26
Watershed Management[1]

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Overview

• Management at the watershed scale is a major challenge facing present and future generations. Watershed management requires integrating scientific knowledge of ecological relationships within a complex framework of cultural values and traditions to provide socio-environmental integrity. This implies that socioenvironmental integrity can operate for the long term and over large spatial scales—especially within hydrologically identifiable boundaries.

• Development of a watershed management perspective incorporates variability in time and space, takes a holistic approach toward the persistence of ecological features, treats human cultures and institutions as inherent features, and addresses system connectivity and uncertainty.

• Several approaches are presented for implementing watershed management that relate to public stewardship (monitoring and education), accepting and dealing with risk, addressing uncertainty, formulating a shared vision, quantitatively analyzing socio-environmental conditions, and structuring institutional organization.

• Although there is no set methodology for achieving effective watershed management, fundamental principles related to cooperation, balance, fairness, integration, trust, responsibility, communication, and adaptability are essential for guiding the process.

Introduction

Fresh water, and freshwater ecosystems, are the most basic components of watershed management (Naiman et al. 1995a,b). Freshwater issues, more than ever, embody the complexity that characterizes natural resource management. Changes in human demography, resource consumption, cultural values, institutional processes, technological applications, and information all contribute to the increasing complexity. Despite attempts to manage change, changes continue to occur and the consequences remain difficult to predict at scales commensurate with the changes themselves (Naiman 1992, Lee 1993). Understanding the abilities and limits of freshwater ecosystems to respond to human-generated pressures is central to long-term social stability as well as ecological vitality. Yet, even though human actions and cultural values drive the environmental issues, few holistic approaches for watershed management offer effective resolution.

In the current debate over the scope of watershed (and ecosystem) management (Grumbine 1994, U.S. MAB 1994,

[1] This chapter is an expanded version of the original chapter in Kohm, K.A., and J.F. Franklin (editors). 1997. Creating a forestry for the 21st century: The science of ecosystem management. Island Press, Washington, DC.

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 important issues as identifying appropriate spatial and temporal scales, monitoring and assessment, developing an adaptive management process, and developing cultural values and philosophies that allow watershed management to be successful (Levin 1993, Grumbine 1994, Harwell et al. 1996). 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 there is to be a healthy resource base for future generations.

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

Fundamental Elements of Watershed Management

Initially, it is important to recognize that there are four watershed-scale features which provide the foundation for effective management: variability in time and space, persistence and invasiveness of species, system connectivity 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, U.S. MAB 1994; Table 26.1).

The Natural System: Variability in Time and Space

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

The vitality of natural ecosystems is created and maintained by substantial variation in time and space (Reice et al. 1990, Reice 1994). Natural systems are constantly changing in a complex mosaic of time periods and spatial dimensions (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 26.1). Variability in time and space

TABLE 26.1 Principles for management at the watershed scale.

- Use an ecological approach that would recover and maintain the biological diversity, ecological function, and defining characteristics of natural ecosystems.
- Recognize that humans are part of ecosystems—they shape and are shaped by the natural systems; the sustainability of ecological and societal systems are mutually dependent.
- Adopt a management approach that recognizes ecosystems and institutions are characteristically heterogeneous in time and space.
- Integrate sustained economic and community activity into the management of ecosystems.
- Develop a shared vision of desired human and environmental conditions.
- Provide for ecosystem governance at appropriate ecological and institutional scales.
- Use adaptive management as the mechanism for achieving both desired outcomes and new understandings regarding ecosystem conditions.
- Integrate the best science available into the decision-making process, while continuing scientific research to reduce uncertainties.
- Implement ecosystem management principles through coordinated government and non-government plans and activities.

Modified from U.S. MAB 1994.

