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HEALTHY WATERSHEDS INTEGRATED ASSESSMENTS WORKSHOP SYNTHESIS

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Table of Contents

List of Figures

List of Tables

List of Acronyms

ACE	Air, Climate, and Energy
AFWA	Association of Fish and Wildlife Agencies
ASIWPCA	Association of State and Interstate Water Pollution Control Administrators
ASWM	Association of State Wetland Managers
BCG	Biological Condition Gradient
BMPs	Best Management Practices
CWA	Clean Water Act
ECOS	Environmental Council of the States
ELOHA	Ecological Limits of Hydrologic Alteration
EPA	U.S. Environmental Protection Agency
EMAP	Environmental Monitoring and Assessment Program
FEMA	Federal Emergency Management Agency
FPZ	Functional Process Zone
GDE	Ground water Dependent Ecosystem
GIS	Geographic Information System
HGM	Hydrogeomorphic
HUC	Hydrologic Unit Code
HW	Healthy Watershed
HWI	Healthy Watersheds Initiative
HWIA	Healthy Watersheds Integrated Assessments
IBI	Index of Biotic Integrity
LCC	Landscape Conservation Cooperatives
MD	Maryland
MN DNR	Minnesota Department of Natural Resources
NFHB	National Fish Habitat Board
NFIP	National Flood Insurance Program
NGOs	Nongovernmental Organizations
ORD	Office of Research and Development
OW	Office of Water
SES	Social-ecological system
SGs	Strategic Goals
SG1	Strategic Goal 1
SLICE	Sustaining Lakes In a Changing Environment
WA DE	Washington Department of Ecology
WSWC	Western States Water Council

Executive Summary

The U.S. Environmental Protection Agency, in partnership with others, is embarking on the new Healthy Watersheds Initiative to protect our remaining healthy watersheds, prevent them from becoming impaired, and accelerate our restoration successes. In November 2010, a *Healthy Watersheds Integrated Assessments Workshop* brought together technical experts and practitioners to advance the state-of-the-science on integrated healthy watersheds assessments and to consider the role of green infrastructure (i.e., networks of natural land cover) in maintaining watershed health and resilience. The focus of the workshop was on the technical matters of conducting, and the state-of-the-science supporting, healthy watershed assessments, and not on the policy issue of the approach for watershed assessment appropriate for environmental decision making. This document synthesizes, and builds on, the ideas discussed at the Workshop. It represents the ideas and views of the contributors, and should be considered as a starting point for further exploration. **This document is not EPA policy nor is it EPA guidance; rather it reflects the further development of ideas by some of the workshop participants.**

Watershed function and aquatic ecological integrity are dependent on the interaction of multiple processes and conditions across many spatial and temporal scales. Organizing these multiple processes and conditions into a coherent set of relationships is necessary to better understand the functions that support a healthy watershed, and to guide management actions that sustain ecological integrity of aquatic ecosystems. “Health” can be viewed as a relative measure of the deviation from some “natural” or baseline condition, and it is usually measured by some static indicator(s), such as an index of biological integrity or landscape condition (e.g., connectivity). However, it is the underlying watershed process regimes that generate the necessary dynamic conditions that maintain ecological integrity, so a measure of “health” would more appropriately be based on the extent to which watershed process regimes are modified relative to the baseline, or their natural ranges of variation. Key to protecting healthy watersheds is understanding how particular conditions and process regimes within a watershed should be managed to maintain the ecosystem in some desired state within the natural range of variation. When disturbances, changes, and shocks occur within a watershed, processes may be pushed outside of their natural range of variability. In such cases, the system may recover because its adaptive capacity has not been exceeded, or it could pass a threshold and change into another ecosystem state. Increasing a system’s resilience to pressures includes ensuring that watersheds retain their adaptive attributes such as meander belts, riparian wetlands, floodplains, terraces, and material contribution areas. For example, a disturbance may lead to temporary changes in the timing, volume, or duration of flow that are outside the natural range of variability; but within a resilient watershed, these perturbations will not cause a permanent state change because riparian areas and floodplains help to absorb some of the disturbance.

With an understanding of the hierarchical organization of the drivers, processes, and functions of aquatic ecosystems, the appropriate framework for an assessment can be developed. A "tiered approach" is one potential strategy for conducting an integrated watershed assessment that allows users to address the range of management actions for a watershed within the limitations of available time and budget. A truly integrated assessment will include an assessment at the broad or watershed scale since it informs analysis at the subsequent finer scales. A watershed scale assessment can provide information on key processes, stressors, and conditions within the landscape based on broad geographic information and land use patterns. However, a broad scale analysis is limited primarily to issues addressing planning level decisions that deal with land use patterns (e.g., zoning, designations, and policies) and water use as it affects hydroecological requirements (e.g., instream flow, ground water input, lake levels, hydrologic connectivity). Finer scale assessments (i.e., waterbody and local scale) are performed within the context of the watershed scale and can address issues regarding reach and site scale processes, and specific protection and restoration designs.

Tiered assessments create efficiency by using existing data for an initial screening. A healthy watershed classification system based on large-scale remote sensing data may then identify where finer scale, more intensive assessments should be prioritized. It may also reveal those development patterns that are most protective of watershed processes and functions, and avoid costly environmental issues such as flooding, ground water contamination, and low flow concerns that cannot be readily resolved with site level actions. Smaller-scale assessments may be used to classify and map specific areas that are important to protecting watershed processes and resiliency, and at the same time identify specific stressors that may threaten or impede the recovery of healthy watershed functions.

As tiers of assessment are completed, and results are shared with the public, care must be taken to explain what the data may or may not be telling us. To ensure the appropriate application of assessment results, data has to be accessible in a manner that is appropriate to the user's goals, objectives, and decision process. Without clear written and visual explanations of the basis and need for strategic and prioritized watershed actions, public support will not be easily achieved.

A process-oriented approach of protecting the ecological processes that naturally create and maintain habitats will enhance the traditional site-specific and stream reach surface water quality approach. Further, the protection of ecological processes will benefit from a broader landscape approach of not only maintaining stream buffers, but integrating watershed components such as meander belts, lake shores, riparian wetlands, and floodplains into protection programs. All of this will require aquatic resource managers to work at larger scales with a whole new set of partners concerned with land use planning and management.

Land and water protection through non-regulatory and regulatory programs, conducted at all levels of government in partnership with nongovernmental organizations and landowners, is central to implementing the Healthy Watersheds Initiative. However, protection and restoration are often part of an integrated approach, as many states consider opportunities to protect healthy watersheds *and* restore impaired watersheds with a high recovery potential. A process-based approach that considers watershed resiliency and sustainability is important for restoration success. In addition to restoring natural flows, this could mean adding green infrastructure, removing constraints (e.g., dams), or working to ensure that land-water ecosystems remain dynamically connected. To restore and protect dynamic processes, planning should bring together different interest groups and provide opportunities and incentives to bundle "project" components and achieve a net ecological benefit. Regulatory, technical assistance, and funding program managers should strive to integrate land conservation; wetland, riparian, and floodplain protection and restoration; urban stormwater and agricultural best management practices; channel and shoreline management; and instream ecological flow protection and restoration.

Protecting healthy watersheds is cost-effective in the long run. The goal of the Clean Water Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. Historically, greater emphasis has been placed on the restoration element of the goal. A shift in emphasis from restoration alone, to more of a balance between "avoidance" or maintenance of the integrity of the Nation's waters and restoration, at all levels of government, would better achieve the integrity goal of the Clean Water Act. Much can be done at very little cost, especially with support and coordination from regional entities and federal agencies. Local and state Healthy Watersheds initiatives can get off to a fast and efficient start by learning from the successes and failures of one another. EPA and other federal agencies should consider working together to emphasize integrated assessments and Healthy Watersheds protection in their research and grant programs, and support a web-based clearinghouse where states are encouraged to post their accomplishments and success stories.

A number of research gaps and data needs relevant to Healthy Watersheds have been identified as priorities. In order to increase protection of healthy waters, the following research priorities have been identified: 1) Evaluate core metrics and methods for measurements of healthy watersheds; 2) Conduct cost-benefit analyses to explore the long-term net benefit of protecting healthy watersheds, green infrastructure, and processes sustaining healthy watersheds; 3) Identify characteristics of aquatic ecosystems and their surrounding watersheds that make them resilient to changing land use and climate for use in predictive models; 4) Understand interdependence of existing and proposed stratification frameworks; 5) Develop regional models to predict natural and altered flow, ground water, and thermal regimes; 6) Develop efficient and cost-effective methods for assessing status and trends in geomorphology and material transport; and 7) Explore consistency of assessment results across endpoints and spatial and temporal scales.

In order to enhance watershed resiliency, the following significant gaps in out scientific knowledge have been identified: 1) Understand responses of aquatic systems to the effects of climate change; 2) Identify the indicators and develop the sampling schemes needed to monitor and detect changes in condition or drift in reference sites due to climate change; and (again) 3) Identify characteristics of aquatic ecosystems and their surrounding watersheds that make them resilient to changing land use and climate for use in the design of predictive models.

Finally, recommendations for improving restoration of degraded waters include: 1) Enhance existing monitoring approaches to include representative systems for Healthy Watersheds evaluation and adaptive management; 2) Use Healthy Watersheds principles when coordinating protection and restoration across multiple scales; and 3) Promote the establishment of partnerships to explore the socioeconomic conditions that favor healthy watershed protection.

Chapter 1 Background

Healthy Watersheds Initiative Background

In partnership with states, tribes, local governments, nongovernmental organizations and others, the Healthy Watersheds Initiative (HWI) is intended to protect our remaining healthy watersheds, prevent them from becoming impaired, and accelerate our restoration successes. Healthy watersheds are protected using a holistic, integrated, systems approach to protecting aquatic ecosystems that recognizes their dynamics and interconnectivity in the landscape. This includes not only protecting aquatic biota and habitat, but also the key hydrologic and geomorphic processes and landscape conditions that sustain them.

A healthy watershed (HW) is one in which natural land cover maintains hydrologic and geomorphic processes within their natural range of variation, habitat of sufficient size and connectivity supports native aquatic and riparian species, and water quality supports healthy biological communities. An interconnected network of natural land cover throughout a watershed, and especially in the riparian zone, provides critical habitat and supports maintenance of the natural flow regime and fluctuations in water levels. It also helps to maintain natural geomorphic processes, such as sediment storage and deposition, which form the basis of aquatic habitats. Connectivity of aquatic and riparian habitats, in the longitudinal, lateral, vertical, and temporal dimensions, helps to ensure that biotic refugia are available during floods, droughts, and other extreme events. Part of the definition of a healthy watershed is resilience to disturbances. Resilience is related to the concepts of adaptive capacity (ability to adjust without degrading) and recovery potential (ability to recover after a temporary degradation) discussed in Chapter 3.

The HWI is intended to be proactive and strategic in its implementation. Its key elements are (US EPA 2011g):

1. Establish partnerships to identify and implement protection of healthy watersheds;
2. Identify healthy watersheds and intact components of altered watersheds state-wide through integrated assessments;
3. Implement state-wide strategic protection plans and programs based on vulnerability and other opportunities;
4. Implement local protection programs based on priorities from state and local assessments;
5. Provide information to inform ecological recoverability and help set priorities for restoration of impaired waters; and
6. Provide information to the public on healthy watersheds, including the socio-economic benefits of their protection.

Goals and Scope of the Workshop

The purpose of the *Healthy Watersheds Integrated Assessments Workshop* was to bring together national experts and practitioners to advance the state of the science on integrated healthy watersheds assessments and to consider the role of green infrastructure (i.e., networks of natural land cover) in maintaining watershed health and resilience. At the state level, integrated assessments are beginning to be used to identify healthy watersheds and intact components/processes in other watersheds for protection and restoration prioritization decisions. Watershed components examined in integrated healthy watersheds assessments include green infrastructure, biota, habitat, water quality, and the key processes that determine their natural state: hydrology, fluvial geomorphology, and natural disturbance regimes. Thus far, most of the integrated assessment approaches developed by states have combined assessments of various watershed components in indices that are spatially displayed in a geographic information system (GIS).

In addition to exploring the interrelation between watershed components and ways to capture that integration in assessments, this workshop also sought to identify methods that could be used to assess the resilience of healthy watersheds and strategies for building on existing resources to implement integrated assessments in state, tribal, or regional programs. The utilization of existing resources in the process of developing healthy watersheds lists was particularly emphasized. Data gaps and research needs that may hinder the development of accurate healthy watersheds lists were also considered.

The goals of the *Healthy Watersheds Integrated Assessments Workshop* were to:

- Improve the healthy watersheds conceptual model[1] to capture more accurately the relationships among healthy watershed components (including green infrastructure);
- Improve the understanding of watershed resilience and resilience-based management;
- Identify potential state-level approaches to integrated assessments;
- Identify strategies for promoting HWI objectives through partnerships; and
- Identify existing data gaps and areas in need of future research.

Audience and Intended Use for Synthesis Document

The purpose of this synthesis document is to build on the discussions from the workshop to further develop and synthesize ideas on a Healthy Watersheds integrated assessment conceptual model, watershed resilience, integrated assessment approaches, applications of healthy watersheds assessments, and data gaps and research needs. The ideas and views presented in this document are not necessarily those of the U.S. Environmental Protection Agency (EPA), but rather those of the individual authors and contributors. The ideas and approaches presented here should be considered as a starting point for further exploration of concepts related to Healthy Watersheds Integrated Assessments and protection programs.

[1] Based on EPA Science Advisory Board's Essential Ecological Elements

The target audiences for this synthesis document are scientists, program managers, and policy makers at the state, federal, and local levels who have a technical understanding of the topics and will be implementing management programs (Chapter 5). However, this document should not be interpreted as program implementation guidance. This synthesis document will also inform future research to support Healthy Watersheds Integrated Assessments, especially in EPA's Office of Research and Development (ORD).

Overview of Chapters

This synthesis document is organized around five chapters, each addressing a different goal of the *Healthy Watersheds Integrated Assessments Workshop.*

Chapter 2: Conceptual Model

What is a "healthy watershed?" This chapter presents a hierarchical framework of the relationships among the interacting processes that govern watershed integrity and function. Selecting the appropriate spatial and temporal scales for monitoring, management, protection, restoration and other actions is necessary to capture the natural variability of a watershed's physical, chemical, and biological process regimes and treat the causes, not the symptoms, of watershed impairment.

Chapter 3: Watershed Resilience

The purpose of this chapter is to explore concepts of ecological resilience and how they overlap with healthy watersheds concepts. This chapter discusses the various ways in which disturbance, resistance, and equilibrium can be used to identify resilient watersheds and develop management priorities. Examples of characteristics of resilience and implementation of resilience-based management are included.

Chapter 4: Integrated Assessment Approaches

This chapter provides an overview of possible approaches that can be used to conduct integrated assessments of healthy watersheds. The assessment approaches emphasize the conceptual model of interacting watershed processes discussed in Chapter 2. Tiered assessments are presented as an approach to incorporating varying spatial and temporal scales. Equally important to data collection and assessment approaches are methods for interpretation, display, and communication of results.

Chapter 5: Implementation of Healthy Watershed Programs

This chapter discusses strategies for setting up government programs to implement healthy watershed programs in states. It discusses actions that could be taken to enable those programs to succeed. Possible structures for coordination among federal, regional, state, and local agencies to jointly promote healthy ecological, economic, and social systems are considered.

Chapter 6: Data Gaps and Research Needs

This final chapter uses a logic model to identify data gaps and research needs associated with Healthy Watersheds Integrated Assessments based on desired outcomes. From the desired outcomes, long-term, intermediate, and short-term goals can be derived. Three overarching goals are identified; the inputs required to achieve these goals have been used to structure a list of data gaps and research needs.

Chapter 2 Conceptual Model

Scientists understand that watershed function and aquatic ecological integrity[2] result from the interaction of multiple processes and conditions operating across many spatial and temporal scales. Organizing these multiple processes and conditions into a coherent set of relationships is necessary to allow a meaningful definition of watershed "health" and to guide management actions that can maintain or restore watershed health and thus sustain ecological integrity of aquatic ecosystems.

In general, watersheds are land surface areas that function to deliver water, sediment, wood, chemicals, and nutrients via gravity flow to streams and river networks, wetlands, lakes, and the sea. The delivery of these materials shapes the physical, chemical, and biological characteristics of the receiving aquatic systems. Watersheds are also influenced by ground water dynamics. Watersheds differ naturally in the magnitudes, frequency, timing, and episodic nature of material inputs and dynamics in response to regional climatic patterns, and to watershed land surface features. Therefore, it is important to adopt a framework for defining natural watershed function and health that reflects this natural variation.

A Hierarchical Perspective on Watershed Health

A hierarchical, nested framework can be used to organize the functional relationships between multi-scale processes and conditions that define watershed function and aquatic ecological integrity, as shown in Figure 2-1. Hierarchical constructs for depicting the organization of physical, chemical, and ecological processes within watersheds are common for both habitat or landscape characterization (Frissell et al. 1984; Thorp et al. 2006, 2008; Beechie et al. 2010) and for ecological organization (Tonn et al. 1990; Maxwell et al. 1995; Poff 1997; Higgins et al. 2005). A basic premise of the hierarchical approach is that processes and patterns observed at one spatial or time scale are constrained by processes acting at a larger spatial extent or time scale. For example, the frequency of local streambed movement or disturbance in an individual stream riffle depends on both the watershed geology (e.g., the coarseness of the bed particles and the local streambed slope) and on the regional climate (i.e., frequency of storm-generated high flows). Thus, in a conceptual hierarchical perspective (Figure 2-1), climate is considered a high level "driver" because temporal patterns of precipitation and temperature characteristic of a region directly regulate the volume, seasonality, and form (rainfall vs. snowfall) of atmospheric water delivery to any particular watershed. Climate acts to regulate watershed-scale processes such as water and material flux between terrestrial and aquatic systems. Seasonal temperature patterns and extremes also directly influence the types and productivity of terrestrial plants that help regulate watershed runoff, as well as the types and abundances of aquatic organisms that comprise regional biological integrity. Geographic variation in climate creates associated variation in watershed processes and ecological patterns.

[2] Defined as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region." Karr and Dudley (1981).

Within a climatic setting, watershed-scale "controls" such as physical and biological landscape elements act to govern the rates and routes by which precipitation moves across or through the land surface to discharge into aquatic ecosystems. These coupled climatic-landscape controls act to regulate the structure and function of streams, rivers, wetlands, lakes, and tidal systems. These controls include the geology, soils, and vegetative cover of a watershed, as these factors jointly determine rates of infiltration and the balance of overland vs. subsurface water delivery to aquatic systems. Likewise, the physiographic setting (topographic relief) of a watershed influences the propensity for overland flow and thus runoff rates to receiving channels. The rates and routes of runoff interact with soils and surface features to transport materials (soils, nutrients, wood) downhill to aquatic systems. Where topographic relief is low and the geology favorable for high infiltration, ground water recharge occurs, and this can contribute to ground water discharge in down-gradient wetlands, lakes, and stream channels. This discharge delivers dissolved chemicals and nutrients and promotes a more dampened hydrograph (less flow variability) in streams and natural water level fluctuations in wetlands and lakes. Ground water discharge also helps to dampen seasonal temperature variations in rivers, lakes, and wetlands. In summary, the combined climatic and geologic controls on runoff can help identify where watershed hydrologic response varies at broad geographic scales (Winter 2001; Wolloch et al. 2004).

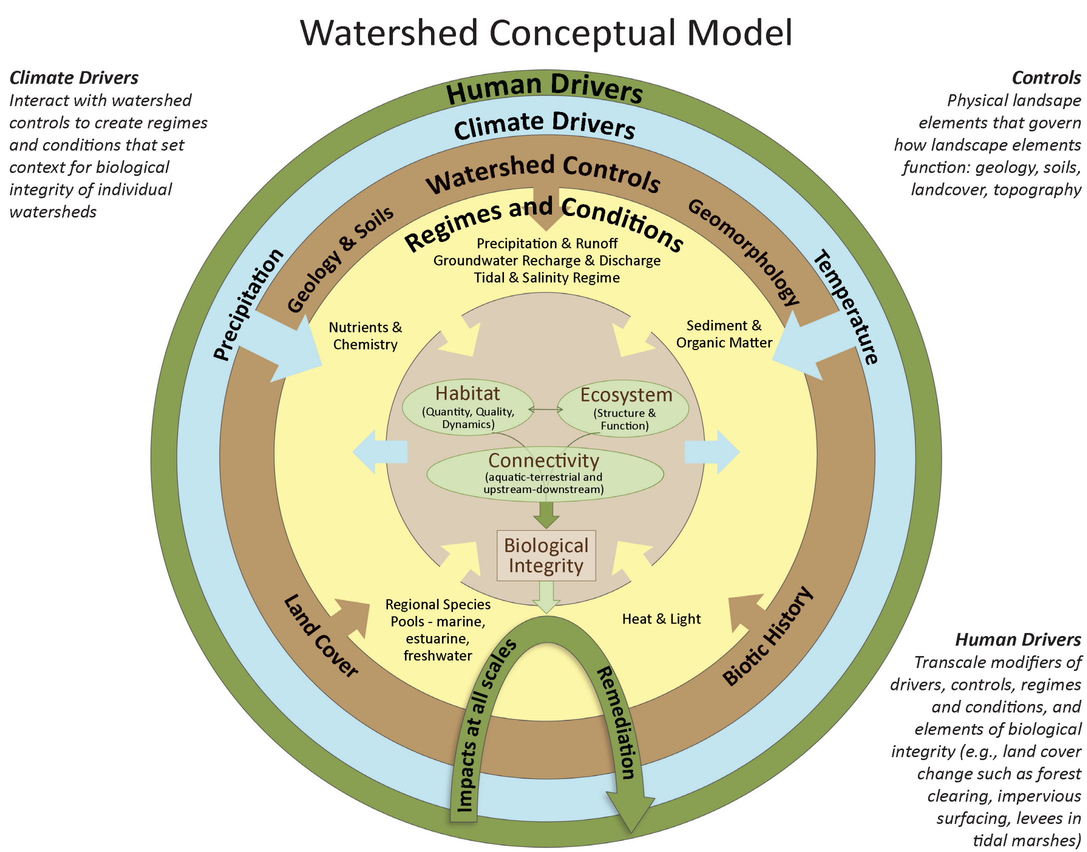


Figure 2-1 Conceptual model of a watershed showing the hierarchical relationship of drivers such as climate and human activities and physical landscape controls in a watershed such as geology, soils, and land cover to processes that govern key regimes and conditions acting to regulate the structure and function of watershed ecosystems (lentic, lotic and tidal).

