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16 Approaches to Management at the Watershed Scale

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Management Perspectives at the Watershed Scale 240
The Natural System: Variability in Time and Space 240
A Holistic Perspective: Persistence and Invasiveness 240
Connectivity and Uncertainty 241
Human Cultures and Institutions 241
Quantitative Approaches for Implementing Watershed Management 242
Watershed Analysis 243
Quantitative Measures 245
Integrated Socioenvironmental Models 245
Indices of Socioenvironmental Conditions 246
Addressing Institutional Organization 247
Formulating Shared Socioenvironmental Visions 247
Public Stewardship in Watershed Management 249
Monitoring 249
Public Outreach 250
Conclusion 251
Literature Cited 251

Freshwater and freshwater ecosystems lie at the heart of the challenge of ecosystem management (Naiman 1992, Lee 1993, Naiman et al. 1995a, 1995b). Because they integrate natural resource and socioeconomic systems, freshwater issues embody the complexity that will characterize natural resource management as we move into the 21st century. Changes in human demography, resource consumption, cultural values, institutional processes, technological applications, and information all contribute to that complexity. If we are to achieve long-term social stability as well as ecological vitality, we must understand the abilities and limits of freshwater ecosystems to respond to human-generated pressures. Yet, even though human actions and cultural values drive environmental issues, few holistic approaches for watershed management offer effective resolution.

In the current debate over the scope of ecosystem management (Grumbine 1994, Montgomery et al. 1995), it is widely recognized that there are significant technical and cultural constraints to effective implementation. These constraints are related to such issues as identifying appropriate spatial and temporal scales, monitoring and assessment, developing an

adaptive management process, and developing cultural values and philosophies that allow ecosystem management to be successful (Levin 1993, Grumbine 1994). Nonetheless, the ability of a rapidly increasing human population to dramatically impact local, regional, and global ecosystems makes it essential to incorporate an ecological perspective into watershed management if we are to leave a healthy resource base for future generations.

The first part of this chapter suggests several features that are fundamental to contemporary watershed management. The second part then presents several practical approaches for implementing effective watershed management programs.

Table 16.1 Special goals fundamental to ecosystem management

- Maintain viable populations of all native species in situ
- Represent, within protected areas, all native ecosystem types across their natural range of variation
- Maintain evolutionary and ecological processes (i.e., disturbance regimes, hydrological processes, nutrient cycles, and so forth)
- Manage over periods of time long enough to maintain the evolutionary potential of species and ecosystems
- Accommodate and balance human use and occupancy within these constraints

Source: Grumbine (1994).

Management Perspectives at the Watershed Scale

Four watershed-scale features provide the foundation for effective management: variability in time and space, persistence and invasiveness of species, system connectivities and uncertainties, and the role of human cultures and institutions. These features are closely related to specific goals frequently endorsed as being fundamental to ecosystem management (Grumbine 1994) (Table 16.1).

The Natural System: Variability in Time and Space

Natural processes, such as climate, soil formation, and geological disturbances, structure the diversity, productivity, and availability of natural resources that human societies depend upon. The challenge is to understand how naturally variable systems operate and to predict the environmental consequences of human activities in these systems (Naiman 1992, Naiman et al. 1995a, 1995b).

The vitality of natural ecosystems is created and maintained by substantial variation in time and space (Reice et al. 1990, Reice 1994, Turner 1990). For example, the ecological characteristics of riparian forests are structured by a complex array of dynamic and spatially variable hydrological processes that erode and deposit materials, deliver nutrients, and remove waste products (Gregory et al. 1991)(Figure 16.1). Variability in time and space results in the biological diversity and productivity characteristically found in riparian environments (Fetherston et al. 1995, Naiman et al. 1993). A key managerial challenge is balancing human needs with variations in physical and chemical characteristics so that significant declines or losses of species and ecological attributes do not occur.

A Holistic Perspective: Persistence and Invasiveness

The persistence of ecological attributes for the long term (decades to centuries) requires maintenance of naturally variable environmental regimes as well as isolation from invading organisms that can alter those regimes. When the natural environmental regime is altered, adjustments occur within the ecosystem producing new combinations of biophysical environments susceptible to the invasion of exotic organisms and the establishment of non-native ecological processes and structures (Drake et al. 1989). Understanding and quantifying persistence and invasiveness of species and their ecological processes are important for watershed management because these components are sensitive to change, integrate change over broad spatial and temporal scales, and can be used as measures of change. Moreover, many species are linked to a cultural identity, and many ecological processes are essential for sustaining human populations (Botkin 1990).