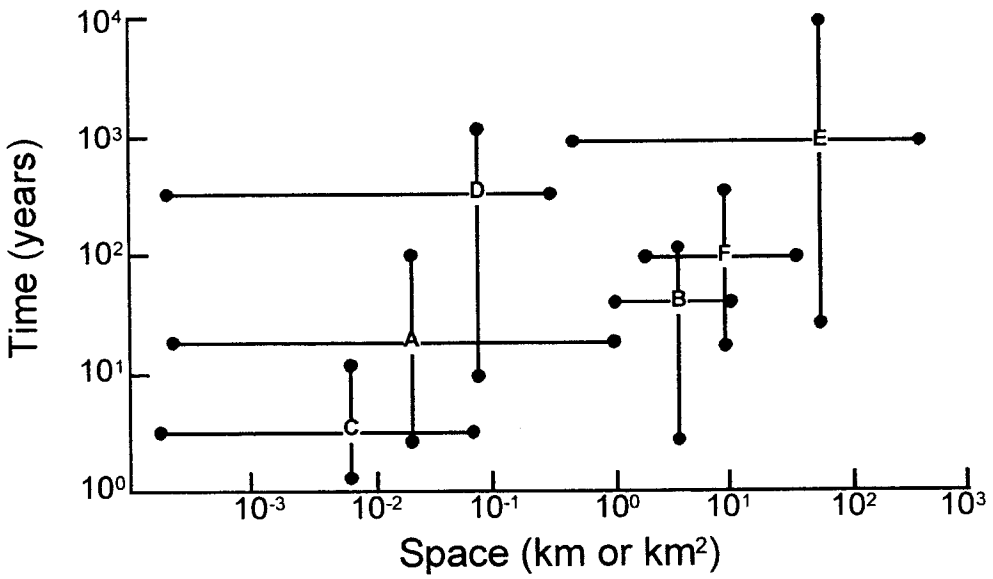

FIGURE 26.1. Illustration of the diversity of spatial and temporal scales influencing the creation and maintenance of riparian forests in the coastal temperate rainforest of North America. Colonization surfaces created by flooding (A), colonization surfaces created by debris flow (B), seedling germination and establishment (C), longevity and size of species patches (D), perisistence and movement of dead wood in channel (E), and impact of herbivores (F).

results in the biological diversity and productivity characteristically found in riparian environments (Fetherston et al. 1995, Naiman and Décamps 1997). 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 (i.e., biodiversity, productivity, resilience) do not occur.

A Holistic Perspective: Persistence and Invasiveness

The persistence of ecological attributes for the long term (i.e., decades to centuries) requires maintaining a naturally variable environmental regime as well as isolation from invading organisms that can alter the natural regime. When the natural environmental regime is altered, adjustments occur within the ecosystem (i.e., relative abundance of species or biogeochemical processes) 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. There is often a cultural identity with many species, and, in addition, the ecological processes are essential for sustaining human populations (Botkin 1990). There are a variety of quantitative approaches and technical tools that already exist for analyzing persistence and invasiveness at the watershed scale, and many other techniques are in the design and testing stages (see later). Existing techniques include new approaches to statistical analyses, patch and boundary analyses, modeling cumulative effects, indices of biotic integrity, and knowledge-based land-use analysis systems (Karr 1991, Risser 1993, Fortin and Drapeu 1995, Turner et al. 1996). These techniques are especially useful tools 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. 1996).

Connectivity and Uncertainty

The goal of watershed management is to let all components of the human and nonhuman communities exist in a relative but dynamic state of balance (Naiman 1992, U.S. MAB 1994). This goal explicitly recognizes strong connections between the social and environmental components at multiple scales. This means managing for connectivity between components, as well as managing the components themselves. For example, consideration must be given to water, fish, soils, forests, education, resource extraction, and cultural values, as well as to the strong interactions which occur 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, while the magnitude of current socioenvironmental issues requires decisions now. This means accepting risk since actions cannot wait until all the information is available. How can this be accomplished at the watershed scale? There is no definitive answer or one right way. However, from a wide range of empirical studies from many scientific disciplines, it is known that major advances often come at the interfaces between human, natural, and management sciences (Figure 26.2). Following is a discussion of approaches used by small organizations addressing risk, groups helping to define social and environmental viewpoints for future conditions, and researchers and managers struggling to monitor and assess change at regional scales.

