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WATERSHED ANALYSIS AS A FRAMEWORK FOR IMPLEMENTING ECOSYSTEM MANAGEMENT[1]

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ABSTRACT: Implementing ecosystem approaches to land use decision making and land management requires new methods for linking science and planning. Greater integration is crucial because under ecosystem management sustainable levels of resource use are determined by coupling management objectives to landscape capabilities and capacities. Recent proposals for implementing ecosystem management employ analyses organized at a hierarchy of scales for analysis and planning. Within this hierarchy, watershed analysis provides a framework for delineating the spatial distribution and linkages between physical processes and biological communities in an appropriate physical context: the watershed. Several such methods are currently in use in the western United States, and although there is no universal procedure for either implementing watershed analysis or linking the results to planning, there are a number of essential elements. A series of questions on landscape-level ecological processes, history, condition, and response potential guide watershed analysis. Individual analysis modules are structured around answering these questions through a spatially-distributed, process-based approach. The planning framework linked to watershed analysis uses this information to either manage environmental impacts or to identify desired conditions and develop land management prescriptions to achieve these conditions. Watershed analysis offers a number of distinct advantages over contemporary environmental analyses for designing land management scenarios compatible with balancing environmental and economic objectives.
(KEY TERMS: watershed analysis; ecosystem management; watershed management; environmental planning.)

INTRODUCTION

Societal concern over the historical degradation of natural ecosystems and resources once considered inexhaustible resulted in laws intended to provide some ecological safeguards (e.g., ESA, 1973; NEPA, 1982; NFMA, 1982). Laws intended to protect species, however, were established independent of scientifically founded strategies for managing ecosystems, in spite of the dependence of individual species viability on ecosystem-scale processes. The continuing practice of managing or protecting primarily on an ownership-, site-, or species-specific basis emphasizes both short-term economic perspectives and localized consideration of environmental degradation. Hence, the integrated effects of local management decisions can be incompatible with broader-scale management objectives. Despite dramatic increases in the effort and expenditure for environmental protection over the past 20 years, the overall condition of natural ecosystems generally continues to decline. This fundamental flaw in linking land management objectives and practice set up inevitable legal confrontations pitting species survival against resource use, giving the false perception that they are incompatible. A new land management paradigm, loosely termed ecosystem management (e.g., Slocombe, 1993), seeks to reconcile this paradox by applying an ecological perspective to addressing land use and environmental degradation. Implementing ecosystem management, however, requires a framework for gathering and interpreting environmental information at a resolution, scope, and scale necessary for addressing the tradeoffs between economic and ecological considerations inherent to making land management decisions.

Ecosystem Management

Ecosystem management is founded on the principle of preserving ecosystem integrity while maintaining sustainable benefits for human populations (see

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Norton, 1992). Ecosystem management thus presupposes land use will occur, although it assumes neither the location nor intensity of any particular activity. Preserving ecosystem integrity, however, involves sustaining naturally reproducing populations of all species. Ecosystem management therefore involves a fundamental restructuring of historical practices of land use planning and decision making based on evaluating the impacts of individual projects. Several additional principles provide the basis for implementing ecosystem management. The most important of these involves tailoring land management to landscape conditions, processes and potential. This involves defining the intrinsic capabilities and limitations of different parts of the landscape to support a particular suite or style of activities. A related concept is acknowledging the variable capacity of different parts of the landscape to sustain those activities through time and the potential for some disturbances or impacts to propagate downslope and downstream. A wealth of historical examples support the thesis that ignoring the relation between land use and the intrinsic capability and capacity of the land invites dire long-term consequences for both ecosystems and human societies (e.g., Marsh, 1864; Carter and Dale, 1955; Thomas, 1956).

Tailoring land management to the landscape requires a more symbiotic relationship between science and land use planning (Leopold, 1933). At present scientific expertise is principally used to achieve, rather than define, land management objectives by altering landscape capabilities to provide desired commodity production. Under ecosystem management, science precedes planning and analyses are oriented around resources rather than potential projects. This involves expanding the role of science to include evaluating alternative management scenarios against intrinsic landscape capabilities to mold societal expectations to the landscape. Scientific methods are essential to assessing landscape capacity, often complex and interwoven with a legacy of natural and anthropogenic disturbances. Such understanding is essential for informed management decisions. Hence, planning needs to recognize the spatial and temporal scales over which natural systems operate (Odum, 1969; Caldwell, 1970). This represents a fundamental change from planning based on political or administrative units, and it requires broadening planning horizons to include multiple ownerships, land uses, and interests, a goal difficult to achieve under the current legal and regulatory system.

A variety of regional planning protocols are applied to environmental management, particularly for development and flood control issues. These analyses rarely if ever tailor land use to the landscape. Rather, they generally are oriented toward either developing plans for modifying landscape processes to better suit human desires or for identifying thresholds that trigger land use restrictions. In contrast, ecosystem management requires a proactive approach to environmental impact mitigation, an argument advanced by Leopold (1934) as the most cost-effective societal approach to managing soil erosion. This requires input management through identifying the impacts of human actions on ecological processes and systems, and redesigning land use and management to minimize these impacts [see also discussion by Montgomery (1995)]. In short, it focuses on treating causes rather than symptoms of environmental degradation. This approach requires process-oriented analyses rather than the threshold-based and blind sampling approaches used in most current watershed management and monitoring programs. Only by developing a process-oriented understanding of how a landscape works in a spatially-distributed context can we begin to develop effective input-oriented approaches at the landscape scale. While this already is done for some projects, ecosystem management provides a unified framework for implementing such an approach at larger scales.

A key element of any decision-making system that involves consideration of both economic and ecological resource management objectives is a broader landscape-scale context for developing an understanding of interacting environmental and ecological processes. Such a framework should be founded on using analyses organized around ecologically relevant units to guide planning and implementing management activities. Ecosystem management therefore must consider physical and biological interactions occurring over spatial scales ranging from individual organisms up to entire regions. This can be considered to involve analyses at four distinct spatial scales: region, province, watershed, and project (FEMAT, 1993). A region represents a broadly defined area, such as the Pacific Northwest, that encompasses several physiographic provinces (Fenneman, 1931) or ecoregions (Omernik, 1987) across multiple states. Regional-scale issues may include biodiversity (Noss, 1983), economic and social expectations, and patterns of public and private ownership. Provinces cover areas on the order of 1000s of square miles and are defined by either major drainage basins or collections of smaller basins (e.g., small coastal watersheds). Province-scale issues include: (1) impacts of large-scale water development (i.e., hydropower and agricultural water diversions); (2) historical and future urbanization and land use patterns; and (3) distributions of some threatened and endangered species. In many landscapes, watersheds covering approximately 20 to 200 square miles are practical analysis and planning units within provinces. Watershed analysis at this scale allows landscape-specific assessment of the status of and linkages between physical and biological resources and processes. At finer scales, it becomes difficult to represent relevant processes and connect upstream causes to downstream effects; at broader scales, data interpretation and assimilation become impractical. The finest scale of planning necessary for ecosystem management involves specific sites where management actions are implemented. While consideration of this full range of scales is necessary to encompass the spatial and temporal dynamics of human influences on environmental processes and resources (Preston and Bedford, 1988), analyses at these different scales could be based on modifying the basic framework developed here.

