Desirable functional processes: A conceptual approach for evaluating ecological condition

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Abstract.-Determining what "desired future condition" actually means has been viewed as a moving target approach for developing ecosystem management plans. The difficulty arises from trying to define what the desired condition are for any given site. In addition, definitions may be plagued with inconsistencies, contention and argument, indeterminate time frames and less than the best knowledge available. Herein, we propose a conceptual approach called "Desirable Functional Processes," or DFP, for evaluating the ecological condition of an ecosystem or parts thereof. It is founded on the premise that ecosystems and their components display varied degrees of functionality. It is based on the degree to which one can observe the interaction of ongoing processes involving the vegetation, soils, and hydrological components that determine the functionality of the system. Hence, an ecosystem or its components are considered functional if the processes observed are those that move the system to a higher state of dynamic equilibrium, as opposed to a state that is dysfunctional and demonstrates a trend towards system degradation. The identification of processes and their functional status requires a multidisciplinary approach, wherein most elements of the environment are examined to determine functioning condition. Examples using a watershed approach are used to illustrate the concept and its framework. As a concept, it recognizes the public's needs in the decision-making process, and as such provides a mechanism by which the resource managers can communicate environmental concerns in a non-argumentative manner.

INTRODUCTION

A resource manager's decision of what he wants ultimately determines what he gets. This view of reality catalyzes current thought about how to manage our natural resources most effectively. The USDA Forest Service has adopted this concept as policy and as a framework to guide resource management of our national forests and grasslands (Robertson 1992, Kaufmann et al. 1994). Ecosystem science provides the foundation of ecosystem management, which connects the basic and applied sciences of the natural world with human factors (Pastor 1995). Resource managers employ tools such as the Integrated Resource Management Model to reach consensus about what an ecological site/unit should look like, be managed for, or to be the desired future condition (USDA Forest Service 1993). As a management concept, desired future condition (DFC) describes the character of the ecological unit for a given time and space. The description reflects environmental criteria deemed desirable by resource managers and the public.

DFC is more described than defined because the specific context is arguable. Different resource

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managers often hold different views about the resources for which an ecological unit should be managed and about how the unit should look. Consequently, traditional management objectives become a moving target, which is fundamentally unachievable because ecosystems are constantly changing. Therefore, predicting an outcome of management activity is difficult.

Another problem with DFC is the time period needed to achieve it. Some DFC's are achievable in months or years. However, others are probably beyond the time frame of land management plans, and well beyond the careers and lifetimes of the managers. DFC's of short term are realizable but those beyond 25 years are subject to change as society's needs or desires change. Hence, the latter are apt to become moving targets.

We propose an alternative context for the concept of desired future condition. Our context shifts the emphasis from the desired outcome to the essential process of achieving the outcome. The desirable functional processes (DFP) context focuses on the natural processes and natural functions that define individual ecological units. The processes include physical, chemical, and biotic components sustained through time and over space. A holistic management concept, DFP uses the best current knowledge to examine specific functions and processes of an ecological unit. Both basic and applied knowledge are interpreted into criteria that holistically describe the observed functions and processes. Management emphasizes achieving functionality of an ecological unit rather than maintaining a set of predefined, static, environmental conditions as in DFC. As a management concept, DFP provides a mechanism by which an ecological unit can be assessed in relative terms of functionality, with the understanding that data must be periodically collected and analyzed to reassess functionality. In this context, the DFP concept allows managers to assess the functional condition of an ecological unit at any point in time and to continue managing justifiably within the limits of the current knowledge and societal needs.

DFP assesses the whole ecological unit at any scale whether landscape, forest, habitat, or site. The DFP concept assumes that if ecological units of the lower levels, e.g. site, are functional, then the next larger hierarchical level is also functional or will become functional. The rationale is that processes operating at one scale can affect others at another scale (Gregory et al. 1991). The over riding question is simply this: Is the ecological unit functional or are parts thereof dysfunctional? Also, in DFP, inventory data are used to define the functional condition of an ecological unit. After a specific element has been determined to be dysfunctional, that element gets identified as a potential focus of management goals and activities. As such, DFP is considered a component of ecosystem management. It is principally focused on the functionality of the environment and on human activities that become modifiers of the functional condition of an ecological unit. In simple terms, DFP is the quantitative diagnosis of ecological units. Managers can utilize this science-based approach as well as other components of ecosystem management such as social and economic analyses to improve their decision making. The concept of desired future condition was seemingly intended to be like DFP (USDA Forest Service 1992) in its intentions, but rather has caused confusion in terms of its definition of a set of static conditions versus functionality.