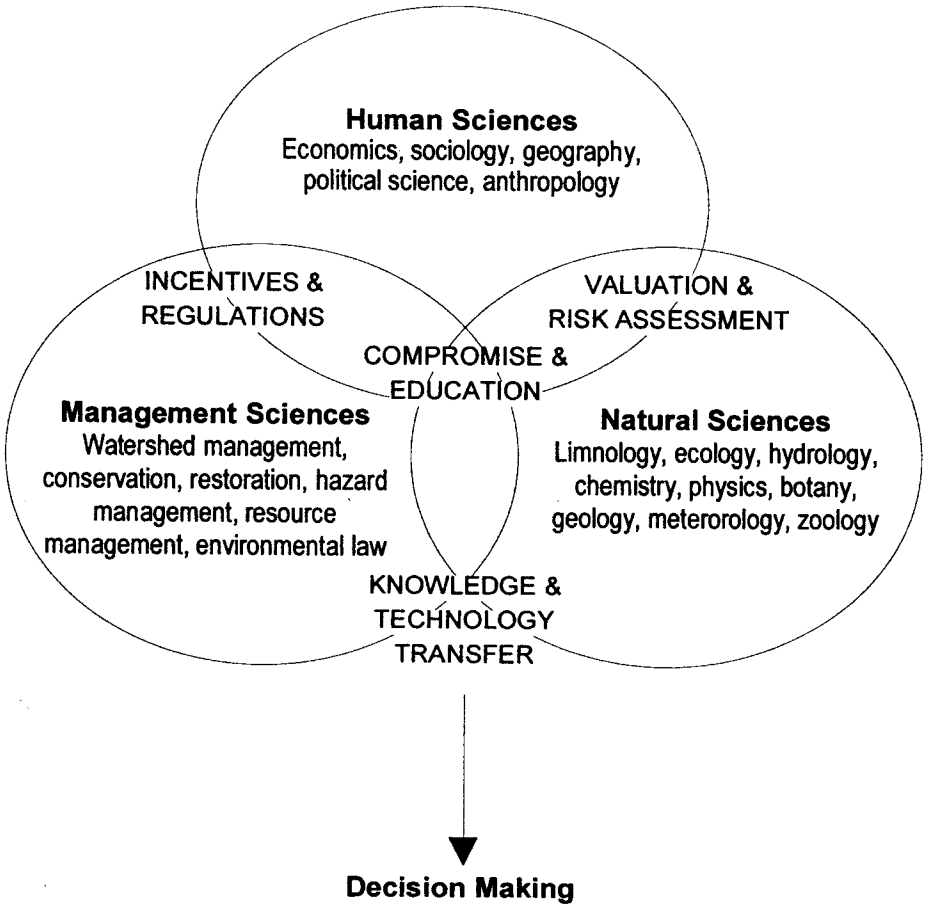

FIGURE 26.2. Advances in watershed management come at the interfaces between natural, human, and management sciences (from Naiman et al. 1995a, with permission).

Human Cultures and Institutions

In human-dominated watersheds, the land mosaic (i.e., patches and boundaries) is created by a mixture of cultural practices, traditions, myths, and institutions (Lee et al. 1992, Décamps et al. 1998). The spatial extent and temporal duration of each patch and boundary type are ultimately determined by laws, regulations, taxation, technologies, cultural values and beliefs, and traditional land use practices that pertain to the utilization of natural resources (Turner 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 peoples away from traditional homelands and cultures (i.e., cultural mixing), 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.

Practical Approaches for Implementing Watershed Management

Quantitative Analyses

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-San Joaquin rivers, and the Colorado River watersheds. An inability to identify appropriate spatial and temporal scales for management, cumulative effects from multiple users, conflicting management goals, lack of accepted statistical or realistic modeling approaches, and a dearth of indices for evaluating a dynamic socioenvironmental system all contributed to the difficulties (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 that 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 26.2 summarizes the available empirical approaches and their advantages and disadvantages. While the availability of quantitative tools may improve the ability to address watershed management issues, past failures cannot be totally attributed to the absence of such tools. Moreover, quantitative tools alone will not solve current or future problems.

Watershed Analysis

Quantitative approaches to document 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 26.2) but there are notable exceptions such as South Florida (Harwell et al. 1996). The intent of watershed analysis is to provide a scientifically based understanding of the environmental processes and their interactions occurring within a watershed (U.S. Government 1994, Washington Forest Practices Board 1994). This understanding, which focuses on specific issues, values, and uses within the watershed, is essential for making sound management decisions. The fundamental steps involved in watershed analysis and some of the basic products to be expected from the process are summarized in Table 26.3. Protecting beneficial uses, such as those identified by state and federal environmental laws (e.g., Clean Water Act and Endangered Species Act), is a fundamental objective for watershed analysis. Watershed analysis encompasses the entire watershed because of the strong fluvial linkages among

TABLE 26.2. Summary of empirical approaches for watershed management, applicability, and advantages and disadvantages of selected approaches and relevant case studies.

Approach	Description	Applicability	Advantages	Disadvantages	Case studies
1. Watershed analysis	Provides a scientifically based understanding of environmental processes and their interactions	Largely limited to forested watersheds of 50–500 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; is adaptable to new technological methodologies	Requires highly trained, inter-disciplinary teams, familiar with the terrain; assumes demonstrable linkages between physical patches and biological processes	Washington Forest Practices Board, 1994; Montgomery et al., 1995
2. 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	Often requires a substantial investment in database development; data availability is often incomplete; requires long-term monitoring and analyses to be useful	Turner and Gardner, 1991; Turner et al., 1995, 1996
3. Integrated socioenvironmental 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 a wide range of social choices to be evaluated	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. 1996
4. Indices of socioenvironmental conditions	Components contributing to the long-term vitality of an 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 26.3. Fundamental steps and basic products expected from watershed analysis.

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,
3. when supporting data allow, statements about compliance with water quality standards.
4. A description of the distribution, type, and relative importance of environmental process.
5. A description of the watershed's present condition relative to it's associated values and uses.
6. A map of interim conservation areas.

headwater areas, valley floors, and downstream users.