The interaction of watershed-scale controls with the climate signal drives key watershed processes that are measured as time-varying fluxes of water, sediment and organic matter, heat and light, and nutrients and chemicals. These "process regimes" act to regulate ecosystem structure and function, aquatic habitat formation and dynamics, species and community composition, and, ultimately, aquatic biological integrity (Figure 2-1).

These regimes may be viewed in terms of key components that drive ecological processes and species performance and thus regulate biological integrity. For example, flow regime in streams and rivers (or hydroperiod in wetlands) can be characterized in terms of critical components such as magnitude, frequency, duration, timing, and predictability of ecologically critical flow and water levels (e.g., extremes in low or high flows) that directly influence ecological integrity (Poff et al. 1997) and thus can form the foundation for ecologically relevant water management (Bunn & Arthington 2002, Poff et al. 2010).

Process regimes have characteristic or "natural" ranges of variation that reflect the interaction of climate with the land surface or watershed controls, and this natural range varies geographically. For example, runoff regimes will vary among watersheds having different climates, or within watersheds (subwatersheds) where land surface controls vary substantially (e.g., contrasting geologic or land cover controls on runoff) or climate conditions shift (e.g., high elevation snowmelt vs. low elevation rainfall dominance). Many other watershed process regimes are tightly coupled with flow. For instance, nutrient or chemical fluxes to receiving waters often occur in association with high flows that are generated by intense precipitation or rapid snowmelt (Likens et al. 1970). Likewise, sediment inputs to aquatic systems are associated with erosion-generating storms (Dunne & Leopold 1974).

The ecological integrity of streams, rivers, wetlands, lakes, and tidal systems therefore reflects the long-term adjustment of ecological processes and species composition to prevailing watershed process regimes. For example, watersheds in arid lands have naturally intermittent streams and are characterized by relatively few species, which have adapted to harsh conditions (Dodds et al. 2004), whereas watersheds in humid climates have perennial streams that sustain higher diversity, especially if they are also hydrologically stable (Townsend 1989). Both of these situations are "healthy," but in a specific regional and historical context. Accordingly, the biological metrics that comprise the aggregate measure of ecological integrity can vary among major watershed "types." Similarly, climate interacts with wetland morphology and landscape position to control water source and inundation regimes that determine wetland-specific ecological integrity (Keddy et al. 1993). Coupled with lake morphometry (patterns in depth), climate can regulate water depths and associated anoxia to determine species composition and baseline ecological integrity (Tonn & Magnuson 1982).

The regulation of ecological integrity by the hierarchy of climate-watershed controls on process regimes is an important perspective in understanding biophysical and ecological organization within and among watersheds. Ecological integrity also depends on at least two other sources of natural variation that differ significantly across the landscape: natural species composition and physical habitat connectivity.

First, biological composition of aquatic systems varies naturally at geographic scales due to differences in species biogeography. Evolutionary processes have created distinct regional differences in flora and fauna, such that species-level indicators of biological integrity can vary notably among watersheds that have similar physical organization. This is particularly true for species having solely aquatic dispersal, such as fish, which have diverged along drainage basin divides and in response to long historic isolation. Indeed, fish zoogeographic zones can be constructed to delineate watersheds of intrinsically different natural fish species composition (Maxwell et al. 1995) and provide a basis for biologically-based watershed conservation (Higgins et al. 2005; Sowa et al. 2007).

Second, a key regulator of biological integrity that is not easily captured by the climate-watershed-control-process regime hierarchy is the condition of habitat connectivity in space and time. The emergence of metapopulation theory (Hanski 1998) and metacommunity theory (Leibold et al. 2004) has emphasized that local ecological processes and patterns are embedded in a broader regional context where movement of organisms and materials across the landscape (or through the riverscape) is key to understanding the spatial distribution of species abundance or community composition and hence local biological integrity. In other words, the species composition or biological integrity of a particular locality depends on the influx of organisms from other localities and hence reflects the extent to which movement between localities is allowed by landscape structure. A simple example is provided by fish. Watersheds with similar physical-chemical integrity may have naturally variable species composition (and different baselines for biological integrity) if there is a natural barrier that prevents movement into otherwise suitable habitat. This has been shown, for instance, in New Zealand streams (Townsend & Flecker 1994) and Alaskan lakes (Hershey et al. 1999). Similarly, the connectivity of lakes via streams is important in determining within-lake fish species richness (Jackson et al. 2001). In addition to upstream-downstream or longitudinal connectivity, the lateral connectivity between a waterbody and its adjacent terrestrial landscape can influence ecological integrity. Lateral connectivity between river channels and floodplains is widely understood to be a key contributor to the integrity of river ecosystems, both aquatic and riparian (Junk et al. 1989; Naiman et al. 2005).

The above relationships provide a context for characterizing watershed health from local habitat to whole network scales across broad geographic extents, where climate and key landscape controls bound watershed functions and define regionally based ecological integrity independent of human intervention. Thus a "healthy" watershed can be defined by the degree to which climate-defined watershed process regimes are intact (within a natural range of variation) and sustain naturally dynamic physical, chemical, and biological components that are well connected from local to whole watershed scales.

The Human Dimension of Watershed Health

Human activities are an integral part of any definition of watershed health because humans have extensively and intensively modified the landscape and thus disrupted most aspects of natural watershed function. Incorporating humans into the hierarchical driver-process-regime framework for watershed ecological integrity requires recognition that humans can modify all levels of the hierarchy from the local to global scale, and over a range of time scales, as depicted in Figure 2-1. For example, human modification of land surface features and climatic warming is elevating surface water temperature in rivers (Kaushal et al. 2010) and lakes (Magnuson et al. 2000). Various watershed controls have been extensively altered (e.g., land cover changes and land use practices that regulate runoff, erosion, and nutrient/chemical inputs to receiving waters; Allan 2004). Human activities have pushed many process regimes well outside their natural ranges of variation, from flow regimes (Poff & Zimmerman 2010, Bunn & Arthington 2002) to thermal regimes (Olden & Naiman 2010) and sediment regimes (Syvitski et al. 2005). Humans also diminish watershed health directly by modifying natural aquatic connectivity (e.g., levee placement on rivers severs floodplain connections, and mainstem dams fragment river networks; Nilsson et al. 2005) or by introducing non-native species that alter ecological processes and species interactions (Rahel & Olden 2008). Thus, humans have "trans-scale" effects that act to degrade ecological integrity and watershed health in myriad ways. For watersheds that have had high human impact, attaining desirable levels of watershed health will require restoration of key processes, regimes, and landscape conditions through active management.

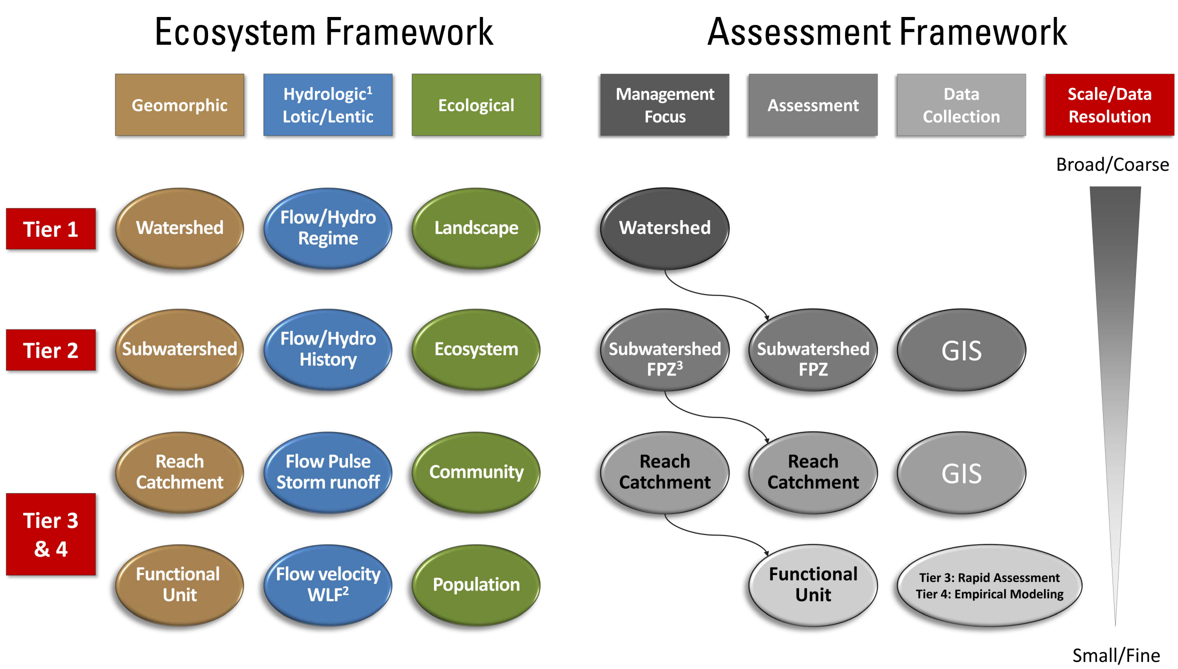
Assessing Watershed Health

"Health" can be viewed as a relative measure of the deviation from some "natural" or minimally-altered baseline condition. Indicators such as the Index of Biotic Integrity (IBI) use characteristics of biotic assemblages to measure the relative integrity of freshwater ecosystems. This approach provides an expression of the integration of all patterns and processes in freshwater ecosystems, but does not indicate which specific patterns, processes, or dynamics are healthy or in need of restoration. Thus, to maintain or restore watershed health, it is necessary to understand the underlying watershed process regimes that generate the dynamic conditions that maintain ecological integrity. A key indicator or measure of "health" can be based on the extent to which watershed process regimes are modified relative to the unaltered baseline, or their natural ranges of variation (Wohl et al. 2005; Palmer 2008). The key to successful protection and restoration of watershed health is in understanding how particular conditions and process regimes within a watershed need to be addressed and can be protected or managed to shift the ecosystem towards some desired state within the natural range of variation. This requires knowledge of many individual processes and stressors, as well as their interactions.

Minimally altered watersheds are intrinsically healthy, because their key process regimes are, by definition, within the natural range of variation. These systems can typically serve as reference conditions for other, degraded watersheds that share similar climate, watershed controls, and species pools. Watershed health, just like human health, includes a range of conditions rather than the simple dichotomous states of "good" or "bad." Therefore, it does not follow that those watersheds with some measure of degradation are, by definition, unhealthy. Indeed, just as with humans, watershed health can be improved by diagnosing the cause of the impairment and taking action via watershed management at the appropriate scale(s) to restore process regimes that will move the watershed to a healthier state of greater ecological integrity. Science can provide a method for quantifying deviation from baseline and offer understanding as to the relative efficacy of restoring the watershed to a healthier state. The decision to achieve a given level of watershed health is based more broadly on social and economic considerations.

The health of a watershed can be assessed using sample-based indicators of physical and biological patterns and processes at multiple temporal and spatial scales and comparing them to a reference or defined baseline conditions. Because stream, river, wetland, lake, and tidal systems are arranged in a hierarchical organization of drivers, processes, and functions (Figure 2-1), assessments should consider the influence of the broader scale controls and processes on intermediate and fine scale patterns and processes, and vice versa will be of greater value. This hierarchical approach allows for selection of those key processes or controls that act as limiting factors for successful restoration or enhancement of ecological integrity. In other words, simply focusing restoration activities on the symptoms of watershed degradation at the small scale is unlikely to lead to improved watershed health. For example, creation of off-channel spawning habitat or anchoring of large wood at the local reach scale in a stream does not address the larger issue of channel erosion caused by poor land use management at the whole watershed or riparian zone scale (Palmer 2008).

With an understanding of the hierarchical organization of the drivers, processes, and functions for lotic, lentic, and tidal fringe systems, the appropriate framework for an assessment of watershed health can be developed. Ideally, a framework can be implemented that matches spatiotemporal scales with ecological variables and that is amenable to management action. Some useful frameworks for freshwater classification have been developed (e.g., The Nature Conservancy's Freshwater Classification Approach; Higgins et al. 2005), but a framework for healthy watershed management would ideally capture the key dynamic processes and regimes that form the basis for watershed health. Figure 2-2 provides a general depiction of a process-based assessment framework applicable at the management scale. For example, assessments at the watershed scale (Tier 1) can address management or planning questions on the best location and type of new development by using indicators of the health of water flow processes such as forest cover and impervious surfaces (Booth et al. 2002). Existing state and national GIS data sets can be used at this landscape scale without the collection of additional data at finer scales. However, management questions aimed at local habitat quality or community and species composition would require assessment at the reach scale and data collection at the functional unit scale (Tiers 3 and 4). Chapter 4 provides more detail of the type of assessment methods and sampling required to address specific questions on watershed health at different scales. The following sections of this chapter address these habitat and process scaling issues in three major types of systems: lotic systems (streams and rivers), lentic systems (wetlands and lakes), and tidal systems.



1 Other processes are included but not shown, including movement of sediment, nutrients, large woody debris…
2 Water Level Fluctuations
3 Subwatershed scale (HUC 12) may be used for assessment of lentic systems; FPZ or functional process zones for lotic systems

Figure 2-2 Depicts the hierarchical relationship of the ecosystem components (geomorphic, hydrologic and ecological) across spatial and temporal scales for lotic and lentic systems, and the associated combination of assessment and data collection elements. The "tier" levels refer to different levels of assessment discussed in Chapter 4 Integrated Assessments. (Figure modified from Thorp et al., in review).

Lotic Systems

Climate, geology, soils, land cover, valley topography, channel geomorphology, and land cover interact to determine the hydrogeomorphic (HGM) nature of the fluvial system. The natural flow regime and geomorphic nature of the riverscape (primary and secondary channels and backwaters) influence interactions with the floodscape (terrestrial floodplains, cutoff channels, lakes, and wetlands) within the all-encompassing riverine landscape. The relative contribution of upstream and local riverine landscape processes to the community structure (taxa richness, evenness, etc.) and ecosystem function (e.g., nutrient processing, system metabolism, carbon sequestration, food web complexity, and water filtration) at the valley scale within a watershed will vary with the nature of the local HGM patch (Thorp et al. 2006, 2008). Some of these community and ecosystem attributes are most affected at the reach scale (10's to 100's of meters), whereas others are influenced at the valley scale (1000's of meters), referred to as functional process zones (FPZs). The FPZs represent large HGM patches nested between the reach and watershed scales as shown in Figure 2-3 (Thorp et al. 2006, 2008).

FPZs are repeatable from upstream to downstream and only partially predictable in position, especially when comparing different ecoregions and physiographic regions. The degree of variation in community structure and ecosystem processes from upstream headwaters to the river mouth and the predictability of downstream change will vary directly with the HGM complexity of the total watershed ecosystem. The variation in HGM structure from headwaters to the mouth of a river generally increases with watershed size and the diversity of ecoregions and physiographic provinces within the watershed. In very small watersheds, only a single FPZ may be present, and the focus of sampling should be on the reach subunits of the valley. A GIS-based computer model for delineating FPZs has been developed through collaboration between the University of Kansas and EPA's National Exposure Research Laboratory in Cincinnati (Thorp et al. in review; B.S. Williams, pers. comm.).

The hierarchical structure of riverine habitat in a watershed can be used to provide an example of how to match data scales with management questions (Thorp, pers. comm.). The three habitat sublevels within a watershed depicted in Figure 2-3 are associated with different hydrologic and geomorphic processes operating at separate temporal scales, as shown in Figure 2-2. Similarly, different ecological processes and response variables are associated with these habitat sublevels, and these relationships guide the appropriate types of ecological data that should be collected for a management question at a particular habitat scale. As a general principle, for a management focus at a particular scale, hydrogeomorphic and ecological assessment would occur at a scale one level below the management scale (illustrated in Figure 2-2). The kinds of data that are needed to characterize the properties of the habitat units at the assessment scale will vary with the assessment scale and focus (Figure 2-2), as discussed more fully in Chapter 4.

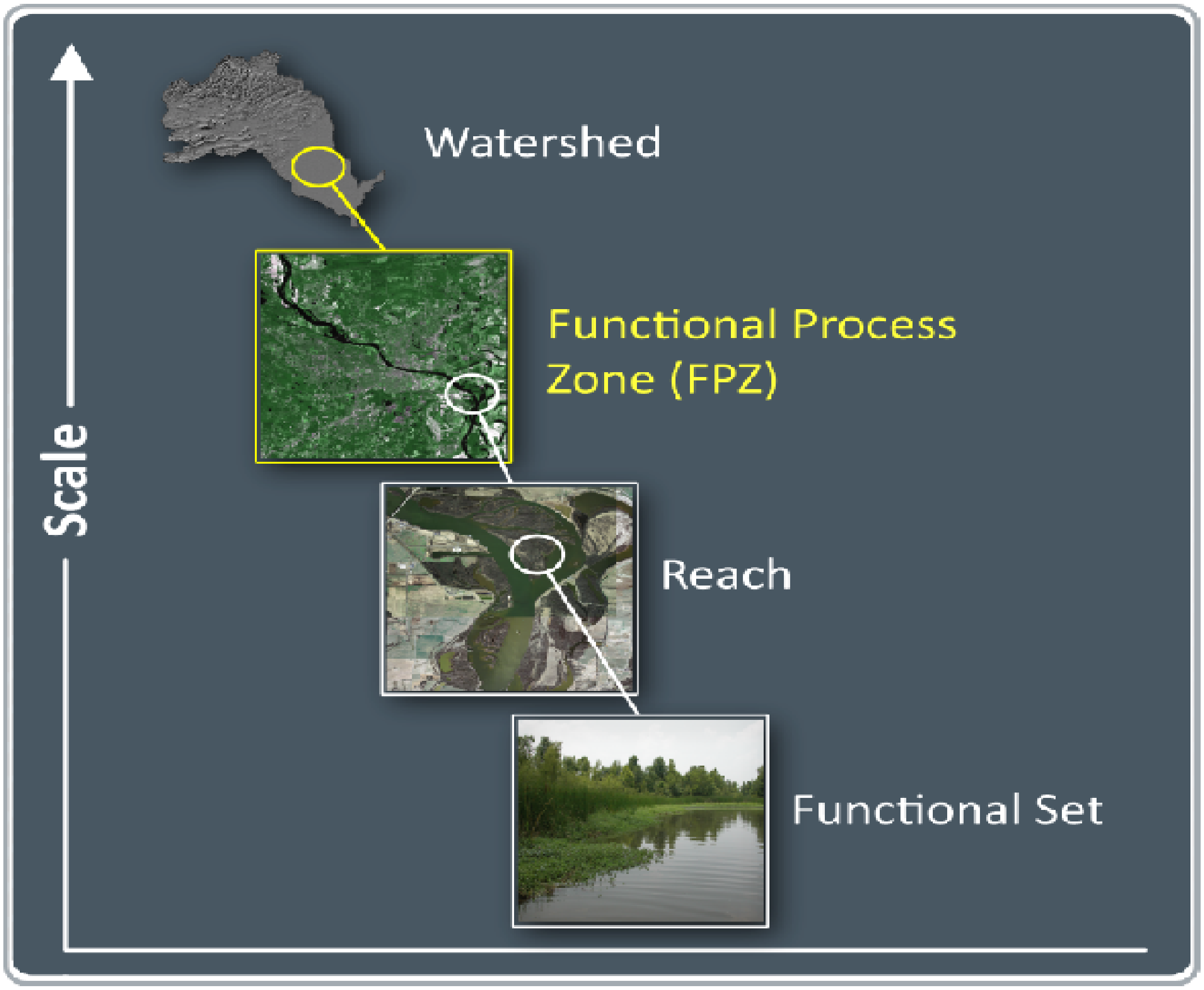


Figure 2-3 Hierarchical habitat structure in watershed.

The connectivity of HGM habitat types within the watershed (longitudinally along river channels or laterally between riverscape and floodscape components) is important for maintaining many ecological processes that contribute to biological integrity. These include nutrient processing, overall community structure, refuges from extreme events, and movement between habitats to reproduce or complete life cycles.