The concept of DFP is not new but is based upon some of the rationale used in the Bureau of Land Management concept of determinating proper functioning condition for riparian areas (Barrett et al. 1993, Bridges et al. 1994). We seek to advance the concept to include all types of ecological units. However, for the purpose of illustration in this paper, we will limit discussion to a lotic riparian ecosystem as an example. To do this, we have modified and developed criteria in a format that invokes examination of five basic components of any ecological unit: air, water, soil, plants, and animals. Specific criteria are listed under each component to specify the principal and characteristic attributes and processes that determine the functional status of an ecological unit.

BACKGROUND

The primary intent of DFP is to focus resource management on a holistic approach to viewing an ecological unit in terms of functionality. In essence, DFP is a form of bio-indication, except physical factors can play a greater role than biotic or chemical factors in some cases. Vegetation generally is the main biotic indicator that expresses the combined interactive effects of physical, chemical, and biotic factors (Zonneveld 1983). Given the impracticality of knowing everything about any ecosystem, it makes sense to initiate a process of functional assessment that is

1. Based on the best current state of ecological knowledge,
2. Flexible enough to accommodate new data, and
3. Applicable at any ecological scale.

Because our present technology often precludes measuring complex interactions that are of interest, we must rely on bio-indicators to express the sum of many individual interactions over time and space (Zonneveld 1983). In this sense, DFP utilizes biotic, hydrologic, and geomorphic indicators to express an environmental condition that is ecologically favorable in terms of site sustainability and productivity. The criteria are qualitative but are based on quantitative assessments of the ecological unit.

Other wetland/riparian scientists have proposed conceptual models for evaluating the functional condition for riparian or wetland areas, generally for specific agency needs. All such models are based on functional relationships and processes, such as those for the hierarchical classification of drainage basins (Frissell et al. 1986) or specifically for wetlands (Brinson 1993). Brinson's model focuses on fundamental processes essential for sustaining wetland ecosystems. Gregory et al. (1991) proposed a model of riparian zones that integrated the physical processes that shape valley-floor landscapes, the succession of terrestrial plant communities on these geomorphic surfaces, the formation of habitat, and the production of nutrition resources for aquatic ecosystems. A major argument made is that despite spatial and temporal differences between systems, fundamental ecological links that are functionally the same do exist. Smith (1992) and Ainslie (1994) proposed functional models for assessing wetlands based upon functional indicators for use in a regulatory arena of Section 404 of the Clean Water Act. The riparian models developed by the Bureau of Land Management (Barrett et al. 1993, Bridges et al. 1994) are examples of models highly applicable to most if not all regions of the U.S. Some models are specific in context, such as those proposed for aquatic macroinvertebrates (Hawkins and Sedell 1981) or wetland plants (Boutin and Keddy 1993). Reid (1994) presented a framework for evaluating cumulative watershed effects. This treatise contains many citations that are used to derive functional processes of watersheds in particular. Many of these models have not gained acceptance because, as Smith (1992) noted, of concerns over technical validity, time required to gain technical proficiency, and a limited number of functions assessed owing to limited databases. In general, the search for a conceptual approach toward assessing ecological units continues because of the immense need to have a scientifically reliable and defensible protocol that will expedite and alleviate the regulatory workload (NEPA, Clean Water Act Section 404, Endangered Species Act, etc.) placed on resource managers. To date, the better approaches are those models based on an expert systems approach such as that proposed by Gebhardt et al. (1989) and with specific criteria for the ecological unit in question.