Watershed analysis requires a high level of expertise (Montgomery et al. 1995). However, earlier attempts such as the California checklist for cumulative effects required little technical expertise, were largely ineffective, and are no longer used (Chapter 19). The current watershed analysis procedure (Table 26.3) is designed to be 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. Different methods apply to different areas, and teams must use their professional judgment to select or design appropriate methods. Watershed analysis is also an iterative and evolving process. Analytical methods improve or are replaced as experience and knowledge grow.

The results of watershed analysis may include a description of resource needs, capabilities, and opportunities; the range of natural variation; spatially explicit information that will facilitate environmental and cumulative effects analyses for the National Environmental Policy Act (NEPA) regulations; and a description of processes and functions operating within the watershed (Montgomery et al. 1995; Table 26.3). Watershed analysis also identifies potentially conflicting objectives and uses within watersheds. However, watershed analysis is not a decision-making process per se; it is a process that derives information to assist in decision making. Watershed analysis is, nevertheless, a substantial advancement over management approaches used in the past because it brings factual information to the decision-making process.

Watershed analysis assumes there are demonstrable linkages between physical patches and biological processes and that human values and perspectives do not change. These are flawed assumptions that contradict the later discussion on risk. Despite the promise watershed analysis brings to management, there are impediments to its application. 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, and there is little understanding of how biological attributes (i.e., community composition and so forth) modify physical–biological relationships.

Despite these flaws, 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 (5th–6th order river systems) termed Watershed Analysis Units (WAUs) within which 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 forest land, but the drainage also includes a reservoir that supplies water to Seattle. Because the Tolt River contains valuable fishery resources (salmon, trout and steelhead) as well as an important drinking water supply, many interest groups participated in the watershed analysis process.

The Tolt watershed analysis procedure identified areas where salmonid habitat features such as stream temperature and large woody debris abundance 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 Washington 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. The prescriptions for future forestry operations are not voluntary; the land owners must comply or be subject to civil and criminal prosecution.

Over 40 people officially participated in the Tolt watershed analysis in addition to the 12 members of the prescription team. The five-month process itself was at times contentious. This was perhaps to be expected given the diversity of interests. Nonetheless, members of the watershed 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 (i.e., vegetation or habitat) can be identified and its area and perimeter recorded. Analyses of the total number of patches, arithmetic mean patch size, standard deviation of mean patch size, size of the largest patch, weighted average patch size, amount of interior habitat, total edge, and mean patch shape are easily computed (Table 26.2). 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 condition has proceeded rapidly, empirical studies that test for significant relationships between watershed metrics and ecological condition (e.g., presence or abundance of species, 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, the selection of the land cover categories to be used in the analysis in part determines the results, and 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,b).

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, b). An example of such a model is the Land-Use Change and Analysis System (LUCAS) (Berry et al. 1996, Wear et al. 1996). LUCAS is a spatial simulation model at the watershed scale in which the probability of land being converted from one land cover type to another depends on a variety of social, economic, and ecological factors (Figure 26.3). Conditional transition probabilities are estimated empirically by comparing land cover at different times (e.g., from decade to decade) and then used to simulate potential future conditions (Turner et al. 1996).

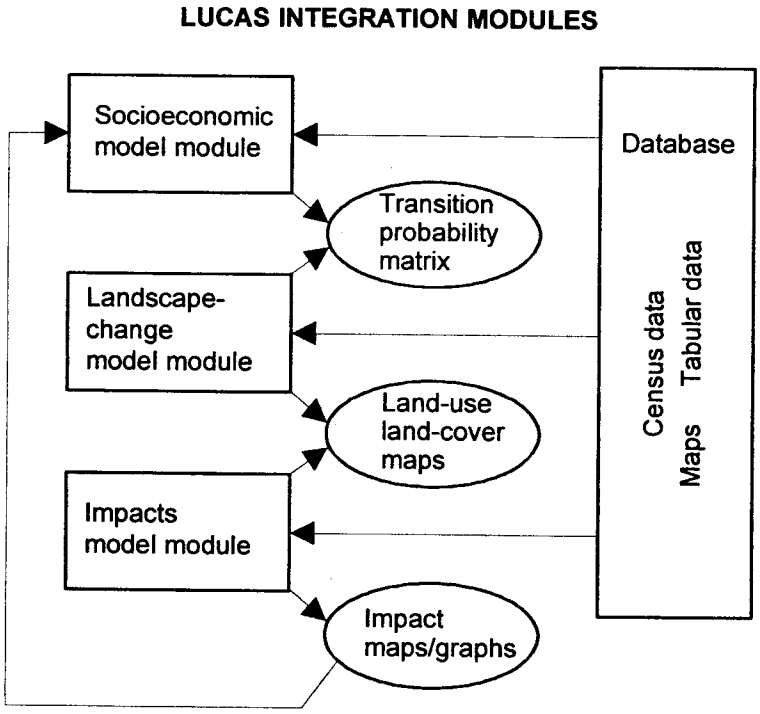

FIGURE 26.3. Integration of social, economic, and environmental aspects of watershed management can be accomplished with the use of the Land Use Change Analysis System (LUCAS), a modeling environment (Berry et al. 1996, with permission © 1996 IEEE).