Anthropogenic changes in the HGM structure of the riverscape, as well as alterations of the floodscape, substantially alter community structure and ecosystem function, and thus modify biological integrity. These include simplifying the channel structure with levees or dredging, building impoundments (deepening and widening the river and changing interactions with the floodscape), and altering sediment load (which can change channel structure). Loss of sediment and wood storage processes (i.e., material sorting and distribution) and alteration of riparian conditions result in reduced shelter, feeding, and reproductive habitats for aquatic and some semi-terrestrial and terrestrial species. Urbanization is a particularly pervasive type of land surface modification that alters hydrogeomorphic processes and associated ecological responses (Booth et al. 2002, 2004; Walsh et al. 2005).

Lentic Systems

Lentic systems include low energy aquatic ecosystems, such as wetlands, springs, and lakes, located in depressions or low gradient areas on the landscape, or areas of ground water discharge. These systems are formed and maintained within the same framework of climate, geology, soils, land cover, and topography (Figure 2-1) as lotic systems. Lentic systems depend on natural regimes of water, nutrients, and sediments, and at the same time have an influence on hydrologic response and delivery of wood, nutrients, and sediment within the watershed. Similar to lotic systems, lentic systems can be classified based on hydrogeomorphic setting (Mitsch & Gosselink 2000). These different types of lentic systems provide different ecosystem service functions and are affected differently by anthropogenic impacts. Anthropogenic changes in watershed conditions that affect these natural processes can have significant effects on the structure and function of lentic systems, with associated effects on other systems. Lentic systems serve as habitat for a diversity of plants and animals, including many endangered or threatened species. Lentic systems host a variety of plant communities that are uniquely adapted to their hydrologic and water quality conditions. This vegetation in turn supports numerous animal species including birds, amphibians, and fish.

Depressional Wetlands and Lakes

Within a landscape context, depressional wetlands and lakes provide several functions important to humans, including reduction of downstream flooding and water quality improvement. The storage of water by wetlands and lakes contributes to desynchronizing runoff and reducing the frequency and duration of downstream flows in streams (Stanley et al. 2009a). The lower energy of these systems (predominately vertical hydrodynamics) also affords significant water quality benefits by allowing the filtering and settling of sediments and the adsorption of phosphorus and associated toxics to those sediments. Additionally, denitrification occurs in the anoxic zones of these aquatic areas (Hruby et al. 1999, Sheldon et al. 2005).

Draining and filling of depressional wetlands and alteration of the hydrology of lakes directly affect habitat availability and quality, as well as downstream hydrology of streams and wetlands (Sheldon et al. 2005). Other impacts, such as direct trampling due to overuse by cattle, can result in reduced wetland extent and function, with corresponding effects on ecological integrity. Land cover changes in the watershed, such as clearing of native cover (e.g., forests, scrub-shrub) and paving with impervious surfaces, can increase the range of water table and water level fluctuations within depressional wetlands and lakes. This increased fluctuation in water levels reduces the habitat function of wetlands and can change community structure and species richness. For example, increased water level fluctuations reduce amphibian richness and allow for establishment of invasive plant species (Richter & Azous 1997; Azous et al. 1997). Additionally, changes in sediment, nutrient, and chemical loads within the watershed can significantly alter the water quality of depressional wetlands and lakes, potentially leading to major changes in community structure and function.

Slope Wetlands

Slope wetlands (also areas of "springs") are typically found at breaks in slopes or at the base of valley walls and play an important "landscape" role in contributing return flows to riparian ecosystems and streams. Direct impacts to slope wetlands include ditching and draining, which intercepts ground water flow and routes it away from downslope wetlands (e.g., riverine, lacustrine) and towards discharge points further downstream (Stanley et al. 2009b). This can increase the temperature of stream waters and reduce seasonal low flows critical to the survival of stream invertebrates and fish. Watershed impacts include the reduction of recharge in areas that contribute to discharge areas (Morgan & Jones 1999). Other landscape impacts to slope wetlands include ground water extraction and routing of water outside of watersheds by stormwater and sewer systems (Stanley et al. 2009a), and ground water contamination by pesticides, nutrients, and other toxic chemicals.

Riverine Wetlands

Riverine wetlands include depressional wetlands located within the floodplain of streams, where the source of hydrologic inputs includes a combination of ground water and overbank flooding. Riverine or floodplain wetlands are dominated by downstream, surface water flow during flood events, but by ground water flow during and after the receding leg of flood events. As such, they play an important landscape role as a storage component and contribute to the reduction of downstream erosion and flooding (Sheldon et al. 2005). These are also important areas for ground water discharge that contribute to water quality functions such as denitrification and temperature regulation (Cox et al. 2005). Most significantly, these areas of ground water discharge help maintain adequate low flows during warmer, drier months when fish survival is most critically threatened.

Direct impacts to riverine depressional wetlands can result in substantial changes in water quantity, quality, and habitat functions. The most common impact is disconnecting a stream from its floodplain through either channelization or channel incision (Kline & Cahoon 2010). Overbank flooding processes are hereby prevented, which in turn eliminates most of the related water quality functions. Activities that reduce the spatial extent or storage capacity of these areas during peak flow events can increase the volume of water and the rate at which it reaches aquatic ecosystems (Gosselink et al. 1981; Reinelt and Taylor 1997; Sheldon et al. 2005). This increases the need for additional channelization.

Tidal Fringe Wetlands and Estuarine Systems

Tidal fringe wetlands (Brinson 1993) are located at the interface of freshwater and marine ecosystems and are primarily influenced by the bidirectional movement of tides. They include both tidal freshwater and salt marshes. Tidal fringe systems are generally included within estuaries and can occur in habitats ranging from the narrow edges of rocky shorelines to broad coastal plains, bays, and river mouths. This includes coastal plain wetlands along the east coast and Gulf of Mexico, as well as large delta systems and estuarine marshes formed at the mouths of rivers, on small deltas, and in large bays (e.g., San Francisco) along the west coast (Mitsch & Gosselink 2000).

Because of their coastal location, many tidal systems are complex mixing zones for fresh and saline waters that govern both the distribution of plants and marsh productivity (Seliskar & Gallagher 1983). The primary productivity and detrital food web of these tidal fringe systems supports a large range and number of benthic invertebrates, marine and freshwater fish, aquatic birds, and mammal species. In addition, terrestrial fluxes of sediment, nutrients, wood, and fresh water play a significant role in the structure and functions of these systems. As a result, land use activities within the contributing basin can have major effects on estuaries. For example, channelization and armoring of upstream riparian areas causes a significant reduction in movement of wood downstream into tidal marshes. Large woody debris plays a significant role in creating habitat structure in tidal marshes (Hood 2007).

Some of the most significant direct impairments to tidal marshes include removal of tidal influence through an extensive dike/levee and tide gate system. This effectively drains the tidal marsh and also reduces the tidal channel complexity seaward of the dike/levee system (Hood 2004). These drained areas are typically used for agricultural purposes and in some areas have a high potential for restoration. More damaging is the filling of tidal marshes for residential, commercial, and industrial development (e.g., San Francisco Bay) or the dredging of tidal marshes for port and marina development. The installation of levees and dikes also has other significant effects upon the tidal marsh food web. Levees and dikes increase the velocity of flood waters in main channels, which in turn prevents migrating fish, such as salmon smolts, from seeking refuge in lower velocity distributary channels. This is believed to increase their mortality. In addition, the diked areas of the marsh are no longer available to salmonid smolts for feeding and physiologic adaptation.

An estuarine system can be defined as “a semi-enclosed coastal waterbody with restricted circulation, or coastal marine waters influenced by significant freshwater inflow during at least part of the year” (US EPA 2010a). In addition to the high level climate drivers for all water body types, influences of oceans on estuaries should not be ignored. Oceanic influences are often categorized according to oceanic ecoregions (Bailey 1998) or coastal/estuarine provinces (Cowardin et al. 1979) based on ocean circulation patterns (Bailey 1998), while inland climatologic influences on coastal systems can be characterized by hydroclimatic zones (Saco and Kumar 2000). The same watershed controls (geology, soils, topography) influencing upstream water bodies and rivers also moderate the effect of climate on estuaries. In addition, estuarine morphometry is a critical factor because it influences tidal exchange (and thus freshwater residence time), the probability of stratification, and the light environment (Kurtz et al. 2006). Many of the same process regimes that influence freshwater systems are important for estuaries. However, two-way exchanges are also important in estuaries. Thus, normal tidal and salinity regimes are an important component of protecting estuarine systems (Figure 2-1). Finally, upstream-downstream connectivity and oceanic connections are both important for migratory species while circulation patterns may be critical for recolonization following disturbance. Impacts on estuaries related to watershed activities include hydrologic/hydrogeomorphic changes (channelization, dredging, draining, fill, alteration of estuarine mouth dimensions, shoreline armoring), eutrophication, thermal pollution, toxic discharges and contaminated sediments, ocean acidification, and change in volume and/or timing of freshwater inputs and associated materials.

Thus, the “health” of a tidal ecosystem is dependent on many of the same interacting factors that are governed by upper watershed drivers and controls for lotic and lentic systems and their alteration by human activities. Restoration of a tidal marsh should not be based solely on creating a set of physical habitat features such as importing large wood, but upon understanding at the landscape scale why that wood is missing from the system and taking action to restore that limiting factor (e.g., remove armoring on key channel migration zones; Simenstad et al. 2006).

Chapter 3 Watershed Resilience

Introduction to Ecological Resilience

The previous chapter focused on the components and regulation of ecological integrity that determine watershed health, including the need to incorporate human activities into that determination. This chapter focuses on understanding how to incorporate resilience into that determination since human activities will continue to modify watersheds through land use changes, development pressures, invasive species, climate change, and other stressors. The chapter begins with a review of the ways in which resilience has been defined, and the benefits and challenges of employing this concept in watershed management. Next, indicators and methods to assess resilience are discussed along with ways to incorporate it into watershed management. Several examples are then provided of how resilience has been incorporated into watershed management planning for several ecosystems. The chapter ends with a discussion of how to monitor and adaptively manage for watershed resilience in the future.

Definitions

The concept of ecological resilience was first discussed almost four decades ago (Holling 1973) and is important in its consideration of system dynamics, variability, and uncertainty. This is in contrast to a static view of ecosystem conditions as a predictable response within an envelope of defined environmental conditions. Holling (1973) suggests that natural systems, even in the absence of human disturbance, are often in transient states rather than in a single equilibrium condition, making application of the static equilibrium concept much less useful for describing ecosystem condition.

Resilience has been defined in numerous ways, with differences being largely related to assumptions about whether there are single or multiple equilibria possible in a system, and whether the system is near equilibrium or not (Gunderson 2000) (see Table 3-1 for example definitions). Holling (1973) characterizes resilience as a dynamic condition, representing the naturally high capacity of many ecosystems to absorb disturbance without substantially altering ecosystem state or the variables and processes that control structure. Carpenter et al. (2001) treats resilience similarly, as the amount of disturbance a system can tolerate before moving to another region of state space controlled by a different set of processes. Ecological resilience has similarly been characterized as the ability of a system to maintain its identity in the face of both internal and external drivers (Cumming et al. 2005). Based on these definitions, Walker et al. (2002) highlights resistance as one of several critical attributes of resilience. Resistance is defined as the ability of an organism or a system to remain unimpacted by major disturbance or stress.

The theme that runs through many of these definitions is the consideration of resilience in terms of the ability to absorb disturbance while remaining within a characteristic state with particular structures, functions, and controls (Gunderson & Holling 2002; Folke et al. 2004; Walker & Salt, 2006). These usages focus on the concept of resilience as the ability of a system to persist as a recognizable unit that can be described based on a range of structural and functional characteristics, suggesting that the appropriate measure of resilience would be the magnitude of disturbance that forces a system into a different state or condition (Carpenter et al. 2001).

Two examples of ecosystem state changes illustrate why resilience is so important to sustaining healthy watersheds, where 'healthy' is defined as falling within natural ranges and maintaining natural functions. In the absence of resilience, perturbations, which can be either natural or anthropogenic, may lead to a persistent shift in function. The first example is when slight shifts in river stage height lead to threshold changes in the river from a benthic-algae-based food web to a phytoplankton-based food web (M.D. Delong (pers. comm.). The second is when multiple environmental changes (such as nutrient input from septic systems, sea level change, a lack of hurricanes, drought, water diversions and removal of grazers) cause a major shift in a shallow estuary from an oligotrophic clear water system in which primary production is dominated by seagrasses to a more turbid system in which production is dominated by phytoplankton blooms (e.g., Florida Bay; Gunderson & Holling 2002).

Table 3-1 Selected definitions of ecological resilience.

Definitions	References
Measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables	Holling 1973
The magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior	Gunderson & Holling 2002
The capacity of a system to experience shocks while retaining essentially the same function, structure, feedbacks, and therefore identity	Walker & Salt 2006
…capacities i) to absorb disturbances, ii) for self-organization, and iii) for learning and adaptation	Walker et al. 2002
To apply the concept of resilience, it must be defined or specified as resilience "of what to what"	Carpenter et al., 2001
The ability of the system to maintain its identity in the face of internal change and external shocks and disturbances	Cumming et al. 2005

Since resilience is understood as the ability to absorb disturbance while remaining within a characteristic state, it must by necessity incorporate the concept of thresholds. An ecosystem functioning within a particular range of conditions (or stable domain, or stable state, or regime) has limits to its resilience to perturbation (i.e., its ability to rebound from large or episodic events). Groffman et al. (2006) defined an ecological threshold as the point at which there is a big change in an ecosystem property or phenomenon, or where a small additional change in a driver produces a large response in the ecosystem.

There are many threshold-based environmental problems (e.g., many pollution and nutrient loading questions), as well as interest in managing ecosystems to avoid dramatic regime changes. Three ways to think about the threshold concept (Groffman et al. 2006) are as: 1) a dramatic shift in state due to a small change in a driver; 2) a 'critical load' of a pollutant that can be absorbed before causing a change in ecosystem state or function; and 3) an 'extrinsic factor threshold,' representing a larger scale change in a variable that impacts the relationship between drivers and responses at a smaller scale. The first way of applying the concept of threshold entails identification of key response variables and the disturbances that influence them, as well as the temporal scales at which driver and response variables operate. Then the identified human-related stresses (e.g., runoff and flow) are managed to increase resilience in the face of phenomena that cannot be controlled (e.g., storms and droughts). The second application of the concept of threshold, critical loads, requires development of control strategies to prevent discharge of pollutants (e.g., nitrogen, sulfur) above levels that lead to threshold changes based on scientifically defensible quantitative evidence of where those thresholds exist. The third application involves identification of the level or intensity of key extrinsic factors that lead to alterations in ecosystem structure or function, or in the rate of an ecological process. For example, in urban ecosystems, extrinsic thresholds are identified in environmental impacts associated with amounts of impervious surface that constrain the structure and function of stream and riparian ecosystems.

As described in Chapter 2, attributes of a healthy watershed include the intactness of many processes such as hydrologic flow regime, sediment transport, processing and transport of organic materials, establishment and maintenance of connectivity, water quality, thermal regime, and energy transport. These processes are assumed to have a natural range of variability that may be exceeded when disturbances, changes, and shocks occur to a system. In such cases, the system may still recover because its adaptive capacity has not been exceeded, or it could pass a threshold and change into another ecosystem state. Increasing a system's resilience to such pressures includes ensuring that watersheds have adaptive attributes such as meander belts, riparian wetlands, floodplains, terraces, and material contribution areas. For example, a disturbance may lead to temporary changes in the timing, volume, or duration of flow that are outside the natural range of variability; but within a resilient watershed, these perturbations would not cause a permanent state change because riparian areas and floodplains would help to absorb some of the disturbance.

Some definitions of resilience also address the linked human-environment system (Berkes 2007), recognizing that resilience is affected by complex interactions between human and ecosystem functions over multiple spatial and temporal scales. Simply considering human and ecosystem functions separately may not be adequate to understand system resilience because integrated socioeconomic and ecological systems can behave differently than their separate parts (Alberti & Marzluff 2004). These considerations are important to explicitly address in the context of healthy watersheds where both human and ecological systems are needed to maintain or restore watersheds.

Benefits of Resilience

Resilience of both ecological and human systems provides the basis for maintaining healthy watersheds and the needed level of ecosystem services they provide into the future. Resilient societies are those that manage their resources appropriately, foster stability and adaptation to unforeseen circumstances, and provide equitable and fair access to resources. Resilient ecosystems remain stable in the face of chronic and acute stresses and events (e.g., maintain functionality), and can also provide such services as protection against extreme events (floods, droughts, storm surges) in addition to more common provisions of food, fiber, and recreation. Some benefits of ecosystem resilience are monetary/economic (e.g., costs avoided through flood protection from wetlands, or benefits accrued through commercial production of fish or grains), and some are intangible and noneconomic (e.g., psychological benefits of beautiful scenery or cultural benefits of archeological sites). However, with drivers of ecological change such as population growth, urbanization, and climate change, it is inevitable that the trajectory of natural succession will be affected in ways that are not entirely predictable, and some ecosystems will cross thresholds and experience substantial alterations. Enhancing resilience enables ecosystems to persist in their current state despite increasing pressures, thus delaying the onset of successional or threshold changes (Figure 3-1). This potential delay allows more time for understanding those states into which ecosystems may change, how best to manage transitions into new states, and how to sustain ecosystem service flows throughout (West et al. 2009).

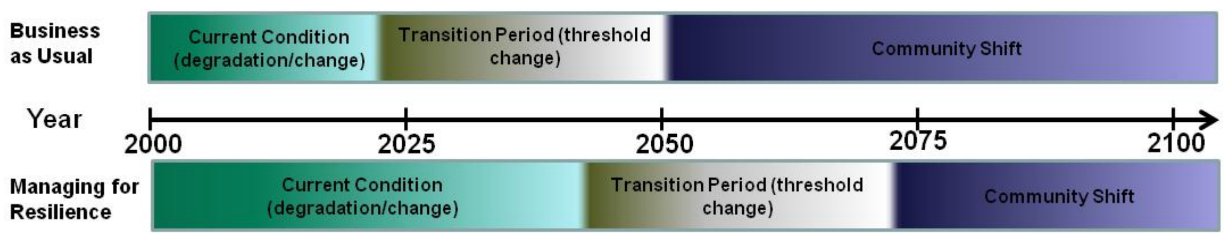


Figure 3-1 **Conceptual illustration of how improving resilience delays onset of the transition period of threshold change from before 2025 further outward toward 2050. This allows time for increased understanding and both human and ecosystem adaptations.**

Challenges of Managing for Resilience

Understanding and assessing resilience is complex for a number of reasons. *First, the resilience of both societies and ecosystems is very likely going to differ in response to natural versus anthropogenic stressors.* These stressors themselves will differ in spatial and temporal extent, in magnitude, and in duration. Some stressor pulses may be able to be absorbed by some systems, unless the timing between pulses is shorter than the recovery time frame. This will lead to degradation and push even resilient systems across a threshold into a different state. Similarly, a system may be adapted to a particular disturbance regime, but anthropogenic influences can modify this regime and push the system into a different state from which it can no longer provide the same ecosystem functions. Complex interactions between resilience of one process and that of another can also engender uncertainty that must be considered when both processes are affected by management decisions.

Second, degraded systems may appear more resilient to prolonged stressors than natural systems due to baseline conditions in which sensitive functional ecological components have already been lost. It is possible that, whereas natural systems may be resilient to a range of stressors and have a large capacity to absorb shocks or disturbances, large or prolonged stressors may lead to more severe changes in natural systems than in impaired systems that have already crossed a threshold. The surviving traits of already altered systems may have a great capacity to absorb the next series of large or prolonged stressors, and those very traits may also serve to impede restoration and recovery efforts. For example, streams that are currently classified as degraded or impaired may show very little effect due to climate change (e.g., changes in stream temperature or flow), because the current species assemblage is highly tolerant. Evidence of this phenomenon comes from modeling species losses due to climate change in North Carolina streams in the Blue Ridge Mountain ecoregion (U.S. EPA 2011a). The scenarios use the current composition of macroinvertebrate species, and then assume the loss of 50% and 100% of coldwater-preference taxa. Resulting species assemblages are then used to calculate the condition of each site. Results show large shifts in status for stations classified as Excellent through Good-Fair and almost no shifts in status for those stations classified as Fair through Poor (Figure 3-2). Therefore, any activities promoting resilience should be aware of the initial state of the system so that any measures of resilience do not reward already degraded systems.

