10

Some Emerging Issues in Watershed Management: Landscape Patterns, Species Conservation, and Climate Change

F.J. SWANSON, R.P. NEILSON, AND G.E. GRANT

Abstract

Emerging issues in watershed management include the need to assess the effects of management activities on a time scale of several cutting rotations (>100 years) and on spatial scales that encompass influences from beyond watershed boundaries. Long-range analysis indicates that today's activities will have strong, long-lasting effects, though the ecological consequences may not be visible when the analysis horizon spans only a few decades. Land use decisions within watersheds are increasingly influenced by broader social, economic, and biological factors (e.g., wildlife management plans, such as the Northern Spotted Owl Conservation Strategy). Global climate change poses an even greaterpotential for altering`watershed management. Consequently, improved social and technical tools are needed for planning management of multiple resources in an increasingly uncertain world.

Key words. climate change, cumulative effects, watershed management

Introduction

Management of natural resources has become increasingly complex and uncertain because of shifts in demography, political power bases, public expectations, and understanding of natural systems. The fields of watershed science and management are likely to undergo rapid change for some years to come. Uncertainties include (1) cumulative, long-term effects of current forest management practices, (2) effects of changing societal values and expectations in regard to natural resource management, especially when it comes to decisions about species of particular concern, and (3) effects of a changing global environment. Consequently, watershed managers are faced with several major challenges, including the sheer size and complexity of 5,000 to

50,000 hectare watersheds. Furthermore, managers must balance all the many demands made by increasingly diverse users of watershed resources.

In this article we discuss three emerging issues in watershed management end science as examples of these three classes of uncertainties. The first concerns the effects of forest management activities on forest patterns over a time scale of several centuries and the hydrological and ecological consequences of alternative patterns. Second, we describe two proposed wildlife conservation strategies that would affect watershed management. Third, the prospects of global climate change are considered in several respects that could impinge on watershed management. Climate change and future wildlife patterns are difficult to predict and will be difficult to manage, especially with current analytical tools and social institutions. However, in the near future they will increasingly influence watershed management decisions. Since the three issues we will discuss are all in an early stage of development, we will focus mainly on needed concepts, models, and data.

In this discussion we consider examples from federal forest lands in the Pacific Northwest, USA, recognizing that many of the issues are distinctly regional. Management of forest watersheds in this region is undergoing rapid change, as is our understanding of the prospective effects of climate change. Thus many of the concepts discussed here are similarly evolving. However, we believe that these examples argue strongly for broadening the traditional temporal and spatial scope of analysis used in watershed management, in this region and elsewhere.

Long-term Cumulative Effects of Present Management

Much analysis of cumulative watershed effects has considered planning horizons of only a few years to a few decades. However, for the federal land designated for timber production in the Pacific Northwest, a planned century-long conversion of natural forests to managed forests is under way; thus analysis of a few decades considers only a portion of the transition period. Spatial patterns created by past disturbances and present cutting will have a strong influence on the pattern of forest age classes distributed across the landscape far into the future.

As of 1991 much of the federal forest land dedicated to timber production in the Pacific Northwest was only partly converted from natural to plantation (previously cut and replanted) forests. This conversion on federal lands is now 20 to over 50% complete (T. Spies, U.S. Forest Service, Corvallis, Oregon, pers. comm.), whereas private forest lands are almost completely converted. The rotation length in federal timber production areas is planned to be 70 to 120 years, with approximately equal areas cut each decade.

Assessing the effects of this conversion of natural forests to tree plantations is a crucial element in analyzing cumulative watershed effects and requires a long-term perspective. It can be argued that planning for more than one to two decades is foolish, considering the rapid pace of change in scientific understanding, technology, and, particularly, societal expectations concerning natural resources. However, present practices create landscape parterns that limit future management options for many decades to centuries. Magnuson’s (1990) concept of the “invisible present” is very relevant to this issue. He argues that we ‘typically underestimate the degree of change that does occur” during slow processes that last for decades.

This is exemplified by analysis of forest cutting patterns used in the Pacifc Northwest. Dispersion of 10 to 20 ha cutting units has been widely used in federal forestry in the region to meet a series of objectives (Franklin and Forman 1987). Initial objectives included: (1) dispersion of the hydrologic and sediment-production effects of forest cutting and road construction, (2) establishment of a road network for fire protection and other puposes, (3) creation of edge and early seral vegetation habitat for game species, and (4) creation of small openings where trees might regenerate naturally from seed from the adjacent stands. But by the time the dispersed cutting system is only 30% implemented, many of the initial objectives have been met or superseded by alternative practices (such as switching from natural regeneration to planting nursery-grown seedlings). In the meantime, other issues and objectives (such as the provision of large blocks of interior forest habitat for wildlife) have emerged. Therefore, it is appropriate to reevaluate the future cutting pattern.

An analysis of cutting patterns by Franklin and Forman (1987) shows the importance of taking the longer range view. They compared effects of dispersed, aggregated, and other cutting patterns on disturbance processes, wildlife habitat, and other properties of landscapes. A critical aspect of their analysis is that the eventual consequences of any long-term strategy, such as the dispersed cutting system, may not be evident for decades. Even very simple modeling exercises can be useful for examining patterns generated by different management systems. This concept has encouraged modeling of alternative pathways of landscape pattern development.