There are a variety of quantitative approaches and

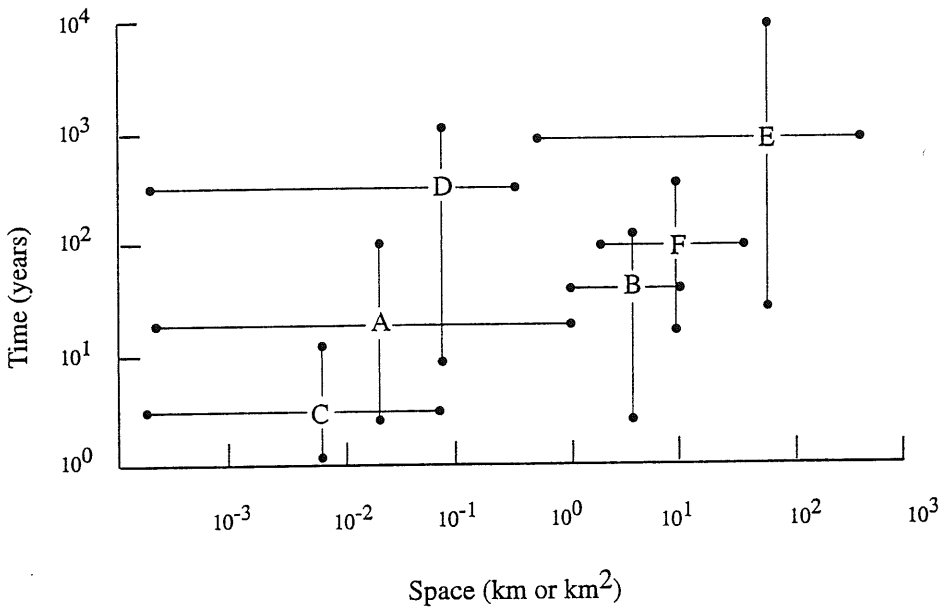

Figure 16.1 Illustration of the diversity of spatial and temporal scales influencing the creation and maintenance of riparian forests in the coastal temperate rain forest of North America. (A) Colonization surfaces created by flooding, (B) Colonization surfaces created by debris flow, (C) Seedling germination and establishment, (D) Longevity and size of species patches, (E) Persistence and movement of dead wood in channel, and (F) Impact of herbivores.

technical tools for analyzing persistence and invasiveness at the watershed scale. Many other techniques are in the design and testing stages. Existing techniques include new approaches to statistical analyses, patch and boundary analyses, modeling cumulative effects, developing indices of biotic integrity, and creating knowledge-based land-use analysis systems (Risser 1993, Fortin and Drapeau 1995, Karr 1991, Berry et al. 1996, Turner et al. 1996). These techniques are especially useful for setting goals related to desired future conditions and for preliminary examinations of the long-term effects of new or anticipated institutional regulations and policy (Turner et al. 1996, Wear et al. in press).

Connectivity and Uncertainty

The goal of watershed management is to let all components of human and nonhuman communities exist in a relative but dynamic state of balance (Naiman 1992). This goal explicitly recognizes strong connections between social and environmental components at multiple scales. This means giving serious consideration to diverse components such as water, fish, soils, forests, education, resource extraction, and cultural values, as well as managing the strong interactions between them (Stanford and Ward 1992).

Unfortunately, quantitative approaches for managing connectivity are not well formulated. There remains considerable uncertainty among scientists and decision makers as to how to proceed. This means accepting risk since the magnitude of current socioenvironmental issues requires decisions that cannot wait until all information is available (Figure 16.2). How can this be accomplished at the watershed scale? There is no definitive answer or one right way. However, we will discuss approaches that are being used by (1) small organizations to address risk, (2) groups that are helping to define social and environmental viewpoints for future conditions, and (3) researchers and managers struggling to monitor and assess change at regional scales.

Human Cultures and Institutions

In human-dominated watersheds, the land mosaic is created by a mixture of cultural practices, traditions, myths, and institutions (Lee et al. 1992, Décamps et