Analyses and decision making at each of these scales reflects issues, information, and constraints inherited from other levels of the hierarchy. Regional issues, for example, define a broad template against which land management prescriptions are made and decisions evaluated at the province scale, which in turn influences management decisions at the watershed scale. Each of these scales of analysis and planning are necessary for implementing ecosystem management because: (1) the distribution and environmental requirements of a number of species are not organized on a watershed basis, and thus need to be considered across levels of the analysis and planning hierarchy; and (2) the spatial context within which a watershed lies is an important factor in evaluating the ecological significance of land management alternatives. Watershed-scale analyses provide the fundamental units structuring the planning hierarchy, as watershed-specific information defines the context for individual projects and can be aggregated as needed to provide information for decision making at the province and regional scales.

Watershed-Scale Analysis

Although a number of recent initiatives and strategies focus on larger-scales and a broader scope (WFPB, 1992; FEMAT, 1993; SAT, 1993), there is not yet consensus on how to implement ecosystem management. A key element is development of a practical operational framework for integrating ecosystem management into land use decision making. Watersheds define basic, ecologically and geomorphologically relevant management units (Chorley, 1969; Likens and Bormann, 1974; Lotspeich, 1980) and watershed analysis provides a practical analytical framework for spatially-explicit, process-oriented scientific assessment that provides information relevant to guiding management decisions. Recently, watershed analysis has been adopted to implement ecosystem-oriented management on state and private (WFPB, 1992; 1993) and federal (FEMAT, 1993) lands in the Pacific Northwest. These approaches are still evolving and may differ in their management objectives; while watershed analysis provides a more complete understanding of landscape-scale processes, balancing economic and ecological priorities lies within the realm of planning. Simply put, watershed analysis is intended to provide the information required to assess such trade offs and develop land management plans for implementing policies that are consistent with meeting management objectives. Coupled to landscape-level planning processes, watershed-scale analyses can provide a framework for generating the information required to accountably assess performance toward achieving environmental objectives, in much the same manner that other systems are set up to measure and evaluate economic success.

Development of a common framework would facilitate integration of results across multiple ownership boundaries, provide a framework for balancing economic and ecological objectives, and thereby contribute toward avoiding situations where management results are inconsistent with management objectives. Here we describe the philosophy and principles that underlie watershed analysis, define the essential components and general approach, and discuss key linkages to the planning process. Recognizing that there likely will be many approaches to watershed analysis (e.g., WFPB, 1992; FEMAT, 1993; USDA, 1994), our intent is both to define a set of criteria essential to any method and to discuss advantages of and impediments to using watershed analysis to implement ecosystem management.

EVOLUTION OF WATERSHED ANALYSIS

The concept of watershed-based analysis and planning is not new (see review in Schramm, 1980), and many previous approaches to land management have incorporated one or more of the principles outlined above (Table 1). The ancient Chinese art of geomancy, for example, emphasized the interpretation of landforms as the basis for siting buildings and other human activities (Pennick, 1979). In the United States, the Organic Act of 1897 establishing the National Forest system implicitly recognized the importance of tailoring land use to landscape capability when it gave equal weight to timber harvest and securing "favorable conditions of flow" (Steen, 1976). More recent approaches have also incorporated a watershed basis for planning. In the 1930s, the National Planning Board developed river basin management schemes (e.g., Tennessee Valley Authority)

TABLE 1. Examples of Landscape-Level Analyses and Planning Incorporating Elements of Ecosystem Management.

	Tailor Decisions to Landscape Capabilities	Protect Ecosystem Integrity	Science Precedes Planning	Flexible and Iterative	Based on Ecologically Relevant Units	Considers Multiple Scales
River Basin Plans (ca 1930s)	O	O	O	O	X	O
U.S. Forest Service Unit Plans	–	O	–	O	X	O
USFS Forest Plans	–	O	–	–	O	O
Cumulative Effects Analysis	X	O	O	X	X	O
Watershed Analysis	X	O	X	X	X	X
Ecosystem Management	X	X	X	X	X	X

X = Central to approach.
– = Addressed but not central.
O = Not addressed.

and pioneered regional land use planning (Platt, 1991). A number of subsequent river basin plans developed for large transnational rivers (e.g., Mekong, Senegal, Rio de la Plata) encountered political problems that hampered implementation (Schramm, 1980). In the mid-1960s, U.S. Forest Service researchers called for watershed-based hydrological analysis to guide forest land use planning (Megahan, 1965). Unit Plans employed by the U.S. Forest Service until the mid-1970s often were defined by watershed boundaries although they did not systematically address ecological considerations in determining levels of resource extraction, which were driven by timber quotas imposed on a forest by forest basis. Forest Plans developed in response to the 1976 National Forest Management Act (NFMA, 1982) attempted to address a broader range of ecological issues, but analyses were typically limited by administrative boundaries. This evolution of approaches to land management coincided with increasing conflict over intensive resource use in the western United States.

The most direct precursors of watershed analysis methods are procedures developed over the past several decades to address the cumulative effects of land management. Many of the techniques for assessing cumulative effects were developed by land managers charged with evaluating the combined impact of multiple activities under the 1969 National Environmental Policy Act (NEPA, 1982) and subsequent Council on Environmental Quality regulations (CEQ, 1971). The need for a watershed-oriented approach to this issue (Coats and Miller, 1981) focused attention on linkages among watershed processes, biological systems, and land management (see review by Reid, 1993). Many of these approaches, however, suffered from procedural inconsistencies, inadequate technical foundations, and difficulties incorporating results into planning (Craig, 1987; FEMAT, 1993); none incorporated all of the principles underlying ecosystem management.

At this time, watershed analysis has been embraced by several processes exploring its use for implementing ecosystem management. Watershed analysis is currently applied voluntarily on forested watersheds of 50-200 km^2 in Washington (WFPB, 1992), and an expanded version is one component of a proposed framework for implementing ecosystem management on federal lands (FEMAT, 1993). Both of these approaches are still evolving, but to date 22 watersheds have been analyzed under the Washington State program. Numerous local watershed initiatives developing around the western United States also integrate some of the principles outlined above.

FRAMEWORK FOR WATERSHED ANALYSIS

Watershed analysis provides a means to resolve a number of problems that plagued previous efforts to integrate an understanding of physical and biological processes into land use planning. In the past, much of the available scientific knowledge was not applied effectively in the land management arena because: (1) landscapes were not viewed as systems, so linkages among processes and landscape elements were not addressed; (2) planning processes lacked adequate mechanisms for incorporating science directly into decision making, so new information was underutilized; (3) many planning procedures relied on simple thresholds and uniform prescriptions to deal with complex problems in highly variable landscapes; (4) information on current conditions was collected haphazardly and without a clear set of questions or hypotheses; (5) historical data and trends were largely ignored; and (6) no provisions were made to adequately test assumptions, results, or effects of management prescriptions. Watershed analysis is intended to address these shortcomings by providing a systematic procedure for characterizing the physical and biological processes active within a watershed, their spatial distribution, history, and linkages; past and current habitat and biological conditions; and the linkages between landforms, surface processes, and biological systems. The information generated in a watershed analysis guides ecosystem-oriented land use planning and development of landscape-specific management prescriptions, identifies and directs prioritization of restoration opportunities, and provides information necessary for developing efficient monitoring programs.