ELEMENTS OF DFP

A key element of the DFP concept is the term "functional." An ecological unit is considered functional if the processes observed are those that move the system to a higher state of dynamic equilibrium, as opposed to one that is dysfunctional and demonstrates a trend toward system degradation. An ecological unit can always be described as functioning, but the important point here is whether the processes that exhibit the function are of the type that enhance the balance of the system and sustain the productivity of the unit. For example, degradation of a stream channel is an interactive hydrologic process that results in channel downcutting, lowering of the water table, and eventually loss of productivity of the riparian zone. In this case, the extent to which degradation occurs and the period within which it occurred would constitute a dysfunctional condition. A functional condition for this example would be one in which a quasi-equilibrium exists between degradational and aggradational processes that maintains the channel and water table in a steady state over time. The processes are measurable by monitoring.

When determining functioning condition, it is important to determine the condition of the entire watershed that influences the site being studied. The whole watershed can influence the quality, abundance, and stability of downstream resources by controlling production of sediment and nutrients, influencing ponding frequency and duration, and modifying the distribution of inorganic and organic chemicals (Barrett et al. 1993). To understand how an ecological site functions and to implement proper management practices, its capability and potential must be understood (Barrett et al. 1993). Capability is defined as the highest ecological status a site can attain given political, social, or economical constraints, often called limiting factors. Potential, often referred to as the potential natural community, is defined as the highest ecological status a site can attain given no political, social, or economical constraints. The capability and potential of a site is determined by the interaction of the air, water, soil, plants, and animals.

Use of the term "ecological site" is consistent with Leonard et al. (1992), who define it as follows:

$$\text{Ecological site} = f\,\{\text{soil, parent material, relief, climate, animals, time}\},$$

where time is the period needed for the biotic community to obtain a dynamic equilibrium with given soil and climate conditions.

Another definition of ecological site is "a kind of land with specific physical characteristics which differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its response to management" (Society for Range Management 1995). Unless otherwise specified, reference to ecological unit is meant to be applicable at the ecological site level, which is the preferred basis for inventories, assessments, and extrapolation of research and management experience.

The assessment of functionality of an ecological unit is not based on Clementsian successional theory. We concur with the Society for Range Management (1995) viewpoint that interpretations of successional status are inadequate to assess whether ecological units are properly protected from site degradation, meeting management objectives, or other characteristics related to biological diversity or nutrient cycling. Furthermore, ecological site status and health of the system are not necessarily one and the same (Gebhardt et al. 1990). Ecological site status is a position on a successional scale that may describe the site. The DFP concept allows an examination of the processes occurring within an ecological unit. Conducted as an assessment, the examination reveals the degree of functionality expressed by individual components of the site. An ecological unit may be at the pioneer level on the successional scale and yet exhibit a high degree of desirable functional processes. As well, an ecological unit may be ranked as climax and exhibit varied degrees of functionality, depending on the present state of the unit.

The term "desirable" is judgmental in context, but its use is founded on assumptions that the manager's goal is to achieve the objectives set forth under the philosophy of ecosystem management, one of which is to manage our natural resources for sustained productivity and diversity (Overbay 1992). As such, functions and processes that produce ecological conditions that enhance and sustain site productivity are regarded as desirable and based on the laws of ecology (Zonneveld 1983).

SPECIFIC COMPONENTS OF DFP

We recognize five basic components that need to be considered when assessing the functional condition of an ecological unit: air, soil, water, plants, and animals. All are essential interactive elements and no emphasis is placed on dominance. A requirement for assessing functional condition is an interdisciplinary understanding of the natural histories of plants and animals, soils, hydrology, geomorphology, and other disciplines. An interdisciplinary team is necessary to analyze the various parameters that provide basic information about the status of the ecological unit. When experience or an expert system is lacking, then far more environmental data are needed to appropriately determine functional condition. DFP utilizes existing databases and models for assessing functional condition.

An example for riparian areas is Rosgen's (1994) stream classification, which permits one to classify the existing condition of a stream and with additional hydrological data, e.g. pebble counts

(Bevenger and King 1995), determine specific elements that are functional or dysfunctional. A braided channel (D type) is an example of a dysfunctional condition, where more sediment has been deposited in the channel than the hydrologic component can process. An analysis using pebble counts would provide insight into recent changes in type and size of sediments also being deposited. The cause could be traced back to the source and found to be roads, grazing or some other disturbance activity.