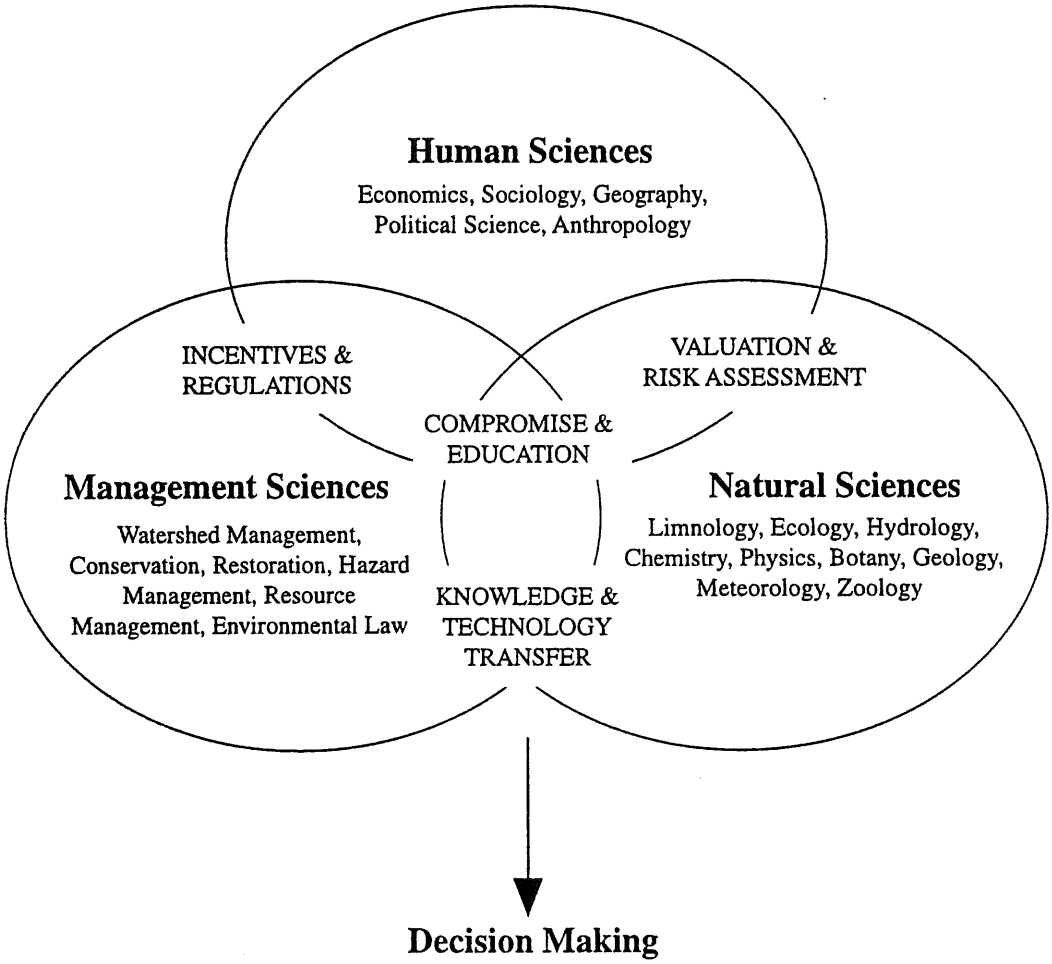

Figure 16.2 Advances in watershed management come at the interfaces between natural, human, and management sciences (from Naiman et al. 1995a).

al. 1997). The spatial extent and temporal duration of each patch and boundary type is ultimately determined by laws, regulations, taxation, technologies, cultural values and beliefs, and traditional land-use practices (Turner et al. 1990).

Developing an integrated socioenvironmental system means confronting and resolving important issues related to social and ecological literacy, the role and accommodation of changing cultural values, the increasing migration of people away from traditional homelands and cultures, balancing consumption rates and population growth, weathering political change, and establishing knowledge-based cooperative institutions (Lee 1993). These issues are closely interrelated and cannot be resolved separately. How to implement an integrated program that addresses these and related issues may not be immediately apparent since each watershed has a unique set of issues to resolve. There are, however, basic principles and practical approaches to guide the development of effective watershed management (Montgomery et al. 1995).

Quantitative Approaches for Implementing Watershed Management

Attempts to manage watersheds with more than one demand on the principal resources have been ineffective for the most part. Well-known examples include the Columbia River, the Sacramento and San Joaquin Rivers, and the Colorado River. These and

other examples have been hampered by the inherent difficulties of identifying appropriate spatial and temporal scales for management, by the cumulative effects from multiple users, and by conflicting management goals. In addition, lack of accepted statistical or realistic modeling approaches and a dearth of indices for evaluating a dynamic socioenvironmental system have confounded problems (Lee 1993, Volkman and Lee 1994). Fortunately, as public awareness of watershed-level issues has improved, so has the array of quantitative approaches for assessing complex issues which have several causes and competitive solutions. Watershed analysis techniques, quantitative measures, assessing risk with integrated socioenvironmental models, and development of socioenvironmental indices are but a few of the empirical approaches available (Table 16.2).

Watershed Analysis

Quantitative approaches to documenting the status and dynamics of entire watersheds are still in the early stages of development (Montgomery et al. 1995). Most of the techniques developed have been concentrated in Western states heavily impacted by forest management (Table 16.2). The intent of watershed analysis is to provide a scientifically based understanding of the environmental processes and their interactions occurring within a watershed (Washington Forest Practices Board 1994, USDA Forest Service 1994). This understanding, which focuses on specific issues, values, and uses within the watershed, is essential for making sound management decisions (Table 16.3). Protecting beneficial uses, such as those identified by state and federal environmental laws (e.g., the Clean Water Act and the Endangered Species Act), is a fundamental objective for watershed analysis. Watershed analysis encompasses the entire watershed because of the strong fluvial linkages between headwater areas, valley floors, and downstream users.

Watershed analysis generally is carried out by an interdisciplinary team of resource professionals who are already experts in their fields and who are familiar with the area to be evaluated (Table 16.3). Different methods apply to different areas, and teams must use their professional judgment to select or design appropriate methods. Because it is an iterative and evolving process, watershed analysis should explicitly allow for methods to be improved and replaced as experience and knowledge accumulate.

Although watershed analysis may identify potentially conflicting objectives and uses, it is not a decision process per se. Rather, it is a process that generates information to assist in decision making. To the degree that it brings factual information to the decision-making process, watershed analysis is a substantial advancement over past management approaches.

Watershed analysis assumes there are demonstrable linkages between physical patches and biological processes, and that human values and perceptions do not change. This is a flawed assumption that contradicts the discussion on risk, to follow. Despite the promise of watershed analysis, it does have features that impede effective watershed management. Local and regional political influences; nonbinding agreements; the lack of long-term accountability for institutions, decision makers, and land managers; and the avoidance of an interactive synthesis of information are potentially fatal flaws in the concept. Further, to date, there has been no scientific validation of the approach, which was developed primarily by physical scientists.

