status of healthy waters and watersheds in Maryland and Virginia (Greg Garman, Virginia Commonwealth University, Personal Communication).

3.7 National Aquatic Resource Assessments

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



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

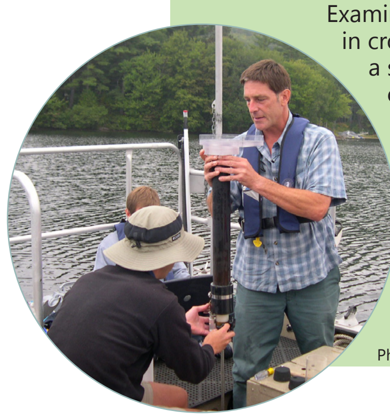
Photo: NEIWPCC.

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

Photo: USFWS.

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

Photo: USGS.



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

Photo: NEIWPCC

National Rivers and Streams Assessment

Author or Lead Agency: U.S. EPA

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

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

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

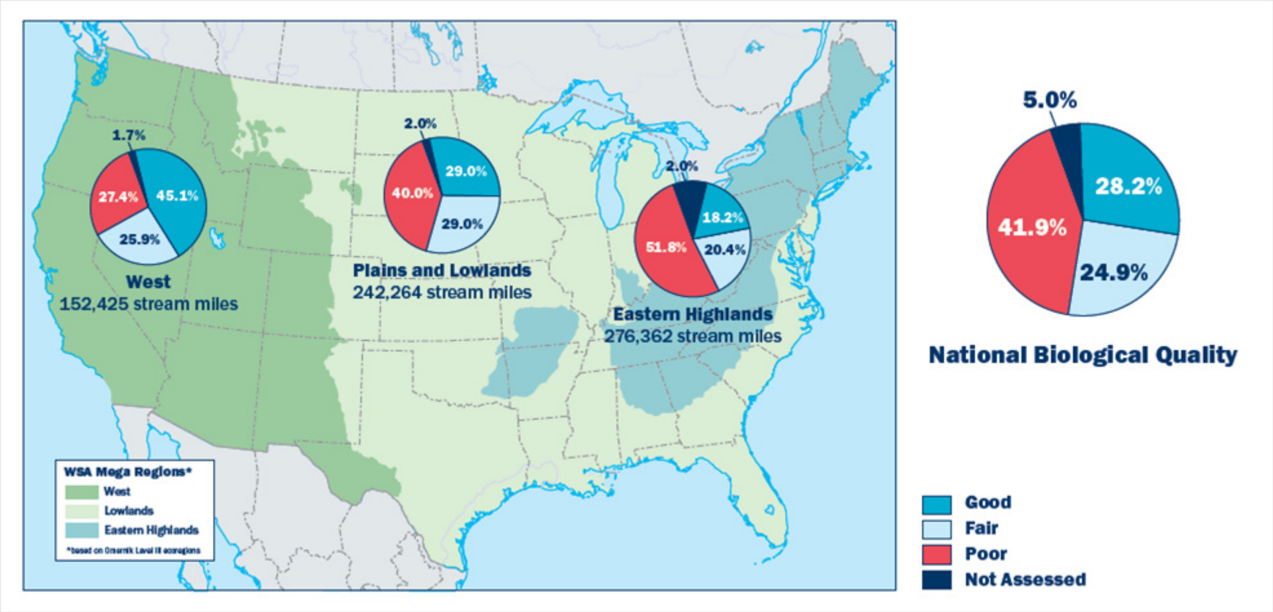


Figure 3-31 Biological quality results from EPA's Wadeable Streams Assessment (U.S. Environmental Protection Agency, 2008c).