Watershed analysis provides a methodology for organizing analyses such that they can be both synthesized into larger regional pictures and provide context for developing site-specific designs and management expectations. This requires satisfying a number of criteria that differ from current analyses. Most importantly, this approach needs to address cause-and-effect linkages in a spatially distributed context because spatially aggregated approaches (e.g., equivalent clear cut area concept and multiple regression correlations between resource conditions and general descriptors of land use intensity) neglect the simple fact that identical actions located in different areas of a basin can have dramatically different impacts. Also, the role and significance of a particular process or resource depends not only on how big or extensive it is, but also on its location, the larger landscape within which it lies, and its relation and connections to other landscape components (e.g., Preston and Bedford, 1988). Watershed analysis also must be process oriented and hypothesis driven in order to establish cause-and-effect relations between management activity and environmental impacts. The historical legacy of past natural and anthropogenic processes and disturbance must be addressed because of the influence of past processes on current conditions and response potential. Field work and analyses are thus essential for establishing current conditions and evaluating potential hypotheses concerning past influences. Hence, watershed analysis cannot be an exclusively GIS-based exercise; neither can it be based on simple correlation between environmental indices and spatially aggregated indicators of land management. Rather, watershed analysis must rely on integrating field analyses and assessments, historical analyses, and landscape-scale models of geomorphological and ecological processes.

The framework for watershed analysis and planning consists of societal goals and desires brought to a place based on regional concerns or issues (Figure 1). The presence of the last spring chinook run in a region, for example, may constrain management options within a watershed if preservation of the run is either valued or mandated by law. Regional concerns and issues thus provide the context for developing land management prescriptions. Watershed analysis can be used to either minimize the impact of land management or to identify desired conditions and develop land management plans to achieve those conditions. Under either approach, watershed analysis should collect the evidence and present the logic underlying land management decisions.

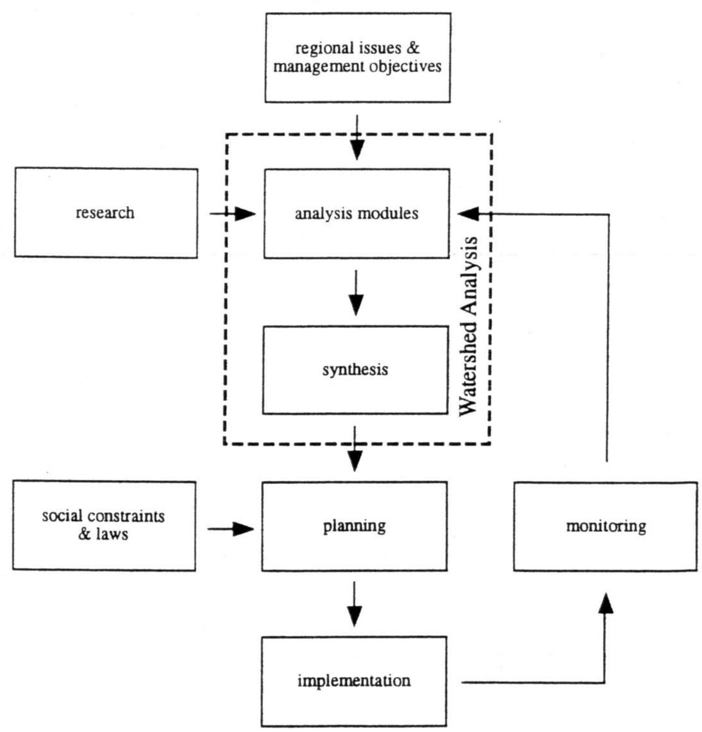


Figure 1. Schematic Illustration of the Context for Watershed Analysis.

The guiding philosophy behind watershed analysis is that although a landscape and its ecosystems are complex and impossible to understand or characterize completely, there is enough pattern to the linkages within and between physical and ecological systems that we can develop reasonable models of how they interact. Watershed analysis provides a limited yet reasonably comprehensive assessment of these linkages and processes. The underlying assumption is that informed land management decisions require high-quality information focused on key processes and linkages that create and shape ecosytems. Thus, one of the most important aspects of watershed analysis is that it is limited in scope; we cannot hope to appreciate, let alone understand, the full detail of system interactions. Hence, output-oriented management or monitoring is necessary to supplement the primary emphasis on input-oriented management and to assess whether management plans are achieving management objectives (see also Montgomery, 1995).

While this limited scope enables watershed analysis to contribute to land use planning, it also raises the possibility that key attributes or processes influencing an ecosystem may be neglected. Consequently, watershed analysis methods and procedures must be both flexible and designed to be updated and revised as new information or understanding of ecosystem processes is either developed or becomes available. The basic framework of watershed analysis (Figure 1) is fixed, but the structure of each component must be periodically revised and updated in order to use watershed analysis to implement ecosystem management. Watershed analysis can support any decision-making priorities; it is intended only to generate the information required to make informed choices about potential land management impacts in a spatially-distributed context. Decision-making inherently involves incorporation and prioritization of many other societal wants and needs.

We describe a structure and method of watershed analysis first developed in Washington by a multi-stakeholder group and adopted by the Washington Forest Practices Board (1992), and then modified by other organizations to fit different management objectives. Watershed analysis consists of a series of analysis modules that guide resource specialists through logical procedures for assessing the physical and biological systems within a watershed. While the general framework and structure of these modules apply to all landscapes, the analysis methods should reflect the geomorphic and biological processes operating within a specific landscape. Products of the analysis modules define conditions, trends, and potential conditions for physical and biological resources within the watershed. Landscape-specific information on geomorphic and biological systems generated through analysis modules is then synthesized into a model of landscape-scale ecological functions and interactions. This synthesis guides identification of potential conditions and trade-offs between management activity and ecological conditions. Planning uses the information generated by a watershed analysis together with social and institutional objectives and constraints to define desired resource conditions and develops plans to achieve these goals. A plan is then selected and implemented and the results monitored and compared with predicted progress toward achieving desired conditions.

STRUCTURE OF WATERSHED ANALYSIS

Watershed analysis itself is structured around a series of questions which, if answered, provide a model of landscape and ecosystem function, disturbance history, and current and potential future conditions (WFPA, 1992; 1993). A question-driven approach is essential for developing landscape-specific, process-based approaches to implementing input management because no simple rigid procedure or analysis will be appropriate in all landscapes or at all locations within a watershed. This approach is similar to a proposed framework for addressing problems of landscape design (Steinitz, 1990). Answering these questions requires the talents and perspectives of an interdisciplinary team of physical and biological scientists and planners. The procedure generates a trail of logic that connects analysis of landscape processes to subsequent management activity.

A critical issue is the level of analysis and resolution needed to answer each question. There are no *a priori* grounds to determine this; it will always depend on the level of confidence desired for the analysis, which in turn reflects acceptable risk. The question-driven approach is meant to guide and focus analyses by using objective, analytical methods. There can be no cookbook approach to watershed analysis because landscapes are inherently variable and simple indices are not always relevant. We need both solid conceptual bases and models within which to work and highly trained, independent thinkers to work within these guidelines. Many other professions (e.g., medicine and engineering) face similar dilemmas, and a common method for addressing this issue is to develop standards for state-of-the-art practices that serve as reference points for judging individual analyses. While this implies some system of peer review and professional oversight, the various approaches to developing standards for implementing watershed analysis are beyond the scope of this paper.

How Does This Landscape Work?