Analysis and Management of Within-Rotation Patterns

Using geographic information systems (GISs), several studies have projected alternative future vegetation patterns resulting from forest cutting in real rather than hypothetical grid landscapes (Hemstrom 1990, Cissel 1990). These studies have lead to several important conclusions: (1) Consideration of a full cycle of cutting is essential to planning future landscape management. (2) Patterns of stand age classes across a landscape can take very different courses, even within current standards and guidelines for U.S. Forest Service management. (3) There is inertia in the rate of landscape pattern change, in the sense that it may require a long time for a particular managed pattern to become established or for an established pattern to be altered once a change has been made in the rules governing pattern development-that is, rate of

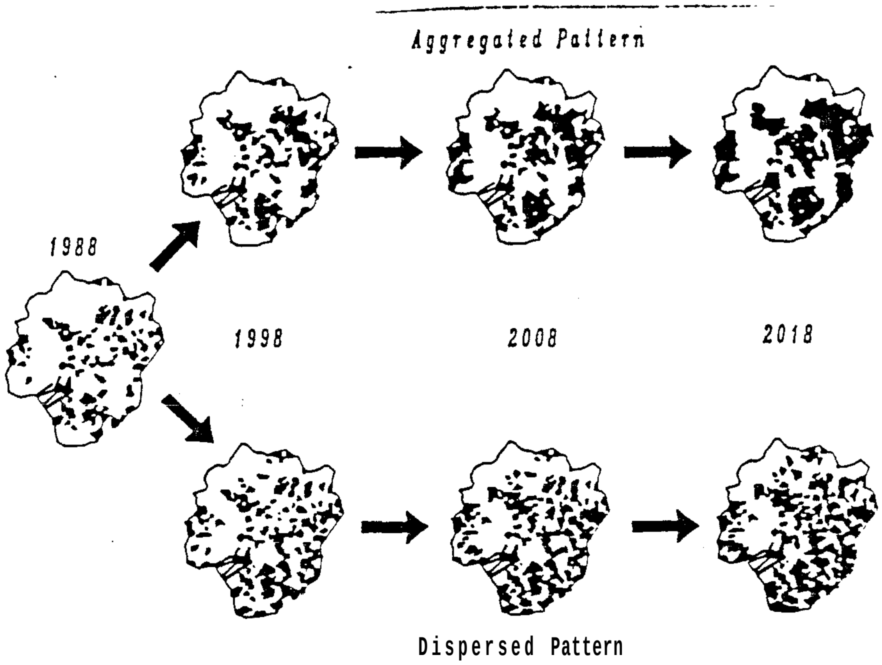

FIGURE 10.1. Example of rate of landscape pattern change aftcr rules of pattern formation arc changed. This example of the 5,000 ha Cook and Quentin creek drainages, Blue River Ranger District, Willamettc National Forest, USA, starts with ap proximately 20% cut in dispersed pattern (condition existing in 1988). Using continued dispersed cutting at 12% arta cut by decade, cutting patterns are projected for the next three decades. Beginning with the pattern in 1988, but using an aggregaded cutting pattern, the pattcrn diverges over the next three decades.

cutting, size distribution of cutting units, age of units at time of cutting, and arrangement of cutting units. These points are expressed in a landscape modeling exercise contrasting dispersed and partial aggregation of cutting units in the 5,000 ha Cook-Quentin drainages in the Blue River Ranger District, Willamene National Forest, western Cascade Range, Oregon, USA (Figure 10.1) (Hemstrom 1990). By 1988 about 20% of this area had been cut in a dispersed pattern. The district planning staff then projected the next three decades of harvest under two different regimes: (1) continued dispersed cutting and (2) aggregated cutting with the objective of maintaining large blocks of contiguous interior forest habitat. In the two alternatives the same area would be cut each decade, the area cut would be distributed similarly by 305kmelevation bands so that there would be no differential effects of rain-on-snow hydrology (Harr 1981), and regional Forest Service standards and guidelines would be followed, including the rule that a patch of forest cannot be cut next to a plantation until the trees in the plantation are 1.5 m tall.

This model displays a substantial range of possible future vegetation patterns even under the quite restricted difference in rules governing pattern development. Assuming an edge effect of two tree lengths into forested areas, Hemstrom (1990) observed 10% greater area in interior forest habitat for the aggregated pattern in the year 2018. The density of forest-plantation edge (kmof edge per km2 of landscape area) would be 42% greater in the dispersed pattern at 2018. Landscapes with higher edge density may be more susceptible to windthrow (i.e., uprooted trees). These are just two of many possible points of contrast between the pair of vegetation pattems shown in Figure 10.1.

The Cook-Quentin example of landscape analysis has drawn criticism on several points. Fist, critics say that since most landscapes where future cutting will occur have already been more thoroughly cut, more restricted than in the Cook-Quentin case. Second, the year 2018 in Figure 10.1 is the point in Landscape development when the patterns of residual forest are most different between the two cutting patterns. After 2018 the vegetation patterns (expressed only as residual forest and plantations) will converge as the scenarios progress toward the end of the first rotation. As discussed below, the resulting vegetation patterns in these two scenarios an quite different in future rotations when the distributions of age classes are considered.