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

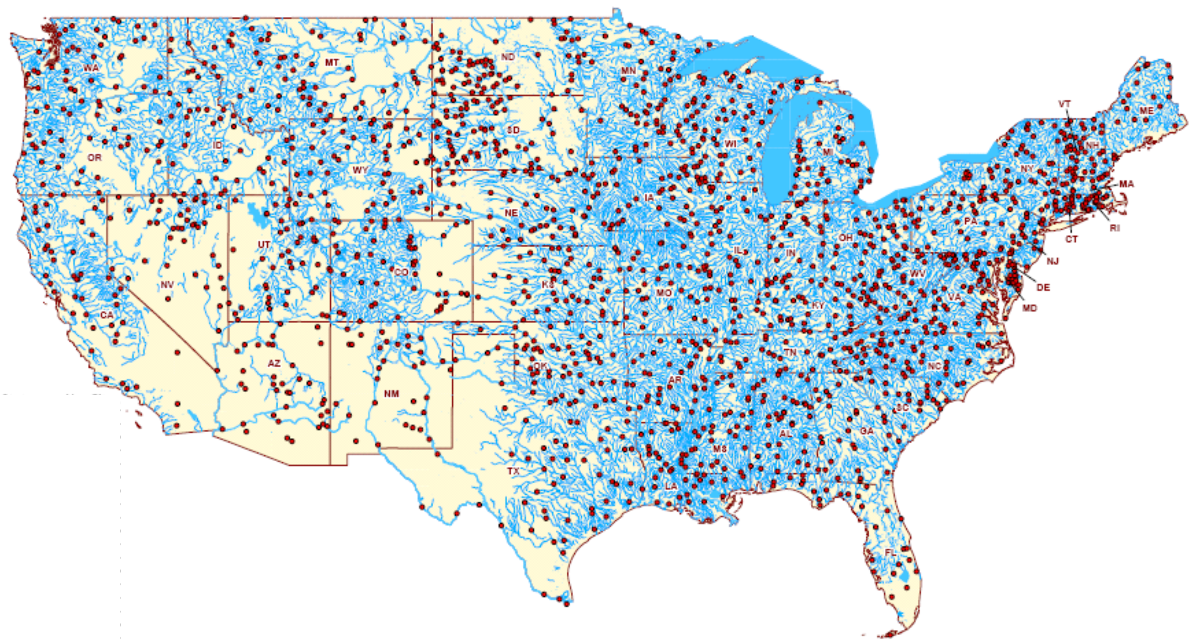


Figure 3-32 National Rivers and Streams Assessment sample sites (U.S. Environmental Protection Agency, 2011d).

Case Study

Oklahoma National Rivers and Streams Assessment

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

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

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

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

National Lakes Assessment

Author or Lead Agency: U.S. EPA

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

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

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

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

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

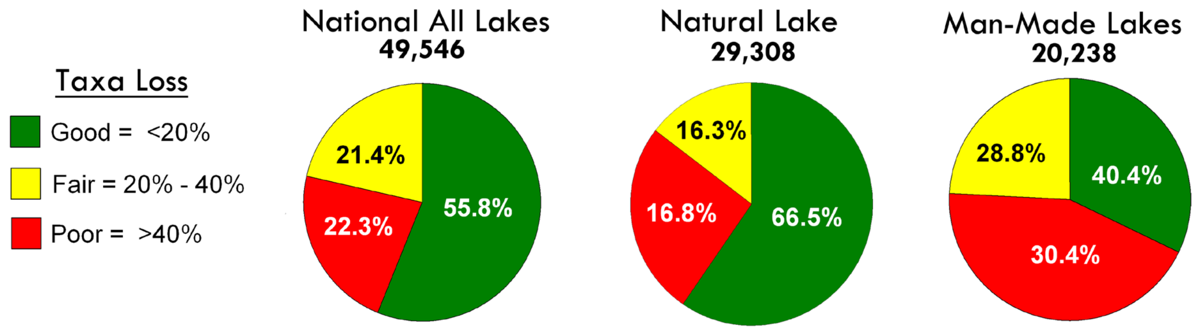


Figure 3-33 Biological condition of lakes nationally and based on lake origin (U.S. Environmental Protection Agency, 2009a).

