Planning Alternative Future Landscapes in Oregon: Evaluating Effects on Water Quality and Biodiversity

David Hulse is Professor and Department Head in Landscape Architecture at the University of Oregon.*

Joseph Eilers is a hydrologist with JC Headwaters, Inc., an applied research firm.

Kathryn Freemark is a landscape ecologist with Environment Canada.

Cheryl Hummon is the Water Resources Program Coordinator for the City of Albany, Oregon.

Denis White is a geographer at the United States Environmental Protection Agency.

***Authors' note:** Authors following the first are listed in alphabetical order.

Abstract: *The development of spatially explicit landscape analyses is a principal activity in research on the relationships between human activities and changes occurring in natural systems. Using geographical information systems and related tools we produced digital and paper representations depicting the past, present, and potential future conditions of a 320 km2 watershed in western Oregon. These tools were used to identify trends over space and time in human occupancy and natural resources. Based on a set of values and desired future conditions developed by working with citizen groups, digital representations of the alternative future landscapes were evaluated for their effects on water quality and biodiversity using hydrological and ecological effects models. The water quality evaluative model, a non-point pollutant source geographic information system model, simulated storm events based on field data to calculate pollutant loads across the five alternative futures, the present, and the past. The biodiversity evaluative model measured the change in species richness and potential habitat area for breeding species in each alternative future and in the past and compared these data to the present.*

Results from the water quality model show increases in the volume of surface water runoff and total suspended solids under the development-oriented futures in catchments undergoing significantly increased residential development or having a high percentage of area in erosive soils on steep slopes. Results from the biodiversity model show that all native species have at least some habitat in all alternative futures. If land use trends in the watershed continue unchanged or become more highly developed, there will be an increased risk to abundance of extant native species. The set of species at risk in the development-oriented futures differs significantly in composition and is placed at risk at a higher rate than in the past, suggesting that the kinds of habitat changes to date differ from those envisioned in the alternative futures.

The United States has made great strides in environmental protection over the last twenty-five years. These accomplishments are based primarily on management strategies that rely on engineering and regulatory solutions. Programs that support the construction of wastewater treatment facilities and wetlands protection are examples of this approach. Yet, there is significant risk that much of what has been gained will be offset by continuing ecosystem degradation. For example, a range of water and land use practices continues to threaten salmon populations in Oregon despite some of the most progressive land use laws in the nation. Such a predicament has spawned a growing consensus among environmental planners that increased regulatory control alone cannot produce the desired recovery of the qualities attributed to stream corridors, threatened species, and other ecological resources. Innovative means are being explored to supplement traditional methods of environmental protection.

"Ecosystem Management" is the favored term given to this new approach to environmental protection. It also is known as the "watershed protection approach," and still other groups call it "community-based environmental protection." Whatever the chosen phrase, the approach is a process of spatially extensive environmental assessment that is unconstrained by specific institutional mandates. It is applied to a domain of places rather than to individual pollutants or other environmental stressors. Environmental results are achieved through community action designed to make progress toward publicly articulated visions of desired future landscape conditions.

Assessing Alternative Futures. During the environmental movement of the 1970s there emerged a simple, elegant innovation in ecosystem protection. Embedded within the National Environmental Policy Act of 1970 (NEPA) is the concept of alternatives analysis. The idea is that the public and their officials should assess the consequences of projects that might significantly affect the environment. The twist is that, at least for projects involving significant federal action, the assessment is focused on identifying project designs and locations presumed to cause less harm to the environment. Assessment usually produces a number of project alternatives, including "no action." Decisions are made by weighing the limitations and benefits of each alternative.

Advances in the science of landscape ecology, the art of landscape design, and the technology of geographic information systems (GIS) have reached a stage where, together with the premises of ecosystem management, the concept of alternatives analysis is ripe for enhancement. The resulting innovation is the application of alternatives analysis to entire land use scenarios bounded by varying extents of space and time. In this manner, the environmental impacts or benefits of a specific project can be viewed in context with the effects of multiple actions. Termed "alternative futures," the framework used for integration stems from land conservation and development work in the United States and rural scenario development work in the Netherlands (Freemark 1995) (Montgomery et al. 1995) (Schoonenboom 1995) (Steinitz 1990). It consists of an endeavor to address four basic assessment questions during land use planning:

1. How has the landscape changed in a particular area? (defining historical trajectories of change).
2. How might human activities and management decisions alter the landscape in the future? (depicting alternative futures).
3. What are the expected ecological, hydrological, and socio-economic consequences of the alternative futures compared to the present? (evaluating alternative futures).
4. What types of human activities or management actions, in what geographic areas or types of ecosystems, are likely to have the greatest effect? (sensitivity/risk assessment).

What is described here under the general heading *alternative futures analysis* is actually a formalized process having several parts. Each part corresponds to one or more of the questions above, but it is important to note that this approach requires iterative cycling among the steps; it is not a linear process. The first part is descriptive, corresponding to Question 1 above, and represents how the landscape is now and how it was some time ago in the past (Anderson 1998) (Bowen 1975). Next is a consultative and prescriptive part, corresponding to Question 2 above, in which professionals work independently and together with public groups of laypeople and their representatives to prescribe a set of future alternatives for land and water use and management in some area of study. The degree of citizen involvement has varied as different research teams have employed the alternative futures analysis approach (Mouat et al. 1998) (White et al. 1997) (Steinitz et al. 1996) (Montgomery et al. 1995). Next comes an evaluative part, corresponding to Question 3 above, in which a set of computerized algorithms, developed by experts in each of several economic and ecological disciplines, compare and contrast the alternative futures for their effects on valued dimensions of the land and water resources in the study area (Freemark et al. 1996) (Schumaker 1996). The concluding portion of the process attempts to determine the sensitivity of various changes which sustain desired ecological goods and services. Successful completion of this final portion leads to changes to the alternative future depictions which should, in turn, result in adaptive community learning and more favorable evaluations (White et al. 1997) (Steinitz et al. 1996) (Steinitz 1990).