Answering this question requires analysts to develop a model for the relations among landforms, physical processes, and biological factors governing the ecosystems developed on a landscape. This approach promotes a system-level view of the dominant processes and linkages controlling and influencing ecosystem structure and dynamics. Realistic assessment of resource conditions or probable responses to management activity requires understanding of the basic environmental template upon which biological systems develop (Southwood, 1977). We therefore need to identify those parts of the landscape dominated by different environmental processes or disturbance regimes. The disturbance regime defines the type of disturbances (i.e., fire, wind, flood, or landslide) and their frequency, spatial extent, and intensity (Sousa, 1984; Swanson *et al.,* 1993). We also need to understand the spatial linkages among landscape components because some processes or disturbances propagate through a landscape. Landslides originating in steep hillside hollows, for example, can become debris flows that scour steep downslope channels and deliver sediment to lower-gradient channels (e.g., Costa, 1984; Benda, 1990). Ultimately, information on the spatial and temporal distribution of a variety of processes is necessary to identify sensitive or critical areas of the landscape.

What Has Happened in the Past?

Assessing the disturbance history of a landscape provides a context within which to interpret current conditions and evaluate potential disturbance patterns. One of the precepts of ecosystem management is that ecosystem stress increases with deviation from the disturbance regime under which the ecosystem evolved (Sousa, 1984; Swanson *et al.,* 1993). This implies that knowledge of historical and pre-historical conditions is essential for evaluating land management options. Another motivation for examining disturbance history is that it provides the information necessary to infer causes of current conditions. It would be difficult to understand the current condition of some stream channels, for example, without knowing the history of log drives, salvage, and stream cleanup operations conducted during the past century (e.g., Sedell and Froggatt, 1984; Sedell *et al.,* 1991).

What are Current Conditions?

The current condition of a watershed provides a snapshot in time of its state, which can be thought of as a collection of attributes that define key system properties (Brooks and Grant, 1992). This includes, for example, the spatial distribution of vegetation age and community composition, current land use patterns, species distributions, and physical characteristics such as channel pattern and substrate size. While this information conceivably could be collected at any level of detail, its usefulness depends on how well it describes the landscape in terms relevant to developing or testing models of landscape function. Detailed species or habitat inventories, for example, are likely to be most useful if synthesized into habitat associations linked to vegetation or landforms. To be useful, however, information collected must be either used in the analysis or provide baseline data for ongoing monitoring.

What are Trends in Watershed Condition?

Comparing historical and current conditions provides the primary means of assessing changes in landscapes and ecosystems. These trends can be expressed in terms of temporal changes in some measure of either watershed or biologic condition (e.g., stand structure or composition, number of owls, width of riparian openings), or landscape processes (e.g., landslide rates, streamflow variability). Evaluating the role of human activities in these changes is accomplished through categorizing trends by their likely causal mechanisms (e.g., distinguishing among rates of landsliding from roads, pristine forests, and clear cuts).

How Sensitive is the Ecosystem to Future Land Management?

Answering this question is crucial for assessing land management options. A synthesis of information on landscape form, function, and history, as well as current watershed and ecosystem conditions provides the basis for identifying areas of the landscape and components of the ecosystem sensitive to future changes. It also requires identifying potential responses to land management activities. This may involve extrapolating current trends over longer time periods and incorporating other factors (e.g., climate) that may change over the same time period (Swanson *et al.,* 1992). Watershed analysis defines the range of potential future conditions in a watershed, which enables identifying desired future conditions and the steps necessary to attain them.

HOW DO YOU DO IT?

The complex problem of analyzing a watershed requires a relatively simple model of watershed processes and organization. A useful model is based on the fundamental differences in form, function, and ecosystem processes between hillslopes and channels. At this general level, a distinction can be drawn between terrestrial and riparian vegetation and terrestrial and aquatic wildlife that are associated with hillslopes and channels, respectively. Watershed analysis is organized around a series of process/condition modules (WFPB, 1992) that reflect this basic framework (Table 2). The impacts associated with roads can be examined in an independent module because they include effects on erosional and hydrological processes that affect both channels and hillslopes.

While analysis modules address different processes and resources, they all follow the same basic structure and flow of logic. This sequence parallels the flow of logic for the analysis as a whole (Figure 2). In each component, critical issues are identified and the scope of inquiry is focused on answering a series of questions; the watershed is stratified into landscape units hypothesized to be dominated by different processes; and field observations and data are collected to document the history and condition of resources within the watershed (WFPB, 1992). This information is used to revise the classification into landscape units that reflect both dominant processes and conditions, which are then used to interpret sensitivity to proposed management activities. Finally, maps of landscape units defined from each of the modules are synthesized to generate a unified landscape stratification that provides the basis for developing management prescriptions specific to individual landscape units.

Define Critical Issues

At the outset of analysis for any particular watershed, there is likely to be a set of critical issues recognized as of primary importance (e.g., declining salmon stocks or grazing in riparian zones). While it is essential to address these issues during the analysis, it is imperative that they do not define the entire scope of the analysis. Otherwise, issues not initially recognized as important may be overlooked. Critical issues help determine priorities in interpreting sensitivity and can override other considerations in the development of management prescriptions during subsequent planning.

Landscape stratification

Landscape stratification provides a means of organizing the landscape into discrete structural and functional units. Each analysis module involves an initial stratification that helps formulate hypotheses about landscape processes and serves to guide subsequent data collection. While no single classification scheme is applicable across modules and from one landscape to another, there are certain scales and attributes that provide a logical foundation for organizing the stratification of each module (Table 2). A number of classification systems for some landscape elements have been proposed; there are several channel classification schemes, for example, that could provide an initial stratification (e.g., Rosgen, 1985; Paustian *et al.*, 1992; Montgomery and Buffington, 1993; Whiting and Bradley, 1993). Other systems exist for classifying vegetation associations (e.g., Franklin and Dyrness, 1986). Developing such stratifications is probably best pursued on a regional basis, since they provide a set of default hypotheses or expectations against which to evaluate conditions examined in the field. This provides a guide for developing analyses and allows flexibility for analyzing different land forms and contexts within a watershed. Imposing an initial landscape stratification also precludes applying uniform assumptions about environmental conditions and processes throughout a landscape.

Data Collection

Collection of historical and contemporary data allows testing and refining hypotheses concerning geomorphological and ecological function embedded in the initial landscape stratification. Such data also defines trends in watershed conditions and allows interpretation of current conditions within the context of historical disturbance regimes. Historical analyses often are limited by a paucity of available data; in many cases the available information is limited to aerial photographs, land management histories, streamflow records, and previous inventories and monitoring data. Although opportunities for historical analyses may be fairly restricted, even limited information on historical conditions can be extremely valuable for interpreting the influence of past land management on disturbance regimes and ecological systems.

The potential to generate information on current conditions, on the other hand, is virtually unlimited. Data collected in the analysis modules therefore must be directed towards assessment of conditions and landscape characteristics that are sensitive to changes in the dominant ecological processes or disturbance regimes. These include characterization of organism and habitat distributions and conditions, as well as linkages among processes (e.g., sediment supply to a channel, hydrologic connection of road and channel networks).

TABLE 2. Examples of Steps in Watershed Analysis in Relation to Analysis Modules.