Simulations begin with an initial map of land cover, and 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 road, distance to market, and population density (Flamm and Turner 1994a, b, Wear et al. 1996). An integrated modeling approach permits the effects of a wide range of alternatives to be evaluated. For example, 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 can be examined. Linking projected land cover maps with effects on ecological indicators (such as species persistence or water quality) allows the potential long-term implications of alternative human decisions to be compared.

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 26.2). 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 the watershed. For example, in the Willapa Bay watershed of western Washington, shellfish aquaculture, 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 26.4). Environmental quality is indi-

cated by oyster condition that reflects water quality, by changes in vegetation cover which reflects terrestrial condition, by escapement of wild and hatchery salmon (*Oncorhynchus* spp.) which reflect 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 (i.e., resource production), income distribution, local unemployment rates, and bank loans per capita (i.e., credit and local investment). Community health is measured by the percentage of healthy birthweight babies, high school graduation rates, and voter turnout in county elections (i.e., participation). Each category has alternate candidates that can be used in developing the socioenvironmental index. Adult literacy rates could replace high school graduation rates, vegetative biodiversity could replace bird abundance, and so forth. Nevertheless, the point is that citizens and resource users within the watershed have an integrated socioeconomic index that can be used to develop a holistic understanding about the watershed and to create the stewardship necessary for long-term sustainability (The Willapa Alliance and Ecotrust 1995).

TABLE 26.4. Socioenvironmental index developed for the Willapa River watershed, Washington.

Natural resource-based industries	Shellfish harvest, timber production, fishing, and agriculture
Socioenvironmental index	
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	Birthweight of healthy babies
	Rates high school graduation
	Voter turnout

The Willapa Alliance and Ecotrust 1995.

Accepting Risk and Addressing Uncertainty

Attempts to make decisions by identifying, evaluating, and formulating management strategies for risks associated with watershed management need to include a broad socioenvironmental perspective, recognition of spatial scales ranging from sites to global ecological and social processes, and an explicit consideration of the temporal transfers of risks, especially those involving decisions that may transfer risks to future generations or impose unacceptable rates of change on current generations.

Risk is a product of the probability of a negative (unwanted) event and the consequences of that event (Campbell 1969, Slovic 1984, Suter 1992). Estimating risks involves identification and evaluation (Schrader-Frechette 1991). Risk management is also part of the process of subjecting unwanted events to rational interpretations because it involves selection of the most effective and efficient means of reducing harm. A comprehensive discussion of risk assessment is beyond the scope of this chapter, but is provided by Fava et al. (1991), Bartell (1992), Harwell and Gentile (1992), and U.S. EPA (1993).

Competing risks are often a basic cause for conflict. Decisions about allocation of land or resources involve judgments about the extent to which the risk should be placed on environmental features or on human well-being. Scientists are poorly prepared for making these judgments, because decisions on how to balance risks involve political and ethical considerations for which scientists are seldom adequately trained and generally unauthorized. Scientists are often best at identifying problems, not resolving them (Ludwig et al. 1993).

The scientific role is to identify what may be at risk, discover what causes risks to increase or decrease (risk attribution), estimate the relative importance of causes (risk assessment), use knowledge to suggest options for reducing risks (risk management), and design effective monitoring programs that facilitate learning. Scientists are most useful to the decision-making process if risk attribution is framed by hypoth-

Null hypothesis is:	Accepted	Rejected
True	Correct decision	Type I error
False	Type II error	Correct decision

FIGURE 26.4. Type I and Type II errors in decision making arise according to inherent philosophies and training of specific disciplines (modified from Sokal and Rohlf 1981).

eses linking causes to effects (i.e., using *If-Then* statements).

Risk assessment requires explicit statements about the degree of confidence scientists and managers have in cause-and-effect relationships. Statements involving statistical confidence limits are generally required but rarely available for large systems. However, they may be approximated by the "best judgment" of knowledgeable experts. Opportunities for risk management improve with knowledge of cause-and-effect relationships, often permitting scientists to suggest management strategies that sufficiently mimic natural structure or processes to allow resource use without imposing unacceptable risks on species, natural processes, or society.