Another model that could be applied is the concept of functional plant groups described by Grime (1979). This model examines the primary strategies used by plants to function within a given habitat, as competitors, stress tolerators, and ruderals. In a disturbed site, ruderals are generally abundant, whereas competitors would be much less abundant. Stress-tolerant competitive species such as Nebraska sedge (*Carex nebraskensis)* are an example of a key native, aquatic/riparian plant tolerant of flooding to mesic soil conditions (Medina, this issue). Kentucky bluegrass (*Poa pratensis*) would be an example of an exotic competitor in a riparian system. In this example, Nebraska sedge is a species indicative of a functional condition and Kentucky bluegrass is indicative of a dysfunctional condition.

Tables 1-5 contains specific criteria to be examined in assessing functional condition. The criteria are not all inclusive at this point but serve to illustrate the utility of DFP. Much of the information suggested by Barrett et al. (1993) in their model is used here, with additional criteria.

APPLICATION OF DFP

DFP applies whenever an ecological unit is being assessed for functional conditions. The criteria listed in Tables l-5 were derived specifically for a riparian site. However, criteria can be derived for other sites. Depending on the discipline relevant to the site, specific information is collected and analyzed. Analyses of data are the basis for determining the functional condition of the site relative to a specific component.

These data will also identify specific elements of a component that are not functional. For example, if one or more criteria are not met, then this is an element that requires priority attention and is addressed accordingly in the Integrated Resource Management process as a management goal. The latter has been defined (by default) from the data analyses. As such, elements identified as dysfunc-

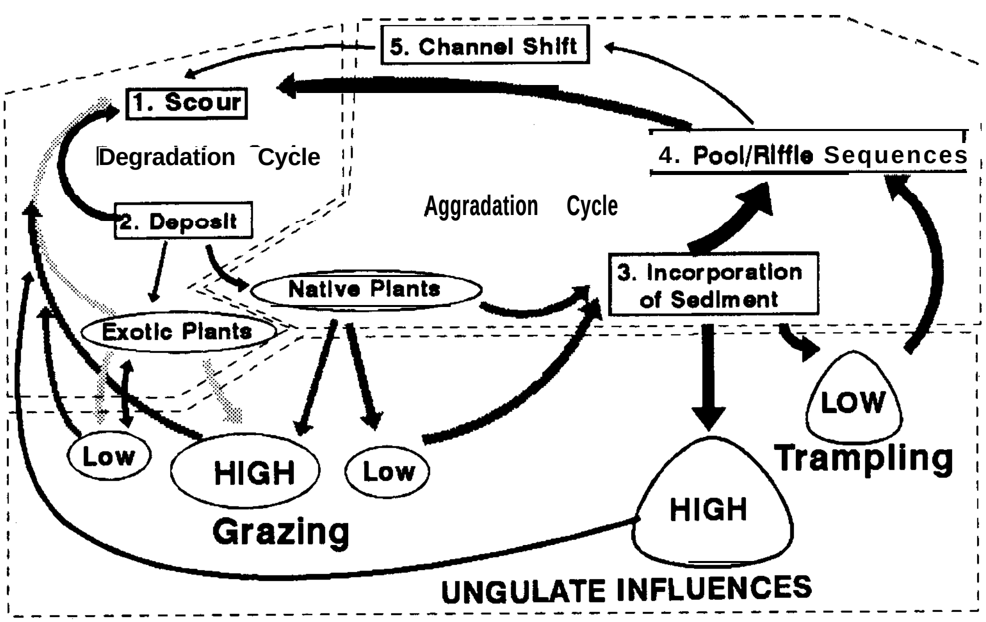

Figure 1. A conceptual model illustrating the interactions between physical and biotic components of a montane riparian meadow.

Table 1. Preliminary list of vegetation criteria that signify a functional condition for a riparian system.

Plants-Vegetative components	Yes	No	N/A
Composition-native herbaceous, aquatic plants, (sedges, rushes, etc) dominant on streambanks			
Composition-species present are native and indicative of soil moisture conditions for the site			
Composition-woody plants do not contribute to streambank erosion			
Structure-vegetation is multi-age			
Structure—riparian area has an adequate source of coarse and/or large woody debris			
Cover/Density-cover sufficient to protect banks during high flows; complete coverage of soil surface when plants are laid prostrate			
Vigor—plants exhibit vigorous growth of roots and aboveground biomass			

Table 2. Preliminary list of hydro/geomorphologic criteria that signify a functional condition for a riparian system.