Watershed analysis is now a part of the regulatory framework for managing state and privately owned commercial forests in Washington (Washington Forest Practices Board 1994). The Washington Department of Natural Resources, the agency charged with implementing watershed analysis, has identified a number of forested subbasins (fifth- and sixth-order river systems) termed watershed analysis units (WAUs). Within these units, watershed analysis forms a basis for local forest practice decisions. The first WAU to be analyzed was the Tolt River drainage, located in the Puget Sound basin of western Washington. The Tolt River watershed includes mixed ownership dominated by private forestland, as well as a reservoir that supplies water to Seattle. Because the Tolt River contained valuable fishery resources (salmon, trout, and steelhead) as well as an important drinking water supply, many interest groups participated in the analysis process.

The Tolt watershed analysis procedure identified

Table 16.2 Summary of practical approaches for watershed management

Approach	Description	Applicability	Advantages	Disadvantages	Case Studies
Watershed Analysis	Provides a scientifically based understanding of environmental processes and their interactions	Largely limited to forested water-sheds of 50 to 500 km^2, although it can be adapted to other situations	Provides a spatially explicit description of resources, hazards, environmental variation, and potentials, as well as potential conflicts over resource use; adaptable to new technological methodologies	Requires highly trained, interdisciplinary teams, familiar with the terrain; assumes demonstrable linkages between physical patches and biological processes	Tolt Watershed Analysis Prescriptions, 1993, Montgomery et al. 1995
Quantitative Measures	Inventory of the abundance and spatial arrangement of vegetation land cover, or habitat characteristics	All watersheds	Provides a resource inventory for establishing spatial and temporal trends; takes advantage of existing GIS databases; acts to centralize storage of information; requires personnel with only moderate levels of training	Database development often requires a substantial investment; data availability is often incomplete; requires long-term monitoring and analyses to be useful	Turner and Gardner, 1991; Turner et al. 1996
Integrated Socioenviron-mental Models	Models explicitly combining the social, economic, and environmental factors influencing watershed characteristics	Still in an experimental stage; best applied to watersheds with few, direct human influences on resources	Allows a holistic (and more realistic) perspective to be developed where human activities and values are a central component of the ecosystem; allows evaluation of a wide range of social choices	Database development is expensive and time consuming; essential data are often incomplete; requires a moderate-to-high level of technical expertise	Le Maitre et al. 1993; Warwick et al. 1993; Berry et al. 1996; Wear et al. in press
Indices of Socioenviron-mental conditions	Components contributing to the long-term vitality of a social-economic-environmental system	Watersheds with a significant human population	Provides a regular report to the citizens; improves literacy about watershed-scale issues; develops stewardship for the long-term; easily maintained	Requires regular monitoring and analysis of data, some of which may be difficult to obtain	Willapa Alliance and Ecotrust 1995

Table 16.3 The fundamental steps involved in watershed analysis, and some of the basic products to be expected from the process.

Steps

1. Identify issues, describe desired conditions, and formulate key questions
2. Identify key processes, functions, and conditions
3. Stratify the watershed
4. Assemble analytic information needed to address the key questions
5. Describe past and current conditions
6. Describe condition trends and predict effects of future land management
7. Integrate, interpret, and present findings
8. Manage, monitor, and revise information

Products

1. A description of the watershed, including its natural and cultural features
2. A description of the beneficial uses and values associated with the watershed and, when supporting data allow, statements about compliance with water quality standards
3. A description of the distribution, type, and relative importance of environmental processes
4. A description of the watershed's present condition relative to it's associated values and uses
5. A map of interim riparian reserves

areas where salmonid habitat features, such as proper stream temperature and abundance of large woody debris, were degraded, as well as areas where delivery of sediment to streams would be likely from unpaved logging roads and geologically unstable slopes. Prescriptions for preventing or mitigating these problems (Tolt Watershed Analysis Prescriptions 1993) were developed by a team that included six foresters representing the Department of Natural Resources and the Weyerhaeuser Company, a forest road engineer, a tree physiologist, an environmental analyst from the Washington Department of Ecology, two aquatic biologists from the Tulalip Indian tribe, and a forest hydrologist. Their prescriptions for future forestry operations are not voluntary; a landowner who does not comply is subject to civil and criminal prosecution.

Over 40 people officially participated in the Tolt watershed analysis. The five-month process was at times contentious. This was perhaps to be expected given the diversity of interests in the watershed. Members of the analysis team generally agreed that the process of working together was at least as important as the process of using available data to guide management decisions.

Quantitative Measures

Watersheds can be characterized by a variety of quantitative measures when digital data are available. Most simply, the total area and proportion of the watershed occupied by each cover type (vegetation or habitat) can be identified and its area and perimeter recorded. Analyses of the total number of patches, of arithmetic mean patch size, of standard deviation of mean patch size, of size of the largest patch, of weighted-average patch size, of amount of interior habitat, of total edge, and of mean patch shape are easily computed. In addition to metrics describing individual cover types, edges between habitats (which are sensitive measures of habitat fragmentation) can be tabulated as the length of edge between each pair of land-cover classes (e.g., forest-grassy, forest-unvegetated, grassy-unvegetated) or as edge-to-area ratios.