Both of these concernsare valid, but it is important to look ahead into subsequent rotations. The two landscape management systems shown in Figure 10.1 are creating landscape patterns of very different grain size (i.e., scale of pattern), which will project into future rotations. The traditional dispersed cutting pattern creates a landscape with a 15 ha grain. The aggregated patterns used in the Cook-Quentin example have a dominant texture of >500 hectares, consisting of aggregates of cutting units harvested within a few decades and then left to grow into mature forest. Different future landscape structures art created, and their effects on wildlife habitat, watershed, and other aspects of ecosystems await analysis.

An interesting aspect of the Cook-Quentin exercise is the effect of inema in changing landscape patterns. Landscape pattern inertia refers to the propagation far into the future of patterns of vegetation patches created by past and present events. Consider, for example, creation of landscape pattern under rule set A (e.g., maximum dispersion constrained by simultaneous development of a road network). Application of rule set A to a hypothetical or real landscape creates the pattern resulting from that rule set. If at some point we convert to rule set B, which produces another pattern (such as aggregated cutting from nuclei with a particular spacing), another pattern is created, but it will take some timeto convert the landscape from type A to type B.

Factors that control the rate of vegetation pattern change include: (1) rates of cutting (percentage of area cut per unit of time) and vegetation regrowth, (2) magnitude of difference between the two pattern types, (3) extent of development of type A before imposition of rule set B, and (4) the flexibility of rule set B in overriding the pattern createdby ruleset A (i.e., there could be application of an initially modified form of rule set B to hasten the transition from type A to type B.

The effects and the rate of pattern change are evident in the Cook-Quentin study (Figure 10.1). Here we see that after 20% of the area was cut with a dispersed cutting pattern, it took another three decades to create the aggregated pattern after changing the rules for pattern development. The extent of aggregation was determined largely by the initial conditions (i.e., extent of previous dispersed cutting); and the rate of change is greatly constrained by the cutting rate of 12% of area per decade.

Considerations at the Multirotation Time Scale

Analysis of long-term consequences of pattern management on Pacific Northwest forests should include: (1) distinction of the transition rotation (i.e., conversion of natural forest to plantations) from subsequent rotations of fully regulated forest and (2) the inertia of patterns created in the first (transition) rotation which may carry through into the second and subsequent rotations.

A multirotation analysis is essential for two main reasons: (1) An analysis of a few decades of management activities, only a fraction of the rotation length, simply leaves invisible the long-range effects on forest age-class and associatd system properties. Examples of relevant system properties include wildlife habitat and vegetation effects on peak streamflows (Franklin and Forman 1987). (2) Activities in the middle of the transitional rotation may have different effects than the same activities in later rotations. In the middle of the transitional rotation, for example, about half of the landscape is in residual, yet-to-be-cut mature and old-growth stands. In subsequent rotations these areas are much younger plantations. Therefore, residual forest remaining during the firstcutting rotation may buffer certain environmental effects of cutting that would be observed in subsequent rotations.

We can portray aspects of the contrast between the transition and subsequent rotations by a schematic representation of the percentage of a watershed area in forest stands over 100 years old (Figure 10.2). To assess cumulative effects, we would prefer to present the variation in a watershed aspect of interest (e.g., percentage variation in peak flows generated by a particular precipitation event) rather than the extent of a single age class, as depicted in Figure 10. 2, but our analytical techniques are not that sophisticated yet.

Past analyses of long-range effects of cutting have focused on the transition rotation (Franklin and Forman 1987, Li 1989, Cissel 1990, Hemstrom 1990, Hansen et al. 1991). We are in the early stages of extending this analysis through two rotations. Ideally we would examine the effects of historic natural disturbances as well as management activities and consider the

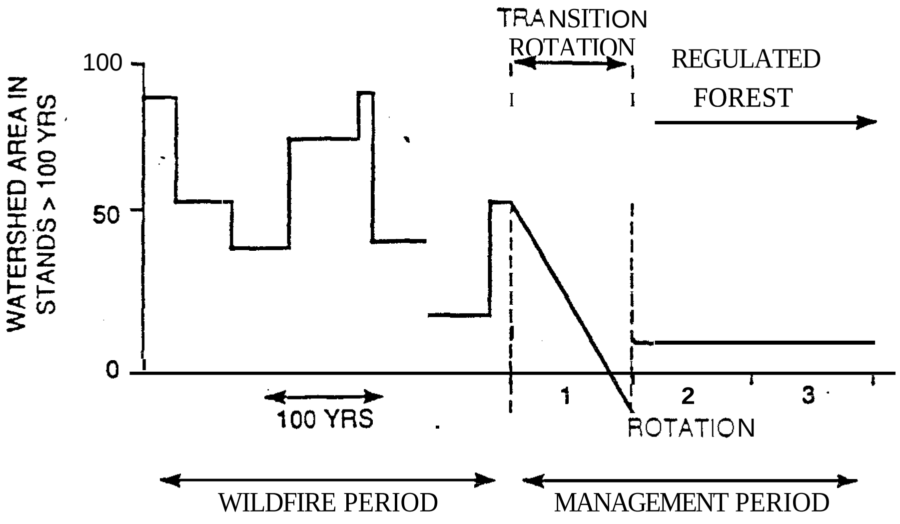

FIGURE 10.2. Hypothetical change in the extent,of forest age classes exceeding 100 years in age in a large watershed. Time scale depicts a period of natural disturbance (wildfire) through the first (transitional) rotation of forest management as natural forest is converted to plantations and into the subsequent, 'fully regulated" rotations of cutting in the fully developed forest, where the only patches of natural fonst are those dedicated to remain as such.

temporal variance of landscape parttern under the conditions of natural disturbance, transition, and fully developed states. For example, we might hypothesize that there was much greater decade-to-decade variation in the distribution of forest age classes and the grain size of patches in the prehistoric, wildfire-dominated 'disturbance regime than in the fully managed forest-landscape (Naiman et al., this volume). This would provide a frame of reference for analysis of long-term-effects of management on ecosystem attributes such as streamflow regime and biological diversity.