Unfortunately, it remains difficult to frame decisions based on the allocation of risk because scientists are trained to avoid making Type I errors (rejecting a null hypothesis when it is true) while paying less attention to Type II errors (failing to reject the null hypothesis when it is false; Figure 26.4). Scientists are generally concerned about avoiding false-positives because the professional mission is to contribute accurate information for building an understanding of fundamental processes (Schrader-Frechette 1991). When contributing to risk assessment, it is far more important to avoid overlooking important cause-and-effect relationships that are true (avoid Type II error) which could, for example, result in loss of a species or the disintegration of a human community. The appropriate scientific role is, of course, to pay attention to both types of error.

Addressing Type I and Type II errors becomes especially complex when there are competing risks. Concern about losing a species or causing unnecessary human suffering often leads to placing emphasis on avoiding a Type II errors while minimizing Type I errors. For example, mistakenly accepting the hypothesis that sustaining coho salmon (*Oncorhynchus kisutch*) requires preservation of all remaining ancient forests and unregulated rivers, could cause unnecessary human suffering and economic losses. Similarly, mistakenly accepting the hypothesis that timber harvest reductions will cause a large increase in rural poverty could place the survival of certain animal species at risk. Hence, extra effort needs to be paid to minimizing both Type I and Type II errors through better interdisciplinary communication. It is a natural tendency to ignore risks that are not well understood. This is especially true if the implications of research conclusions allow scientists to externalize Type II errors on subjects understood better by other disciplines.

How Can Organizations Deal with Risk?

Formal organizations, especially those that have persisted for a long time, tend to conserve their mission and structure (Selznick 1966, Meyer and Scott 1983). Organizational mission and structure are threatened by an uncertain environment, especially one that imposes risks. For example, natural disturbances such as fires, insect outbreaks, floods, and windstorms often exceed the capacity of land management organizations to cope with the disruption. Similarly, the emergence of new and powerful political clients bring risks of diminished political support and stability.

Organizations tend to limit actions that will threaten organization structure and mission, even when those actions might better position

the organization to deal with emerging risks (Meyer and Scott 1983, Bella 1987). These tendencies are related to the statistical concepts of Type I and Type II error discussed previously (Figure 26.4). Organizations, like individual scientists, are usually concerned with minimizing the risk of making a Type I error. Likewise, organization members are worried about false-positives (asserting an effect where none exists) because they do not want to needlessly upset organizational relationships and purposes upon which they depend for security, rewards, and identity (Schrader-Frechette 1991).

Consumers or clients depending on the organization for service or protection are, by contrast, concerned with minimizing Type II errors. They are more concerned about the social acceptability or environmental safety of technologies or organization practices. Hence, they do not want to allow an organization to increase the risk of public injuries or losses (Schrader-Frechette 1991).

As in statistics, there is an inverse relationship between these two types of error—these two sources of risk. Customers or the public might be hurt by decreasing risk to the organization, and the organization might be hurt by decreasing the risk to customers or public. These inverse relationships are well illustrated in land management organizations responsible for implementing watershed management plans.

Federal land management organizations are placed at risk by dramatically changing management practices (such as timber harvest, fishing or grazing) to avoid the risk of losing species valued by society. Normal routines are disrupted, changes in work force are implemented, insecurity becomes contagious, and the identity provided by organizational culture becomes confused by drastic institutional change. The very existence of an organization can be threatened by sudden change in organization and mission. A frantic search for new mission, or paradigm, generally accompanies these periods of unrest and insecurity, with stability returning if the organization is successful in finding a new mission and a structure for implementation. Watershed management and ecosystem management are now part of such a search for a new mission by many of the large, material resource-based industries and the provincial, state, and federal agencies in Canada and the United States.

Adaptive organizations avoid risks accompanying such turmoil by continually striving to maintain a balance between Type I and Type II errors. Large industrial organizations, such as those responsible for managing forested lands, have sought to manage internal and market or regulatory risks that accompany increasing uncertainty by reorganizing their structure and diversifying their mission. Horizontal, team-based management with accountability to attain performance objectives is replacing the centralized and homogeneous mission characteristic of traditional, bureaucratic command-and-control structures (Reich 1991). This often includes product diversification and relative independence of production units. Greater flexibility and efficiency are gained by down-sizing salaried staff and contracting for services such as roadbuilding, resource extraction, inventory, and environmental assessment. These innovations have enabled large formal organizations to capture some of the advantages of flexibility characteristic of market systems that have a large number of independent producers.

Large public organizations seldom have the opportunity to develop decentralized structures suitable for adapting to an uncertain environment. Government, as opposed to markets, centralizes power and defines organizational mission and structure from the top down. One of the greatest challenges (and opportunities) facing public land management organizations in North America is to develop permissible ways of diversifying organizational mission and developing a structure capable of responding to diverse and dynamic social, political, and geographic concerns and conditions. Successful implementation of watershed management may depend on how well public organizations meet these challenges.