Methods and Goals. By linking computer models of ecological and economic processes to geographic information system (GIS) representations of the past, present, or alternative futures, scientists can model geographic and ecological processes that are otherwise difficult or impossible to see. Over the past decade, coupling models with GIS has added significantly to our understanding of natural processes that operate across different spatial and temporal scales (Johnson et al. 1999) (Kiester et al. 1996) (Costanza and Sklar 1985) (Swanson et al. 1982). Between 1994 and 1996 a case study landscape planning approach based on linking ecological process models with GIS representations of alternative future landscape plans was developed and applied in the Muddy Creek Watershed (Figure 1), a 320 square kilometer area of productive forest and farm lands within western Oregon's rapidly developing Willamette River Basin. The goals of the project were: 1) to improve understanding of the relationship between human use of land and its effects on ecological resources; 2) to use this improved understanding to enhance the ability to predict the effects of people's activities on the valued water quality and biodiversity functions of these resources; 3) to provide products useful to local communities in their efforts to create, evaluate, implement, and monitor land conservation and development plans; and 4) to clarify which aspects of this approach are locally specific and which are transferable to other communities, landscapes, and regions.

An earlier analysis identified the Muddy Creek Watershed as a place of comparatively high water quality and native wildlife biodiversity at potential risk of degradation from future changes in land use and management (Hulse et al. 1997). Our aim was to work with local stakeholders to develop alternative future plans and then work with a group of research colleagues to evaluate each alternative in relation to maintenance of native wildlife diversity and water quality. The research method employed is described using the four basic assessment questions above.

1. Defining Trajectories Of Change.

To set bounds on what types of change are plausible, it is important to understand how a landscape evolved, where it is within its dynamic

Figure 1. Context of the Willamette River Basin, Oregon, and the Muddy Creek watershed within it.

history, and what its future trajectory might be in relation to current or alternative ecological and cultural trends. In Muddy Creek, General Land Office (GLO) surveys from the mid to late 1800s were used by the Oregon Natural Heritage Program and Oregon Division of State Lands to create a map of vegetation as it existed prior to Euro-American settlement in the mid-nineteenth century (Figure 2). Maps derived from GLO survey notes are becoming a more commonly available tool in much of the United States for depicting land cover conditions prior to Euro-American settlement (Anderson 1998).

The Seventh Population Census compiled by the federal government for the year 1850 is the most thorough record available of early settlement in the Willamette River Basin (United States Census Office 1854). Cross-referencing the 1850 Census with other information records, an even more complete picture emerges. In 1850, there were between 11,300 and 12,500 people living in the Willamette Valley (Bowen 1978). By this time, the population of native peoples in the Valley, which numbered about 11,500 in the late eighteenth century, had declined to between 200 and 500 persons (Boag 1992). The approximately 12,000 settlers had, by 1850, accrued some 6,000 head of horses, an equal number of oxen, over 19,000 head of cattle and over 30,000 pigs (Bowen 1978). Settlement patterns demonstrate the powerful effect of kinship affiliation on where immigrants chose to locate their new farms. A propensity to avoid flood-prone and wet areas is also evident in that the majority of farms were located at the margin of the valley floor, near the forests which also served as a primary source of building materials (Bowen 1975).

Due in part to the land management of native peoples, the vegetative cover encountered by settlers around 1850 differed significantly from the landscape of Muddy Creek today (Figure 2). Vegetative species associations in the present landscape are less complex than those of the past. For example, the coniferous forests of the present are less diverse in their species mix than they were in the mid-nineteenth century and cover a greater percentage of the watershed. Prior to European-American settlement more than three-fourths (78 percent) of the Muddy Creek Watershed was covered by wet and dry prairie, oak savanna, or thinly timbered woodland. Changes in the use of land and in the management of natural and human systems such as annual flooding, grazing by large herbivores (e.g., elk and deer) and regular burning by indigenous peoples are responsible for these differences (Towle 1983) (Bowen 1978) (Habeck 1961). The next four paragraphs provide brief descriptions of landscape types prevalent in the watershed during the early nineteenth century.

Wet and Dry Prairie. The lower elevations in the eastern half of the Muddy Creek Watershed were comprised of wet and dry prairie. Wet prairie communities tended to be in the valley bottom lands and swales and consisted of plants adapted to wet conditions year round (Figure 3). Dry prairies occurred in higher elevations and the plants were adapted to seasonal patterns of winter rains and summer droughts.

Oak Savanna. Oak savanna vegetation characterized areas along the margins of the valley, where large trees survived the human-set, low-intensity fires (Figure 4). Three types of savanna occurred, each one distinguished by the dominant tree species: white oak, white oak and Douglasfir, and white oak and ponderosa pine. The savanna understory of grasses