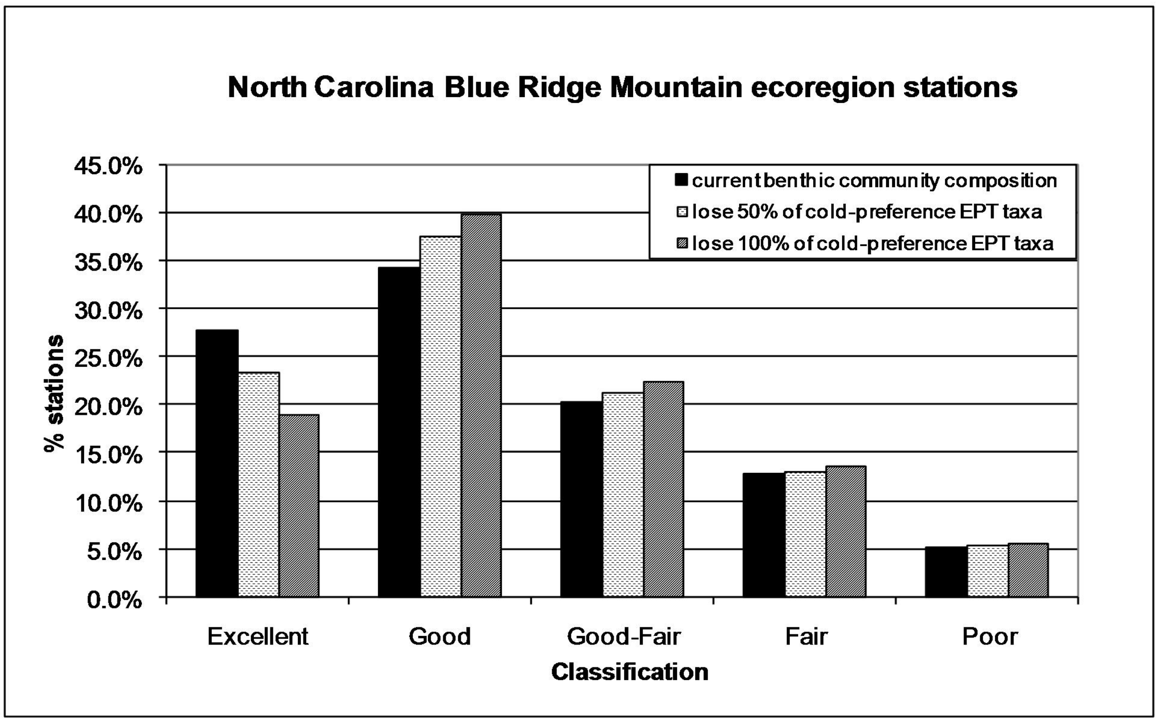


Figure 3-2 Example of how reference station status can degrade over time due to climate-induced increases in stream temperature.

Third, interactions among stressors can lead to outcomes that are difficult to predict, creating an even more uncertain management context. For example, as mentioned earlier, temporal and spatial changes in such factors as human population and development patterns, climate, and other drivers of change will continue, and they will affect watersheds significantly, but are highly uncertain and difficult to predict. Impervious cover in watersheds is a well documented source of aquatic ecosystem impairment. Based on Bierwagen et al. (2010), a higher rate of population growth coupled with greater suburban and exurban development will result in increases in impervious surface cover that cause significant shifts of watersheds into lower categories of condition. This assumes, however, that current relationships between population growth and impervious surface remain the same in the future. Changes in technology and human behavior could alter these relationships, making predictions based on historic relationships inaccurate.

Finally, more knowledge is needed about where thresholds exist and what indicators would give sufficient advance warning to truly inform management decisions. If more information were available on reliable indicators of resilience and approaching thresholds, monitoring systems could be modified appropriately. One caveat is that resilience is interpreted comparatively through the lens of societal values. This means that increasing the resilience of one system against crossing a threshold may be a higher priority than increasing the resilience of another system that is equally at risk, ultimately causing that system to cross a threshold. Thus, the science and management of ecosystems depends largely on society's answer to increasing the resilience "of what, to what."

Indicators and Assessment Methods

Assessing watershed resilience at statewide or major basin scales can be a time-consuming task involving hundreds or thousands of watersheds. This type of analysis will only become common practice if highly efficient, rapid screening tools and available data sources are made readily accessible. Using an indicator-based approach, measures could be developed of specific, resilience-relevant watershed attributes that have a basis in the literature and practice and are easily measurable using common and consistent data. These indicators could be assembled into multi-metric indices. How universal are measures associated with resilience? Results from efforts such as EPA's development of a biological condition gradient (BCG) suggest that some physical and community properties consistently reflect watershed condition despite regional ecological differences (Davies & Jackson 2006). Development of condition gradients also allows historical information, when available, to be used for determining a baseline. The existence of these common physical and community properties suggests the feasibility of developing a general framework to characterize watershed resilience. Such a framework will require flexibility and professional judgment to select from an array of assessment metrics as varying program goals and state-to-state ecological differences may warrant.

As we consider the potential role of resilience in healthy watersheds assessment and watershed protection and restoration programs, key questions include:

- What are the key indicators and methods for assessing and predicting watershed resilience?
- What can we learn from existing indicator work (e.g., recovery potential) that can be translated to assessments of resilience in watersheds?
- How could predicting differences in resilience in the face of climate change and increasing development pressures be applied to healthy watersheds assessment?
- Which methods are most useful and appropriate for applying an understanding of resilience to improve watershed management decision making?
- What indicators capture both system resilience and sub-components of special interest?

Critical Concepts for Resilience Indicators and Assessment

One useful approach for assessing and applying resilience in watershed programs is to examine not only resilience traits themselves, but also the broader array of factors that influence resilience. Resilience is an inherent property of ecosystems and watersheds; thus, many ecological, physical structure, and process characteristics evidently related to resilience are of interest. In addition, the pressures of numerous additional factors such as development, agricultural and silvicultural land conversion, climatic changes, and other stressors are of interest since they affect a watershed's current resilience and may significantly reduce its capacity for resilience in the future. Since resilience in one factor may rely on interactions with other factors, potential cumulative effects need to be addressed. The societal context – the community behavior and values, laws, economics, and other drivers – that forms an external backdrop for these pressures and responses is capable of further influencing resilience and ultimately watershed condition; in fact, human communities exhibit resilience characteristics of their own. All of these factors may not be encompassed in watershed resilience, but clearly can influence it and thus should be considered in assessment approaches.

Recovery potential screening (Norton et al. 2009) has explored the development and application of indicators of watershed restorability for use in rapid, comparative screening assessments across large areas, and may provide some insights for resilience indicators and assessment approaches. In a review of restoration literature and practice that compiled evidence of watershed attributes associated with increased or reduced restorability, investigators found numerous factors that had a plausible relationship to recovery and were measurable from commonly available GIS or water quality monitoring data sources (Table 3-2; U.S. EPA 2009a). These factors were organized into three classes that arguably represent the major drivers of restoration success: ecological capacity to regain function, stressor exposure, and social context and process. Development and refinement of ecological, stressor, and social indicators from these factors enabled the development of multi-metric indices in each of the three classes as the basis for a comparative, 'three-dimensional' recovery potential screening methodology. By generating sub-indices, restorability could be characterized in terms of three major types of driving factors as an alternative to masking the unique influences of each in a single, overall score. Many of the recovery potential indicators and related literature are available at a recovery tools and resources website (Norton et al. 2011).

Similar to planning for restoration of impaired watersheds, resilience and the external factors that influence resilience are critically important in healthy watersheds assessment and planning. Specific indicators and the three sub-indices approach in general may be usefully adapted for assessing healthy watershed resilience. In the ecological sub-index, indicators characterize resilience directly in terms of physical structure and key natural processes by measuring properties of the water column and biota, the channel, corridor, and watershed. Key metrics for this sub-index might include biotic community indices, the integrity of channel form, a natural flow regime, and natural land cover in the river corridor and watershed. Stressor indicators that negatively affect resilience, the second sub-index, focus on specific stressors and their sources from water column to watershed scales, and could address hydrologic alteration, biological stressors, fragmentation, and the severity and complexity of corridor and watershed stressor sources. Social indicators relevant to resilience, the third sub-index, do not influence watershed condition directly as do stressors, but rather affect resilience indirectly via societal context and processes interacting with ecological condition or stressors. Social context factors with potentially developable linkages to watershed resilience include natural resource protection mechanisms, economics, complexity, certainty, community engagement and incentives, leadership, and critical mass for effective action.

Table 3-2 Example recovery potential screening indicators used to compare relative differences in restorability among impaired waters or watersheds rely heavily on resilience traits and the external factors that also influence resilience.

60 Example Recovery Potential Indicators		
Ecological Capacity	Stressor Exposure	Social Context
natural channel form	invasive species risk	watershed % protected land
recolonization access	channelization	applicable regulation
Strahler stream order	hydrologic alteration	funding eligibility
rare taxa presence	aquatic barriers	303(d) schedule priority
historical species occurrence	corridor road crossings	estimated restoration cost
species range factor	corridor road density	certainty of causal linkages
elevation	corridor % U-index	TMDL or other plan existence
corridor % forest	corridor % agriculture	university proximity
corridor % woody vegetation	corridor % urban	certainty of restoration practices
corridor slope	corridor % impervious surface	watershed org leadership
bank stability/soils	watershed % U index	watershed collaboration
bank stability/woody vegetation	watershed road density	large watershed mgt potential
watershed shape	watershed % agriculture	government agency involvement
watershed size	watershed % tile-drained cropland	local socioeconomic conditions
watershed % forest	watershed % urban	landownership complexity
proximity to green infrastructure hub	watershed % impervious surface	jurisdictional complexity
contiguity w/green infrastructure corridor	severity of 303(d) listed causes	valued ecological attributes
aquatic community integrity	severity of loading	human health and safety
soil resilience properties	land use change trajectory	recreational resource
watershed % wetlands	legacy land uses	iconic value

Implementation

In the context of protecting healthy watersheds, the goal is to maximize the resilience of watershed functions when facing existing and anticipated stressors and their accompanying detrimental effects. Implementation of management practices to enhance resilience within a specific watershed or area is founded on: 1) an assessment of the current water-land-biota-human system (e.g., water flows, habitats, biological communities, land use patterns, interaction processes, dynamics, and thresholds); 2) identification of ecosystems and their services within a watershed that are of high value and high priority to retain; and 3) consideration of current and future threats, pressures, and stressors within the watershed social-ecological system (SES). The identification of options and selection of management practices can then be guided by optimizing for resilience of the watershed components that support high priority ecosystems and their services under anticipated stressor conditions, and for specific areas and scales.

Managing to optimize resilience means retaining the ability to rebound from natural fluctuations, and seeking increased capacity to both buffer against unwanted fluctuations in magnitude or frequency of events and resist or slow transitions between states, beyond thresholds, or over tipping points. Where ecological systems are high-functioning, conservation and protection from threats can maintain current resilience. Where threats and stressors are expected to encroach on a currently robust system, management practices can be put in place to reduce the impact. It is important to remember that watersheds are comprised of both ecological and human systems and that processes are often linked across these systems and across multiple scales. Techniques to frame decisions and to understand and quantify factors are becoming increasingly available. For example, the Resilience Alliance (Resilience Alliance 2010) provides a workbook for practitioners to assist in evaluating context, systems, interactions, and potential adaptations.

Legislative or regulatory requirements for regional or watershed-scale management plans, such as those for Washington (WA DE 2011), Minnesota (MN DNR 2010), the National Estuary Program (U.S. EPA 2011b), and the National Ocean Policy (CEQ 2010), can offer both structure and incentive to develop and implement integrated, multi-issue resilience and sustainability plans. For example, a primary purpose of enacting the Washington Watershed Planning Act (Revised Code of Washington 90.82) was "…to develop a more thorough and cooperative method of determining the current water situation in each water resource inventory area of the state and to provide local citizens with the maximum possible input concerning their goals and objectives…" (WA DE 2011). Methods developed for Puget Sound can easily be used elsewhere. With the focus on assisting local planners to optimize water flow and retention (Stanley 2010), assessment data were incorporated into a model of *degradation* (or *impairment*) that evaluates the watershed in its 'altered state' and considers the impact of human activities on the water flow process. When combined with an *importance* model (the watershed in its unaltered state), the results can be used to identify sectors suitable for management actions of protection, conservation, restoration, or development, such that benefits of water supply, flood protection, denitrification, and critical habitats are accrued (see Figure 3-3).

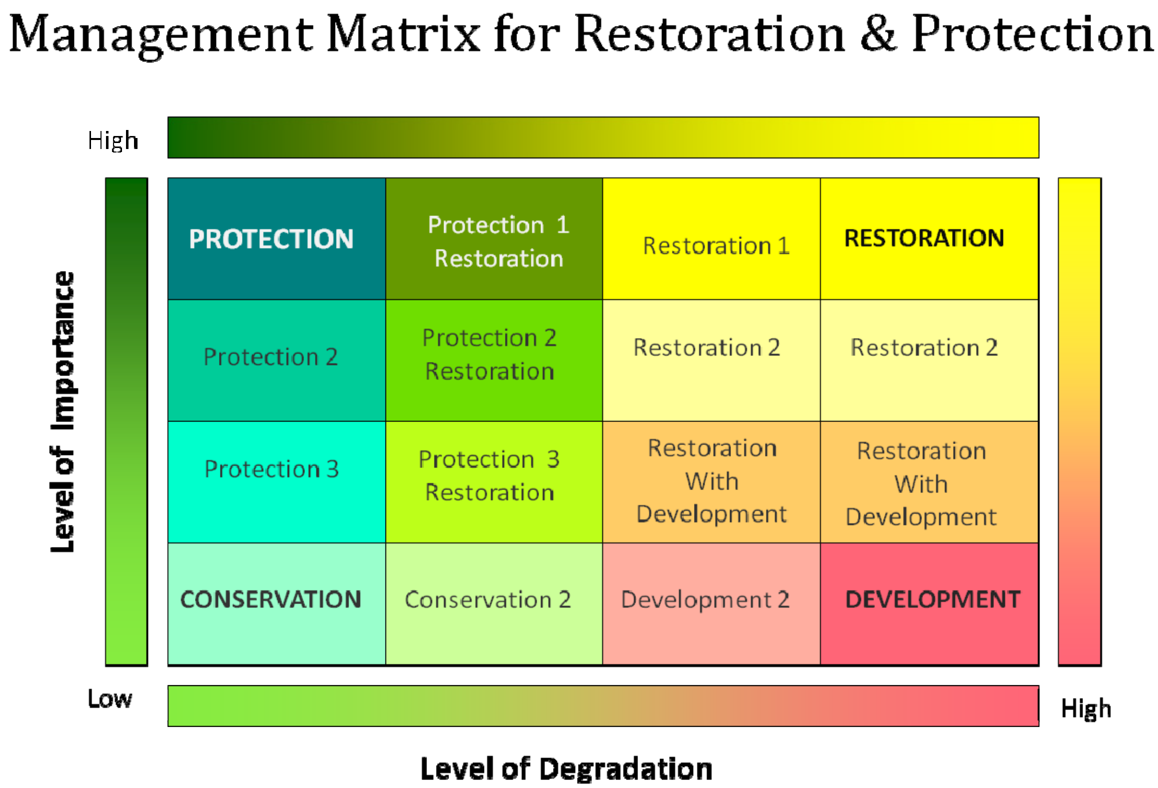


Figure 3-3 **This matrix (Figure 4 from Stanley 2010) shows how results of importance and impairment models can be combined to identify potential watershed management approaches (e.g., identification of areas most suitable for protection, restoration, development, or conservation). Numbers reflect prioritization, with 1 denoting the highest priority for protection or restoration and 3 the lowest. For example, areas with high importance and low degradation (upper left corner) are most suitable for protective actions, while undegraded areas of lesser importance (2 and 3) could be considered for less protective conservation actions (lower left corner). Areas with low importance and high degradation are most suitable for development, since land use changes will have the least impact on water flow processes in these areas**

Resilience is desired to accommodate uncertainty in recognizing stressors, identify threats and vulnerabilities, predict interactions, and evaluate risk. The uncertainty in knowledge and prediction are compounded by variability in temporal and spatial scales, as well as linkages across scales. Indicators of resilience specific to a process, system, or threat can be combined with assessments of functionality (e.g., flow modulation) and importance (e.g., flood prevention) to target enhancement for resilience, thus also reducing vulnerability. For example, if the combination of projected climate change and urban growth is taken as the focus for a future scenario, then potential watershed management approaches must consider resilience to stressors, such as increased flashiness, higher temperatures, power demands, and habitat loss. Climate Readiness and Climate Action Plans (e.g., King County, WA 2007) being developed by many municipalities and organizations incorporate considerations of resilience into adaptation planning.

Charge questions for discussion at the Healthy Watersheds Integrated Assessments Workshop included two that were specific to resilience: 1) What are the key indicators for assessing watershed resilience? and 2) What are the methods for assessing watershed resilience? Discussions around these two questions took place in the context of other questions that were directed at developing, implementing, and applying Healthy Watersheds Integrated Assessments (HWIA). A common view of general sustainability and resilience strategies was articulated. Some noteworthy points included:

1. It is critical to develop a baseline from which to consider response and resilience, using monitoring, mapping, and modeling indicators of landscape condition, biological integrity, water quality, habitat, geomorphology, hydroecology, stressors, social conditions, regulation, and vulnerabilities.
2. Legislative and stakeholder discussion and determination of goals and incentives are instrumental in establishing targets to guide evaluation of risks and management options.
3. When local governments can access and integrate complex natural resource information, and understand that healthy watersheds provide benefits to them socially and economically, managing for resilience against disasters and threats to watershed functions and services becomes a high priority.

Examples

Watersheds

The State of Maryland used recovery potential screening to assess and compare differences in resilience and overall restorability among non-tidal watersheds statewide, and specifically in their three ecoregions. Their work demonstrates how a primarily restoration-oriented screening could easily be adapted for protection screening purposes. The goal was to identify which impaired watersheds (black circles in Figure 3-4) were the strongest prospects for successful restoration, but all of the state's healthy watersheds (blue circles in Figure 3-4) were also screened with the same indicators. Despite the main focus on impaired watersheds, the screening secondarily revealed many patterns about the healthy watersheds that may also be relevant to their management. For example, the watersheds that passed bioassessment but still show elevated stressor scores may be at risk. Further, wide differences in social score imply that some of the healthy watersheds have far better social context for continued protection than others. In addition, several of the impaired watersheds that scored nearly as well as the healthy watersheds (see upper left quadrant in Figure 3-4) provide useful information for prioritizing restoration targets in the future.

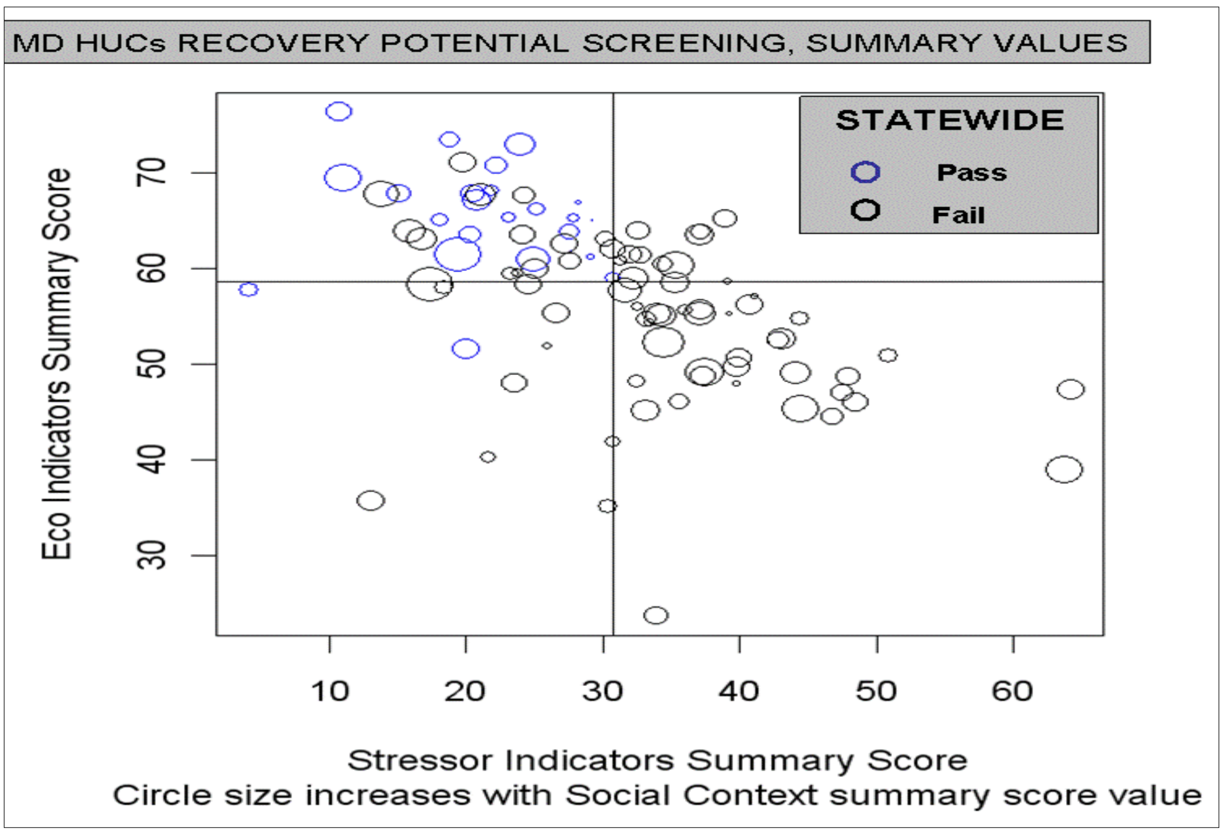


Figure 3-4 A recovery potential screening assessment of healthy (blue) and impaired (black) watersheds was conducted to inform and help prioritize statewide restoration strategy.