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


Case Study

Minnesota National Lakes Assessment

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

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

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

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

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

Regional and National Monitoring and Assessments of Streams and Rivers

Author or Lead Agency: U.S. Geological Survey

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

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

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

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

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

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

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

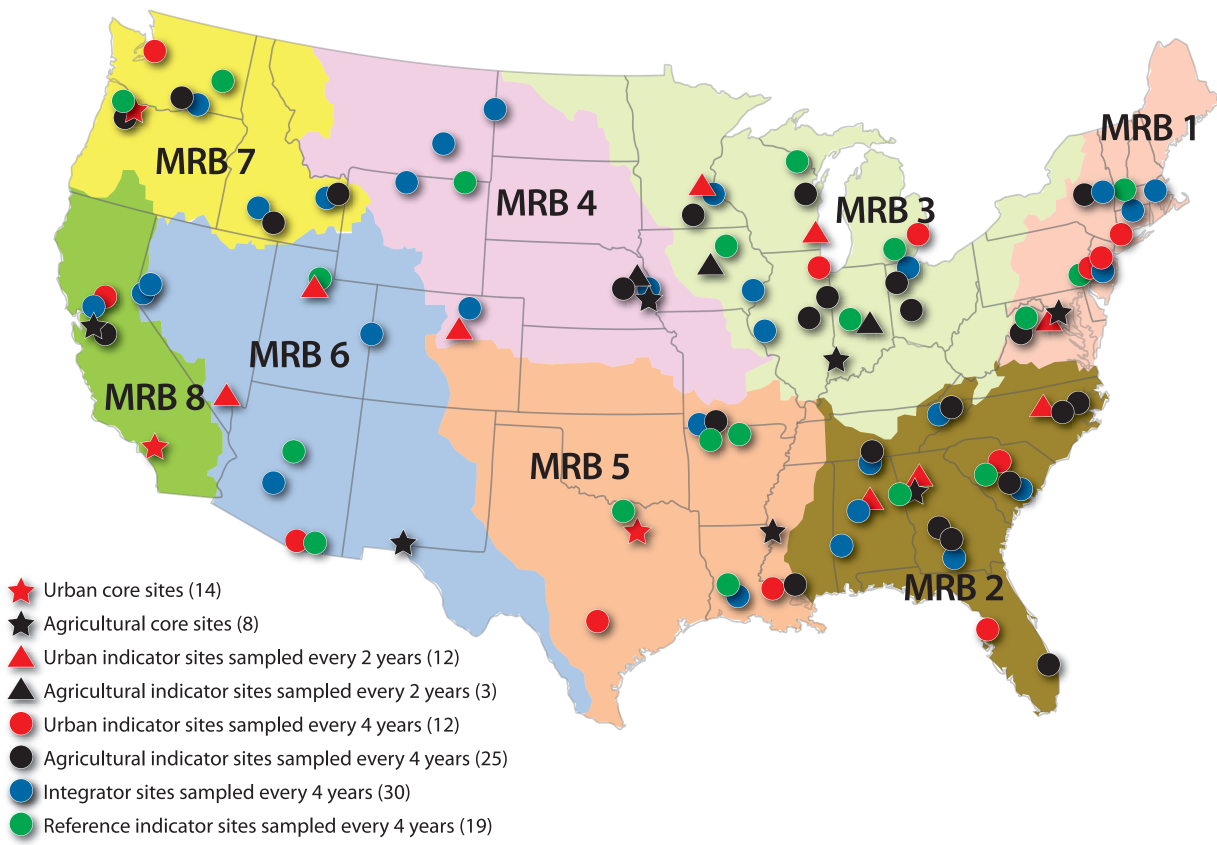


Figure 3-34 Sites for Regional and National Monitoring and Assessments of Streams and Rivers within Major River Basins (MRB) (U.S. Geological Survey, 2009c).