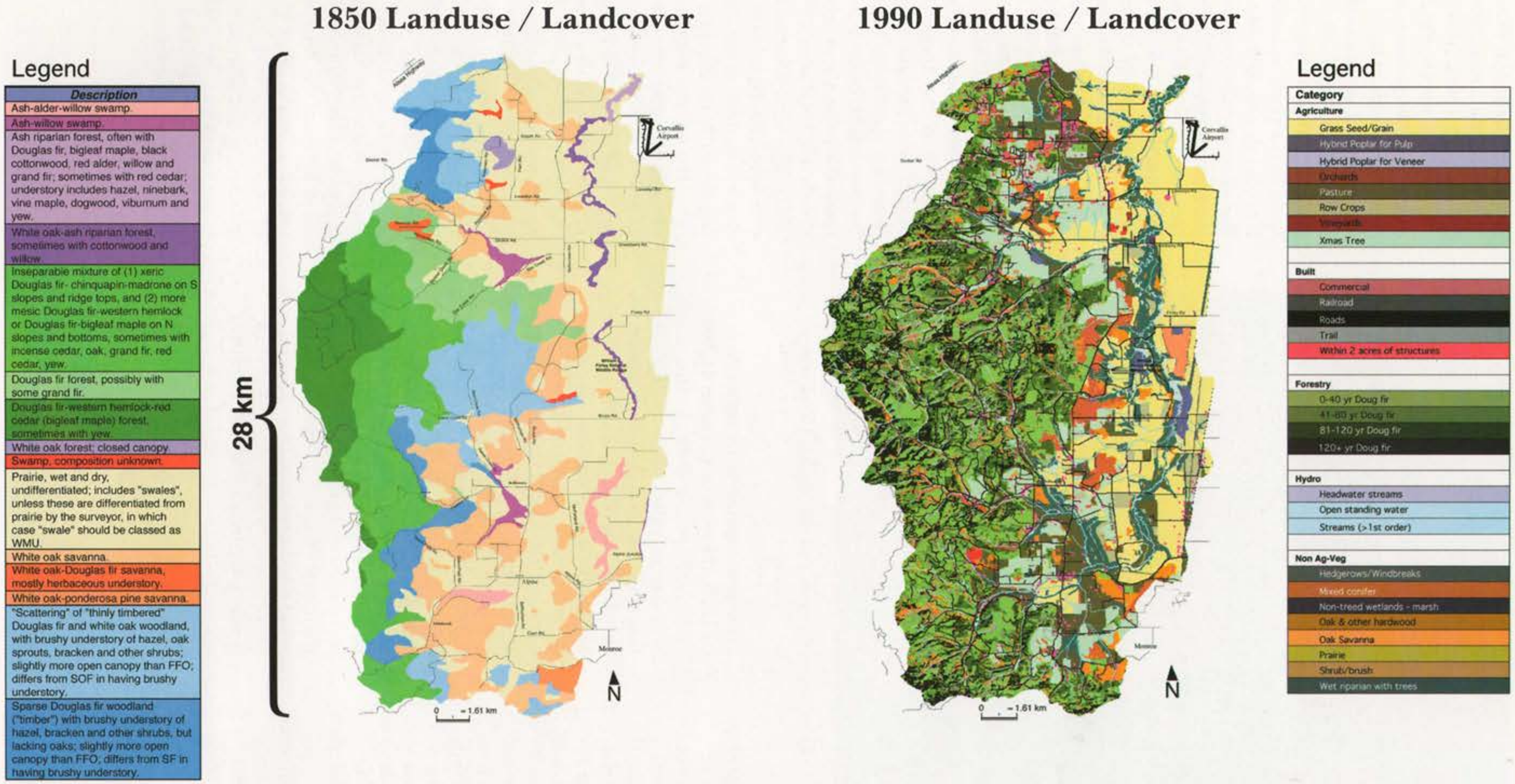


Figure 2. ca. 1850 landcover and 1990 land use/land cover maps. 1850 Source: Historic Vegetation in the Muddy Creek Watershed ca. 1850, used with permission, from Christy, J.A., E.R. Alverson, M.P. Dougherty & S.C. Kolar. 1996–1997. Presettlement Vegetation of the Willamette Valley, Oregon. Version 1. Oregon Natural Heritage Program, The Nature Conservancy of Oregon and Steven J. Whitney, Oregon Division of State Lands. 1990 roads are shown on 1850 landcover map for locational reference. 1990 Sources: Most vegetation is taken from the Oregon Dept. of Fish and Wildlife's "Oregon Actual Vegetation Map, Draft 3" (Oct. 5, 1994). The map was derived from interpretation of 1:15,000 scale 1993 color airphotos by Clair Klock. The minimum mapping unit used was approximately 4 acres. Classification accuracy is unknown. Christmas trees, vineyards and orchards were split out from the original aggregated classification based on limited field work (June 1996). The forest classification was by Tom Maiersperger (Oregon State University) from a 1993 Landsat TM scene. Structures were derived from both USGS quadrangles and from parcel data provided by Benton County Planning Dept. All other data were obtained from the 1:24,000 scale USGS quadrangles for the area.

Figure 3. Wet and Dry Prairie. A prevalent landscape type in the watershed in the mid-19th century, wet/dry prairie now occupies less than 2 percent of its former extent. Photo: Tracy MacEwan.

and herbaceous plants varied in composition in response to soil moisture.

Forest. Forests occupied the western edge of the higher elevations. The Douglas-fir/western hemlock forest included western red cedar, big leaf maple and in the understory, pacific yew. Red alder was present in forests along riparian corridors and grand fir was present in forests under 300 meters in elevation. The drier forests along south slopes and ridge tops were influenced by naturally occurring fires and typically had a thick understory dominated by chinquapin and madrone. Forested areas in lower elevations bordering the prairie generally included a mix of white oak, incense cedar, grand fir, western red cedar, and pacific yew (Figure 5).

Woodland ("Thinly Timbered" Forest). The open-canopied, thinly timbered forests were dominated by Douglas-fir and a mixture of Douglas-fir and white oak. These woodlands occupied the border between forest and prairie-savanna lands. The understory was thick with western hazel, bracken fern, oak sprouts, and other shrubs, making it nearly impassable (Figure 6).

Characterizing Contemporary Land Use and Land Cover. Oregon's comprehensive land use planning regulations, adopted in the 1970s, establish a planning process and policy framework as a basis for all decisions and actions related to the use of land. These policies attempt to conserve productive agricultural and forest lands while concentrating development within defined urban growth boundaries (UGB) and rural residential (RR) zones. Within this framework, agricultural lands and forest lands are zoned uniquely to be maintained in agriculture and forest uses.

Today, eighty-eight percent of the Muddy Creek Watershed is privately owned. Within the framework of Oregon's statewide land use planning system, most of this private land is zoned for exclusive farm use (42% of the watershed), forest conservation (35%), or secondary forest (11%) uses.

Approximately twelve percent of the watershed is in public ownership. Slightly more than ninety acres of uplands in the central-western portion of the watershed are managed by the US Forest Service (USFS) as a tree nursery. The US Bureau of Land Management (BLM) manages over six thousand acres in the headwaters and the US Fish and Wildlife Service (USFWS) manages a five thousand acre wildlife sanctuary, the Finley National Wildlife Refuge, in the lower elevation, central-eastern portion of the watershed.