	Hillslopes			Vegetation		Wildlife		
	Mass Movements and Surface Erosion	**Hydrology**	**Channels**	**Terrestrial**	**Riparian**	**Terrestrial**	**Aquatic (fish)**	**Roads**
Stratification	• Geology • Soils • Slope • Drainage area • Geometry (convergent, divergent, planar) • Stability models	• Dominant hydrologic process (rain, snow,-rain-on-snow) based on: • Elevation • Aspect • Soil depth/water holding capacity • Bedrock conductivity	• Valley segment types • Reach types • Gradient/ confinement	• Geoclimatic zone • Elevation	• Dominant disturbance regimes: • Debris flow • Flooding • Channel migration; evulsion • Snow avalanche	• Habitat associations (based on vegetation, other)	• Habitat associations • Stream size • Stream gradient • Reach type	• Road location (ridge, midslope, valley) • Road type (paved, gravel, skid) • Road age
Data Collection: Historical	• Landslide/debris flow inventory by classification strata plus land use (aerial photos) • Sediment production and delivery rates to channels	Stream flow changes (historical stream gage records) in relation to land use, other strata	Inventory of channel changes through time (aerial photos)	• Fire history • Blowdown history • Vegetation pattern changes over time including land use (aerial photos)	Riparian canopy condition changes with time (aerial photo)	Inventory of habitat changes through time (aerial photos) Historical population census data	Inventory of habitat changes through time (aerial photos; old field surveys) Historical population census data	Historical pattern and rates of road development through time
Data Collection: Current	Inventory/sampling of current processes (gullies, surface erosion, etc.); field estimates of current sediment production	Location of channel heads; springs, seeps	Assessment of channel condition and morphology	• Age/seral stage • Species composition • Structure (stand density)	• Age/seral stage • Species composition • Structure (open, closed canopy)	• Current census data • Current habitat condition and distribution	• Current census data • Current habitat condition and distribution	• Road condition • Percent road length integrated with stream network • Field estimate of road sediment production
Reclassification/ Map Unit Delineation	Mass movement and erosion hazard map based on initial stratification, historical and current condition	Potential for contributing to high and low flows based on stratification, landuse history, historical data	Map of potential for channel change by reach type for changes in land use, hydrology, mass movement potential	Map of potential vegetation pattern and structure based on hillslope disturbance regime, land use history	Map of potential riparian vegetation pattern based on hillslope and riparian disturbance regimes, land use, channel change potential	Map of habitat potential based on vegetation, historical use patterns, and current conditions	Map of potential habitat utilization, based on riparian vegetation, channel conditions, and historical use patterns	Map of road/ channel network integration and extension

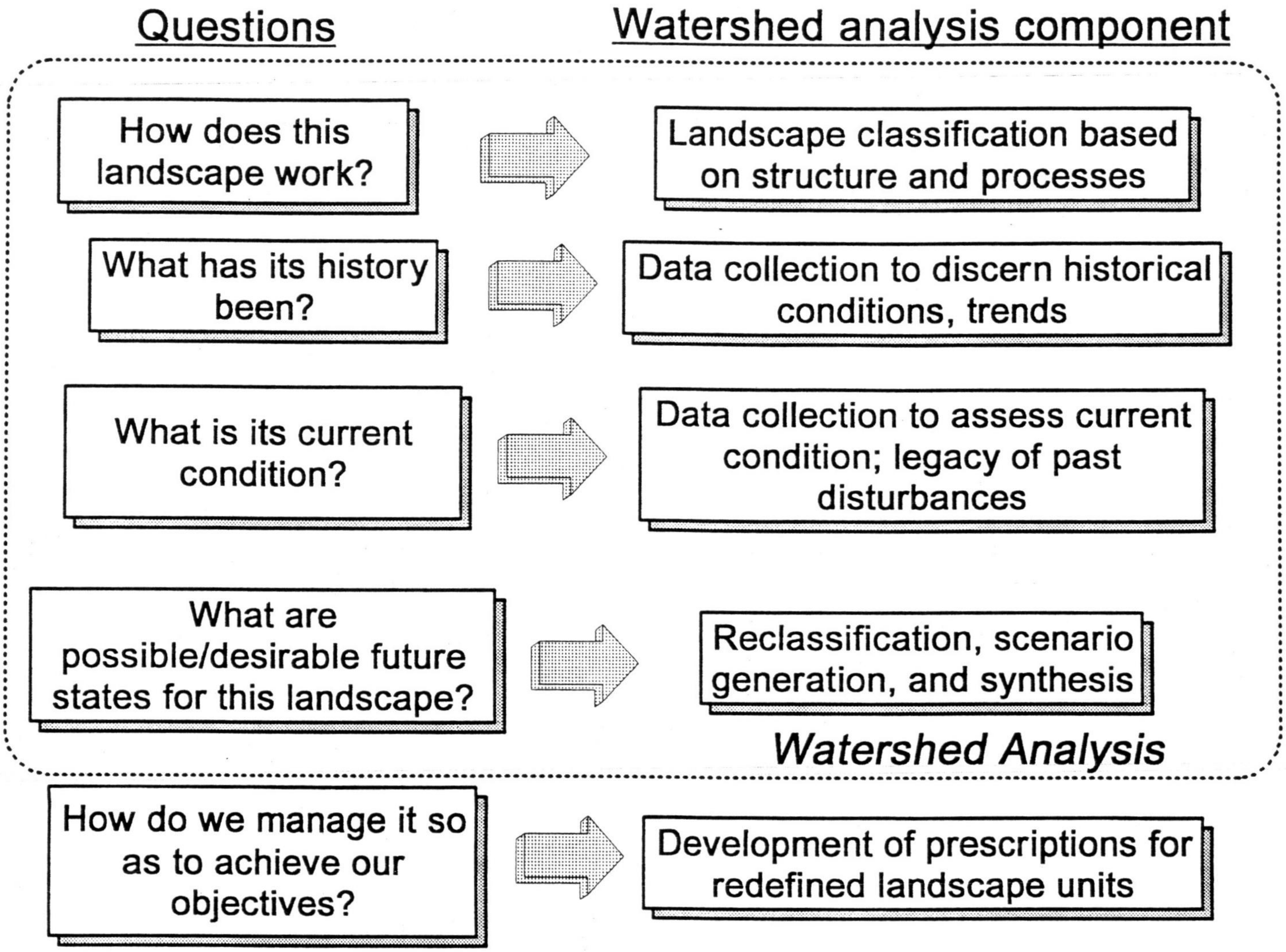


Figure 2. Linkage Between Overriding Questions and Analysis Procedures Conducted Within Each Module.

Analysis of the current state or condition of a landscape should allow analysts to answer critical questions with specific information as follows: What are the dominant disturbance regimes in this landscape? How are they distributed spatially? How frequently do they occur and what impacts do they have on ecosystems? What are trends in hillslope and channel conditions, and how tightly coupled are these trends to each other and land management activity within the basin? How are wood, water, and sediment delivered to and routed through the stream channels? How are terrestrial and aquatic species distributed through the watershed, and what are the dominant controls on their distribution and abundance? Such information allows development of a watershed-specific model both for the processes creating, modifying, and destroying habitat and for the past, current, and potential conditions of the biological systems inhabiting the watershed.