Modeling efforts to date have emphasized degree of aggregation of cutting units as the key variable (Franklin and Forman 1987, Li 1989, Cissel, 1990, Hemstrom, 1990). These exercises have used rather limited ranges of values for two landscape pattern variables: size distribution of cutting units and rotation length. These two variables have potentially great effects on wildlife habitat, hydrologic regimes, and other landscape functions. An initial step in a broader analysis could take the form of a sensitivity analysis of computer simulated vegetation patterns to evaluate the effects of varying unit size and rotation length, as well as arrangement of cutting units. Habitat assessment and process models, such as hydrologic models, could then be used to estimate effects of these patterns on key landscape functions.

The rates of vegetation pattern change have implications for management, including maintaining desirable system features as long as possible, predicting which features among those that will be reduced or eliminated from landscapes may create undesired effects, and developing management strategies to rebuild features that have been largely lost.

Species Conservation and Watershed Management

The beginning of this decade marks a critical turning point in watershed management, for species conservation has become a major factor determining the context in which management decisions aremade. Two cases from the western United States provide examples of regional scale plans for species conservation that strongly affect watershed management andcreate opportunities for research in hydrology, stream and riparian ecology, and related fields. These examples also indicate the nted for improved social mechanisms for management in an uncertain future, as well as the need for new scientific understanding and technology (Lee, this volume; Lee et al., this volume).

Northern Spotted Owl

The conservation strategy for the northern spotted owl (Strix occidentalis caurina) (Thomas et al. 1990) proposes establishment of a series of habitat conservation areas (HCAs) distributed across northern California and westem Oregon and Washington. A majority of HCAs range in size from 20,000 to 40,000 ha, and each is intended to encompass habitat for approximately 20 pairs of spotted owls. The strategy also prescribes limits on forest cutting in lands between HCAs, with the intent of providing dispersal paths between HCAs. The geographic pattern of HCAs is designed to provide for owl dispersal and to use lands where timber harvest is already prohibited (e.g., legislated wilderness).

Consequently, HCAs assume a variety of configurations with respect to watershed boundaries and areas, including some that partly coincide with wilderness areas along the crest of the Cascade Range and therefore result in protection of large (50,000+ ha), complete headwater basins Figure 10.3). In the central part of the western Cascades in areas removed from large wildernesses, individual HCAs typically straddle drainage divides, and therefore cover multiple, smaller (2,000-10,000 ha) watersheds. Complex patterns of HCA boundaries exist where several ownerships are involved.

Furbearers in the Sierras of California

Another system for species conservation is contained in the proposal for ‘Sustainable Resource Management for Forest Landscapes developed by several national forests in California (M. Chappel, Tahoe National Forest, Nevada City, California, pers. comm.). This proposal derives from a desire to better protect furbearers and other special interest species in the Sierra

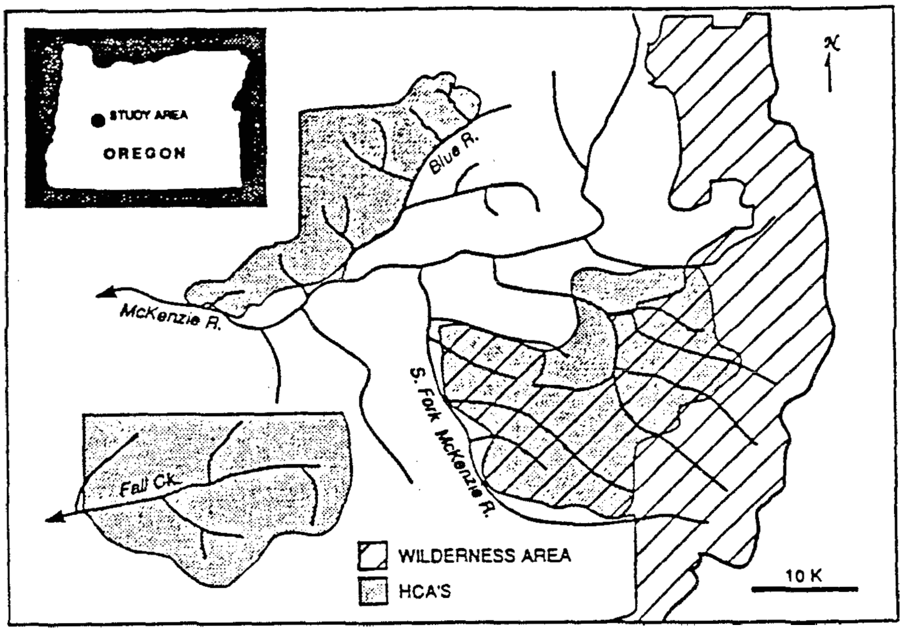

FIGURE10.3. Portion of the habitat conservation area (HCA) system inthe conservation strategy for northern spotted owls (Thomas et al. 1990). Note that HCA 0-7 (top) encompasses a series of small watersheds and straddles mainstem Blue River and McKenzie River, 0-8 (middle) encompasses lown elevation portions of larger watersheds, the upper reaches of which areoutside the HCA but within Three Sisters Wilderness; 0-9 (lower left) encompasses the full, single watershed of upper Fall Creek.