Water—Hydro/Geomorphic components	Yes	No	N/A
Channel type — is of the appropriate type for the landscape setting, i.e. W/D ratios, sinuosity, etc.			
Bedload — is in balance with flow and sediment supply, with no net change in geomorphology			
Flow — instream flows maintained			
Flow — floodplain inundated during relatively frequent events (l-3 years)			
Morphology — upland watershed not contributing to channel degradation			
Water Table — s maintained at level adequate to sustain native riparian/aquatic vegetation			
Water Table -sustains site productivity at high level			
Structure — active/stable beaver dams			
Structure — instream substrates do not significantly change in composition between years			
Structure -floodplain characteristics (i.e., rocks, coarse and/or large woody debris) adequate to dissipate flow energies			
Structure — point bars are colonized by plants			
Morphology — lateral stream movement is associated with natural adjustments to stream-channel-flow conditions			

Table 3. Preliminary list of soil quality/erosional criteria that signify a functional condition for a riparian system.

Soil--Soil quality/Erosional components	Yes	No	N/A
Moisture regime — mesic to hydric, with periodic saturation to the surface			
Nutrient Cycling — adequate to sustain rapid plant growth, no deficiencies			
Organic Matter-accumulating or in equilibrium, not oxidizing			
Infiltration -depending on soil texture, at the high end of the range, exceeds most rainfall intensities			
Density -generally <1.2g/cc, decreasing with incorporation of organic matter			
Pore Space — contains macropores as a percent of pore volume			
Erosion — soil surfac e aggrading due to plant growth			
Erosion — rills and gullies not present			

Table 4. Preliminary list of air quality criteria that signify a functional condition for a riparian system.

Air -Air quality components	YES	NO	N/A
Deposition — particulate deposition of oxide compounds is insignificant			
Deposition — air-borne deposits from mines not present			
Deposition — wind eroded, deposited or transported particulates absent			

Table 5. Preliminary list of animal-effects criteria that signify a functional condition for a riparian system.

Animal -Animal effects components	YES	NO	N/A
Trampling — ungulate trampling does not significantly increase soil bulk density between years			
Trampling — ungulate trampling does not significantly change the structure of the plant community			
Trampling — ungulate use of streambanks does not significantly alter and/or impede geomorphological development of streambank-channel geometry			
Herbivory — herbivory within the streambank zone is within acceptable limits to sustain bank stability and site productivity			
Herbivory — herbivory within the riparian zone is within acceptable limits to sustain site productivity			
Density — animal density does not significantly affect plant composition of the riparian community			
Density — animal density does not significantly change the structure of the plant community			

tional become the projects or targets and identify where expenditure of monies could occur. Barrett et al. (1993) identify this stage as a condition known as "functional - at risk," meaning that the overall condition of the ecological unit is subject to dysfunctionality if the individual elements are not restored to fully functional. This equates, for example, to having a functional condition but grazing is at an unacceptable level.

Neary and Medina (this issue) illustrate the function and processes occurring within a montane riparian meadow in Figure 1. In this model, major hydrological, geomorphological, and biological processes occur continuously to produce a functional condition. The erosional processes of degradation (scour) and aggradation (deposit) in union with the water flow produce an instream effect resulting in a unique channel geometry. Sediments are exported based on the system's inherent flow characteristics, while other sediments are incorporated into the channel and streambanks through the interaction of riparian vegetation, channel gradient, and flows. In time, aquatic vegetation establishes on the streambanks to produce an additional interaction between the previous physical components. This biotic component serves as an agent of resistance against the erosive forces of the physical components. An additional biotic component (animals) can be added to produce other interactions between the biotic, physical, and chemical components of the system. In the case of the latter, excessive use by animals results in an adverse effect on the vegetative component, which in turn results in lowered erosive resistance, and finally resulting in geomorphological changes within the channel.