The watershed can be generally described as having three prevalent landscape types: forests, rural residential areas, and agricultural lands. In the western part of the watershed is an upper elevation area dominated by Douglas-fir and managed for timber production (Figure 2). Much of it has been logged within the past fifty years, although significant tracts of forest greater than 120 years in age still exist, resulting in a patchwork forest landscape in various stages of growth and regeneration, managed under a variety of mandates. Prior to

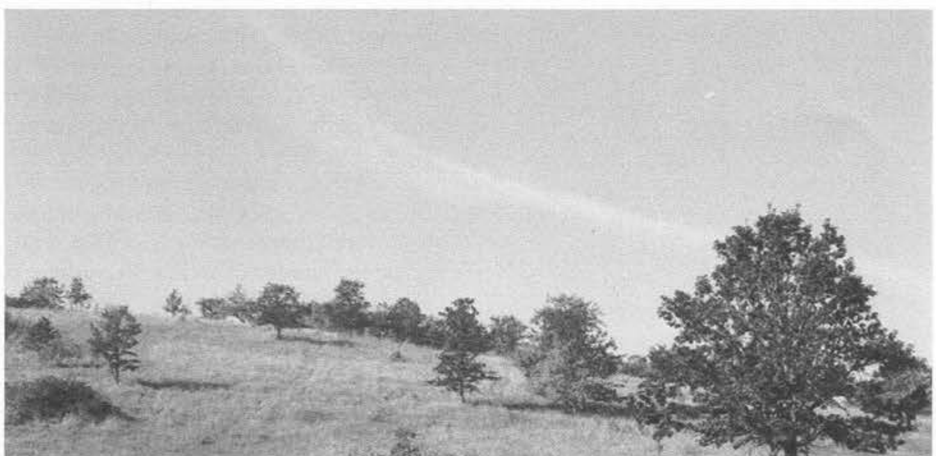


Figure 4. Oak Savanna. Also common in the regularly-burned pre-settlement landscape, oak savanna has been replaced by grazing lands and Christmas tree farms in the watershed. Photo: Tracy MacEwan.

the 1950s, private lands were the predominant source of timber harvested in the Willamette River Basin. In the late 1970s and early 1980s, the proportion of total basin-wide harvest from publicly owned, federally managed lands increased markedly. As the supply of timber from federally managed public lands declined in the early 1990s, higher timber prices and market pressure to harvest privately-owned forest land increased. The response to these pressures varies among current forest land owners and managers throughout the Willamette River Basin and within the Muddy Creek Watershed. Major forest land owners and managers in the watershed include the BLM, private forest industry landholders (large and small), and small woodlot owners.

In the mid-elevations of the watershed is a zone trending roughly north-south, that comprises a second landscape type. It is home to most of the approximately 3,000 residents living within the watershed and is dominated by Christmas tree farms, vineyards, mixed coniferous and oak woodlands, rural residential areas, pasture lands and livestock (Figure 2). The community of Alpine is located here, in the southern portion of the watershed, and is zoned as rural residential, with typical lot sizes ranging from two to five acres. Rural residential zoning makes up approximately three percent of the watershed. There is also extensive single-family housing in the northern portion of the watershed which predates the current zoning. Most houses in the watershed depend on wells for domestic water supply and have septic systems for wastewater treatment. As is the case along much of the eastern slope of the Coast Range in this region of Oregon, water availability, principally groundwater to service domestic wells, is a potential limiting factor on new residential construction in parts of the watershed.

In the lower elevations are the agricultural lands, dominated by grass seed farms (Figure 2). The economics of grass seed farming encourage large, contiguous fields to produce a harvest of grass seed free of contaminant weed seeds. The resulting openness of the lowlands is one of its salient visual qualities. Some drainage investments and stream channelization are evident in this portion of the watershed. Anecdotal information indicates that this work was subsidized by the federal Agricultural Soil Conservation and Stabilization Service in the 1950s and 1960s. Private funds continue to support expansion of tile drain networks. The USFWS Finley National Wildlife Refuge and a large riparian floodplain forest along the main stem of the Muddy Creek are also prominent features in the lowlands of the watershed.

Figure 5. Forest. Contemporary forests cover a greater area today than in pre-settlement times, although the mix of tree species has been simplified in preference for trees, e.g. Douglas-fir, with the fastest growth rates and highest market values. Photo: Tracy MacEwan.

As with forestry, agriculture in the Muddy Creek Watershed remains a primary source of livelihood and of pride for many residents. Perennial and annual rye grass seed, along with Christmas trees and hay, are now the major crops in the lower and mid-elevations of the watershed. Although particular crops and management practices have changed significantly within the past several decades, forest and agricultural landscapes and the rural ways of life necessary to sustain them have been part of this watershed for the past one hundred and fifty years. A review of maps of past land use illustrates the changes that have occurred during this time. Projected population increases for this portion of the Willamette River Basin promise more changes.

2. Depicting Alternative Futures.

Stakeholders involved in the process of creating the mapped alternative futures met bi-weekly with the research team for a seven month period, from January to July 1996, to develop five alternative future scenarios for the Muddy Creek Watershed. The futures originated from a current conditions map, the 1990 land use/land cover map (Figure 2). Initial meetings were devoted to refining the 1990 land use/land cover map, clarifying the scope and purpose of the project and developing a common vocabulary. During the development of the futures, the research team facilitated the meetings and stakeholders acted as the primary decision makers determining the specific properties of each alternative future.