Nevada Range of California. This plan calls for management of (1) 'old forest zones" in valley bottoms and steep lower valley walls of major river drainages in the central Sierras and (2) 'bridges" of continuous forest cover over drainage divides to connect the old forest zones. In this scheme the old forest zonewould receive low levels of timber harvest, and aerial logging systems would be used so that natural forest habitat could be maintained with minimal human disturbance. The bridges are intended to provide dispersal corridors between watersheds in case of wildfire, climate change, or other major disturbance. 'Young forest zones" are located on the gentler, upper slopes where habitat value for furbearers is fairly low, timber harvest can be emphasized, and relatively inexpensive cable and ground-based yarding systems can be employed.

Implications for Watershed Management and Research

These two proposals reflect a trend emphasizing management for biological diversity as a driving force in landscape planning and management. More generally, new issues are setting the context of watershed management. The watershed management community needs to address these issues early in their formulation.

The conservation strategy for the northern spotted owl, complete with research and monitoring programs to test assumptions and effectiveness, has compelling implications. If protection of one species requires this level of analysis, design, and public consternation, how will we arrive at a plan to manage for biological diversity in the aggregate? A key question for watershed management is: How do we create landscape designs that integrate biological diversity objectives with a variety of other objectives?

These proposed approaches to habitat management create a need for landscape planning much broader than the 5,000 to 10,000 ha scale considered in analyses by Franklin and Forman (1987), Hemstrom (1990), and Cissel (1990), when individual treatment units are 15 ha clearcut areas. Analysis should encompass reserved areas as the treatment units, such as Research Natural Areas, wilderness, and HCAs, many of which are >20,000 ha. Analysis areas to assess effects of such reserve systems should be large enough (perhaps exceeding 100,000 ha) to incorporate multiple treatmentunits. New approaches to field and modeling studies are needed to meet objectives at this broad scale.

These proposed reserve systems for species conservation raise questions concerning the integration of stand- and landscape-scale management practices. For example, many proposed HCAs contain extensive young plantations of Douglas-fir (*Pseudotsuga menziesii*). How should these stands be managed to meet widlife as well as hydrologic objectives, suchas &mizing peak streamflows generated during rain-on-snow events (Harr 1981)? Some of these young stands will stagnate if left unattended, thereby slowing the rate at which they might reach desired habitat conditions. How should woody fuel loads be managed in reserve and nonreserve areas to balance objectives of maintaining woody debris-related habitat with the desired frequency and extent of wildfire across landscapes? Because large-scale disturbances by processes such as wildfire are highly probable in many parts of the Pacific Northwest on the time scale relevant to this land use planning, such events should be an explicit consideration in landscape design.

The proposed system of HCAs, if enacted, will createan important new set of large-scale experimental treatments that enhance the opportunity for understanding effects of various management systems. Forest lands in many HCAs have been substantially cut in the past few decades. Since establishment of HCAs will eliminate further harvest for some time, vegetation in HCAs will undergo succession without interruption, resulting in a net increase in age of vegetation.

HCAs would add an interesting and important new element to the matrix of landscape management treatments defined in terms of the trends of past and future cutting. The federal land management system without HCAs includes three treatments: (1) past and future cutting conducted in the forest land available for timber cutting, (2) no past or future cutting in wilderness areas and research natural areas, and (3) no past curling, but future cutting in roadless areas released for future forest cutting through the federal forest planning process. The HCA system would be made up of areas of past cutting and no future cutting. The importance of the HCA landscape treatment is that it sends large pieces of landscape on a trajectory of vegetation change unlike anything existing previously.

Given the large-scale, complex nature of these land management designations, the best opportunity to capitalize on this important, ad hoc landscape experiment may be through an adaptive management approach (Walters 1986). The essential theme of adaptive management is to acknowledge our present imperfect understanding of natural resource systems and learn answers to crucial questions by conducting management through experiments. This approach is aproposed part of the conservation strategy for the northern spotted owl (Thomas et al. 1990), and is equally relevant for landscape management. Monitoring of hydrologic, ecologic, and other system responses to these treatments would prove useful in evaluating the cumulative watershed effects of management activities (such as road building, harvesting) and in testing models developed to simulate them.

Climate Change

Past management activities and those being considered for the future largely assume a static climate (see Thomas et al. 1990). In this section, we will relax that assumption and address a few of the potential combined impacts of current land use in light of a rapidly changing climate.