Lakes

Lake-watershed systems are affected by agricultural phosphorus flows, draining and development of wetlands, removal of riparian vegetation, overfishing, and spread of invasive species. From a review of the literature, Carpenter and Cottingham (2002) found eight factors to be useful as indicators of a lake's capacity to maintain normal dynamics:

- *Livestock density within the watershed* as a correlate with phosphorus imports.
- *Wetland area per unit lake area* as an index of the landscape's capacity to hold water and export humic substances.
- *Proportion of riparian zone occupied by forest and grassland* as an indication of the potential attenuation of nutrient inputs.
- *Lake color* as an indication of humic content.
- *Slow-to-moderate piscivore growth rates* as an indication of strong piscivore control of planktivores.
- *Grazer body size* as a correlate with the capacity to suppress algal growth.
- *Partial pressure of carbon dioxide in surface waters* as an indicator of ecosystem metabolism.
- *Hypolimnetic oxygen depletion* as a symptom of eutrophication and a driver of phosphorus recycling from sediments.

Comparisons of these indicators with long-term records and regional surveys can provide an understanding of a lake's resilience and movements away from resilience to inform management actions.

Coral Reefs

Some characteristics of coral ecosystems that increase resilience to climate change have been theorized to be the availability of locations where cooler waters exist due to upwelling/mixing, where rapid currents exist that flush toxins, or where ultraviolet radiation is reduced or eliminated by cliffs, shelves, or turbid waters. Resilience also exists where there are coral communities that are adapted to higher temperatures and ultraviolet radiation or where conditions favor recolonization. These characteristics were considered in the design of a network of marine protected areas in Kimbe Bay, Papua New Guinea. The design was composed of four parts, the first of which was to spread the risk by protecting representative and replicated areas of major habitat types so that local disturbances will not completely eliminate some species or ecosystem types. The second component was to safeguard special and unique sites, particularly those that provide key sources of larvae such as fish spawning aggregation sites and areas that may be naturally more resistant or resilient to coral bleaching. The third was to preserve ecological connectivity among coral reefs and related ecosystems due to ocean currents, larval dispersal, and movement of adults to maintain natural patterns of connectivity and facilitate recovery of areas affected by major disturbances. The final part of the design was to continue to manage other threats, such as water quality and overfishing, to ensure that reefs are as healthy and naturally resilient as possible to improve their chances of surviving global change.

Monitoring for Resilience and Employing Adaptive Management

To manage ecosystems for resilience, indicators are needed that can be monitored to give advanced warning of an approaching regime shift (Contamin & Ellison 2009) and aid in forecasting thresholds (Luck 2005). How much warning is needed is, in part, driven by how responsive a state or driving variable is to management actions (Biggs et al. 2009, Contamin & Ellison 2009). Unfortunately, existing monitoring systems were often established with goals in mind other than resilience or threshold detection; thus their utility for identifying potential regime shifts is limited. For example, biological monitoring systems at the state level are designed to detect sources of stream or river impairment. Sites with suspected sources of impairment are sampled and then compared to sites that are similar, but still in high ecological condition. The sampling design required to answer these questions cannot inform other questions that require a different spatial or temporal distribution of monitoring sites. Monitoring watershed health is likely to require a higher density of sampling sites that may need to be monitored yearly or seasonally in order to provide adequate information on approaching thresholds or resilience.

Another problem is the length of time and frequency with which existing networks have been set up to monitor ecosystems to enable careful time-series studies to be conducted (CCSP 2008). If the spatial and temporal coverage is not sufficient, or existing networks cannot be maintained into the future, it will not be possible to develop a deeper understanding of ecosystem sensitivities and resilience attributes to inform management.

Monitoring can provide the necessary empirical data to confirm and resolve the relative importance of hypothesized characteristics of resilience in order to support improved quantification and prediction of species and ecosystem resilience within and across watersheds. If done carefully, monitoring can not only help to identify ecosystem sensitivities and resilience, but can also support adaptive management. Adaptive management is a process that promotes flexible decision making through adjustments in policies or operations as outcomes from management actions and other events are better understood (Gregory et al. 2006; West et al. 2009). It emphasizes management based on observation and continuous learning, and provides a means for effectively addressing various degrees of uncertainty in our knowledge of ecosystem processes and sensitivities to environmental stressors and attributes of resilience. Models can be used to guide decisions and monitoring can improve the models. In order to employ adaptive management successfully, scientific hypotheses about ecosystem responses need to be explicitly stated, and monitoring programs must be designed with predefined triggers. Those triggers should initiate a re-examination of management approaches in order to make appropriate adjustments.

An example of a program employing monitoring for resilience and adaptive management is Minnesota's Sustaining Lakes In a Changing Environment (SLICE) Program. The Department of Natural Resources selected a representative sample of lakes to monitor for biological and chemical changes that feed back to management approaches to prevent or minimize negative impacts from sources such as development, agriculture, loss of native aquatic plants, invasive species, and climate change. The first step of this program is to measure a number of watershed, water quality, zooplankton, aquatic plant, and fish metrics in 24 sentinel lakes. These metrics are evaluated according to their capability of, and efficiency in, capturing the condition of lake habitats and fish communities. Once a subset of metrics has been chosen as indicators, monitoring schedules are developed for sentinel lakes and randomly selected additional lakes to broaden the types of lakes and geographic areas covered in the program. Monitoring data gathered from the sentinel lakes inform condition assessments, assist in evaluating causal mechanisms of stressors and responses, and are used in predictive modeling and early detection of problems. The large number of randomly selected lakes are monitored less frequently, using fewer indicators for the purpose of identifying geographic scales of trends and comparing results with observed patterns in the sentinel lakes (see http://www.dnr.state.mn.us/fisheries/slice/index.html).

Summary of Resilience Challenges and Responses

Ecosystems within watersheds will cross thresholds at different points in time and in different locations, possibly resulting in substantial alterations. The timing and location of threshold occurrences will depend in part on the attributes of the ecosystems themselves and on the magnitude of pressure these systems are exposed to from natural and human sources. Greater understanding of those attributes and their associated indicators is needed to maintain resilience and manage risks associated with ecological thresholds within healthy watersheds. The spatial variation in threshold occurrences necessitates integration of existing monitoring information at all spatial scales to identify ecosystems approaching and undergoing critical transitions.

With improved understanding of resilience attributes, thresholds, and hypothesis-driven monitoring data covering multiple spatial and temporal scales, comes an improved capability to forecast and plan for future threshold events using alternative management scenarios. Even watersheds designated as healthy today are likely to undergo critical transitions and threshold changes at some point in the future due to global stressors. This necessitates not only protection now, but also restoration in the future (CCSP 2008, 2009).

Key to making appropriate changes in monitoring, modeling, forecasting, and management is identifying the characteristics of systems that make them more or less resilient to individual and multiple stressors and identifying early warning signals of impending threshold changes. Also important is developing hypotheses about anticipated changes and employing adaptive management strategies to increase the resilience of healthy watersheds in the near term and recognize the new successional ecosystem states or novel combinations of species that may occur in the long-term (see discussion about Figure 3-1 under the section above entitled “Benefits of Resilience”). The research community is beginning to address this difficult task of balancing resilience against succession. A few selected publications with helpful guidance include Galatowitsch, Frelich, and Phillips-Mao (2009), West et al. (2009), and the Climate Change Science Program (2008). Finally, since some changes in ecosystem states are inevitable over time, managers may have to adjust some of their goals for healthy watersheds away from historic benchmarks that may no longer be achievable because of ongoing urbanization, climatic changes, and other global changes (CCSP 2008, West et al. 2009).

Chapter 4 Integrated Assessments

The primary goal of the Healthy Watersheds Integrated Assessment Workshop was to support the identification of healthy watersheds at state and regional scales so that they could be better protected. Integrated assessments to support identification of healthy watersheds serve a screening role, making the best use of available data. Ancillary goals of healthy watersheds assessments, discussed in Chapter 3, are to: 1) evaluate the restoration potential of impaired watersheds, and 2) evaluate factors affecting the resistance and resilience of watersheds in the face of climate change and continued population growth to ensure that watershed health is sustained in the long run. Discussions during the workshop highlighted the additional need to assess the effectiveness of watershed management activities in the context of the conceptual model for healthy watersheds (i.e., to determine what watershed processes and function need to be considered in protection and restoration efforts in order to protect aquatic communities and ecosystems). In this context, integrated watershed assessments can be used to help implement adaptive management.

Some states and NGOs have already implemented screening assessments to identify and prioritize healthy watersheds for protection. For example, the National Fish Habitat Board (NFHB, 201 0) developed a Landscape Disturbance Index for the entire United States. Using five natural environmental variables and 17 human disturbance variables, an index representing the relative quality of fish habitat was developed and a score assigned to every stream reach in the nation. Scores are aggregated at multiple spatial scales, from the local catchment to the river basin. The scores are calibrated based on fish community data gathered from a variety of local and regional partners. NFHB is working with these same partners to communicate the results of the assessment and prioritize protection and restoration actions. The State of Kansas has developed a Least Disturbed Watersheds Approach that relies on a similar process for screening watersheds across the state and identifying those that are likely to contain streams in reference condition. The state plans to monitor physical habitat, water chemistry, and biological communities at the verified reference streams to develop a database that can be used to inform regulatory, incentive-based, and interagency efforts to protect reference streams and their watersheds from degradation.

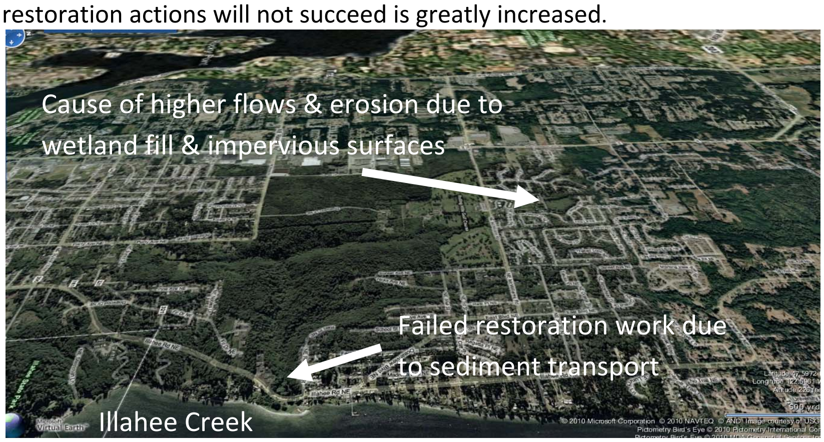
As presented in Chapter 2, ecosystems within watersheds are influenced by many interacting processes that operate at multiple spatial and temporal scales. To protect aquatic and terrestrial ecosystems effectively, watershed managers, nongovernmental organizations (NGOs), federal and state agencies, and local governments will benefit by focusing not only on the condition of aquatic resources, but also on protecting and restoring key watershed processes that govern the interaction of water, sediment, plants, and animals at these multiple scales (Beechie et al. 2010; Beechie & Bolton 1999; Dale et al. 2000; Gove et al. 2001; Hidding & Teunissen 2002). This chapter will present a framework for integrating data and assessments of landscape characteristics, hydrology, geomorphology, water quality, habitat, and biological communities with the types of management issues and questions that can be addressed at each of these different scales. This includes identifying the best locations for new development and protection and restoration actions.

Watershed Framework

In order to undertake and implement a successful process-based approach to protecting aquatic resources within one or more watershed(s), it is helpful to establish a framework (see Figure 2-2) that integrates watershed aquatic resource data and information for all watershed aquatic resources and processes. An example of such a framework was developed by the City of Issaquah and King County in Washington State (Stanley et al 2009b). A watershed technical team comprised of watershed scientists (geomorphologist, hydrologist, ecologist, wildlife biologist, fisheries biologist, water quality scientist) is needed to assist watershed managers in interpreting and applying information from the watershed framework. The framework should:

- Identify stakeholders and existing data, inventory aquatic resource condition, and characterize/assess watershed resilience and the condition of watershed processes and functions over multiple spatial and temporal scales;
- Use a tiered approach that addresses specific questions/issues for the watershed;
- Incorporate process-based models for the system you are assessing (lotic, lentic or tidal) - this could consist of either conceptual or mechanistic models, depending on the complexity of the issues and the availability of data;
- Identify problems in the watershed (i.e., where, why, and to what extent have watershed processes and functions been degraded);
- Identify solutions including regulatory, programmatic, and capital measures needed to protect and restore processes and functions;
- Take action through implementation (non-regulatory and regulatory approaches); and
- Develop a monitoring program to evaluate and apply results through adaptive management.

Why Are Integrated Assessments Needed?
Along the west side of the glacially sculpted Puget Sound estuary, a small but important coastal watershed drains to its marine waters. Illahee Creek supports a locally valued salmon run that is declining due to several interacting factors. In the last ten years, local salmon recovery groups have attempted to enhance the salmon run by restoring side channel habitat in the lower reaches. The channel enhancements were rapidly "filled in" by sediment pulses during larger storm events. A subsequent watershed assessment of sediment and water flow processes demonstrated that high flows and bedload transport were being caused by conditions in the upper watershed. These included filling of wetlands, high levels of impervious surfaces, and the presence of unconsolidated outwash deposits. In addition, the recent increase in the intensity of storms appeared to be accelerating the erosion and movement of sediment. By attempting to design a restoration project at the site scale without understanding the overall condition of the watershed processes and controls, the probability that restoration actions will not succeed is greatly increased.



Using a Tiered Approach

A "tiered approach" (Figure 4-1) is one potential strategy for conducting an integrated watershed assessment that is designed to address specific issues occurring in a watershed within the limitations of available time and budget. An integrated assessment includes an assessment at the broad or watershed scale since it informs analysis at the subsequent finer scales. A watershed scale assessment can provide information on key processes, stressors, and conditions within the landscape based on broad geographic information and land use patterns. However, a broad scale analysis is primarily limited to issues addressing planning level decisions that deal with land use patterns (e.g., zoning, designations, and policies) and water use as it affects hydroecological requirements (e.g., instream flow, ground water input, lake levels, hydrologic connectivity). Finer scale assessments (i.e., waterbody and local scale) are performed within the context of the watershed scale and can address issues regarding reach and site scale processes, and specific protection and restoration designs.

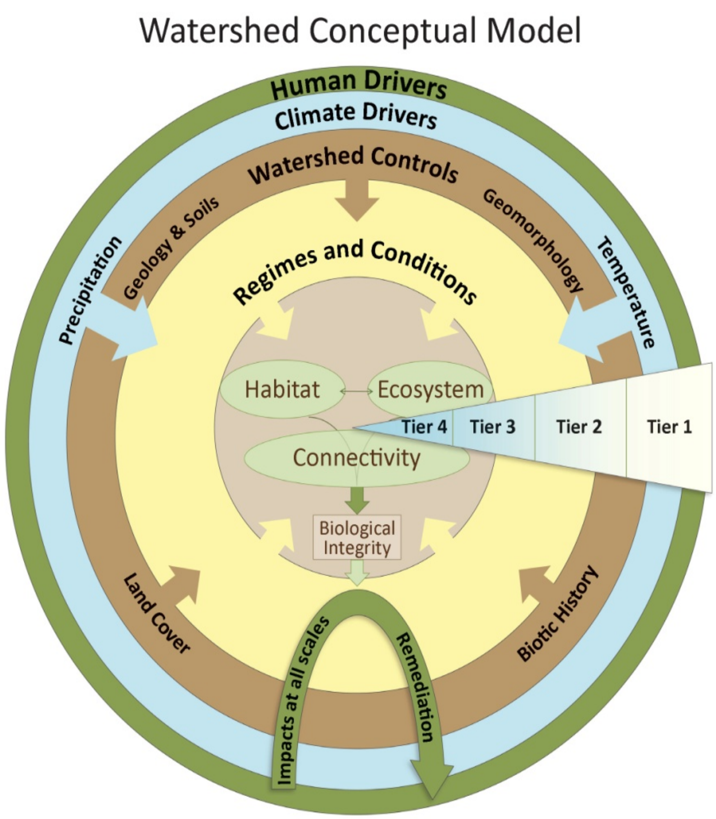


Figure 4-1 Conceptual model from Chapter 2 showing the relationship of the "assessment tiers" to the components of the model. This generally illustrates the type of data that must be used in each assessment and the resolution of the results. Tier 1 analyses require coarse scale data on the controls of processes (geomorphology, soils, and land cover) and can address questions involving management of land cover. Tier 4 analyses require fine scale data (biological, physical and chemical) at the waterbody scale and can address management questions of restoration measures and design.

Other Factors to Consider – Data Quality and Accuracy of Results

Available data at the local and watershed scales are sometimes inaccurate and often inconsistent in extent and coverage.[3] For example, hydrography data do not always capture the presence of headwater streams. This complicates efforts to understand fully the relationship between the impacts of land use activities at the watershed level and the resulting environmental responses at the local scale (e.g., ground water withdrawals and low baseflow regimes). Furthermore, watershed assessments require the integration of knowledge from multiple scientific disciplines (e.g., geomorphology, hydrology, and ecology). Barriers to successful integration include the lack of common languages and terminology, mismatches between datasets and methodology, and varying levels of precision and accuracy in predicting environmental responses (Benda et al. 2002). Therefore, it is important that a watershed analysis always seeks to explore the links between assessments of physical, chemical, and biological processes at different spatial and temporal scales in order to improve the accuracy and interpretation of watershed information. Further, the selected analytical methods must be achievable within the available budget and expertise while addressing the key issues identified by watershed stakeholders and experts.

Tiered Integrated Assessments

The following descriptions of tiered assessments are based on the Chapter 2 overview of how landscape processes, their controls, and stressors interact to form habitat structure and drive the type and level of performance of the associated functions (see Figure 2-2).

Watershed Scale, Tier 1 – Application: Planning (best location of protection and restoration actions). Characterizes landscape scale processes at watershed/sub-watershed scale; highest uncertainty in results.

Tier 1 assessments are desktop exercises using existing GIS data layers to characterize landscape and watershed conditions using simple categorical ratings without detailed data analysis. Tier 1 analyses focus on characterizing landscape scale processes at the watershed scale that drive both the structure and function of aquatic ecosystems at the reach and site scales. Examples of ecological functions that could be examined in a Tier 1 assessment include surficial and ground water hydrology, potential nutrient loading, landscape cover type, disturbance regimes, buffer integrity, and connectivity (e.g., the potential for movement of woody debris). A Tier 1 assessment provides important information on how a watershed functions at the broad or watershed scale and can serve as an initial filter to determine where potential problems may exist and where additional finer scale analysis is warranted. Tier 1 assessments involve the use of existing remote sensing data to define watersheds for the assessment of watershed scale controls, such as topography, hydrologic network, and surficial geology; land use/land cover; and anthropogenic modifications (see Figure 2-1). A method of grading the ecological health of watersheds at a Tier 1 level could be developed to provide information to target audiences. There is generally a much lower capital cost associated with Tier 1 assessments, as there is no field work required, and they are generally conducted with existing or easily obtainable datasets. There is, however, a higher level of uncertainty in Tier 1 assessments due to the coarse scale at which they are conducted.

[3] This should not discount the value of local data in identifying problems that exist within a watershed.

Waterbody Scale, Tier 2 - Application: Planning (best location of protection and restoration actions). Characterizes landscape scale processes at sub-watershed/FPZ scale; high uncertainty in results.

Tier 2 assessments are desktop exercises using GIS extensions and other simple spreadsheet and modeling tools that begin to analyze a combination of watershed and sub-watershed scale characteristics and conditions. Existing and new remote sensing data are used to hydrogeomorphically define reference reaches (i.e., functional process zones) using: valley geometry, hydrologic network, and surficial geology; land use/land cover; and anthropogenic modification to channels, floodplains, and watersheds (flow and runoff characteristics). Flow characteristics (i.e., magnitude, frequency, duration and timing) are developed using assessments such as the Ecological Limits of Hydrologic Alteration (Poff et al., 2010). Tier 2 assessments build upon information derived from Tier 1 analyses and begin to provide interpretative information over different spatial and temporal scales on how watershed controls and land cover changes result in different regime conditions (see Figure 2-1) and ecological functions. Tier 2 assessments are used to suggest probable ecological structure, type and condition of ecosystem services, and the resiliency or recovery potential of the waterbody as described in Chapter 3.

Local Scale, Tier 3 (Rapid Field Assessment Methods) - Applications: Restoration designs and identifying comprehensive solutions to environmental issues. Low degree of uncertainty in results.

Tier 3 assessments are conducted at the reach or catchment scale to evaluate general ecological health using water quality investigations and testing, and relatively simple field measurement of hydrologic, geomorphic, and habitat indicators. Rapid assessment methods can be developed to analyze factors such as regime departures, condition of buffers and habitat, water chemistry, connectivity, and hydrologic modifications. Tier 3 assessments, when combined with Tier 1 and 2 data, can provide information related to potential stressors to ecologic health.

Local Scale, Tier 4 (In-Depth Field Assessment and Empirical Modeling) - Applications: Restoration designs and identifying comprehensive solutions to environmental issues. Lowest degree of uncertainty in results.

Tier 4 assessments are intensive site or functional unit level assessments that provide a more thorough and rigorous measure of ecological condition by gathering direct and detailed measurements. Examples include measurement of biological taxa, habitat, hydrogeomorphic function, and pollutant loadings. Tier 4 assessments should be integrated with information already derived from Tier 1 – 3 assessments. Costs associated with Tier 4 assessments are higher due to intensive field work and potential laboratory costs, but the information they provide is much more site-specific and accurate. Tier 4 assessments are likely to be used at targeted locations where restoration or conservation opportunities already exist.