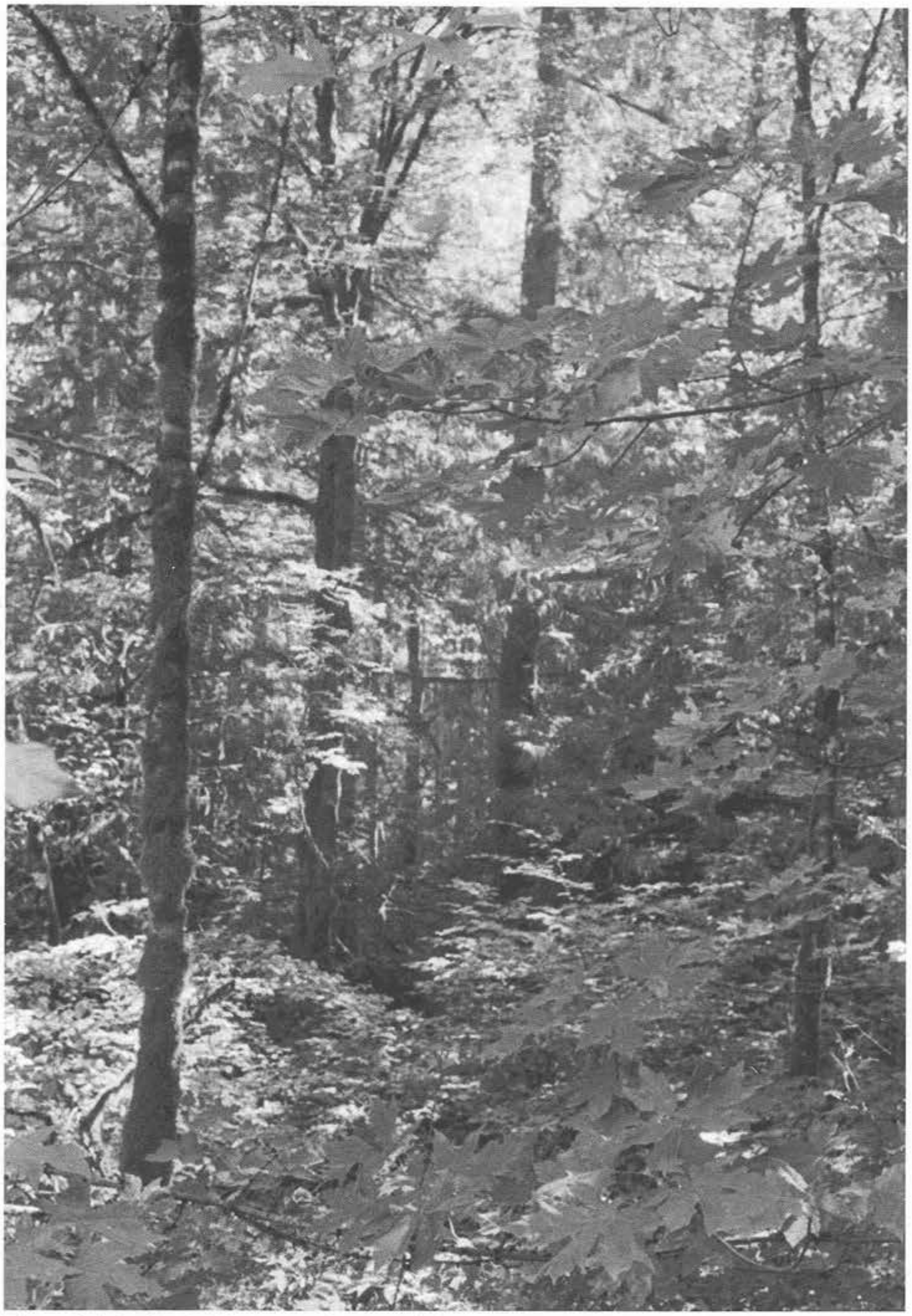


Figure 6. Woodland. These mixed zones of deciduous and coniferous species are still common, however their locations have changed. In the pre-settlement landscape they were found at the transition between upland forest and prairie-savanna lands. They are now most frequently found in riparian zones and as an early successional community following clear-cuts. Photo: Tracy MacEwan.

Working with members of the research team, stakeholders decided to act as one group while at the meetings, instead of separating into their areas of expertise, such as farming or forestry. This was to help stakeholders learn about each others' concerns and facilitate the exchange of knowledge. To better reflect stakeholder experience and information in the different futures, research team members met individually with some stakeholders who were knowledgeable in specific areas, such as forestry or agriculture.

Alternative futures depicted the study area in the year 2025, with specific decisions guided by different assumptions about prevailing land management. A generalized framework of broad land use future types was preliminarily outlined by the researchers early in the process to help stakeholders identify a spectrum of possible land use futures. These ranged from a High Development Future, through a Plan Trend Future (envisioning the study area in 2025 under current zoning/regulations), to a High Conservation Future. Working with the researchers, the stakeholders also developed two additional Futures, a Moderate Conservation and a Moderate Development Future, to make a total of five alternative futures depicted for the year 2025.

Human Population Projections. Human population demographers have long struggled with the challenge of producing accurate projections of population increases over thirty to fifty year planning horizons. To increase confidence in the plausibility of the alternative futures envisioned in this project, the research team recommended that the stakeholders not simply accept a single population projection and use it in all futures, but instead use a range of projections each of which is consistent with the broad conservation or development-oriented nature of the scenario in which it appears. To this end, residential lands in each future were influenced by a projected number of new people moving into the watershed, a number which varied from scenario to scenario. Represented by the number of new households added to 1990 levels, and calculated at 2.5 people per household, they range across the scenarios from a high of 1,250 new households (above 1990 conditions) in the High Development Future, to a low of 125 new households (above 1990 conditions) in the High Conservation Future. Thus, the population growth scenarios on which the mapped futures were based cover an order of magnitude of variation. While it is difficult to predict with confidence which of these projections will prove closest to true in 2025, our analysis of past projections of present population levels indicate it will occur within this range, and closer to the low end than the high. The population numbers are based on projections of two agencies, Benton County Development Department and Portland State University's Center for Population Research and Census (PSUCPRC 1993) as well as the experience and judgments of the stakeholders.

Benton County Development Department projects 1,000 new people (or 400 new households) in the watershed by the year 2015. If projected to the year 2025, this translates into an increase above 1990 levels of 1,500 people or 600 dwellings. Using Portland State University's Center for Population Research and Census projections for the growth rate of Benton County between 2015 and 2025, and assuming Muddy Creek Watershed receives its area-weighted proportional share, this alters the projection to an increase of 1,188 new people or 475 new dwellings by 2025 (PSUCPRC 1993). This became the basis for the residential portion of the Plan Trend Future.