While the development of quantitative measures of watershed conditions has proceeded rapidly, empirical studies that test for significant relationships between watershed metrics and ecological conditions (e.g., presence or abundance of species or water quality) are still few in number (Johnston et al. 1990). There is a clear need to identify the most important watershed metrics to monitor as well as the levels beyond which socioenvironmental conditions change significantly. In addition, it is essential to be aware of the assumptions and constraints that are implicit in the metrics. For example, selection of land-cover categories can determine the results of an analysis. Similarly, the spatial scale of the data—both the total extent of the area and the resolution, or grid cell, size—can strongly influence the numerical results (Turner et al. 1989a, 1989b).

Integrated Socioenvironmental Models

The risk of undesirable future conditions can be assessed by using integrated socioenvironmental models to explore alternative land management scenarios

(Le Maitre et al. 1993, Warwick et al. 1993, Flamm and Turner, 1994a, 1994b). An example of such a model is LUCAS, the Land-Use Change and Analysis System (Berry et al. 1996, Wear et al. 1996). LUCAS is a spatial simulation model in which the probability of a land being converted from one land-cover type to another depends on a variety of social, economic, and ecological factors (Figure 16.3). Conditional transition probabilities are estimated empirically by comparing land cover at different times (Turner et al. 1996).

Simulations begin with an initial map of land cover. Next, equations are used to generate a transition probability for each grid cell in the watershed map based on ownership type, elevation, slope, aspect, distance to roads, distance to markets, and population density (Flamm and Turner 1994a, 1994b, Wear et al. 1996). An integrated modeling approach permits the effects of a wide range of alternatives to be evaluated. For example, one can examine the effects of residential development in different locations within the basin or the effects of moving a large parcel of land into or out of intensive timber production. Linking projected land-cover maps with effects on ecological indicators (such as species persistence or water quality) allows comparison of the potential long-term implications of alternative human decisions.

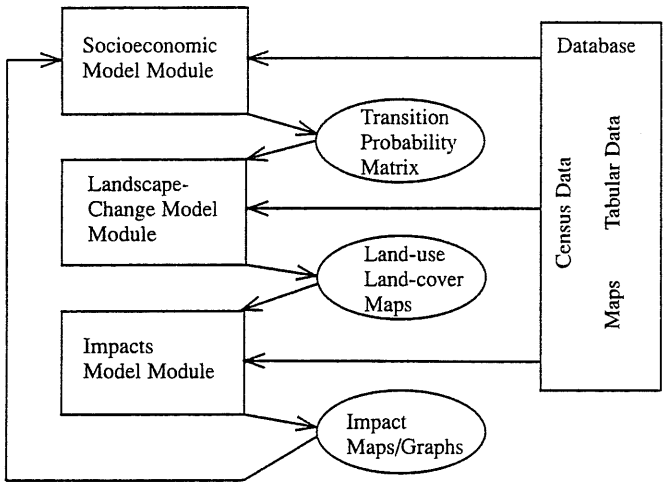

Figure 16.3 Integration of social, economic, and environmental aspects of watershed management can be accomplished with the use of the Land Use Change Analysis System (LUCAS), a modeling environment (after Berry et al. in press).

Indices of Socioenvironmental Conditions

Methods for separately examining the status and trends of environmental, social, and economic factors are well established (Finstenbusch and Wolf 1981, Burch and DeLuca 1984, Karr 1991). However, watershed management requires integrated socioenvironmental indices that provide a holistic understanding of watershed condition (Table 16.2). In a broad sense, a socioenvironmental index is a report to citizens, resource users, and government agencies on the vitality of a space they hold in common. Ideally, a socioenvironmental index should provide usable information on the important aspects of a watershed's environment, economy, and communities.

Components of a socioenvironmental index are chosen to reflect the unique characteristics of a watershed. For example, in the Willapa Bay watershed of western Washington, shellfish harvest, timber production, fishing, and agriculture are important in maintaining the local economy and culture. The Willapa Alliance, a consortium of concerned citizens and resource users, has developed an index based on indicators of environmental quality, economic vitality, and community health (Table 16.4). Environmental quality is indicated by oyster condition, which re-

Table 16.4 Socioenvironmental index

Natural resource–based industries: shellfish harvest, timber production, fishing, and agriculture	
Environmental quality	• Oyster condition • Vegetation cover • Salmon escapement • Bird abundance
Economic conditions	• Finfish, shellfish, and timber harvest • Income distribution • Unemployment rates • Bank loans per capita
Community health	• Healthy birth-weight babies • High school graduation rates • Voter turnout

Note: This socioenvironmental index was developed for the Willapa River watershed, Washington State (Willapa Alliance and Ecotrust 1995).

flects water quality; by changes in vegetation cover, which reflect terrestrial condition; by escapement of wild and hatchery salmon, which reflects ecological conditions in the rivers and streams; and by counts of wetland and riparian birds, which reflect habitat condition. Economic conditions are gauged by annual finfish, shellfish, and timber harvests, income distribution, local unemployment rates, and bank loans per capita. Community health is measured by the percentage of babies born with healthy birth weights, high school graduation rates, and voter turnout in county elections. Each category has alternate candidates that could have been used in developing the socioenvironmental index. Adult literacy rates could replace high school graduation rates, vegetative biodiversity could replace bird abundance, and so forth. Citizens and resource users within the watershed can use this index to develop a holistic understanding of the watershed and to create the stewardship necessary for long-term sustainability (The Willapa Alliance and Ecotrust 1995).