Addressing Institutional Organization and the Paradox of Scale

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: in some cases large-scale (regional) ecological systems can be most effectively regulated by small-scale (local) social organizations (Lee and Stankey 1992). Since peoples' interests, commitments, and knowledge are generally 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 greater variability in land use practices and, within limits of critical biological thresholds, allowing and encouraging localized fluctuations in management practices (Korten 1987, Ostrom 1990, Wheatley 1993).

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 larger-scale processes arises when the smaller-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 larger-scale organizations.

Maintenance of 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-level policies for regulating ecological systems are generally 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, and result in levels of unpredictability that discourage local initiatives requiring long-term commitments and investments of time and money. Sustainable watershed management requires the social and political stability often associated with local initiatives (also see Firey 1960).

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. 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 (Lee 1993). Experimental practices are insulated from the influence of political elites, fostering commitments to undertake experiments, and ensuring that a diversity of trials will be put in place (McLain and Lee 1996).

Formulating Shared Socioenvironmental Visions

The paradox in many environmental and social approaches is that they have not proven to be effective over the long-term (>10yr). The evidence is clear: 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 26.5). 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-term 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 the persistence of viable populations of ecologically or culturally valuable plants and

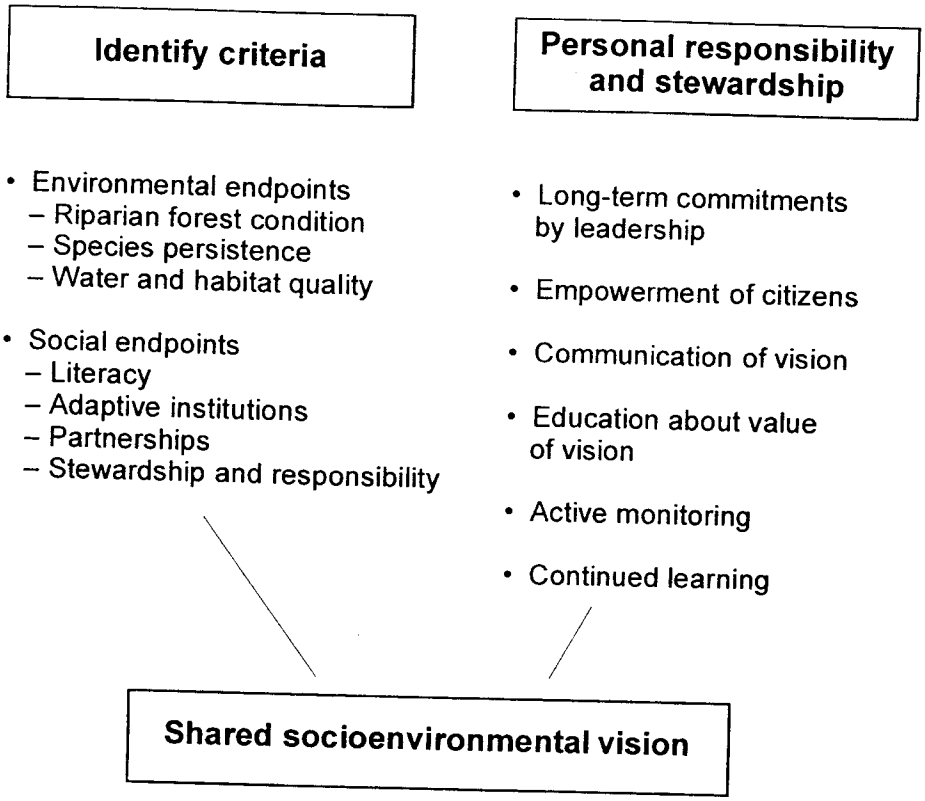

FIGURE 26.5. Components of a shared socioenviromental vision for watersheds.

animals. Social endpoints may relate to the level of literacy about the structure and functioning of the socioenvironmental system, the development of flexible (or adaptive) institutions that are able to respond to new and as yet unforeseen issues, the formulation of unique partnerships between private industry, citizens, academia, tribes, and government, and 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 various methods used to attain those visions, can be found for British Columbia (Fraser River), Florida (Kissismee River), New England (Connecticut River), Northern California (Metolius River), western Washington (Willapa Bay), and many other watersheds where citizens share a common concern about their future. However, there are two fundamental aspects inherent in the successful attempts: long-term commitment by the citizens who initially provide much of the vision and leadership, and empowerment of citizens with the responsibility for their own future (Lee 1993).

Public Stewardship in Watershed Management

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

Monitoring

Public involvement in coordinated monitoring activities instills a sense of ownership. Citizens taking an active interest in changes within the watershed provide inputs to decision makers based on firsthand, objective observations. This is a learning opportunity for those setting policy as well as those seeking to influence watershed management decisions.