The efficacy with which DFP is employed depends on the individual and collective skills of the interdisciplinary team. An interdisciplinary team is a requirement (Barrett et al. 1993, Bridges et al. 1994) because of the tremendous amount of knowledge and experience that is required to provide a concise assessment. The long-term goal is to develop an expert system with the capacity to inventory and interpret diagnostic data into meaningful assessment criteria of functional condition. A by-product is the identification of priority concerns that should be the mandate for field projects. The concept, as stated before, is still in developmental form to incorporate all facets of any ecological unit. DFP requires extensive thought on behalf of the resource professional to visualize the ecological unit in a holistic context.

To determine functionality of an ecological site, its capability and potential must be determined. One approach to take is the following (Barrett et al 1993):

- Look for relic areas (exclosures, preserves, etc).
- Seek historic photos, survey notes, and/or documents that indicate historic condition.
- Search for species lists (animals and plants, historic and present).
- Determine species habitat needs (animal and plants) related to species that are/were present.
- Examine soils and determine if they were saturated at one time and are now well drained.
- Examine the hydrology; establish the frequency and duration of flooding/ponding.
- Identify vegetation that currently exists. Are they the same species that occurred historically? In what proportions?
- Determine the entire watershed's general condition and identify its major landform.
- Look for limiting factors, both human-caused and natural, and determine if they can be modified.

Some sites will be prevented from achieving their potential because of limiting factors such as human activities. However, most limiting factors can be changed through proper management.

An ecological site is functioning properly (Barrett et al 1993) when adequate vegetation, landform, or debris are present to:

1. Dissipate energies associated with wind or water, thereby reducing erosion and improving water quality;
2. Filter sediment, capture bedload, and aid floodplain development;
3. Improve flood-water retention and ground-water recharge;
4. Develop root masses that stabilize channel banks against cutting action;
5. Develop diverse ponding characteristics to provide habitat and water depth, duration, and temperature necessary for fish production, waterbird breeding, and other uses;
6. Support greater biodiversity; and
7. Produce commodities desired by society at a rate commensurate with ecosystem function.

A key concept to remember is that all sites, such as riparian-wetland areas have fundamental commonalities in how they function, but they also have their own unique attributes. Similar riparian-wetland areas can and do function quite differently. As a result, most areas need to be evaluated against their own capability and potential. Even for similar areas, human influence may have introduced components that have changed the area's capability and potential. These factors and the uniqueness-of each system must be considered to assess an area correctly.

To the extent that a resource manager uses DFP as a tool to base environmental decisions, such decisions are ultimately strengthen bv the additional information provided from the public. DFP does not preclude or diminish the public's voice in management of resources. DFI' provides the basis from which the public can be informed as to current environmental conditions in an improved, understandable, and non-argumentative manner. Everyone can agree to having functional conditions, but few can agree much less define a set of prescribed conditions owing to individual perspectives.

In conclusion, the concept of desirable functional processes is better for assessing the status of an ecological unit because it focuses on the natural processes and natural functions that define the ecological unit. DFP is adaptable to changing conditions in the status of the best current knowledge, recognizing that we don't know everything about our environment. The management emphasis is on achieving functionality of ecological units rather than attempting to reach a predefined, static, environmental condition as in DFC. DFP is dependent on collection of environmental data and a sound analysis thereof in order to best describe the functional criteria to be used in resource assessments. These assessments are used by the resource manager to determine justifiable courses of action within the limits of the current knowledge and societal needs. Moreover, DFP is in keeping with the spirit of ecosystem management and the sustainability of ecosystems (USDA Forest Service 1992, Kaufmann et al. 1994).

LITERATURE CITED

Ainslie, William B. 1994. Rapid wetland functional assessment: its role and utility in the regulatory arena. Water, Air and Soil Pollution 77:433-444.

Barrett, Hugh, Jim Cagney, Ron Clark, Jim Fogg, Karl Gebhart, Paul L. Hansen, Brenda Mitchell, Don Prichard, and Dan Tippy. 1993. Riparian area management TR 1737-9: Process for assessing proper functioning condition. USDI Bureau of Land Management, Denver, CO. Technical Reference 1737-9. 60p.