Addressing Institutional Organization

Watershed-scale activities must ultimately be integrated across a larger region, including the landscapes that make up that region. The challenge of integration involves a paradox of scale: Large-scale (regional) ecological systems can be most effectively regulated by small-scale (local) social organizations (Lee and Stankey 1992). Since people's interests, commitments, and knowledge generally are localized, bottom-up approaches that aggregate the local initiatives of citizens may be the most likely to succeed in achieving regional goals (Dryzek 1987). Experience throughout the world has shown that regional ecological stability is more likely to be achieved by permitting variability in land-use practices and, within limits of critical biological thresholds, by allowing and encouraging localized fluctuations in management practices (Ostrom 1990, Wheatley 1993, Korten 1987).

The paradox of scale is a general principle found to apply to systems as diverse as business organizations, chemical and physical processes, and ecological systems (Wheatley 1993). Stability in large-scale processes arises when the small-scale processes are allowed freedom to operate. This is illustrated by business organizations when individual and small-group initiatives respond to prices or other incentives by developing resources within the limits set by large-scale organizations.

Maintaining local initiatives, commitments, and knowledge also helps promote sustainability by insulating the management of ecological processes from the political cycles that affect large-scale organizations. National and state (or provincial) policies for regulating ecological systems generally are affected by the policies and preferences of political elites currently in power. Since political elites cycle in and out of power, especially in democratic systems, top-down control becomes a source of substantial instability. Hence, ecological regulations that rely on top-down control become highly unstable. Moreover, they may result in levels of unpredictability that discourage local initiatives requiring long-term commitments and investments of time and money.

The continuity of commitments and knowledge embodied in small-scale local organizations also helps foster effective adaptive management (Lee 1993, Pinkerton 1993). Political cycles in top-down administrations make it difficult to sustain long-term data gathering and monitoring. But even more difficult for large-scale organizations are commitments to take experimental actions for purposes of monitoring results. And when commitments to experiments are made, they often lack the diversity of trials necessary for eliminating multiple rival hypotheses about the operation of complex systems. Local initiatives, when supported by the generalized commitment of large-scale organizations, can be far more effective in implementing adaptive management. Experimental practices are insulated from the influence of political elites, fostering long-term commitments and ensuring that a diversity of trials will be put in place (McLain and Lee submitted).

Formulating Shared Socioenvironmental Visions

Loss of species, destruction of habitat, declining productivity, unstable social systems, and the disintegration of cultures are occurring on regional to global scales. How might these trends be reversed? Can it

be accomplished by accepting risk at individual to institutional scales? One approach is to develop a shared socioenvironmental vision of future conditions (Figure 16.4). In an ideal sense, this may prove to be a nearly impossible task—although the process of trying to identify socioenvironmental endpoints for the short and long terms is an exercise that aids communication and acts as an effective form of education about the diverse cultural beliefs and values embedded in a watershed. For example, environmental endpoints may be related to the extent and condition of riparian forests, to acceptable levels of water quality and aquatic habitat, or to the persistence of viable populations of ecologically or culturally valuable plants and animals. Social endpoints may relate to the level of socioenvironmental literacy, to the development of adaptive institutions, to the formulation of unique public and private partnerships, and to the realization of levels of personal stewardship and responsibility that allow for the long-term maintenance of a balanced socioenvironmental system.

Successful examples of the development of shared socioenvironmental visions and the methods used to attain those visions can be found in British Columbia (Fraser River), Florida (Kissimmee River), New England (Connecticut River), northern California (Metolius River), and western Washington (Willapa Bay), among many others. There are two fundamental traits inherent in these successful attempts: (1) a long-term commitment by the citizens who initially provide much of the vision and leadership and (2) an empowerment of citizens with the responsibility for their own future (Lee 1993).