Landscape Unit Delineation

A primary product of each analysis module is delineation of landscape units defining areas within a watershed that are dominated by different processes, history, conditions, and sensitivities (i.e., response potential). Landscape unit boundaries can differ among analysis modules because the factors and processes examined in each analysis module differ. Additionally, landscape units may be organized around individual sub-basins within the larger watershed. Landscape units developed in the channel module might include: (1) debris-flow dominated headwater channels in portions of the watershed without evidence of recent disturbance; (2) headwater channels disturbed by landsliding; (3) low-gradient channels with abundant large woody debris and little evidence of historical change; and (4) low-gradient channels with evidence of historical channel widening (Figure 3A). Landscape units defined in the mass wasting module may delineate, for example, areas where: (1) shallow landsliding is a major geomorphic process but there is little evidence for historical changes in landslide frequency; (2) widespread landsliding followed road construction and timber harvest; (3) deep-seated landsliding is a major process; and (4) surface and gully erosion are the major processes potentially influenced management (Figure 3B). A map defining dominant disturbance regimes for vegetation may include units where fire, windstorms, debris flows, floods, or snow avalanches, each with different return periods, are the primary controls on stand structure and age (Figure 3C). The information generated at finer scales is tied to specific places and will be used in subsequent syntheses; the unit delineation maps simply provide the spatial context for addressing management options at scales larger than individual projects.

The information generated during these analyses provides a process- and landscape-specific framework for assessing the capacity of a landscape to sustain a particular style of land use. Linkages and relations among landscape attributes (e.g., hillslopes, channels, and fish communities), however, need to be synthesized from the information gathered by the analysis modules.

Synthesis

Synthesis is a phase of watershed analysis during which results from the analysis modules are combined into a watershed-level assessment of conditions and linkages among physical and biological resources (WFPB, 1993). Process linkages between hillslopes and channels, for example, are examined and related to the condition and history of other resources. Hack and Goodlett's (1960) classic paper on the relation between geomorphology and forest ecology provides a superb example of such a synthesis. This exercise may identify further information needs or reveal previously unrecognized relationships. Based on this synthesis, the watershed is reclassified into a final set of landscape units. These revised units serve as the basis for developing management prescriptions, identifying both potential and desired conditions, and developing monitoring programs.

An example of this process involves reorganization and generalization of landscape units (Figure 4A). In the example, we distinguish between channels and associated riparian zones that have and have not been recently disturbed. Similarly, lower-gradient areas of the watershed with little evidence for historical impacts on channel conditions are combined into a single landscape unit, as are steeper areas with more frequent fires. A data-rich narrative that is developed for each of the final landscape units should describe both the basis for identification of the unit and an assessment of its potential response to different types of land management. This information provides the basis for interpreting potential future conditions within each landscape unit and developing an assessment of the potential trade-offs between management opportunities and potential future conditions.

LINKING WATERSHED ANALYSIS TO PLANNING

Watershed analysis produces information, knowledge, and understanding necessary for scientific interpretation to support informed decision-making, but it is not equivalent to making management decisions. Determining the activity appropriate for a watershed rests on weighing potential future conditions against planning objectives, legal mandates, and management constraints. Watershed analysis modules do not determine which management options should be implemented; rather, they are designed to provide the information necessary to make an informed choice. Planning is the forum within which management options are identified and developed based on coupling knowledge with objectives.

Successfully implementing ecosystem or watershed management as a means for preserving ecosystem integrity requires recognizing and considering not only physical and biological processes but also the social context within which decisions will be made and managed [see Lee (1992), Ludwig (1993), and Stern (1993) for further discussion]. This involves both local contexts and larger regional and global contexts that influence decision making [see also Blaikie (1985) and Knuth and Nielsen (1991)]. While this paper does not focus on these issues, a key to successfully bridging watershed analysis and planning involves assuring public participation and/or input in both analysis and subsequent decision making. This should foster an atmosphere of cooperation but will not guarantee conflict resolution, especially among parties with fundamentally incompatible objectives. Nonetheless, watershed analysis provides a manageable and logical framework for organizing stakeholder input and coupling local public input with larger-scale interests and issues. Involvement of all interested