Effects of change in the physical and chemical properties of the atmosphere present many uncertainties for future watershed management (Risser, this volume; Dolph et al., this volume). Clearly the concentrations of radiatively active gases in the atmosphere are rising (Houghton and Woodwell 1989, Keeling et al. 1989), but the effects on important ecosystem functions, such as biotic regulation of hydrology, are poorly known. Hydrologic effects of climate change could include increased evapotranspiration in response to warming and change in vegetation cover type and amount, change in amount and type of precipitation (e.g., snow versus rain), change in the water use efficiency of vegetation in response to elevated CO_2 levels in the atmosphere, and change in soil properties resulting from altered disturbance regimes and vegetation cover. The timing and magnitude of future climate change are similarly unclear. Despite these uncertainties, we believe that it is worthwhile to consider some of the potential broad-scale implications of climate warming in order to stimulate our thinking about major changes that watersheds may experience.

Several studies have addressed potential changes in the distribution of tree species in response to climate warming on the basis of $2xCO_2$ increases, using low resolution general circulation models (GCMs). Grid size of these

GCMs is coarse relative to the Pacific Northwest of the United States, so the GCMs do not reproduce the,Current climate or project future climate well, but may provide some idea of potential broad-scale effects of increasing atmospheric CO_2 (Jenne 1988). The greatest change in temperature predicted for this region by a group of widely published GCMs is +5ºC (Wilson and Mitchell 1987). Studies employing vegetation modeling and analysis of lapse rates (Dale and Franklin 1989, Neilson et al. 1989, Franklin et al. 1991) suggest that this magnitude of warming would result in a 1,000 m upward shift in elevation of temperature-controlled features, such as boundaries of species habitat and snow hydrology zones. This would amount to latitudinal shifts in species ranges of hundreds of kilometers.

Climate change effects on watersheds are likely to be diverse. Here we comment on some examples of direct effects on watershed hydrology, vegetation and habitat distributions, and land use and disturbance considerations.

Hydrology Considerations

Watershed hydrology can be expected to change in direct response to climate change and as an indirect result of changes in vegetation structure and composition that affect hydrology (Dolph et al., this volume). Direct effects of climate on hydrology, for example, will result from shifts in the location of boundaries between rain-dominated, transient snow (elevation band where snow may accumulate and melt several times each winter), and seasonal snowpack zones (Harr 198 1). Climate warming could cause these boundaries to rise in elevation thereby altering the quantity andstorage time of water stored as snow within a watershed and the magnitude and timing of peak and low streamflows. The magnitude of such effects will depend on the distribution of boundaries between snow hydrology zones in relation to watershed topography. Some watersheds, for example, may have a reduced percentage of area in the transient snow zone after climate warming, and would therefore be expected to have reduced peak flows, assuming no change in the timing and amount of precipitation; that is, only the form (snow versus liquid) would be altered.

Potential effects of warming on snow hydrology can be seen by comparing the 68 km’ Lookout Creek and the 83 km2 French Pete Creek watersheds in the western Cascade Range in Oregon. These two watersheds are similar in area and total relief but differ somewhat in elevation. In the present climate, 77% of the Lookout Creek watershed is in the transient snow zone-more than twice the percentage of the French Pete watershed (Table 10.1). To give some sense of the potential magnitude of this contrast, the estimated 10-year return period discharge per km2 is 1.5 m3/s on Lookout Creek but only 0.5 m3/s on French Pete Creek.

Assuming the scenario of a 5°C warming and an associated 1,000 m increase in elevation of boundaries between hydrologic zones, French Pete watershed would still have about a third of its area in the transient snow

Table 10.1. Percentage of basin areas in various hydrologic zones under present climate compand with a 1,000 m increase in boundaries between zones.

	Lookout Creek		**French Pete Creek**	
Hydrologic Zone	**Present**	+1.000 m	**Prescnt**	+l.000 m
Snowpack	23	0	65	0
Transient	77	6	35	33
Rain dominated	0	94	0	67

zone; however, it would be in the upper third of the watershed rather than the lower third, as it iS in today's Climate. The Lookout Creek watershed would be nearly exclusively in the rain-dominated zone, and neither watershed would have any seasonal snowpack under the altered climate scenario. Based only onconsideration of shifting hydrologic zones, these projected changes would be likely to result in substantially reduced summer low flows inboth basins (more SO in French Pete) and possibly reduced peak flows in the Lookout watershed. Such changes in streamflow would affect the biology of stream and riparian systems. Geomorphic processes would also be affected by change in the type, amount, and pathways of water movement in relation to topography.

Another effect of climate warming would be increased evapotranspiration, which could have profound hydrologic effects, even with no change in pre cipitation. Franklin et al. (1991) estimate that a 5°C increase in temperature would result in a 64% increase in potential evapotranspiration at the sites of selected meteorological stations in the western Cascade Mountains of Oregon and the western Olympic Peninsula in Washington. Actual evapotranspiration will depend on available soil moisture and the amount of leaf area; which appears to be set by the landscape water balance (Woodward 1987, Neilson et al. 1989). The very high leaf areas of Douglas fir-western hemlock (Tsuga heterophylla) forests are likely toresult in a rapiddrying of soils and reduction of base streamflows in response to warming. This would lead to plant death and thus a reduction in leaf area.