Using Integrated Tiered Assessments to Identify Healthy Watersheds

In the past, achieving watershed health has been associated specifically with the management of species at the site or reach scale without consideration of ecosystem processes (Beechie & Bolton 1999). The general approach described here uses watershed processes and resulting regime and habitat conditions, ideally linked with available biotic data, as measures of healthy watersheds. The analysis is based on climatic drivers (e.g., precipitation) and watershed controls as described in Chapter 2. These drivers and controls result in various regimes and conditions associated with places on the ground. Processes and functions are linked among watersheds, waterbodies, reaches, and sub-reaches, and the resulting conditions and impacts are evaluated at different spatial scales (see Table 4-1).

Without considering these linkages, identification of healthy watersheds will be incorrectly based on the use of one scale or tier of data. For example, macro/micro habitats that support healthy populations at a single reach may seem to indicate a healthy watershed. However, by scaling up to the larger "functional" watershed for this reach, it could be revealed that the driving processes are significantly altered and will not sustain this finer scale population for the long-term. Therefore, it is wise not to use single biological samples to characterize watershed health at larger scales without hierarchically linking habitat features with larger scale formative processes. Conversely, watershed scale information should not be used to predict site scale biological conditions.

Biological data are also critical for verifying and validating the process-based approach. Depending on the scale of the analysis and level of detail, data on high priority locations, such as habitat conditions and status of biological communities, are needed as feedback on the identification of healthy watersheds using the above approach. Without this validation, important opportunities are missed. Many states that begin an HWIA may have Tier 1 watershed/landscape data and Tier 4 biological data, because those are the data that were collected and used to identify impaired waters. The Tier 1 data may be used to start mapping HWs, using the Tier 4 biological data as initial verification, while some amount of Tier 2 and 3 data is being collected to define the process linkages between habitat scales.

Ultimately, HW Teams may want to devise a method for ranking the healthiest watersheds, sub-watersheds, reaches, and waterbodies where protection and restoration activities may be focused. To assist in selecting an appropriate method, Table 4-2 summarizes for each tier the types of processes and the resiliency and stressor features used to develop mapping products and actions to protect and restore healthy watersheds. Ranking healthy watersheds and supporting protective actions are aided by an understanding of the ecosystem services, sensitivity, and threats that come into sharper focus through a tiered assessment. Actions may become finer-scaled with each successive tier and may include the protection of vegetated riparian corridors and shorelines, hydrologic connectivity, floodplains, and wetlands with assessments at any tier through land acquisition, conservation easements, land stewardship, permits, education, and outreach.

Table 4-1 Types of data collected in four hierarchical tiers of watershed assessment (see Figure 2-2 for ecological and assessment framework). Tiers are primarily defined by the spatial scale at which data are collected and secondarily by the type of effort. Each tier overlaps a pair of the concentric rings depicted in the Watershed Conceptual Model (Figure 2-1).

	Tier 1	Tier 2	Tier 3	Tier 4
Scale	Watershed / Subwatershed	Subwatershed / Valley Segments (FPZ)	Reaches / Waterbodies	Segments / Sites
Type of Effort	Existing GIS data layers	New GIS data /modeling	Field data collection	Field data collection/ empirical modeling
Integration w/ Conceptual Model (Figure 2-1)	Climate drivers (precipitation), watershed controls, broad ecosystem and hydrological conditions	Watershed controls, regimes, conditions, & resiliency/recovery potential	Regimes, conditions, habitat, ecosystems, and connectivity	Regimes, conditions, habitat, ecosystems, & biological integrity
Hydrology	Digital hydrography data, Land use / cover, wetlands, Precipitation mapping, Hydrologic connectivity, Roads, ditches, dams, % impervious cover	Flow characteristics: magnitude, frequency, duration, and timing of flows; Historical land use/cover	LiDAR/bathymetry data, Flow modifiers, Bedrock and surficial geologic mapping to support ground water recharge and discharge delineation	Channel geometry and hydraulics, Distribution and sorting of sediment & wood, Boundary conditions and vegetation (soil erodibility testing, roughness elements and coefficients)
Geomorphology	Geology: bedrock and surficial, Soil resistance properties, Geography - continental, mountain, valley, and coastal land forms	Delineation of: geomorphic reaches, functional process zones, active river areas, ground water-dependent ecosystems: springs, seeps, wetlands, lakes; Historical planform and floodplain modification	Channel, floodplain, and valley geomorphology; Hydrologic, sediment, and woody regimes; Geomorphic stability and stage of channel evolution	
Water Quality	Surficial geology and soil chemistry, Temperature zones, Permitted wastewater and stormwater discharges	Mapping of human disturbance gradients and critical source areas using land use nutrient loading coefficients	D.O., sediment, nutrients, conductivity Temperature conditions, NPDES monitoring data, Illicit discharge detection, Agricultural soil nutrient management data	Chemical pollutant loading data: nutrients, toxins, contaminants of emerging concern Pathogen data
Habitat	Climatic and physiographic regions, Spatial extent / connectivity of native vegetative cover, Natural disturbance regimes (wind, flood)	Ecological Drainage Unit (EDU) mapping (soils, slope, and vegetation);, Riparian mapping, Habitat Suitability Index mapping, Green infrastructure assessment	Habitat conditions and dynamics evaluated from: wetland soils, vegetation, and hydrology; littoral zones/shorelands; instream cover types, depth/velocity combinations, riparian banks, buffers, and corridors; habitat connectivity: lateral and longitudinal	
Biological	Biotic history; Zoographic distribution of species from natural heritage data: rare, threatened, and endangered species and regional species pools		Biological integrity and community health of the resident biota (fish, invertebrates, riparian organisms, wetland and upland plant communities, periphyton, plankton, macrophytes, amphibians, and other wildlife); Invasive species surveys	

Table 4-2 Features and process-based components used in developing mapping products to protect healthy watersheds (see Figure 2-2 for ecosystem and assessment framework).

	Tier 1	Tier 2	Tier 3	Tier 4
Mapping Scale	Watershed, subwatershed landscape	Subwatersheds, valley segments, ecosystems	Reaches, waterbodies, natural communities	Segments, sites, and functional habitat units
Functional Process Features	Watershed hydrologic features identified at broad scales driven by climate as controlled by geologic and biological landscape elements and explaining overland & subsurface water delivery to aquatic ecosystems. Other regimes characterized broadly at the watershed scale.	Spatial and temporal refinement of hydrologic regime and valley-scale zonation of disturbance; sed./organic/nutrient; and heat/light regimes based on existing gage data and finer scale measurement of watershed controls. Upstream connectivity and zoo-distribution.	Spatial refinement of regimes at the reach scale; mapping of ecosystem structures & presence/extent of functional habitat units (e.g., depth, velocity, and substrate patches); upstream, riparian, and upland connectivity.	Spatial refinement and regime dynamics at the micro/macro habitat scales (i.e., mapping of habitat patches). Measurement of "habitat integrity" and "biological integrity" in response to regime and connectivity conditions and invasive species.
Resiliency Features	Elevation, Watershed size/shape, Soil resistance and chemical properties, Forests and wetlands, Connectivity of native vegetative cover, Rare taxa/species occurrence	Contribution and storage areas for water, sediment, organics and nutrients Natural channel forms, Hydrologic connectivity, Forests and wetland areas in corridor/buffer, Corridor slope, Contiguous green infrastructure	Equilibrium channels, Upstream and upland connectivity,; Bank stability, soils, woody vegetation, Diversity of habitat cover types, Ground water seeps, Buffered chemistry	Habitat integrity, Aquatic community integrity, Lack of invasive species Rare taxa present
Human Stressor Features	Hydrologic alterations, Impervious cover, Road/ditch density, Dams & road crossings, Agricultural land use, Wastewater discharges, Connectivity breaks in native vegetative cover	Alterations in magnitude, frequency, duration and timing of flows; Channelization, Structural encroachments in corridor/floodplain, Crop tillage and tile drains in corridor or buffer, Removal of buffer vegetation	Dredging, snagging, berming, ditching, and bank-armoring Undersized crossings & other aquatic barriers, Channel incision, Vegetative response to nutrient enrichment, Unstable or embedded beds/banks/shores, Loss of habitat cover types	Low index of aquatic community integrity, Poor habitat integrity, Invasive species, Disequilibrium (sediment transport imbalance) verified in hydraulic modeling
Healthy Watershed Identification	Map landscapes and watershed areas using simple categorical ratings of condition without detailed data analysis. Intact resiliency features with the fewest human stressors would be rated highest (see Chapter 3: recovery potential rating).	Condition ratings from Tier 1 are refined and assigned to smaller scale, hydrogeomorphically defined reaches, corridors, or valley areas. Important process-related areas are rated higher. Stressors within corridors and buffers used in HW/Recovery are identified.	Map areas of ecological (habitat) health at the reach or waterbody scale, including physical/chemical conditions. Tier 3 reach data used to refine Tier 1/2 scale HW maps. Separate stressor maps assist with restoration work.	Map sites or locations with high habitat and biological integrity nested within Tier 3 healthy reach condition maps. Tier 1/2 HW maps depicting larger scales are refined.
Healthy Watershed Protective Actions	Land use planning and zoning, i.e., location, type, and intensity of new development to avoid and buffer existing, mapped watershed features.	Refinements of Tier 1 land use planning and zoning to protect existing, mapped watershed features and green infrastructure serving important watershed process and function.	Reach and watershed-scale strategies for land and water protections, e.g., water use permits protective of instream flow. Reach specific BMPs to protect and restore conditions associated with healthy watersheds.	Protection of biodiversity and other critical areas. Adaptive management (bio) feedback and site and reach scale project designs for the specific BMPs to remediate stressors to restore and protect healthy watersheds.

Example of Tier I Assessment

One example of a Tier 1 assessment is an assessment of water flow processes in Puget Sound, developed by the state of Washington. Watershed and subwatershed scales were used for mapping and assessment. The assessment methods identified the types of “controls” or important areas on the landscape that govern the movement of water and associated processes, and how land use activities impair each process. This included identifying precipitation types and patterns, and areas of storage (wetlands/floodplains), recharge, and discharge. Impairments assessed included loss of forest, extent of impervious surfaces and change in recharge, and ground water withdrawals. The goal of watershed assessment is to inform decisions on where protection and restoration of watershed processes will be most effective, and which areas on the landscape are most appropriate for development. A ***watershed management matrix*** (Figure 4-2), summarizes the information from the assessment. The matrix is a graphical representation used to identify analysis units most suited for protection, restoration, and other land use activities for a watershed process. The matrix results from two factors: 1) the importance of the analysis unit in maintaining watershed processes, and 2) the degree to which the processes in the analysis unit have been impaired by human activities.

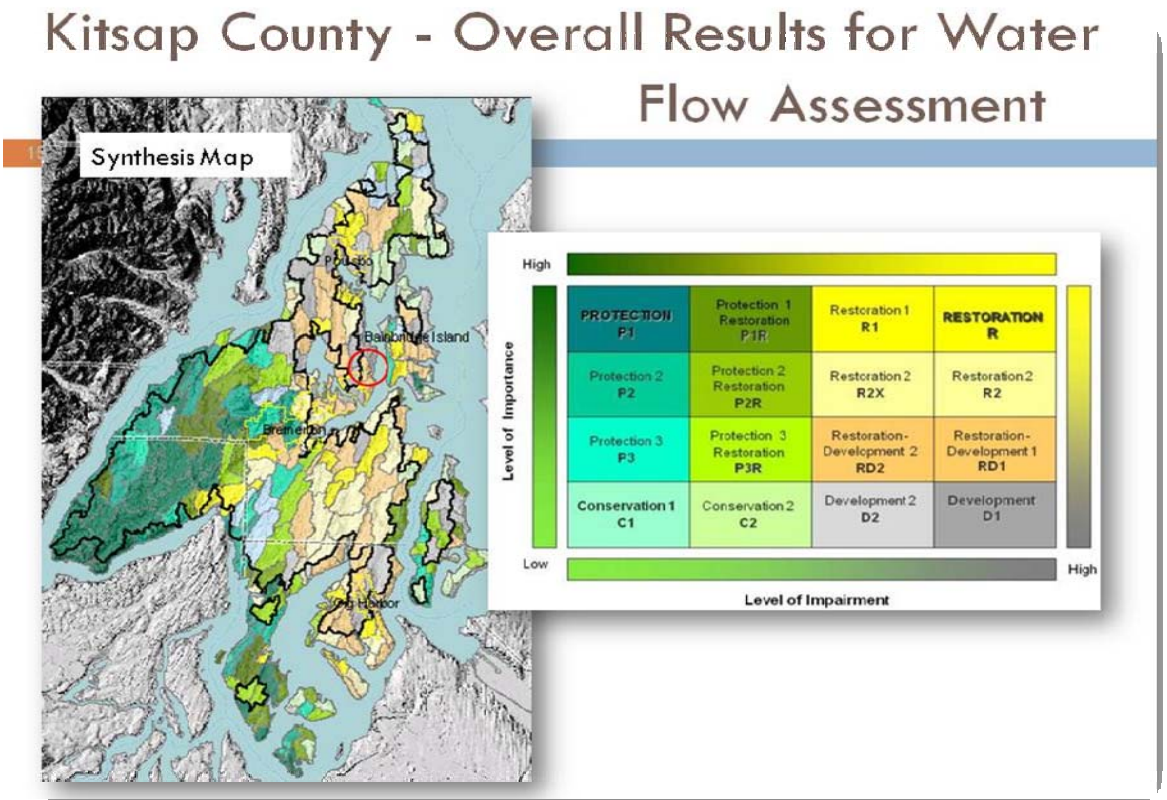
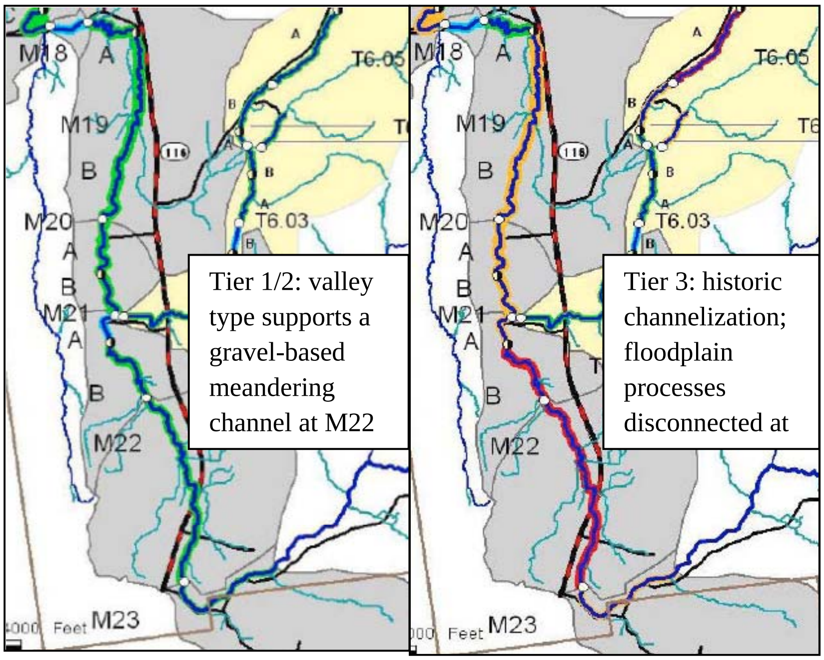


Figure 4-2 Results of Tier 1 assessment of water flow processes in Kitsap County, Puget Sound, Washington. For planners, this type of information can be used to identify the most appropriate development patterns and land use designations that will maintain watershed processes. Areas of green suggest land use activities and policies that protect processes; yellow suggests potential restoration areas and grey areas have higher development intensity. Tier 2 through 4 assessments can address specific issues such as the appropriate restoration design for a creek in a yellow “restoration” watershed.

Example of Tier 3 Assessment

The state of Vermont has developed a fluvial geomorphic-based assessment methodology to support its river corridor protection program. Floodplains, which promote sediment and nutrient storage processes, have been identified as key functional units for protecting and restoring healthy watersheds. The method involves using Tier 1 and Tier 2 data to define meander belt-based river corridors using regime equations and GIS modeling. River corridors encompass the amplitude of meanders that exist or would exist in a given set of watershed controls that define sediment regime. Tier 3 field data are then collected to assess sediment regime departures. In this example, a river corridor plan prepared by *South Mountain Research and Consulting* for the Lewis Creek Association has assessed Reach M22 as a gravel-based meandering channel that has been straightened into an incised, sediment transport dominated reach. Due to limited human encroachment, the M22 corridor is identified as an intact HW component and an exceptional opportunity to increase sediment storage and restore ecological processes. A corridor easement is proposed to restrict land uses and channel management, allow the Creek to re-meander and, in the process, restore floodplain connectivity and function.



River Reach	Corridor Protection Priority	Protection upstream of constrained or altered reaches	Protection downstream of constrained or altered reaches	Key sediment attenuation area	Channel -contiguous wetlands	Alluvial fan or point of marked valley slope reduction	Downstream from major trib. or large sediment source	Moderate or major departure from equilibrium	Accompany passive or active restoration, incised/aggraded
M23	Very high	✓				✓		✓	
M22	Exceptional	✓		✓		✓		✓	✓
M21-B	Very high		✓	✓	✓			✓	✓
M21-A	Moderate							✓	
M20	High	✓					✓	✓	
M19	Very High		✓	✓	✓			✓	
M18	Low	Bedrock Channel							

Figure 4-3 Lewis Creek in Vermont is a watershed with very high recovery potential. Tier 1, 2, and 3 data are used to identify the reach M22 corridor as a priority for a conservation easement to protect sediment/nutrient storage processes.

Principles for Interpreting and Applying Assessment Results

In applying assessment results the following three principles, as put forth by Beechie et al (2011), should be observed:

1. Target the root causes of habitat and ecosystem change. Restoration and planning actions should always identify why a particular environmental problem is occurring and not resort to simply treating the symptom(s). This should always include consideration of the interaction between multiple processes and stressors. For example, if wood is not present in a stream reach, then the response should not be to anchor more wood without first considering the upstream processes delivering wood. Investigation of these watershed processes may reveal that a combination of high flows due to deforestation and channelization is both reducing the supply of wood and destabilizing channels so that any remaining wood is transported out of the system.
2. Restoration and protection actions may need to consider human constraints in the watershed that otherwise limit the full potential of those restoration and protection actions. These types of constraints would typically involve permanent impacts to processes such as those associated with urban development. This would not be considered the case with working and rural lands (agriculture, forestry), since the impacts to processes there do not involve converting land cover to impervious surfaces.
3. Match the scale of the restoration actions to the temporal and spatial scale of physical and biological processes (Figure 4-4). In the Ilahee Creek example provided at the beginning of this chapter, restoration of side channel habitat in the lower watershed requires restoring natural rates of erosion and runoff processes at a larger spatial scale (upper watershed). These upper watershed runoff processes occur on a temporal scale of 10^{-1} to 10^{2}. Therefore, restoration of lower reaches should be delayed until overland flow and erosion have been reduced and downstream sediment fluxes have returned to normative levels. This delay could range from 1 year to more than a decade after upper watershed restoration actions are completed.

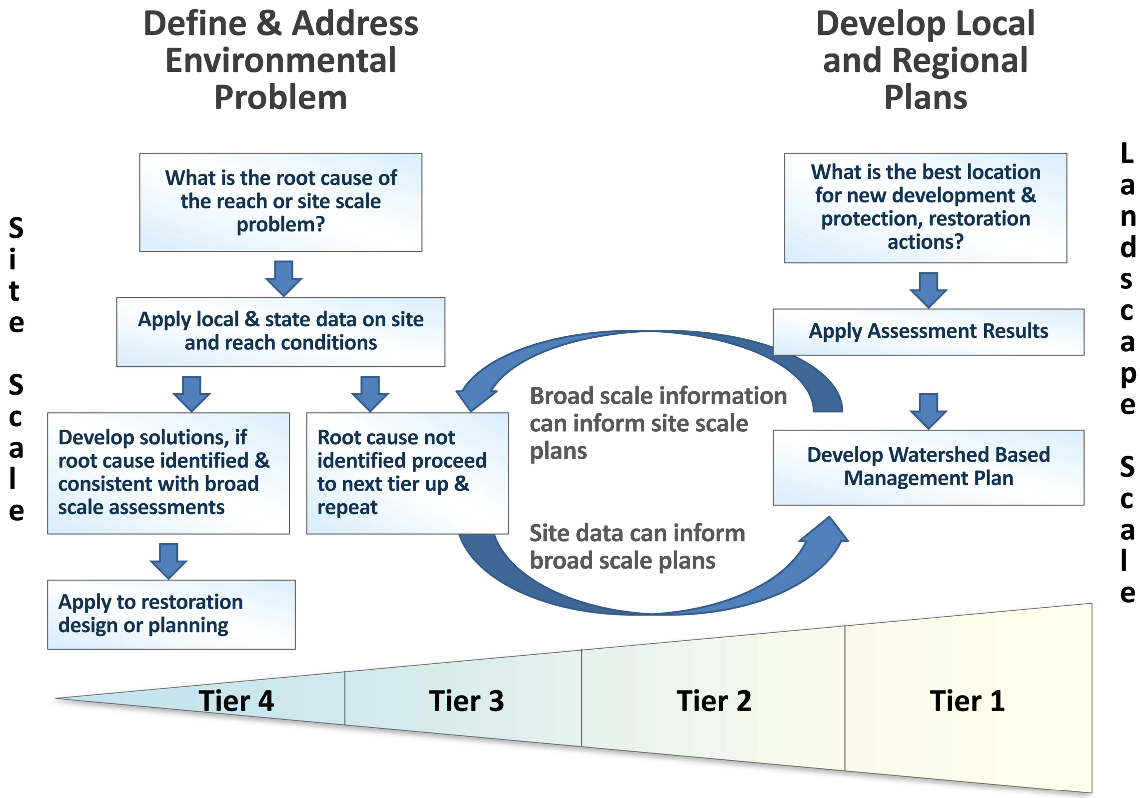


Figure 4-4 The primary use of Tier 1 and 2 information from these assessments is to address planning issues. Level 3 and 4 data are typically used to address reach and site scale issues, but such analyses should be done within the context of Tier 1 and 2 information and plans. Broad-scale plans can also be refined with data and analysis from Tiers 3 and 4 that identify causes of specific environmental problems.