The stakeholders used these figures and their own experience to set the full range of population projections, varying the number of new dwellings, as well as how they were distributed on the landscape (Figure 7). Among their decisions, stakeholders chose to concentrate new residential development in and around Alpine, a small community at the southern end of the watershed currently zoned primarily for rural residential uses, where more social and physical infrastructure exists. This area came to be known as the "southern development zone" of the watershed. Its counterpart, a less compact area to the north, became known as the "northern development zone."

Figure 7. Siting of new residential development in the Southern Development Zone for the High Development Future. Using the corresponding population projections, designers created site-specific plans to accommodate the number of new dwellings needed for each future scenario. Once combined with corresponding plans for agricultural and forest-dominated lands within the watershed, each draft was iteratively reviewed with the stakeholder group until consensus was reached that the map adequately represented the intentions of the written scenario and its assumptions.

Key Assumptions about residential, agricultural, and forest lands. Detailed assumptions about residential, agricultural, and forest land use were developed and recorded for each future by the stakeholders and research team. A summary of these assumptions follows, with a more detailed listing accompanying the alternative future maps.

Within the residential component of the alternative futures, key variables include the total number of dwellings added relative to 1990 levels, the locations of those dwellings (including compact versus dispersed patterns), how their water supply needs are met, and whether or not all the new dwellings added are located within 1990 rural residential zones.

Agricultural land use across the scenarios varies primarily by the introduction of hybrid poplar as a short rotation paper pulp crop. The acreage devoted to hybrid poplar and the length of rotation (longer rotation poplar is grown for veneer) changes in each alternative future. What crops are replaced by hybrid poplar change across the alternative futures as well. In the High and Moderate Conservation Futures, the introduction of windbreaks, hedgerows, and streamside buffers comprise an additional significant variation in agricultural land use.

Forested lands are divided into public and private ownership, with different policies governing each. Further, small privately owned forest lands are assumed to be guided by land management mandates different from those governing the large, industrially managed private forest lands. Primary assumptions, which vary from future to future, governed the length of rotation (harvest) cycle and the type, location, size, and distribution of harvest cuts, the treatment of riparian zones during harvest, and the approach taken to replanting following harvest. We asked the stakeholder group to describe both standard practices and their level of adoption by different identifiable groups within the watershed (for example, the percentage of small private woodlot owners expected to clear-cut their timber holdings of a given age class in a given year). As employed, this leakage or noncompliance factor was higher, for example, for the small private forest land owners than for the large industrial private forest land owners in all scenarios. That is, a smaller percentage of small private forest land owners were expected to employ the standard practice assumptions in a given year than were the large industrial private forest land owners.

Stakeholder/Research Team Process. With the research team facilitating, stakeholders used paper maps, tracing paper, and markers to develop location-specific depictions of land use and land cover patterns for each of the alternative futures which were then translated to GIS by the research team. Each future was reviewed and refined three times at three separate meetings by the stakeholders and members of the research team, with each iteration producing a more complete mapped depiction.

The maps shown here present possible arrangements of forests, farms, and towns for the Muddy Creek Watershed in the year 2025, with accompanying explicit assumptions about land and water management practices which sustain these patterns through time (Figure 8). Each map shows several different land uses, including existing and new dwellings and different strategies for forestry and farming. The maps represent a spectrum of possible futures, from a landscape arranged to maximize short-term economic return on the left, the High Development Future, to a landscape arranged to maximize ecological function on the right, the High Conservation Future. In the middle of the five is the Plan Trend Future, representing what is foreseen for the year 2025 if the current trends of land use policy and population growth continue as projected for the next thirty years.

3. Evaluating Alternative Futures For Their Water Quality And Biodiversity Effects.

Water quality model overview. The risks to water quality were simplified by focusing on three parameters of water quality: total suspended solids, total phosphorus, and nitrate. Suspended solids are an indicator of erosion, whereas phosphorus and nitrate indicate nutrient losses from the watershed. The water quality in Muddy Creek was measured at ten sites during base flow in August 1995 and intensively at three sites during two storm events in winter 1996. Water quality data from Muddy Creek and elsewhere in the Willamette River Basin were used to calibrate a distributed water quality model for the Muddy Creek Watershed. The water quality model is based, in part, on the Modified Universal Soil Loss Equation, but it has been further revised to compute pollutant loads for individual storms. The pollutant loads are generated for an entire year using simulated hydrologic flows for each of seventeen smaller watersheds, called catchments, within the Muddy Creek Watershed. Each catchment is further divided into relatively homogeneous units based on soil properties such as erosivity, permeability, and watershed features such as slope, aspect, vegetation, and land use. Precipitation and precipitation intensity are adjusted for differences in elevation within the watershed. The partitioning for the Muddy Creek Watershed resulted in over 100,000 polygons used in the water quality model. This level of spatial resolution makes it possible to evaluate how changes in land use might affect erosion and the resulting changes in water quality. The principal objective of the GIS modeling effort was to predict hydrology, sediment transport, and nutrient transport within the Muddy Creek Watershed by applying the model to two catchments for which water quality data were collected and extrapolating the calibrated results to the other fifteen catchments within the watershed.

Water Quality Model Description: Hydrology. The model consists of a hydrologic subroutine for computing individual storm hydrographs for the study watershed. In the case of Muddy Creek Watershed, hydrologic budgets were measured on the main stem of Muddy Creek near the base of the watershed and for two catchments within the watershed. The watershed hydrology was subdivided into six components: precipitation, interception, evapo-transpiration, overland flow, unsaturated flow, and saturated flow. A tipping bucket rain gauge was installed in one of the catchments during the study and additional precipitation data were obtained from stations immediately adjacent to the watershed. Interception was estimated using the model by Gray (1973). Evaporation during the winter was estimated at two percent of total precipitation. Runoff (overland flow) was estimated using the SCS curve number methods (USDA 1972). The model calculated infiltration to the saturated and unsaturated zones using the method developed by Holtan and Lopez (1973). The remaining components, saturated and unsaturated flow, were estimated as the differences between stream discharge and the first four components. The reasonableness of the flow compartmentalization was assessed by computing peak flow using the rational formula and by computing time of concentration using the kinematic wave approximation (Henderson and Wooding 1964).