Vegetation and Habitat Change

Climate change would also lead to migration of species andshifts in boundaries between biomes. Neilson et al. (1991) have been analyzing limitations to the geographic distribution of major biomes (e. g., forest, grassland, &-sert) for the United States by relating seasonal timing and magnitude of temperature, precipitation, and runoff patterns to life-cycle and physiologic requirements of plants. Their success in simulating biome distributions from simple rules suggests that if climate warms to the extent predicted by GCM analyses, and plant species respond to moisture and temperature conditions as predicted, major shifts in species distribution should be expected. Significant unknowns include dispersal rates across either natural or managed landscapes (Davis 1988), possible effects of soil incompatibility as a Limit on dispersal rates (Perry et al. 1990), and CO2 induced changes in plant water-use efficiency (Bazzaz 1990).

Shifts in biome boundaries that are triggered by climate change can be viewed as creating zones of biome stasis, retreat, and invasion (Holland et al. 1991. Neilson 1991). For example, if a forest biome moves northward in response to climate warming, the forest may invade tundra to the north but retreat on the southern forest biome border, permitting northward invasion by shrublands. If climate change is not so extreme that the biome is completely displaced, thecentral part of the forest biome may remainin the forest vegetation type. Actual elevational and latitudinal shifts of biome boundaries will be complicated by many physical and biological effects on the stability of individual boundary segments. For example, where environmental gradients are steep, such as mountain fronts, major climate change may lead to only minor horizontal shifts in the location of boundaries of species ranges. The most extreme latitudinal shifts in plant distributions may take place where environmental gradients are not steep.

This concept of biome displacement, in all its naked oversimplification, has important implications for management of landscapes and watersheds, if climate change of the projected magnitude should occur (Holland et al. 1991). Watershed management considerations may differ Substantially among thedifferent zonesof vegetation change, depending onthe watershed-specific change in vegetation. For example, the most profound changes in vegetation structure and the physical processes mediated by vegetation are likely to occur in the forest retreat and invasion zones; smaller change may occur in the stasis zone. In terms of species conservation, the leading edge of biome shift probably deserves particular emphasis because it would be expected to develop improved habitat for advancing species in the future; whereas the trailing edge may experience degrading habitat conditions for reneating species. Of come, the advance zone of one species is the retreat zone of another.

In the face of dramatic climate warming, bcth advance and retreat zones may benefit from intensive management to facilitate species dispersal and establishment. Under such circumstances, it may be desirable to reconsider restrictions on management of wilderness areas and reserves suck as HCAs. Benefits of such management may include better control of disturbance regimes (e.g., wildfire) and establishment of vegetation with beneficial effects on habitat and on water quantity and quality. This issue of the interaction of land use and climate change demands great attention. How will land use accelerate or decelerate the transition between vegetation types? How will land use interact with projected climate change to moderate or exacerbate watershed functions? What are the effects of what seem to be subtle system changes created through land use, even where land use retains vegetation type and dominant species e.g., reduced carbon stores; Hannon et al. 1990), and broad-scale albedo increases (W. Cohen. U.S.Forest Service, Forestry Sciences Laboratory, Corvallis, Oregon, pers. comm.) when natural mature and old-growth forests are converted to intensive plantation forests in the Pacific Northwest?

Concept, Model, and Data Needs

We have discussed three broad categories of potentially important issues in watershed management: long-termconsequences of alternative management systems for timber production; conservation of particular species (and, more broadly, biological diversity); and climatechange. Pesent watershed management activities will produce future conditions very different from the current ones-conditions that are evident to us only through long-range projection of landscape structure and function.

These considerations suggest the following needs:

1. Tools are needed to predict changes in biological and physical systems resulting from land use, natural disturbances, climate change, and changes in atmospheric chemistry. Models, and related field observations at appropriate temporal and spatial resolution, are needed to link analysis of watersheds, biomes, and GCM grid cells to predict changes in species distribution, hydrologic and nutrient cycling processes, disturbance regimes, and other system features. It is particularly important that models incorporate water balance considerations at each of these scales. Models and field studies are needed to examine species migration, including limiting factors such as dispersal (natural as well as intentional and unintentional human-induced), impediments to establishment (e.g., soil compatibility for invading species), and disturbance as impediments and facilitators of dispersal. Models and related field experiments areneeded to examine the consequences of alternative management scenarios, such as forest or fish harvesting, over the next century, and to address issues of changing land use, climate, and societal expectations. This can be approached through adaptive management Walters 1986), as is proposed for conservation of the northern spotted owl (Thomas et al. 1990); adaptive management is also appropriate for landscape-level experiments using land use treatments.

2. Spatially explicit local and regional data bases art needed for modeling and monitoring ecosystem change to provide a basis for management prescriptions and policy determination.

3. Policy needs include mechanisms to manage change involving mixed-owner and multiresource objectives in today's political and physical climates. For example, species conservation issues have reached a point where regional biodiversity management plans would facilitate management and policy decisions.

Climate change may create a need for a regional management strategy that sifts down to the local level to deal with lands having different owners with different objectives. For example, climate change will increase movement of species across ownership and political boundaries. Some coordination between neighboring landholders may help minimize negative effects.

For years watershed specialists have stressed the importance of a drainage basin perspective in addressing stream and riparian issues. As this idea has gained wider acceptance, emerging issues of long-range planning, species conservation, and climate change are increasingly forcing land use managers to peer over the drainage divides into neighboring watersheds and landscapes. Watershed research and management are in a rather immature state relative to these rapidly evolving issues. Development of social mechanisms for resolving conflicts over natural resource systems, as well as technical and analytical tools for predicting effects of human activities, will need to keep pace with shifting societal expectations. The themes in this chapter suggest some of the rich and complex array of questions that will confront managers seeking to sustain ecosystems and quality of stream and watershed resources in the face of an uncertain future.