Integration of Assessment Components

The tiered approach described above provides a stepwise method to examine watershed processes and functions at multiple scales, and includes multiple endpoints: biology, water quality, habitat, landscape connectivity, hydrology, geomorphology, and watershed disturbance regimes. There is not yet a single assessment approach that successfully incorporates all of these elements and the interrelationships among them. The November 2010 EPA workshop evaluated existing approaches to integrated assessments that take into account the linkages among two or more of these elements.

At the coarsest scale, the Active River Area concept (Smith et al. 2008) identifies important elements of the landscape within the watershed based on their lateral and upstream-downstream connections with the river and role in key watershed processes and habitat complexes. The framework identifies five key components of the active river area: 1) material contribution zones, 2) meander belts, 3) riparian wetlands, 4) floodplains and 5) terraces. These areas are defined by the major physical and ecological processes associated and explained in the context of the continuum from the upper, mid, and lower watershed. The framework provides a spatially explicit manner for accommodating the natural ranges of variability to system hydrology, sediment transport, processing and transport of organic materials, and key biotic interactions.

The Active River Area framework provides analysis tools for defining the active river area components over a range of spatial scales within a watershed. The framework itself does not provide an integrated assessment approach, but does provide an overview of existing methods to assess biology, habitat, and geomorphology. The Active River Area concept has been applied by Vermont in an assessment program that links geomorphology with local habitat features (VTANR, 2007). EPA's Environmental Monitoring and Assessment Program (EMAP) protocols for physical habitat assessments provide an approach to link riparian zone and channel characteristics with habitat features (Kaufmann and Robison, 1998), which in turn are linked with results of biological assessments (e.g., Maul et al. 2004).

Approaches to link aquatic network connectivity with habitat quality and population persistence of aquatic species are under development. Galatowitsch et al. (2009) applied climate projections from an ensemble of climate change models to assess the midcontinent region of North America to evaluate potential habitat shifts in communities, and proposed management approaches to maintain terrestrial and aquatic reserve connectivity. Landscape Conservation Cooperatives (LCCs; http://www.fws.gov/science/shc/lcc.html) represent public-private partnerships organized at the regional scale to implement strategic terrestrial and aquatic habitat conservation practices. The LCCs are developing methods to link both current and projected future habitat quality and connectivity with population persistence of key species.

The Ecological Limits of Hydrologic Alteration (ELOHA) approach has been successfully applied to assess the natural range of variability in hydrologic regimes for lotic systems and to determine the associated ecological flow requirements (Poff et al. 2010). Attributes of natural flow regimes have in turn been linked with habitat connectivity and channel-forming processes (Bunn and Arthington 2002).

Methods have been developed to map ground water-dependent ecosystems (GDE) and communities, and identify potential threats to these systems (Brown et al., 2010 and Brown et al., 2009). Thus far, these methods have only been tested in Oregon (Brown et al. 2010). The Nature Conservancy and the U.S. Forest Service are collaborating to develop methods and protocols for determining the ground water requirements for GDEs (i.e., the amount and quality of ground water needed to sustain healthy, viable ecosystems).

Displaying and Communicating Results

To ensure the successful application of assessment results, data must be accessible in a manner that is appropriate to the user's goals, objectives, and decision process. It is also very important that results are displayed in a manner that can be readily understood by decision makers and the public. Without clear written and visual explanation of the basis and need for strategic and prioritized watershed actions, needed public support cannot be achieved. Examples of effective communications include:

- New Hampshire communicates 305(b)/303(d) assessments to the public using new HUC12 level report cards, see: http://des.nh.gov/organization/divisions/water/wmb/swqa/report_cards.htm.
- National Fish Habitat Action Plan provides examples of how to display and interpret watershed data: http://fishhabitat.org/images/documents/fishhabitatreport_012611.pdf.
- Whatcom County Planning Department, in conjunction with Washington Department of Ecology (WA DE) and local citizen input, developed a watershed-based plan using displays of GIS-based assessment methods: http://www.whatcomcounty.us/pds/naturalresources/specialprojects/birchbaywatershed-actionplan.jsp
- Mapping examples from the states of Washington and Vermont (shown in Figure 4-2 and Figure 4-3, respectively) integrate data endpoints, display a range of conditions, and communicate resiliency and recovery potential of assessed waterbodies.

Developing assessments to integrate watershed structure and function provides an opportunity to communicate aquatic ecological integrity within the context of supporting watershed processes and influence broad-scale land and water use planning. Watershed technical teams also have an opportunity to tailor assessment outputs in a manner which speaks directly to the implementation of protection programs at the federal, state, or local level. For instance, a state HW team might provide the municipal governing bodies with maps based on a Tier 1/2 assessment that include recommendations to: 1) protect active river areas shown as having intact floodplains and riparian wetlands; and 2) upgrade or replace undersized culverts that are causing sediment discontinuity and aquatic organism passage issues. Involvement of stakeholders is necessary at all steps of the process to define decision context, goals, scale, tolerance for uncertainty, trust, etc. (Cash et al. 2003).

Chapter 5 Implementation of Healthy Watershed Programs

Creating a Government Framework for Program Development

Participants at the *Healthy Watersheds Integrated Assessments Workshop* identified many ideas for effective implementation of HW programs, starting with recognizing that the establishment of a governance framework to nurture and support program development by states and localities would be beneficial. This chapter addresses all stages of HW program implementation, from integrated assessments, to strategic action planning, to program launch and management. The chapter provides an overview of some of the most significant recommendations made by workshop participants. A more complete list of ideas is provided in the workshop proceedings. Subsequent to the workshop and development of this synthesis report, US EPA Office of Water has published a Healthy Watersheds Initiative National Framework and Action Plan 2011 (US EPA 2011g), which addresses many of the issues discussed here.

There was a general sense among workshop participants that Healthy Watersheds assessments and programs should have a whole-system scope and strive to define and create sustainable watershed systems – ecologically, economically, and socially. Healthy watersheds programs should therefore address all characteristics of a watershed, including ecological and physical processes, but also other factors that directly and indirectly affect the ability of resource managers to protect and restore watersheds over the long-term. This can include factors such as usage trends, economic needs, stakeholder perspectives, and development patterns.

With such a broad vision and objectives, it is essential to establish national, regional, and state-level operational structures to support and facilitate the development of Healthy Watersheds programs. Such an operational framework should include strategies to leverage existing programs and funds to enable government entities to jump-start HW initiatives on a broad scale. There was strong workshop support for a "national franchise" approach to HW programs, whereby EPA, through its regional offices, sets certain guidelines and incentives for the HW approach, but remains flexible by encouraging states and localities to define the specific elements of their own programs, based on their unique issues, opportunities, and capabilities.

Stakeholder dialogue is needed to define and establish a national HW program management and accountability structure that will reflect unique regional and state opportunities. The HWIA workshop played a role in fostering this dialogue. EPA brought together NGOs with many state and federal agencies that have had experience in developing important components of a Healthy Watersheds program. States that have mature HW protection programs were invited to bring their experience to the table and contribute to a national framework.

As with any government initiative, it is considered essential to identify HW program "champions" at all levels of government. Empowering individuals should not be difficult. Water resource managers, who have long experienced "one step forward—two steps backward" working on pollution abatement and restoration programs may be eager to establish proactive avoidance-based programs. They know that today's threatened waters will become tomorrow's impaired waters, unless we put the same emphasis on protecting these waters as we do for impaired waters. Workshop participants emphasized the need for strong support from senior political appointees at federal, state, and regional agencies.

State and local agencies (and NGOs) represent the primary delivery mechanisms for an HWI, as they implement the full suite of assessment, planning, funding, and regulatory programs that are necessary to do the job. Federal agencies also have a role in these functions and need to develop and deliver HWI programs as well. Regional, state, and local efforts will be far more successful where they have opportunities to work through joint programs with the EPA, U.S. Fish and Wildlife Service, U.S. Geological Survey, Army Corps of Engineers, Bureau of Reclamation, U.S. Department of Agriculture, and Department of Energy. These federal agencies have programs that affect watershed health, and the HWI can be a means of getting their respective programs to operate in more collaborative ways. Government created HWI task groups responsible for inter- and intra-agency coordination (including NGOs) would be a valuable asset. Healthy watershed initiatives at larger scales may require the utilization of multi-agency groups within and among states to break state silos and encourage collaboration. Examples of such organizations include the Association of Fish and Wildlife Agencies (AFWA), Association of State Wetland Managers (ASWM), Western States Water Council (WSWC), Environmental Council of States (ECOS), and Association of State and Interstate Water Pollution Control Administrators (ASIWPCA).

Workshop participants felt it would be beneficial if EPA and other national organizations convene regional meetings with federal agencies, states, and regional governmental and non-governmental organizations to evaluate the supporting infrastructure and help states create plans for program roll-out. Such facilitated dialogue sessions could address opportunities to integrate HW initiatives into existing assessment, planning, funding, and regulatory programs (i.e., create strategic planning maps tied to larger program objectives and prompt commitments for follow-up action).

Workshop participants suggested that the national HWI program should conduct an assessment of regional and state water programs and identify their current healthy watershed-oriented activities, commonalities, differences, program needs, etc. Opportunities exist to apply the HW approach to traditional water resource management programs (e.g., the Clean Water Act Section 404's compensatory mitigation watershed-based approach).

Regional teams that consist of experts from both state and federal agencies should engage the research and technical community to identify and address gaps in watershed science, explore methods for assessment integration, and develop comprehensive and strategic healthy watershed planning processes. In this way, resource management agencies can align their policies and standards to effectively deliver clear and consistent programs to local governments, landowners, and developers that succeed in protecting the whole aquatic resource.

Given the need to adapt approaches to meet the unique conditions and circumstances of different aquatic ecosystems, it is important to maintain some measure of flexibility in the application of HW protection approaches. Workshop participants also thought that it would be beneficial if EPA encouraged an adaptive management approach by regional and state authorities (i.e., identify desired program outcomes, create conservation strategies, and begin tracking indicators of near and long-term success).

Workshop participants felt sufficient funding sources for regional, state, and local HW programs is critical for any successful watershed program (e.g., that the states, EPA, and other federal agencies may need to consider redirecting funds from restoration and remediation toward avoidance and protection). Clean Water Act (CWA) funding was mentioned as a source that could support HW assessment and planning. For example, workshop participants suggested that it be beneficial if EPA provided national program guidance that identifies the HW approach as a priority for project funding under established CWA programs such as the State Revolving Fund and geographically-based programs (e.g., the Chesapeake Bay program).

Workshop participants agreed that where Large Aquatic Ecosystem programs exist (e.g., Great Lakes, Chesapeake Bay, the Mississippi River basin, and Puget Sound), they represent excellent opportunities to support a faster, more effective scale-up of state and regional HWI programs. However, an inventory of available funding sources and areas where program leverage already exists would be useful, since HWI programs may be most needed in areas outside the geographic scope of large restoration programs.

Some workshop participants expressed concern about the ability of federal, state, and local governments to implement a nationwide HW framework in the current economic climate, where budgets at all levels of government are being cut. While there was apparent agreement that agencies need to leverage existing ecosystem programs in order to implement the HWI at a sufficiently broad scope, many also felt that the value of the HWI whole-system approach is actually greater when government funds are limited.

The HW approach is designed to consider all available data; all trends affecting watershed health, all relevant programs and resources; and all regulatory and non-regulatory options. The approach is specifically aimed at evaluating and prioritizing prospective actions in ways that can maximize return on investment. Aquatic ecosystems provide socioeconomic benefits, and while economic analysis is not part of the HW assessment, local and regional government entities may include economic analysis as part of their planning and sustainability assessments. The HWI can identify overlapping or complementary government programs and prompt collaborative planning to find "bang for the buck" synergies among them. Workshop participants agreed that the HWI has the potential to be much more than simply a mechanism to protect healthy waters. It has the potential to create a governance framework for a much more effective system of water resource management in the United States.

Developing Integrated Assessments and Strategic Plans

Some states have already started watershed protection programs within their environmental or natural resource agencies. Other states may find useful coordination and leadership within their basin planning programs. Workshop participants suggested that states would gain significant value from forming HWI Task Groups with essential "working" members being managers within state programs that play primary roles in the assessment, planning, funding, and regulatory work to protect, manage, and restore rivers, lakes, wetlands, floodplains, estuaries, and ground water. Task group "advisory" members may represent federal, regional, state, and local agencies; universities; conservation organizations; and NGOs.

State HWI Task Groups could collectively define a consolidated and holistic planning process that builds on the synergy of existing program resources by linking their assessment and planning efforts. Well-defined HWI goals and objectives enable the adoption of an HW classification system which is based on a condition and stressor analysis. The resource managers and scientists on the Task Group should challenge themselves to develop a HW condition assessment process such that outcomes represent strategic actions and priorities within their existing aquatic resource protection, management, and restoration programs. Evaluating HW threats, or the lack of threats, based on assessment of different watershed stressors (e.g., encroachment, hydrologic modification, sediment and nutrient loading), will create opportunities to identify high priority, waterbody-specific actions to remediate certain stressors or protect key areas where intact physical and ecological processes occur.

Chapter 4 of this Synthesis Paper describes a tiered HWIA approach that allows specificity to build over time. Tiered assessments create efficiency by using selected data for an initial screening. An HW classification system based on large-scale, remote sensing data (Tier 1 or 2) may identify where the Task Group would work with local groups to prioritize finer-scale, more intensive assessments. It may also reveal what development patterns are most protective of watershed processes and functions and avoid costly environmental issues such as flooding, ground water contamination, and low flow concerns that cannot be readily resolved with site level permits and conditions. Smaller-scale assessments (Tiers 3 and 4) may be used to classify and map specific areas important to protecting watershed processes and resiliency (e.g., key sediment attenuation areas as in Figure 4-2), and at the same time identify specific stressors which may threaten or impede the recovery of healthy watershed functions (e.g., undersized culverts or dams that could be removed to restore connectivity and aquatic organism passage).

State HWI Task Groups should not find it difficult to get started. Tier 1 landscape level data are readily available, including those from the recently completed National Fish Habitat Assessment (http://fishhabitat.org/images/documents/fishhabitatreport_012611.pdf). Many states have Tiers 3-4 type data on water quality, aquatic biology, habitat, natural heritage, etc. Fewer states have completed green infrastructure, geomorphic, hydrologic, and other watershed process assessments. However, making the argument for the role and value of ecological and physical processes from society-valued perspectives (i.e., recreational use, water quality, fish and wildlife, property values, flood hazards, soil development and conservation, and climate change adaptation) will help with securing funds for conducting those assessments and implementing programs to protect those watershed characteristics and functions.

The HWI brings water resource agencies out of the water and onto the land. We cannot truly restore and protect aquatic ecosystems without restoring and protecting the processes that link land and water. Workshop participants felt that EPA leadership would be valuable for empowering and providing incentives for river and lake managers to work with the ground water, stormwater, wetland, and floodplain managers and then seek out land use planners, land-based businesses, natural heritage groups, and local land trusts. Knowledge and appreciation for watershed processes will drive the integration of assessment data and strategic plans from each respective entity. Interpreting the links between landscapes, hydrogeomorphic conditions, habitat, and biota will provide for a much broader evaluation of ecosystem stressors and consensus for applying best management practices (BMPs) to address them.

Technical challenges exist which, for a time, will impede the meaningful integration of assessment data. Many of these were discussed at the workshop in terms of research needs. Existing datasets, created for different purposes, may be useful indicators of ecosystem condition, but at very different spatial and temporal scales. For instance, landscape data gathered for a screening assessment (Tier 1) may indicate healthy forested conditions at a broad scale; but below the canopy, hydrogeomorphic data (Tier 3) indicates fair or less healthy conditions for specific tributaries and reaches (i.e., due to sediment regime departures related to historic deforestation, old mill dams, and undersized culverts); and at even finer scales, biological communities (Tier 4) indicate very good conditions due to the patches of excellent physical habitat that may exist even in systems where there are significant departures in natural physical process.

As tiers of assessment are completed, and results are shared with the public, care must be taken to explain what the maps and supporting data may or may not be telling us. Discrepancies may foretell the need to revisit how data are collected at different tiers and scales to provide for better data integration and ecological assessments; or, they may be very useful in explaining the importance of a process-based approach to managing sustainable healthy watersheds. In the example cited above, large- and site-scale data (landscape and biological communities) indicate a potentially healthy watershed. Long-term sustainability may depend, however, on a public recognition, based on reach-scale condition analyses (geomorphic instability due to legacy effects and easily remediated encroachments), that important physical processes may easily recover where local communities work together to protect the watershed from further encroachments.

Once assessments and strategic planning are underway, State HWI Task Groups may discover that to implement HW plans, the existing suite of land and water protection and restoration programs must be strengthened. State, regional, and federal agencies may need to pursue or create new HW protection mechanisms (i.e., statutory, regulatory, procedural, and funding). For instance, many local land trusts have traditionally focused on protecting viable farmland. If state and federal resources agencies supporting land trusts work to show the connection between sustainable farming and healthy watershed processes, then this effort may elicit the support of agricultural leaders in directing scarce conservation dollars toward HW protection. State HWI Task Groups will also need to explore whether or not any regulations represent barriers to HW protection. For instance, the minimum Federal Emergency Management Agency (FEMA) floodplain development standards, which communities are required to adopt to stay enrolled in the National Flood Insurance Program (NFIP), may be a serious barrier, as they allow for and essentially facilitate development on floodplains.

Finally, workshop participants discussed the importance of communicating the results of integrated assessments and involving public and local communities with the implementation of strategic plans. Many ideas were put on the table (see Workshop Proceedings). Major needs include:

- Visual maps that municipalities, the general public, and other agencies can easily interpret;
- A technical watershed team that can assist the above entities in properly interpreting watershed data and information (i.e., watershed framework);
- Published popular articles, interactive websites, and other media events to show off results and explain the consolidated HW assessment and planning process;
- Institutional mission statements acknowledging that larger scale processes and issues are linked (i.e., HW processes increase resiliency to climate change and result in the soil regeneration critical for sustainable agriculture); and
- Public outreach on the economic and societal benefits of protecting healthy watersheds.

Establishing Effective Healthy Watershed Conservation and Protection Programs

Throughout the HWIA Workshop, participants discussed the importance of not only protecting aquatic and riparian habitat, but also protecting areas in watersheds involved in the ecological processes that naturally create and maintain these habitats. The Nature Conservancy presented the Active River Area methodology it is initiating with its partners that identifies watershed areas important to ecological process (Table 5-1). Water resource managers working in wetlands, and more recently floodplains, have used a management paradigm based on the protection of natural water-related functions that link land areas with surface waters. A process-based approach will enhance the traditional site-specific and stream reach surface water quality approach. Further, protecting ecological processes will benefit from a broader landscape approach of not only protecting stream buffers, but integrating watershed components such as meander belts, lake shores, riparian wetlands, and floodplains into protection programs. All of this will require aquatic resource managers to work at larger scales with a whole new set of partners concerned with land use planning and management.

Land and water protection through non-regulatory and regulatory programs, conducted at all levels of government in partnership with nongovernmental organizations and landowners, is central to implementing the HWI. However, protection and restoration are often part of an integral approach, as many states consider opportunities to protect healthy watersheds *and* restore impaired watersheds with a high recovery potential. A process-based approach that considers watershed resiliency and sustainability is important for restoration success. In addition to restoring natural flows, this could mean adding green infrastructure, removing constraints (e.g., dams), or working to ensure that land-water ecosystems remain dynamically connected.

To restore and protect dynamic processes, HW champions must often promote a package deal in which integrated planning brings together different interest groups and provides opportunities and incentives to bundle "project" components and achieve a net ecological benefit. This may occur where, at every turn, the regulatory, technical assistance, and funding program managers are connecting the dots between land conservation; wetland, riparian, and floodplain protection and restoration; urban stormwater and agricultural best management practices; channel and shoreline management; and instream ecological flow protection and restoration.