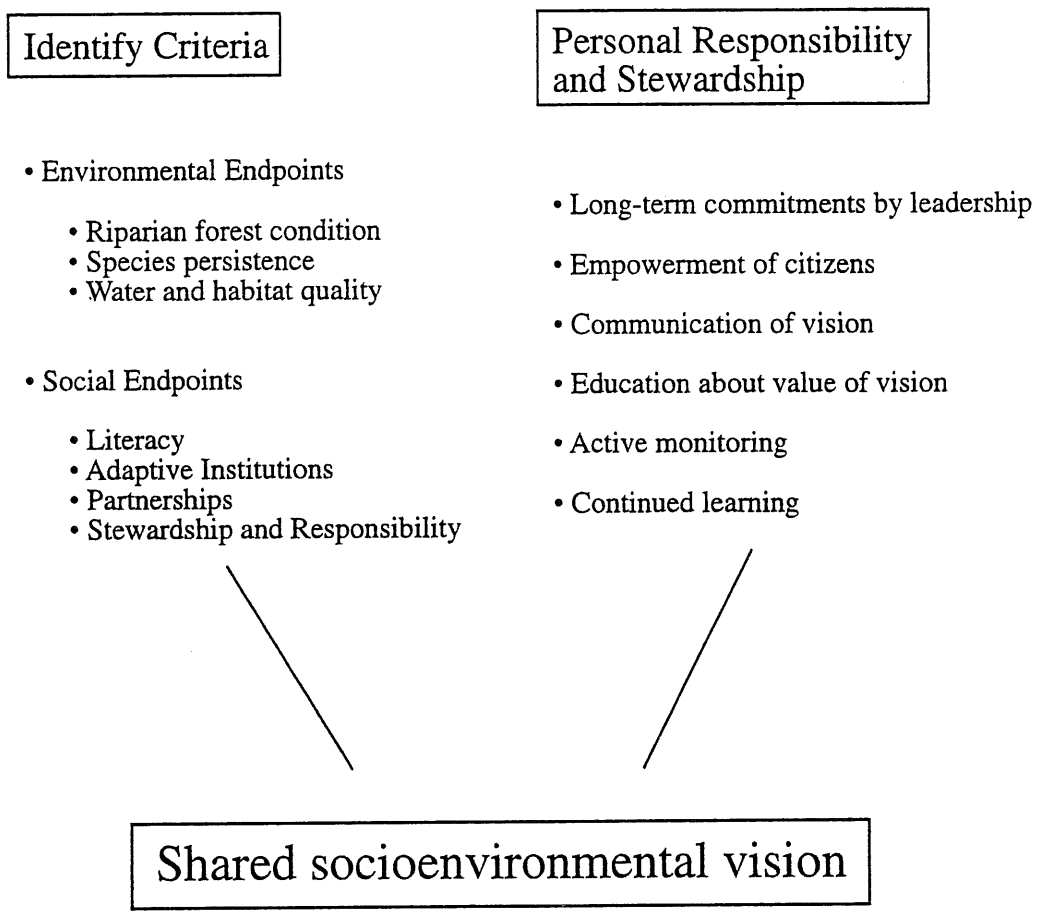

Figure 16.4 Components in developing and attaining a shared socioenvironmental vision for watersheds.

Public Stewardship in Watershed Management

Watershed management requires thoughtful stewardship that cannot be attained solely by government regulations or the work of technical specialists. Thus, concerned and educated citizens are essential. They represent a reservoir of human resources whose involvement can benefit management organizations and increase the overall awareness of socioenvironmental conditions. Citizens particularly can play an important role in monitoring socioenvironmental conditions. However, to do so successfully, they require continuing education to keep abreast of scientific and cultural advances.

Monitoring

Public involvement in coordinated monitoring activities instills a sense of ownership. Through monitoring programs, citizens can provide inputs to decision makers based on first-hand observations. As such, monitoring can become a learning opportunity for those setting policy as well as for those seeking to influence watershed management decisions.

There are unique advantages to including citizens in monitoring programs. First, due to limited budgets and staff availability, funds for collecting information about watershed features are usually directed to severely degraded sites. Many watersheds in need of monitoring are ignored unless volunteer efforts are undertaken. Thus, monitoring by volunteer groups or networks of individuals provides valuable information on watershed conditions that may not be high on political priority lists. Second, public involvement in monitoring projects helps ensure data continuity. Staff turnover in public agencies and large landowner organizations often results in discontinuities in data collection or undocumented changes in techniques. Local citizens, working with public and private organizations, fill gaps inevitably created when monitoring staffs change. They also provide insights to new staff members that otherwise might not be obtained within existing organizational structures. Third, the sheer number of citizens available to assist with monitoring makes it possible to conduct large-scale adaptive management experiments that would be impossible with limited agency or landowner resources.

Understanding changes in watershed conditions requires distinguishing between localized and large-scale effects, assessing system responses that separate human-related impacts from uncontrolled environmental factors, and having institutional agreements that provide for decades-long measurements (Walters and Holling 1990). These requirements generally go beyond the capabilities of individual organizations; thus, cooperative monitoring programs must become the rule instead of the exception.

In most cases, monitoring tasks need to focus on measurements readily understandable and not requiring specialized skills. Often this precludes the collection of biological samples. However, there are a number of monitoring activities well within the abilities of average citizens. These include the following:

Photographs

The importance of time-series photographs cannot be overstated. Some of the most valuable information about historical conditions is derived from photographs, particularly those where locations can be clearly identified. In addition, reference photo-points within watersheds are helpful in tracking long-term trends in vegetative structure and stream conditions. Reference photo-points also can be used to display the effects of seasonal changes and of large disturbances such as floods and fires. Important photographs often exist in family albums or businesses, and public involvement can bring these historical records to light.

Water Samples

Long-term trends in water quality require regularly scheduled sampling. However, the number of sites that can be routinely monitored by agencies is limited by the availability of automated sampling equipment and staff time. The U.S. Geological Survey monitored water quality parameters in many watersheds after passage of federal water laws in the 1960s and 1970s. Yet, it was forced to abandon many sites in the late 1970s when funding for monitoring pro-

grams expired. A network of water sampling locations at which local volunteers obtain periodic samples is an especially effective means of monitoring easily preserved parameters such as suspended sediment. Likewise, maximum-minimum thermometers placed throughout a watershed and checked at regular intervals by citizen's groups or individual landowners provide an indication of temperature fluctuations over time. These easily measured parameters have immediate significant effects on aquatic ecosystems and provide important information about erosion and upstream riparian conditions.