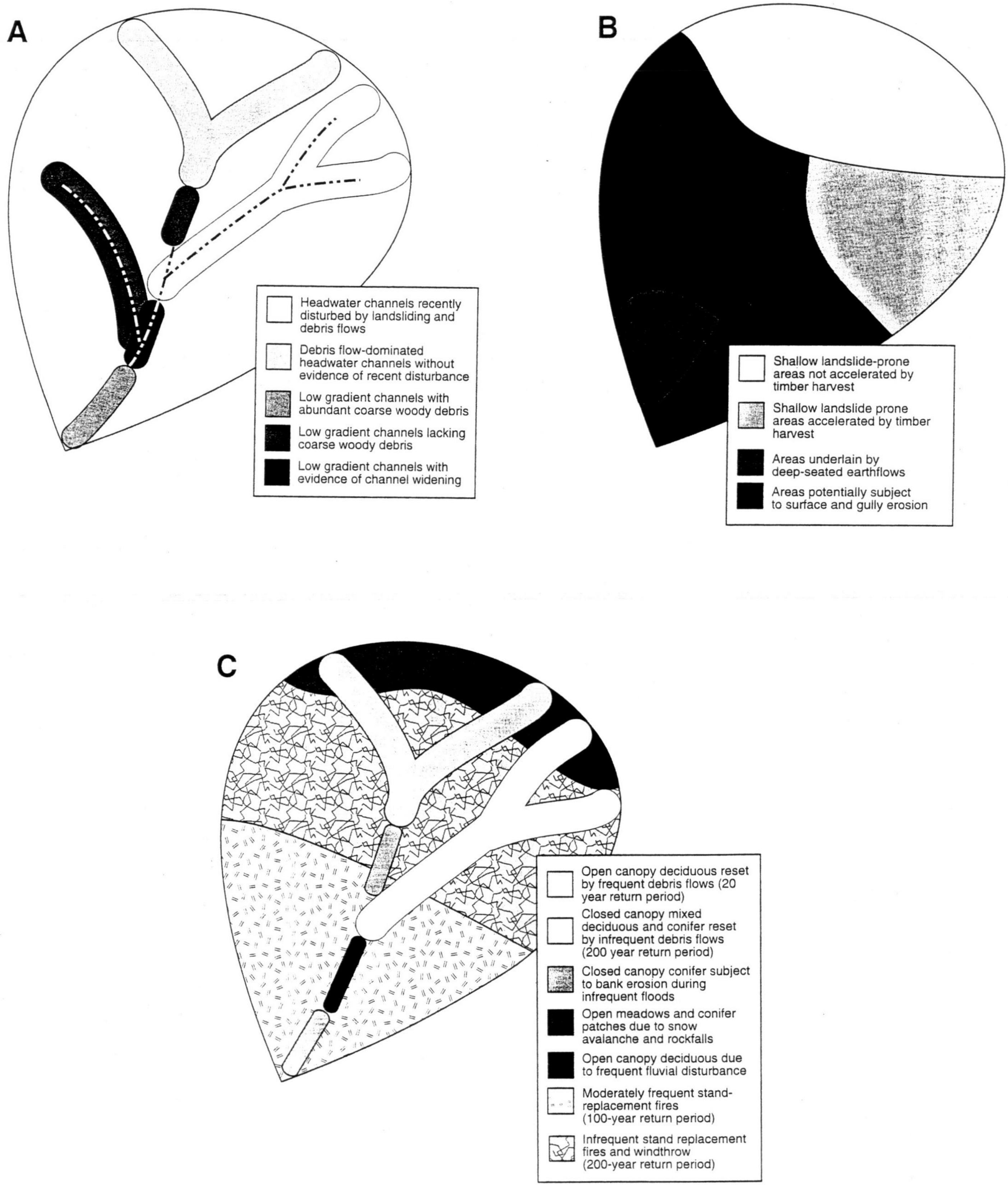
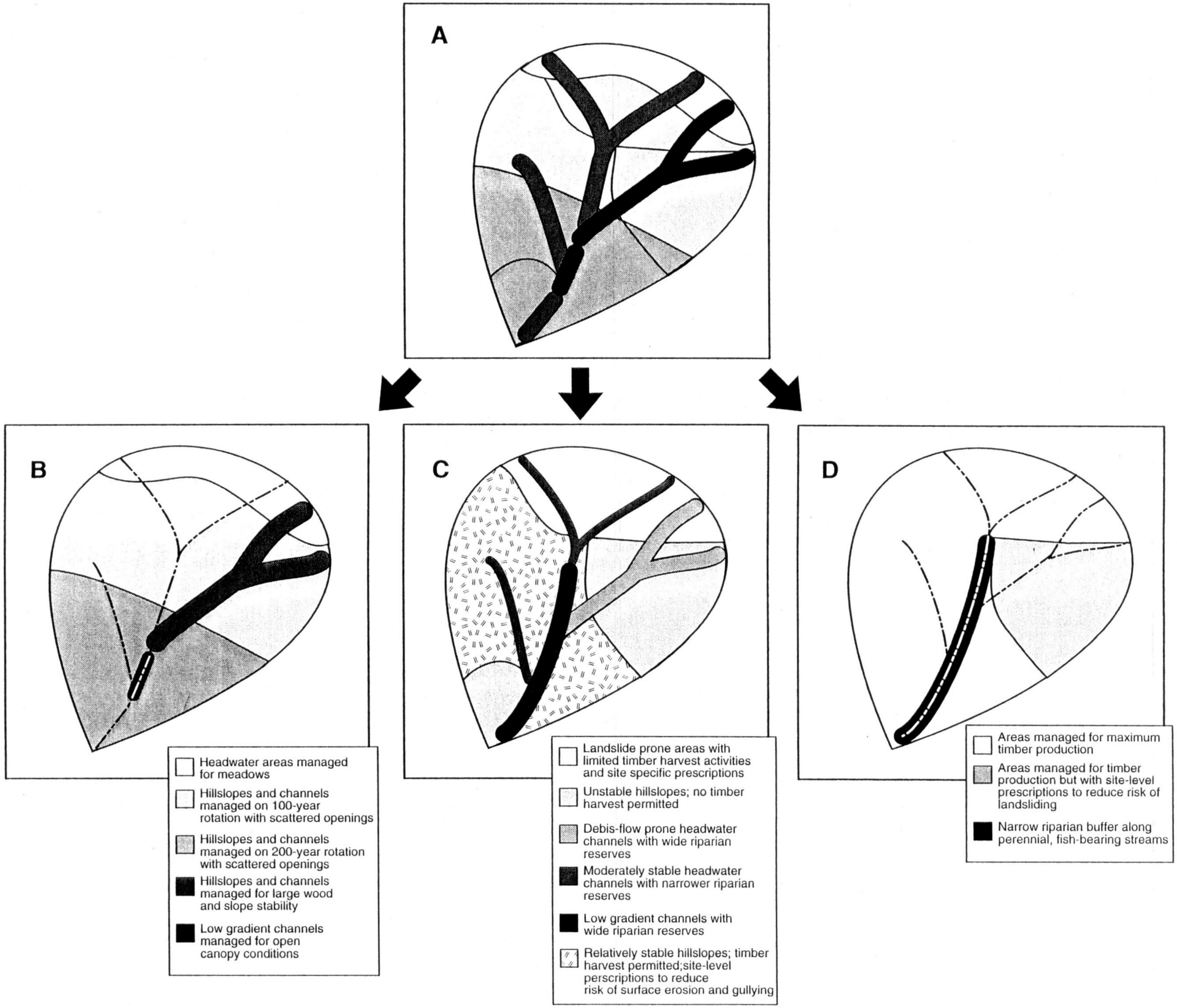


Figure 3. Hypothetical Example of Landscape Units Developed in the (A) Channel, (B) Mass Wasting/Surface Erosion, and (C) Vegetation Disturbance Modules.


A
B
C
D
Headwater areas managed for meadows
Hillslopes and channels managed on 100-year rotation with scattered openings
Hillslopes and channels managed on 200-year rotation with scattered openings
Hillslopes and channels managed for large wood and slope stability
Low gradient channels managed for open canopy conditions
Landslide prone areas with limited timber harvest activities and site specific prescriptions
Unstable hillslopes; no timber harvest permitted
Debis-flow prone headwater channels with wide riparian reserves
Moderately stable headwater channels with narrower riparian reserves
Low gradient channels with wide riparian reserves
Relatively stable hillslopes; timber harvest permitted;site-level perscriptions to reduce risk of surface erosion and gullying
Areas managed for maximum timber production
Areas managed for timber production but with site-level prescriptions to reduce risk of landsliding
Narrow riparian buffer along perennial, fish-bearing streams

parties in analysis and decision making should foster developing reasonable management scenarios.

Further reclassification and definition of landscape units can occur at this phase depending on management objectives (Figure 4B-D). For example, if a decision is made that management objectives can be best achieved by closely matching the spatial extent, frequency, and intensity of management-related disturbances with those interpreted to have occurred prehistorically, then incorporating distinctions between landscape blocks with varying fire frequencies and intensities is critical to developing management prescriptions (Figure 4B). Under this scenario, hillslope disturbance regimes determine the character of vegetation management within riparian zones, except where channel disturbance processes dominate. Alternatively, if protection of aquatic resources is the primary goal, then an extensive network of riparian reserves whose lengths and widths are keyed to dominant channel processes can be developed (Figure 4C). In this scenario, activities on potentially unstable lands are restricted. Where maximizing timber harvest is the primary objective, riparian buffers and potentially unstable areas may be of more limited extent (Figure 4D). Of course, these end-member cases may be hybridized to reflect mixed management objectives.

The distinctions between science and policy, on the one hand, and analysis and planning, on the other, are crucial: land owners and the public provide societal objectives, scientists provide knowledge and understanding of the system under consideration, and planners decide how to balance social objectives and constraints against intrinsic landscape capabilities. Development of an ecosystem-oriented land management strategy should involve close interaction between managers, planners, and analysts to ensure that (1) the analysis is relevant to planning, (2) desired conditions are feasible, and (3) proposed management activities are consistent with attaining those conditions. An effective watershed analysis therefore should identify: (1) current conditions, (2) feasible future conditions, (3) strategies to achieve desired conditions, and (4) methods or criteria by which to assess progress toward those objectives. Previous river basin management schemes generally lacked a framework for generating such information at a resolution and quality sufficient for implementing Ecosystem Management.

A key component of linking watershed analysis and planning is involving both resource analysts and managers in developing management prescriptions based on a watershed analysis. While managers are ultimately accountable for the consequences of management activity, involvement of resource analysts in the prescription process serves two important functions: (1) it ensures direct translation of analysis results and uncertainty into the planning process, and (2) it ensures that proposed activity inconsistent with some management objectives (e.g., habitat protection) is pursued only as part of a clear and explicit choice by land managers. It is crucial to the successful implementation of ecosystem-oriented land management that managers be held directly accountable for the consequences of management activity, especially for impacts resulting from prescriptions that deviate from those developed in concert with resource specialists. This is especially important since ecosystem management is intended to be adaptive and flexible, rather than relying on rigid standards and guidelines. Given both this flexibility and the conflicting interests that land managers often are forced to either reconcile or prioritize (whether explicitly or implicitly), it is important that effective feedback mechanisms are developed as part of ecosystem management.