There are unique advantages to including citizens in monitoring programs. First, with limited institutional budgets and staff availability, funds for collecting information about watershed features are usually directed to sites believed to be severely degraded. 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 condition that may not be high on political priority lists. Second, public involvement in monitoring projects helps ensure data continuity. Staff turnover and job transfers within public agencies and large landowner organizations often occur at rates less than the duration of monitoring programs, resulting 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, and provide insight to new staff members that might not be otherwise obtained within existing organizational structures. Third, the sheer numbers of citizens available to assist with monitoring make it possible to conduct large-scale adaptive management experiments that would otherwise be impossible with limited agency or landowner resources. However, there are some disadvantages which include the challenge of maintaining interest over long periods of time and potential inconsistency in data collection (Ralph et al. 1994).

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.

Expectations of the abilities of citizens to take samples and perform routine scientific tests must be tempered by a general lack of advanced technical training. Therefore, monitoring tasks need to focus, in most cases, 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, including:

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 photopoints within watersheds are helpful in tracking long-term trends in vegetative structure and stream conditions. Reference photopoints can also be used to display the effects of seasonal changes and 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, but the number of sites that can be routinely monitored by agencies is limited by the availability of automated sampling equipment and staff time. For example, the U.S. Geological Survey (USGS) monitored water quality parameters in many watersheds after passage of federal water laws in the 1960s and 1970s, but was forced to abandon many sites in the late 1970s when funding for monitoring programs expired. A network of water sampling locations established within a watershed, with periodic samples obtained by local volunteers, is an especially effective means of monitoring easily observed parameters such as suspended sediment. Monitoring programs can be coordinated by appropriate regulatory agencies, which would supply sample bottles and instructions for handling and process samples. Likewise,

maximum–minimum thermometers placed throughout the watershed and checked at regular intervals by citizen's groups or individual landowners provide an indication of changes in temperature fluctuations over time. Easily measured parameters such as sediment and temperature have immediate, significant effects on aquatic ecosystems. They also provide important information about erosion and upstream riparian conditions.

Habitat Measurements—Stream morphology is an integrative measurement of overall watershed condition, and pools are very sensitive to change. Pools are 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 of a watershed 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. For example, in the Willapa Basin seasonally unemployed fisherman collect fish habitat information throughout the watershed. Training is provided by the Willapa Alliance, who also oversee and coordinate the field effort and compile and analyze the data. Funding is provided by a federal program.

Riparian Forest Surveys—Riparian forests are critical to watershed health, yet insufficient attention is paid to their condition. Riparian plots where surveyors periodically identify and count the number of trees within the boundaries, 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—Socioeconomic conditions are already well monitored, but data are seldom given for conditions within watershed boundaries. Annually based socioeconomic indices may include such factors as annual capital investment, resource exports, unemployment, high school literacy, healthy births and so forth, which provide essential information about human conditions in a larger community including a watershed (Table 26.4). 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 have largely been discontinued by public agencies, but are occasionally sponsored by citizen groups. When asked why these projects have been undertaken, many citizens continue to be unaware of the ecological functions of woody debris or to regard these functions as secondary in importance to the need to provide unimpeded fish passage (even woody debris removal diminishes fish production in the long term).

How can the educational and scientific communities maintain socioenvironmental literacy and instill a sense of stewardship among citizens? First, scientists need to explain the importance of watershed connectivity, the role of natural disturbances in maintaining productivity, the need to view watershed management in terms of large landscape units, and 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 in-

tegrated 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 facilitate increased 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.

Fundamental Principles

Watershed management is an ongoing experiment guided by fundamental principles and a common vision of the future, and 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. Recognize that watershed management demands unparalleled cooperation among citizens, industry, governmental agencies, private institutions, and academic organizations. In most situations, the complexity of information processing and the scope of socioenvironmental change exceeds the capacity of any single group to manage a watershed effectively.

2. Balance technical solutions (e.g., fish hatcheries, waste management, and so forth) to specific human-generated problems with the wide-scale maintenance of appropriate environmental components that provide similar ecological services.

3. Minimize decisions based only on conceptualization and perception; data-driven policy and management decisions need to become the standard for resolving issues.

4. Apply regulations guiding the structure and behavior of the socioenvironmental system evenly and fairly throughout the watershed. For example, basic regulations (such as riparian protection and chemical applications) should not differ across forestry, agricultural, and urban areas but should encourage citizen initiatives and landowner incentives that result in greater protection and reduced chemical applications.

5. Accept human activities as fundamental elements of the watershed along with 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 only the initial steps in achieving effective watershed management. Cultural values, social behavior, and environmental characteristics will continue to evolve. Unfortunately, a 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 implementing appropriate approaches to meet that vision.

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