Bevenger, Gregory S. and Rudy M. King. 1995. A pebble count procedure for assessing watershed cumulative effects. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO. RM-RP-319. 17p.

Bridges, Clay, Warren Hagenbuck, Russ Krapf, Steve Leonard, and Don Prichard. 1994. Riparian area management TR 1737-11: process for assessing proper functioning condition for lentic riparian-wetland areas. USDI Bureau of Land Management, Denver, CO. Technical reference 1737-11. 46p.

Brinson, M. M. 1993. A hydrogeomorphic classification for wetlands. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS. Technical Report WRP-DE-4.

Boutin, Celine and Paul A. Keddy. 1993. A functional classification of wetland plants. Journal of Vegetation Science 4:591-600.

Frissell, C. A., W. J. Liss, C. E. Warren, and M. C. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10:199-214.

Gebhardt, Karl, Mark Vinson, William S. Platts, and William Jackson. 1989. Using expert systems in riparian management. pp 187. In R.E. Gresswell et al. (eds.), Riparian resource management: an educational workshop. May 8-11, 1989, Billings, MT. UDSI Bureau of Land Management.

Gebhardt, Karl, Steve Leonard, George Staidl, and Don Prichard. 1990. Riparian area management: Riparian and wetland classification review. USDI Bureau of Land Management, Denver, CO. Technical Reference 1737-5. 56p.

Gregory, Stanley V., Frederick J. Swanson, W. Arthur McKee, and Kenneth W. Cummins. 1991. An ecosystem perspective of riparian zones: focus on links between land and water. Bioscience 41(8):540-551.

Grime, J. I'. 1979. Plant strategies and vegetation processes. Wiley, New York. 222p.

Hawkins, C. I'. and J. R. Sedell. 1981. Longitudinal and seasonal changes in functional organization of macroinvertebrate communities in four Oregon streams. Ecology 62:387-397.

Kaufmann, M. R., R. T. Graham, D. A. Boyce, Jr., W. H. Moir, L. P. Perry, R. T. Reynolds, R. L. Bassett, P/ Mehlhop, C. B. Edminster, W. M. Block, and P. S. Corn. 1994. An ecological basis for ecosystem management. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO. Gen. Tech.Rep. RM-246. 22p.

Leonard, S., George Staidl, Jim Fogg, Karl Gebhart, Warren Hagenbuck, and Don Prichard. 1992. Riparian area management TR 1737-7: Procedures for ecological site inventory — with special reference to riparian-wetland sites. USDI Bureau of Land Management, Denver, CO. Technical Reference 1737-7. 135p.

Neary, Daniel G. and Alvin L. Medina. 1996. Geomorphic response of a montane riparian habitat to interactions of ungulates, vegetation, and hydrology In USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report, Fort Collins, CO, this issue.

Overbay, J. C. 1992. Ecosystem management. pp3-15. In: Proceedings of the national workshop: taking an ecological approach to management. April 27-30, 1992, Salt Lake City, UT. USDA Forest Service, Washington D.C. Watershed and Air Management WO-WSA-3.

Pastor, John. 1995. Ecosystem management, ecological risk, and public policy. Bioscience 45(4):286-288.

Reid, Leslie M. 1994. Research and cumulative watershed effects. USDA Forest Service, Pacific Southwest Station, Albany, CA. PSW-GTR-141. 118p.

Robertson, F. D. 1992. Ecosystem management of the national forests and grasslands. Memo to Regional Foresters and Station Directors, USDA Forest Service, Washington, D.C. June 4, 1992.

Rosgen, David L. 1994. A classification of natural rivers. Catena 22(3):169-199.

Smith, R. D. 1992. A conceptual framework for assessing the functions of wetlands. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS. Technical Report TR-WRP-DE-3.

Society for Range Management. 1995. Evaluating rangeland sustainability: the evolving technology. Rangelands 17(3):85-92.

USDA Forest Service. 1992. Ecology based multiple-use management. USDA Forest Service, Southwestern Region. 5p.

USDA Forest Service. 1993. Integrated resource management: The road to ecosystem management. USDA Forest Service, Southwestern Region. 28p.

Zonneveld, I. S. 1983. Principles of bio-indication. Environmental Monitoring and Assessments 3:207-217.