MONITORING

Monitoring programs provide information needed to update and revise management decisions and prescriptions. While development of effective monitoring programs is an important assumption underlying the use of watershed analysis to implement ecosystem management, most current monitoring programs are inadequate for one or more of a variety of reasons. A number of workers provide lucid descriptions of problems associated with developing effective monitoring programs (e.g., Messer *et al.*, 1991; MacDonald *et al.*, 1991; Rose and Smith, 1992; Canter, 1993; Davis, 1993; MacDonald and Smart, 1993; Stout, 1993). Common shortcomings involve failure to meet one or more of the following criteria that an effective monitoring program be (1) hypothesis-driven with clearly defined objectives; (2) based on sensitive indicators of change; (3) based on mechanistic or causal relations between observed change and suspected disturbance; and have (4) a sampling strategy appropriate for detecting changes; (5) a format and framework for organizing, analyzing, storing, and retrieving monitoring data; and (6) a procedure for incorporating monitoring results into future decision making. While a comprehensive discussion of the objectives and potential problems of monitoring programs is beyond the scope of this paper, any watershed analysis procedure must develop the landscape-specific questions and information necessary to design an effective monitoring program. Such information includes an understanding of the spatial and temporal distribution of geomorphic processes and the past and potential biological response to natural or anthropogenic disturbance.

RESTORATION

The information on biological and physical resource conditions generated through watershed analysis should provide for identification of existing high-quality habitat and areas where restoration efforts may be efficiently and effectively pursued (e.g., Frissell *et al.*, 1993; Beechie *et al.*, 1994). Prioritization of restoration activities, however, also must account for the probability of beneficial response to potential actions. While acknowledged low-risk behavioral modifications (e.g., limiting timber harvest and grazing access in riparian zones) need not be delayed until completion of a watershed analysis, prioritization and implementation of some restoration activities should be based on the results of watershed analyses. Opportunities for beneficial modification of road drainage or even removal of problem roads and culverts can be identified readily because such methods have been tested and successfully implemented (e.g., Harr and Nichols, 1993). Other restoration strategies, such as anchoring logs in stream channels, are not always successful (Frissell and Nawa, 1992) and need to be carefully planned using information of the kind generated via watershed analysis.

ADVANTAGES OF WATERSHED ANALYSIS FOR IMPLEMENTING ECOSYSTEM MANAGEMENT

Incorporation of watershed analysis into land use planning offers at least five distinct advantages over more traditional approaches to land use decision making:

1. Incorporating scientific input at the front end of the planning process can help avoid crisis management through more effective and complete use of such information in decision-making. Watershed analysis provides a framework within which to explicitly address the ecological impacts of land management decisions. This should generate the structure necessary to avoid policies inconsistent with resource-management objectives.

2. Incorporating available scientific information and theories should decrease the probability of unanticipated conflicts arising from real or perceived incompatibilities between management activity and resource objectives or laws. Decisions are likely to be more defensible if potential impacts are realistically addressed based on current knowledge. Involvement of all interested parties during the watershed analysis process also provides a more productive forum for addressing basic disputes about watershed conditions and processes.

3. By synthesizing available data on landscape history, condition, and potential future conditions, watershed analysis helps focus land use disputes on policy and prescriptions. While ecosystem response may be dauntingly complex, adversaries may be compelled to agree on basic data, thus narrowing the scope of potential differences.

4. Watershed analysis provides a framework for incorporating interdisciplinary, inter-agency, and multi-owner considerations and input necessary to either prevent ecosystem deterioration or restore degraded areas. Present planning procedures often provide little opportunity for either interdisciplinary (as opposed to multi-disciplinary) or holistic assessments of landscape conditions and potential management options.

5. Provides a public and accountable assessment of the degree to which societal expectations are met by land managers.

While there are other advantages to incorporating watershed analysis into land use planning, these key points illustrate how it offers an attractive alternative to adversarial procedures for addressing the potential impacts of land use. The fundamental philosophy behind watershed analysis is that better information leads to better decisions, an assumption that still may fall victim to political pressures (Ludwig *et al.*, 1993).

IMPEDIMENTS

The primary impediments to using watershed analysis to implement ecosystem management are rooted in managerial and political commitment. Managerial impediments center around predicating planning on the analysis. The information generated by watershed analysis has to inform the planning process in order to justify the cost and effort. This requires significant long-term institutional commitment of both people and financial resources because the resolution of the methods employed in watershed analysis needs to be tailored to the questions to be addressed, rather than to take advantage of existing methods. Also, implementation of watershed analysis relies on the judgment of highly-trained resource specialists; it cannot be done without the proper background and training. Low-resolution analyses conducted by untrained personnel will compromise using watershed analysis for implementing ecosystem management. It is essential for land managers to have clearly defined objectives and priorities in order to use the information generated via watershed analysis for resolving potential conflicts between competing interests and goals. Recognizing that different organizations are likely to have different priorities, clearly defined objectives and priorities also facilitate linking and evaluating landscape management efforts across jurisdictional and ownership boundaries. Management decisions still may not be consistent with meeting land management objectives, since better information does not always lead to better decisions. Hence, failure to provide accountability for decision makers could undermine ecosystem management.

Political considerations may compromise implementation of ecosystem management. Imposition of insufficient time for conducting analyses, for example, will lead to low-resolution results inadequate for informing planning. Political directives may further undermine management objectives when such directives exceed the capacity of the natural system. Congressionally mandated harvest levels in the 1970s and 1980s, for example, proved incompatible with the multiple use objectives of the U.S. Forest Service. Moreover, ecological protection measures are especially vulnerable when the potential for short-term profit is high (Ludwig *et al.*, 1993). Hence, the degree to which ecosystem management will succeed at reversing historical trends of ecosystem degradation lies in the political process.

Overcoming these potential impediments to implementing ecosystem management requires broad societal support for and adjustment to the potential consequences for both local and regional economies. In short, society must redefine its expectations and objectives for land management if an ecosystem-oriented approach is to be successful at sustaining both ecological and socioeconomic values. If we choose to pursue a more sustainable course of resource use and management, then we must accept constraints on land management.

CONCLUSIONS

Watershed analysis provides a framework for implementing the new paradigm of ecosystem management in land use planning and management. The approach embodied in watershed analysis is the logical outgrowth of previous methods for land use planning that have evolved from neglecting environmental impacts, to site-, species-, or process-specific analyses, to arguments for holistic assessments of ecosystem-level impacts of land management. Watershed analysis is intended to guide simplification of the history, state, and linkages among complex physical and biological systems into a manageable approach to generating information necessary for well-informed natural resource decision making. While management options adopted by any particular agency or ownership on the basis of a watershed analysis will reflect their primary mission, watershed analysis provides a framework for implementing land management based on a realistic assessment of potential ecological consequences. Although watershed analysis should improve decision making, competing interests still must be reconciled or prioritized. Adoption of watershed analysis as a means to implement ecosystem management should help to bring both visibility and accountability to land management decision making.

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