Erosion and Total Suspended Solids. Sediment yield from the watershed was estimated using the Modified Universal Soil Loss Equation (MUSLE) originally developed by Wischmeier and Smith (1965) and modified by Williams and Berndt (1977). The general form of the MUSLE model is:

$$Ae = 11.8(Qeqp)0.56\ (K)\ (LS)\ (C)\ (P)$$

where

Ae = event soil loss (metric tons/ha)
Qe = event runoff volume (m3)
qp = peak runoff (m3/sec)
K = soil erosivity factor
LS = slope-length factor
C = cropping management factor
P = erosion control practice factor

The flow parameters in MUSLE are described in the previous section. Qe was estimated using the SCS method and qp was estimated using the rational formula. The K factor was obtained directly from the Benton County soils data base. The LS factor was estimated from slope, using the equation proposed by Moore and Burch (1986). Values for the cropping factor (C) were derived from Stewart et al. (1975), Wischmeier (1972), and Wischmeier and Smith (1965). Values for the erosion control practice factor (P) were derived from Wischmeier and Smith (1965) and Ports (1973).

Nutrients. Total phosphorus (TP) was estimated based on empirical relationships between TP and total suspended solids (TSS). Phosphorus is typically transported with the sediment and, unlike nitrogen, is made more complex by clays and organic matter. Consequently, TP can be estimated to a high degree of reliability within a given catchment by regression with TSS. TP/TSS relationships in the two upland catchments monitored in the Muddy Creek Watershed were quite similar to one another, but differed considerably from the Muddy Creek main stem site because of the higher percentage of fine clay particles in the slow-moving Muddy Creek. Nitrate (NO3) concentrations in surface waters are governed by entirely different processes than those affecting TSS and TP. Whereas TSS and TP loads are largely a product of physical erosion, NO3 export is strongly affected by biological processes including biological assimilation, mineralization, nitrification, and denitrification. Nitrate concentrations in streams were first modeled in the Willamette Valley as an empirical model fitted to a zero-order decay function with an initial field value equal to the mean of the first fall storm concentration (Eilers and Bernert 1995). In Muddy Creek Watershed, NO3 concentrations were uniformly lower than values measured by Eilers and Bernert (1995) in the Pudding River Watershed and model fits for Muddy Creek, and although acceptable on an absolute basis, they exhibited high variance in the model calibration and are not presented.

Water quality model application with GIS. The hydrologic/water quality model was linked to the spatial attributes of the watershed through GIS. The GIS aspect of the modeling can be represented as two elements: (1) static data bases which are unlikely to change during the planning scenarios; and (2) dynamic data bases which are highly time-dependent. The static spatial data bases include soils, slope, hydrologic buffer zones, and catchment boundaries. The soil types were obtained from the Benton County Soil Survey at a scale of 1:20,000. The soils attributes incorporated into the spatial data set include slope, water capacity, plasticity, hydrologic group, and depth to seasonal high water. Additional information on soils erosivity (K factor) was derived from the Natural Resource Conservation Service higher order soils data base. Catchment boundaries were delineated from USGS 1:24,000 topographic maps using contour crenulation. The dynamic spatial data bases consist of the various land use scenarios and the pre-settlement vegetation cover.

Biodiversity model overview. For wildlife diversity we computed risks to species breeding in the Muddy Creek Watershed using an approach developed by White and others in a previous study in the Poconos region of Pennsylvania (White et al. 1997). This approach is based on the premise that risk to a species increases as its habitat is depleted or degraded. Applying the approach requires a GIS habitat map for each land use scenario (past, present, and alternative futures), a list of breeding species, and an estimate of the suitability of each land cover class as breeding or feeding habitat for each species. We modeled biodiversity as breeding amphibian, reptile, bird, and mammal species in the watershed. See Scott et al. (1993) for a justification for using non-fish vertebrates to represent total biodiversity.

Risk to biodiversity was calculated from ratios of habitat area adjusted by suitability (hereafter called suitability-weighted habitat) in each alternative future (and in the past) to suitability-weighted habitat in the present. We calculated risks for individual species, and mean risk for all species and for subsets of species. This measure of change in biodiversity is one estimate of change in species populations. More detailed life history requirements of species (e.g., minimum area requirements) were not incorporated in the model because these data were not available for all species. However, in an earlier study, White et al. (1997) found minimal changes to risk results when breeding territory or home range requirements were included.

Compiling the list of breeding species. We consulted multiple sources in compiling a vertebrate species list for the Muddy Creek Watershed. The list includes information for each species about native versus introduced origin, present-day versus past occurrence in the watershed, and season(s) of occurrence in the watershed (Freemark et al. 1996). The biodiversity modeling was subsequently limited to breeding species, based on their breeding-season association with breeding and feeding habitats. Fish were included in the initial working species list, but not in the evaluation because modeling approaches for fish that use the resolution of landscape data available in this project are just being developed (e.g., Roth et al. 1996). Humans, both native (now locally extirpated) and more recent immigrants, should also be considered part of a complete breeding species list for the Muddy Creek Watershed. Humans were not included in the biodiversity modeling because, in this study, human population and resource use are the primary cause (or input variable) of landscape changes, not the result.

We compiled an initial working species list of amphibians, reptiles, birds, and mammals from two primary sources: (1) the Biodiversity Research Consortium (BRC) species database (White et al. 1999) for the three hexagons that cover 99.1 percent of the watershed; and (2) the Oregon Species Information System (OSIS) species list for Benton County, Oregon. The BRC database includes information for each species in each hexagon about certainty of occurrence, season of occurrence, breeding versus non-breeding, and native versus introduced origin. The OSIS database includes information on each species' native versus introduced origin, and federal and state status (e.g., endangered, threatened, sensitive, game species). Several additional sources representing a subset of the species for the watershed area were also compiled: (1) the Breeding Bird Atlas data for the calendar year 1995 (Paul Adamus, personal communication 1996); and (2) vertebrate species checklists for Finley National Wildlife Refuge, which is wholly contained in the study area. Historical sources were consulted to ensure that the working species list was complete. We also used historical sources to identify species that have become locally extirpated since Euro-American settlement began in the mid-1800s.