Acknowledgments. Development of concepts and information in this paper was supported in part by funding for the USDA Forest Service's New Perspectives program and the National Science Foundation's Long-Term Ecological Research program at the H.J. Andrew Experimental Forest, Blue River, Oregon. We thank A. Hansen, R.J. Naiman, J. Pastor, T. Spies, and an anonymous reviewer for helpful reviews and discussions.

References

Bazzaz, F. A. 1990. The response of natural ecosystems to the rising global $C0_2$ levels. Annual Review of Ecology and Systematics 21:167-196.

Cissel, J. 1990. An approach for evaluating stand significance and designing forest landscapes. COPE (Coastal Oregon Productivity Enhancement) Report (Oregon State University) 3:8-11.

Dale, V.H., and J.F. Franklin 1989. Potential effects of climate change on stand development in the Pacific Northwest. Canadian Journal of Forest Research 19:1581–1590.

Davis, M.B. 1988. Ecological systems and dynamics. Pages 69-106 in Committee on Global Change, editors. Toward an understanding of global change. National Academy Press, Washington, D.C., USA.

Franklin, J.F., and R.T.T. Forman. 1987. Creating landscape patterns by forest cutting: ecological consquences and principles. Landscape Ecology 1:5-1 8.

Franklin, J.F., F.J..Swanson, M.E. Harmon, D.A. Perry, T.A. Spies, V.H. Dale, A. McKee, W.K. Ferrell, S.V. Gregory, J.D. Lattin, T.D. Schowalter, D. Larsen, and J.E. Mcans. 1991. Effects of global climate change on forests in northwestern America. In R.L. Peters and T.E. Lovejoy, editors. Global warmmg and biological diversity. Yale University Press, New Haven, Connecticut, USA, in

Hansen, A., D. Urban, and B. Marks. 1991. Avian community dynamics: the interplay of human landscape trajectories and species life histories. In F. di Castri and A. Hansen, editors Landscape boundaries: consquences for biodiversity and ecological flows. Springer-Verlag, New York, New York, USA, In press.

Harmon, M.E., W.K. Ferrell, and J.F. Franklin. 1990. Effects on carbon storage of conversion of old-growth forests to young forests. Science 247:699-702.

Harr, R.D. 1981. Some characteristics and consequences of snowmelt during rainfall in western Oregon. Journal of Hydrology 53:277-304.

Hemstrom, M.1990. Alternative timberharvest patterns for landscape diversity. COPE (Coastal Oregon Productivity Enhancement) Report (Oregon State University) 38-11.

Holland, M.M., P.G. Risser, and R.J. Naiman, editors. 1991. Therole of landscape boundaries in the management and restoration of changing environments. Chapman and Hall, New York, New York, USA.

Houghton, R.A., and G.W. Woodwell. 1989. Global climate change. Scientific American 260:36-44.

Jenne, R.L. 1988. Data from climate models, the CO_2 Warming. National Center for Atmospheric Research,Boulder, Colorado, USA.

Keeling, C.D.. R.B. Bacastow, A.F. Carter. S.C. Piper, T.P. Whorf, M. Heimann, W.G. Mook, and H.J. Roeloffzen. 1989. A three dimensional model of the atmospheric CO_2, transport based on observed winds. I. Analysis of observational data. Geophysical Monographs 55:165-236.

Li, H. 1989. Spatio-temporal pattern analysis of managed forest landscapes: a simulation approach. Dissertation. Oregon State University, Corvallis, Oregon, USA.

Magnuson, J.L. 1990. Long-term ecological research and the invisible present. BioScience 40:495-501.

Neilson, R.P. 1991. Climatic constraints and issues of scale controlling regional biomes. Pages 31-51 in M.M. Holland, P.G. Risser, and R.J. Naiman, editors. The role of landscape boundaries in the management and restoration of changing environments. Chapman and Hail, New York, New York, USA.

Neilson, R.P., G.A. King, R.L. DeVelice, J. Lenihan, D. Marks, J. Dolph, B. Campbell, and G. Glick. 1989. Sensitivity of ecological landscapesand regions to global climate change. United States Environmental Protection Agency EPA/600/3-89/073, National Technical Information Services, Washington, D.C., USA.

Neilsoh, R.P., G.A. King, and G. Koerper. 1991. Toward a rule-based biome model. Landscape Ecology, submitted.

Perry, D., J.G. Borchers, S.L. Borchers, and M.P. Amaranthus. 1990. Species migrations and ecosystem stability during climate change: the below ground connection. Conservation Biology 4:266-274.

Thomas, J.W.. E.D. Forsman, J.B. Lint, E.C. Meslow, B.R. Noon, and J. Verner. 1990. A conservation strategy for the northern spotted owl. United States Forest Service, Portland, Oregon, USA.

Walters, C. 1986. Adaptive management of renewable resources. Macmillan, New York, New York, USA.

Wilson,C.A., and J.F.B. Mitchell. 1987. A doubled CO2 climate sensitivity experiment with a GCM including a simple ocean. Journal of Geophysical Research 92:13315-13343.

Woodward, F.I. 1987. Climate and plant distribution. Cambridge University Press, London,England.