Habitat Measurements

Stream morphology is an integrative measurement of overall watershed condition. Pools, for example, which are very sensitive to change, provide important habitat for certain types of aquatic organisms, including many fish species. Citizen participation in simple habitat measures, such as counting the number of large pools, increases the area for which inventory information is available. Sportsman's clubs and conservation organizations (including adopt-a-stream groups) are especially suited to this type of project.

Riparian Forest Surveys

Riparian forests are critical to watershed health, yet insufficient attention is paid to their condition. Riparian plots in which surveyors periodically identify and count the number of trees, measure changes in species composition and growth, and note causes of mortality provide integrated long-term information about watershed characteristics. Plots do not have to be revisited every year, as long as their locations are well documented; they can be resurveyed by the same group or rotated among several groups over longer periods. Information generated by these surveys is useful for verifying remote sensing data, providing riparian vegetation information for watershed analysis, and teaching citizens about the dynamic nature of watershed processes.

Socioeconomic Conditions

Although socioeconomic conditions are already well monitored, data are seldom compiled for conditions within watershed boundaries. Annually collected socioeconomic indices, such as annual capital investment, resource exports, unemployment, high school literacy, healthy births, and so forth, provide essential information about human conditions in a larger community that includes the watershed (Table 16.4). Commitments to maintain and enhance the biological and physical conditions of watersheds are most likely to arise when local economies and societies are healthy and the population is well informed.

Public Outreach

Effective watershed management requires that scientists and managers provide knowledge about watershed processes and management techniques to citizens on a regular basis. Although citizens and local groups usually act with good intentions, they do not always have the benefit of current professional insights into human and environmental processes. The result may be that restoration and enhancement projects fail to achieve their objectives—or worse, that they actually impair socioenvironmental functions. For example, stream-cleaning projects largely have been discontinued by public agencies but are occasionally sponsored by citizen groups. Many citizens continue to be unaware of the ecological functions of woody debris or to regard these functions as secondary to providing unimpeded fish passage—even though this activity diminishes fish production in the long term.

How can educational and scientific communities maintain socioenvironmental literacy and instill a sense of stewardship among citizens? First, scientists need to explain concepts such as the importance of watershed connectivity, the role of natural disturbances in maintaining productivity, and the need to view watershed management in terms of large landscape units. They also need to articulate how social and environmental components work as an integrated system. Agricultural and forestry extension services, where citizens turn for advice from local specialists familiar with the region, serve as models for the establishment of an integrated watershed extension service. Watershed extension specialists, serving as local sources of the latest information, can act as liaisons between small and large landowners, natural resource consumers, and management agencies.

Second, colleges and universities must do more to educate citizens about important watershed management issues. Although educational institutions sponsor many meetings, the presentations are often too technical for citizens. Weekend or evening workshops aimed at communicating applied watershed science to a general audience are needed to increase public understanding of management options. Workshops featuring a combination of university faculty, research scientists, resource managers, citizens, and environmental policy makers are essential if we are to develop effective watershed management based on an integrated socioenvironmental perspective.

Conclusion

Watershed management is an ongoing experiment guided by fundamental principles and a common vision of the future. It utilizes a multitude of approaches to achieve an integrated and balanced socioenvironmental system (Naiman 1992, Lee 1993). There is no universal methodology for achieving effective watershed management. However, fundamental principles related to cooperation, balance, fairness, integration, communication, and adaptability can help guide the process:

1. It is important to recognize that watershed management demands unparalleled cooperation between citizens, industry, governmental agencies, private institutions, and academic organizations. In most situations, the complexity of information processing and the scope of socioenvironmental change exceed the capacity of any single group to manage a watershed effectively.

2. Technical solutions (such as fish hatcheries and waste management) to specific human-generated problems need to be balanced with the wide-scale maintenance of appropriate environmental components that provide similar ecological services.

3. Data-driven policy and management decisions need to become the standard for resolving issues; decisions based on conceptualization and perception should be minimized.

4. Regulations guiding the structure and behavior of socioenvironmental systems need to be evenly and fairly applied throughout a watershed. For example, basic regulations in areas such as riparian protection and chemical applications should not differ between forestry, agricultural, and urban areas. Regulations should encourage citizen initiatives and offer landowners incentives to provide greater protection and reduce chemical applications.

5. Human activities need to be accepted as fundamental elements of the watershed, as are the structure and dynamics of the environmental components. Both have inherent rights to exist for the long term.

These principles, when combined with approaches outlined in this chapter, provide initial steps toward achieving effective watershed management. Cultural values, social behavior, and environmental characteristics will continue to evolve. Unfortunately, critical evaluation of the approaches for watershed management outlined here will not be possible for several decades. Will the evaluation be positive? If so, it will be because citizens, regulators, educators, and industries shared a common long-term vision and adapted to change by adopting appropriate actions to meet that vision.

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