Terrestrial ecosystem protection proponents have been working with land use planners and conservation organizations for decades. Aquatic ecosystem protection proponents are just beginning to develop these relationships. As with any meeting of cultures, each discipline must patiently learn the language and practices of the other. For instance, the Vermont Rivers Program, a group represented at the workshop, reported being in its seventh year of developing a river corridor and floodplain protection program. Much of this time was spent cross-training with municipal planners and conservation organizations. River managers are learning about zoning bylaws, easements, and land appraisals. Their land use and conservation counterparts have been learning about meander belts, floodplain restoration, and dynamic equilibrium and most importantly, why these concepts are important to their traditional clients. Flood and erosion hazard avoidance and mitigation have become the common ground and incentive for land and water managers in Vermont. These mutual interests and cross-training are starting to pay off, with more than a dozen towns adopting zoning bylaws that keep structures out of meander beltways and floodplains, and agricultural land trusts adding river corridor development and channel management restrictions to their easements.

Table 5-1 The Active River Area framework (Smith et al. 2008) provides a systematic approach to identifying those areas, based on valley setting, watershed position, and geomorphic stream type that can be used to identify conservation targets and guide the protection and restoration of freshwater resources (Adapted from Schiff et al. 2008).

Natural Processes/ Key Attributes	Description	*Active River Area* Components
Hydrologic flow regime	The timing, volume, duration, and distribution of flow events over the hydrologic year that are influenced by climate, geology, watershed land cover, connectivity, and valley/stream morphology.	Meander belts, riparian wetlands, floodplains, terraces, material contribution areas.
Sediment transport	The size, quantity, sorting, and distribution of sediments that are a function of geology, hydrology, connectivity and valley/stream morphology.	Meander belts, riparian wetlands, floodplains, terraces, material contribution zones.
Processing and transport of organic materials	The abundance, diversity, and physical retention of organic material available for biological uptake and physical refuge that are a function of bank and riparian vegetation, climate, hydrology, connectivity, and valley/stream morphology.	Material contribution areas, meander belts, floodplains.
Establishment of connectivity	The maintenance of connectivity in and between the channel and riparian zone to support the unimpeded movement of water, sediment, organic material, and organisms longitudinally up and down the watershed and laterally/vertically between the stream channel and its floodplain.	Meander belts, riparian wetlands, floodplains.
Water quality maintenance	Transformation and transport of suspended sediments, ions, and nutrients that are a function of geology, climate, hydrology, and watershed land cover.	Material contribution areas, meander belt, riparian wetlands, floodplains, terraces.
Regulation of the thermal regime	The maintenance of daily and seasonal instream water temperatures influenced by climate, hydrology, riparian canopy, and valley/stream morphology.	Material contribution areas, meander belts, riparian wetlands, floodplains, terraces.
Energy transport	Sources of nutrient and energy inputs, primarily in the form of sun and changes to organic compounds via bond breaking (respiration) and bond assembly (production or photosynthesis) and the associated ecosystem responses such as changes to dissolved oxygen and pH.	Meander belts, riparian wetlands, floodplains, material contribution areas.

Technical teams comprised of watershed scientists (e.g., geomorphologist, hydrologist, ecologist, fish and wildlife biologist, and planner) are needed to help peer review the data and research contributing to regional or statewide HW frameworks. Technical teams need to provide NGOs and local governments with assistance in interpreting data and maps correctly and applying the information in a scientifically acceptable manner to local land use plans. This technical support will contribute to more defensible and credible local watershed protection plans.

Over the last several decades, a variety of state and federal regulatory protections have been developed to protect and restore healthy watersheds. In very general terms there are water, including wetland- and floodplain-based protections, and land-based protections. Many of the protections for healthy waters are based on elements of the state and federal implementation of the CWA, Wild and Scenic Rivers Act, and Farm Bill Programs (e.g., Wetlands Reserve Program). Others are based more directly on fish and wildlife, streamflow, and channel or floodplain management regulations.

State water quality standards, implemented pursuant to CWA regulations and procedures, identify tiers of protection in several broad areas; designated uses, criteria to protect uses, and antidegradation policies. All states must have antidegradation policies that protect existing instream uses, high quality waters, and outstanding natural resource waters. Some states have also chosen to designate or classify certain waters as exceptional ecological waters (e.g., Vermont Class A (1), Maine AA waters, and Pennsylvania's Exceptional Value waters). EPA and the states would benefit from research evaluating the use of antidegradation rules in protecting healthy watersheds.

Some states have developed statewide streamflow protection rules or regulations. Many of these include provisions for providing higher levels of protection to higher quality waters. The Maine DEP Chapter 587, *In-stream Flows and Lake and Pond Water Levels Rule*, for example, provides highest protection to Class AA waters.

States also have programs that are specifically designed for river protection and in some cases are state parallels to the Federal Wild and Scenic Rivers Program. For example, the New Hampshire River Management and Protection Program, established in 1988 with the passage of RSA 483, protects certain rivers, called designated rivers, for their outstanding natural and cultural resources. The program is administered by the New Hampshire Department of Environmental Services.

Land use and wetland regulations and public lands management programs exist in various forms across the country. Some specifically integrate land and water planning and protection in the same program. Excellent examples are the Vermont River Corridor Protection Program and the Washington Critical Areas Growth Management Act.

New state and federal regulatory protections will enjoy very little broad-based support during difficult economic times, and new funding programs will be even scarcer. Protecting HWs is cost-effective in the long-run. Workshop participants offered that this alone could justify state and federal funding and technical assistance programs realigning to enable support for the HWI. The goal of the CWA is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. Historically, greater emphasis has been placed on the restoration element of the CWA goal. A shift in emphasis from restoration or "fixing things" to more of a balance between "avoidance" or maintenance of the integrity of the Nation's waters and restoration, at all levels of government, would be a first step in redirecting some resources toward protecting HWs.

In lieu of state land use regulations, local action would be required. States should pilot projects and create funding incentives for landowners, towns, and local organizations to adopt river corridor, wetland, floodplain, shoreline, and ground water source protection bylaws. Consideration could be given to those communities which take action to protect HW areas relative to priority for emergency management, transportation, community development, and environmental infrastructure grants. As one community takes action without mandates, others will follow. States can also provide towns with administrative and technical assistance (e.g., developing a model ordinance that protects watershed processes and HW attributes, or assisting with a package of federal grant applications to address a number of local water-related issues and opportunities as an incentive for, and in tandem with, HW protections).

Much can be done at very little cost, especially with support and coordination from regional entities and federal agencies. Many great HWI examples were presented at the HWIA workshop. Local and state HW initiatives can get off to a fast and efficient start learning from the successes and failures of one another. EPA and other federal agencies should work together to emphasize integrated assessments and HW protection in their research and grant programs, and support a web-based clearinghouse where states are encouraged to post their accomplishments and success stories.

Chapter 6 Data Gaps and Research Needs

Logic Model for Healthy Watersheds Integrated Assessments

A logic model was created to reflect the steps necessary to support development of HWIAs, and is applied here to highlight important gaps in the science related to watershed assessment. A logic model is a systematic and graphical approach to identifying the resources, participants, activities, and outputs needed to achieve program short, medium, and long term goals. Typically, logic models are constructed by defining long term goals, then working backwards to determine intermediate objectives that support long term goals, then short term conditions needed to support intermediate objectives, and so forth (W.K. Kellogg Foundation, 2004). A logic model is used to represent the interrelationships among program inputs, products, and desired outcomes; to prioritize activities; and to identify gaps in existing programs.

A logic model framework for the support of HWIAs was set up based on three of the strategic long term goals (SGs) outlined in EPA's Strategy to Protect America's Waters (U.S. EPA 2011c). The three strategic goals chosen for focus are:

1) Increase Protection of Healthy Waters—Increase focus on the protection of source waters and healthy watersheds to ensure that they remain protected from degradation and depletion;
2) Enhance Watershed Resiliency and Revitalize Communities—Implement sustainable approaches and technologies that will reduce the impacts and risks associated with climate change, population growth, increased urbanization, infrastructure gaps, and other factors; and
3) Restore Degraded Waters—Enhance the ability of EPA, states, and tribes to restore degraded waters, restore ecosystems, and take action to increase the number of restored water bodies, including nutrient-impaired waters.

EPA's Healthy Watersheds Initiative National Framework and Action Plan 2011 (US EPA 2011g) was not yet available at the time of the workshop and subsequent preparation of this synthesis document. However, the goals and underlying objectives outlined in that document are generally consistent with the EPA Strategic Goals above:

1) Identify, protect and maintain a network of healthy watersheds and supportive green infrastructure habitat networks across the United States;
2) Integrate protection of healthy watersheds into EPA programs (including watershed restoration); and
3) Increase awareness and understanding of the importance of protecting our remaining healthy watersheds and the range of management actions needed to protect and avoid adverse impacts to those healthy watersheds.

The science gaps and data needs identified by the attendees of the HWIA workshop have been formulated and ranked based on the three SGs of the logic model (Appendix A). The HWIA logic model is consistent with the Sustainability Realization Process outlined by Fiksel (2010) as a parallel for EPA's traditional risk assessment framework (Figure 6-1). Through the HWIA stakeholder workshop, several existing conceptual models for healthy and resilient watersheds were reviewed (System Characterization), and the state of indicator development for HWIA examined (System Assessment). The original watershed assessment framework presented by the U.S. EPA Scientific Advisory Board (U.S. EPA 2002) was extended to encompass multiple system types and to include the concept of watershed resilience in the face of climate change and continued human development pressures.

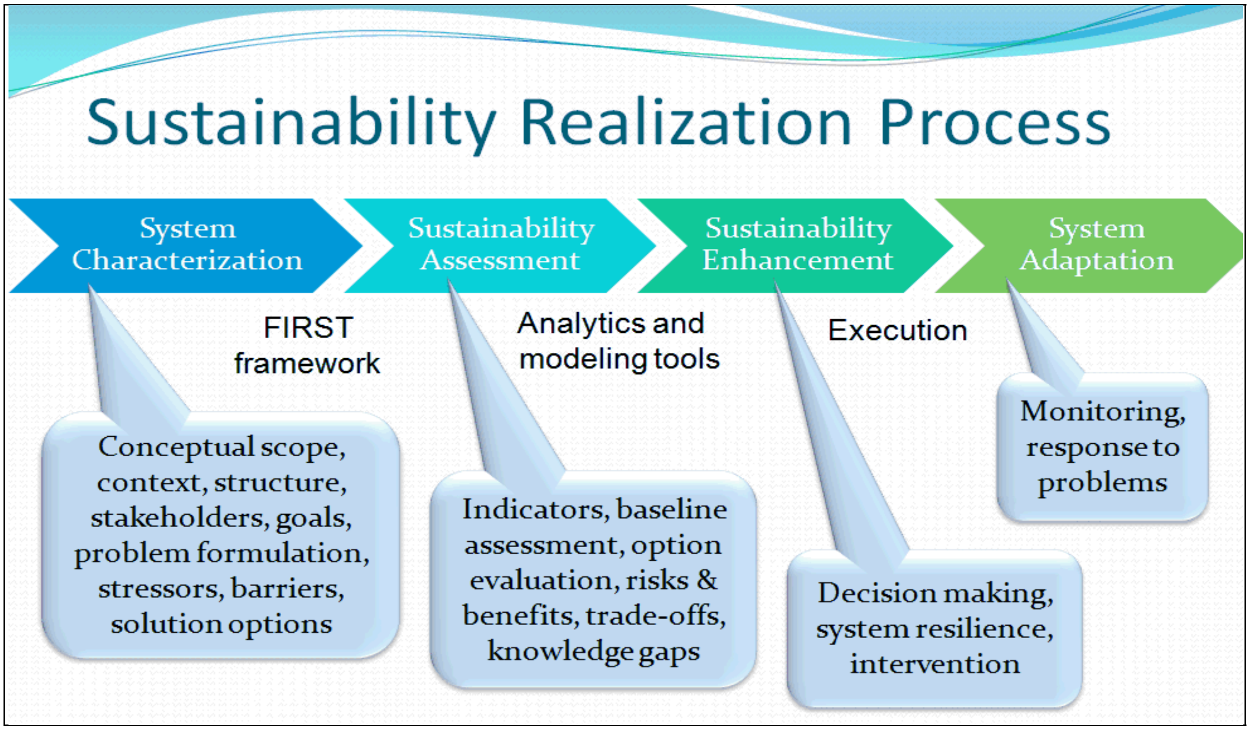


Figure 6-1 Sustainability Realization Process, from Fiksel, "Resilience and Sustainability in Industrial, Social, and Ecological Systems," presented June 8, 2010 (https://intrablog.epa.gov/pathforward/?page_id=802)

The research needs and data gaps associated with the HWIA logic model have been considered in the context of priorities set out by EPA (U.S. EPA 2010b, U.S. EPA 2011c). The HWIA is consistent with themes outlined under EPA's emerging research programs in: Safe and Sustainable Waters (U.S. EPA 2009b, 2011d), Sustainable Communities (U.S. EPA 2011e), and Air, Climate, and Energy (ACE; U.S. EPA 2011f). In addition, HWIA research is consistent with EPA's Green Infrastructure Initiative (U.S. EPA 2009c, 2010c), which considers the role of green infrastructure at both local scales (e.g., rain gardens, green roofs) and landscape scales (connectivity of natural land cover) in sustaining HWs. Priority areas for research under these SGs are based on the following criteria: 1) results support multiple Office of Water (OW) programs or offices, and their anticipated future scientific information needs (e.g., managing multiple stressors, addressing future climate and land use change impacts, integrated monitoring); 2) sustainability is explored through a systems approach, taking climate change effects into consideration; 3) the impact of the research products is important for sustainable environmental management decisions, including those related to climate adaptation; 4) transdisciplinary integrated research is promoted where appropriate; and 5) the intramural and extramural capability and capacity exists to successfully conduct the research.

SG1: Increase Protection of Healthy Waters

Near-term outcomes (FY11-14) required to achieve strategic goal 1 (SG1) of the HWIA logic model include: 1) integration of the HW approach into multiple CWA programs, 2) creation of preliminary HW lists by states based on the best available information and methods, 3) identification of core metrics and measures for HWIA through evaluation of those in current use by multiple entities, and 4) pilot demonstrations of HWIA at the state scale (Appendix A). Analyses to elucidate the long-term net benefit of preservation policies and protection of green infrastructure and processes sustaining HWs will provide critical support for promoting an integrated systems approach to watershed management. The efficient development of preliminary HW lists by all of the states, and subsequent refinement of those lists, will require a comprehensive information infrastructure to deliver data supporting conservation decisions (see Chapter 5). Achieving consensus on a core set of metrics and methods will require a coordinated test of approaches through pilot HWIA programs and fostering of communication across states, other agencies, and NGOs to share and discuss results.

Demonstration and refinement of approaches for HWIA requires a conceptual model, a consistent nationwide nested framework for stratifying assessments, cost-effective methods for assessing individual elements of HWs, particularly those not traditionally included in assessments, knowledge of the interrelationships among HW elements, and, finally, methods to evaluate multiple assessment endpoints simultaneously to prioritize conservation options. Workshop participants identified some of the biggest near-term gaps in data and knowledge needed to support these steps, which include: 1) the interdependence of existing and proposed stratification frameworks (e.g., ecoregions, FPZs, and flow regime classes); 2) regional models to predict natural and altered flow, ground water, and thermal regimes based on limited existing field data, available watershed characteristics, and human water use statistics; 3) efficient and cost-effective methods for assessing status and trends in geomorphology and material transport; and 4) exploration of consistency of assessment results across endpoints and spatial or temporal scales.

SG1 Research Needs

- Evaluate core metrics and methods for measurements of HWs.
- Conduct analyses to elucidate the long-term net benefit of preservation policies and protection of green infrastructure and processes sustaining healthy watersheds.
- Identify characteristics of aquatic ecosystems and their surrounding watersheds that make them resilient to changing land use and climate for use in predictive models.
- Understand interdependence of existing and proposed stratification frameworks.
- Develop regional models to predict natural and altered flow, ground water, and thermal regimes.
- Develop efficient and cost-effective methods for assessing status and trends in geomorphology and material transport.
- Explore consistency of assessment results across endpoints and spatial or temporal scales.

SG2: Enhance Watershed Resiliency

Climate changes will affect all types of watersheds – healthy and impaired – many years into the future. Therefore, it is necessary to understand the extent and magnitude of those effects in order to provide the information necessary to maintain resilient, sustainable, and healthy watersheds over the long-term. The second SG articulated by the HWIA is enhancing the resilience of watersheds to ongoing climatic changes. The research needs to support this goal are summarized below and detailed in the logic model (Appendix A).

Some CWA programs are built on definitions of "natural condition" or on "reference sites." These definitions allow identification of the condition of all other sites through comparisons with natural or minimally-impacted sites. However, climatic changes will affect the physical and biological environments of both reference and non-reference sites and their "natural" and "impaired" conditions. It is probable that watersheds designated as "healthy" today will be affected to a greater degree than impaired watersheds in highly modified landscapes. Therefore, a significant gap in our scientific knowledge identified in the workshop is an incomplete understanding of the physical and biological responses of aquatic systems and their surrounding landscapes within their watersheds to the effects of climate change. In addition research is needed to identify the most appropriate indicators and sampling schemes needed to monitor and detect changes in condition or drift in reference condition due to climate change. Results of this research will support the definition, designation, and maintenance of HWs, taking into account ongoing changes in climate, and provide the basis for understanding how to adjust other OW programs to accommodate climate change effects.

A second significant data gap identified in the workshop is a lack of understanding of key characteristics of aquatic ecosystems and their surrounding watersheds that make them resilient to changing land use and climate for use in the design of predictive models. These models can then provide information on future potential changes in condition due to climate and land use change to aid in evaluating watershed resilience, prioritizing protection and restoration of the most resilient systems, and identifying those management actions that maintain or increase their resilience over the long-term.

Successfully producing the outputs for this SG requires a highly coordinated effort from across EPA ORD National Research Programs and a number of disciplines (e.g., climatology, hydrology, ecology, and socioeconomics), to address processes that occur at a variety of spatial and temporal scales. Integration is necessary to incorporate linkages between the physical and social sciences, as well as feedbacks among physical, chemical, and biological systems. Multiple interacting stressors need to be considered along with human interactions and responses. EPA ORD has significant expertise in the required areas of hydrology, ecology, model development, monitoring design, and climate vulnerability and adaptation assessment relating to both humans and ecological systems. Achieving success in the research outputs articulated for this SG will support OW and its stakeholders in adapting to the impacts of climate change by managing to not only sustain healthy watersheds into the future, but also to improve the condition of those watersheds that are currently impaired.

SG2 Research Needs

- Understand responses of aquatic systems to the effects of climate change.
- Research and develop the indicators and sampling schemes needed to monitor and detect changes in condition or drift in reference sites due to climate change.
- Identify characteristics of aquatic ecosystems and their surrounding watersheds that make them resilient to changing land use and climate to use in the design of predictive models.

SG3: Restore Degraded Waters

Increasing the number of HWs, the third SG of the HWI, depends greatly on our understanding of the characteristics of a watershed functioning as a whole system (whether healthy or impaired), management to sustain these systems, coordination of conservation and restoration with HW principles across multiple scales, and establishment of partnerships to protect HWs and their socioeconomic conditions. The research needs supporting this goal are presented in the logic model (Appendix A).

> ***SG3 Research Needs***
>
> - Enhance existing monitoring approaches to include representative HW systems, for HW evaluation and adaptive management.
> - Coordinate both conservation and restoration with HW principles across multiple scales.
> - Promote the establishment of partnerships to explore the socioeconomic conditions that favor HW protection.

The greatest gap in our scientific knowledge relative to SG3 identified by workshop participants was specific information on characteristics of existing healthy watersheds. Enhancing existing monitoring networks to include regular monitoring of representative HW systems for evaluation and adaptive management, with discrete and continuous real-time reporting and facilitated accessibility would be a significant benefit. This long-term monitoring activity will require collaborative efforts of multiple federal agencies. However, the data collected in this network would support and greatly facilitate many studies on watershed functioning and management, and could easily contribute to an 'early product' in the form of a place-based and/or regional management planning demonstration (FY14).

The second research need for SG3 identified in the workshop was to support coordinated conservation and restoration consistent with HW principles across multiple scales. This can be pursued by: 1) scale convergence, in which optimizing ecosystem-scale conservation and restoration at the local township scale is linked with optimizing preservation and restoration at the watershed scale; and also by 2) endpoint convergence, in which there is joint optimization of conservation and restoration planning (e.g., gap analysis, and green infrastructure network analysis) as well as with protection and restoration of watershed-scale functions (e.g., flow, sediment, thermal and woody debris regimes). Restoration and conservation planning would greatly benefit from cost-benefit analyses of applications of HW assessments in different CWA programs, including relationships between HWs and healthy communities, source water protection, flood damage protection, property values, and reductions in pollutant loads (minimizing needs for total maximum daily loads). Although these varied activities will require several years, some products in the planning arena of green infrastructure may become available at an early stage (FY13-14).

The third and final significant research need for SG3 identified by the workshop participants was to provide information that promotes the establishment of partnerships to protect HWs and to explore the socioeconomic conditions that favor this protection. An analysis of agency roles and responsibilities, potential stakeholders, and user needs will be required to identify vital partners at the local, regional, and national levels. Such analyses can be undertaken, and the results reported as 'early products' (FY13). The relationships between the ecological health of HWs and socioeconomic factors, quality of human life, and economic sustainability should also be studied, and the results reported. In combination with results from research priority 2, these findings will be important drivers for decisions regarding the protection of HWs. It is expected that partners and stakeholders will be involved in most, if not all, decisions on HW protection.

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