The working species list for the Muddy Creek Watershed was revised through consultation with local vertebrate biology and ecology experts, who also assigned each species to one of the following categories: (1) species currently occuring and breeding in the watershed; (2) species locally extirpated (rare or unlikely breeder) in the watershed but might breed successfully with habitat improvement (deemed rare); (3) species permanently extirpated from the watershed and surrounding areas, which will not return even with favorable habitat management. Stakeholders viewed and commented on the revised species lists at joint meetings held with the research teams. Several stakeholders responded with queries about the inclusion or exclusion of a species. We consulted with local experts and/or publications to resolve each case. The final breeding species list for the Muddy Creek Watershed had 234 species, including 220 native breeding species (including eight permanently extirpated, nine rare, thirty-nine vulnerable, i.e., endangered, threatened, or sensitive) and fourteen introduced species. The list includes fourteen amphibians, fifteen reptiles, 134 birds, and seventy-one mammals (species listed in Freemark et al. 1996).

Creating species-habitat associations. We reviewed published and unpublished literature and data to determine species' use of habitats during the breeding season for breeding and/or feeding. Local experts were consulted in order to modify data from the published sources and add suitability ratings. The resulting species-habitat matrix had a single integer between zero and ten for each combination of the 234 species and twenty-six wildlife habitats indicating the suitability of that habitat for that species. Values of zero through two were considered absent in the final analysis, and values of three through ten were used as multipliers of the amount of habitat for the relevant classes in order to arrive at a total suitability-weighted habitat score.

We created a cross-reference table between mapped land cover and wildlife habitat classes to identify the habitats that each species used in the breeding season. To do this, we first compiled a list of wildlife habitats that occur in the Muddy Creek Watershed. Then we created a cross-reference between: (1) land cover classes for the present and five alternative future maps; (2) wildlife habitat classes (data from wildlife publications); and (3) Pre-Settlement vegetation classes. Creating this cross-reference table involved working within the different constraints of these three data sets. Our task was to find a balance between enough detail to capture differences between species' habitat associations, and enough generalization to have a concise set of habitats. The land cover maps were constrained by the minimum mapping unit size (pixels of 30m x 30m), which did not allow the inclusion of some habitat variables, such as small riparian or wet areas and scattered woody vegetation at field edges. In addition, the Pre-Settlement vegetation map was compiled from surveyors' notes from the 1850s based on observations along the grid of section lines that lie approximately one mile apart. These observations were then interpolated by the Oregon Natural Heritage Program (ONHP/TNC) to the landscape between the section lines, resulting in a map with lower spatial precision and lower accuracy than the present and future land cover maps.

Biodiversity risk modeling. Our analysis objective was to measure changes in biodiversity, represented by species' suitability-weighted habitat, between the present and each of the five alternative futures, and between the present and the past. Suitability-weighted habitat was used as an index of the abundance of breeding units for each species and was determined by summing, for all habitats, the product of area and suitability, for each species according to its entries in the habitat association matrix. Spatial configuration of habitat was not considered except to differentiate habitat use of road and aquatic habitats between upland and lowlands and for those aquatic-dependent species for whom a buffered habitat around streams was created. Change in suitability-weighted habitat for a species in each alternative future was calculated as the ratio of future suitability-weighted habitat to present suitability-weighted habitat, using the present as the baseline for comparison. Change in suitability-weighted habitat for each species in the past was calculated in the same manner, as the ratio of past to present. By using the present as the baseline for both the future and the past, species' suitability-weighted habitat ratios and risks are related, allowing a species' future suitability-weighted habitat (or risk) to be directly compared to its past suitability-weighted habitat (or risk).

We calculated summary risk statistics for all species and by taxonomic groups. We used the geometric mean of each set of ratios as a measure of central tendency for all groups of species that we reported on (White et al. 1997). We obtained a mean percentage of suitability-weighted habitat at risk from

(1 - [geometric mean of ratios]) x 100.

Values > 0 percent indicate loss (risk) of habitat weighted by suitability compared to the present; values < 0 percent indicate gain (improvement) of habitat, weighted by suitability compared to the present.

We also constructed maps showing changes in species richness (number of species) for alternative futures and the past compared to the present. To do this, the species-habitat matrix was converted to a zero (zero to five habitat suitability score) or one (greater than five habitat suitability score) binary score. For each future and the past, the number of species present in each pixel (30m x 30m) of habitat for the alternative future or past was subtracted from the number of species present in the same pixel in the present. A positive number indicated a gain in species richness, while a negative number indicated a loss in species richness, for that pixel of habitat in the future or past, compared to the present.

Results

Water quality. The water quality modeling results illustrate that significant deterioration in water quality for selected tributaries to Muddy Creek can be expected under the Moderate and High Development Futures (Figure 9). Most of the reductions in water quality are forecasted to occur where residential development is expected to concentrate. Much of the water quality response is expected to be limited to increases in phosphorus and suspended solids caused by accelerated erosion. Nitrate, often derived from agricultural sources, is expected to remain low in the watershed regardless of the alternative future.

An alternative future in which development is focused on one or two catchments sacrifices the fewest stream miles in the watershed to water quality degradation. Development within a given watershed can be structured to minimize damage to the stream by placement of the sites away from stream channels and in settings with low risk for erosion. Because calibration of the water quality model first requires that an approximate water budget be computed, it is also possible to assess the impact of development on increased runoff and sedimentation. Under the Moderate and High Development Futures the volume of storm runoff is expected to increase approximately five percent over current runoff volumes and ten percent over the estimated pre-settlement runoff.

If the residents of the Muddy Creek Watershed desire a future presenting no greater risk to water quality than the present pattern of land use, then they should plan toward a future with a land use pattern somewhere between the Moderate Conservation Future and the High Conservation Future (Figure 10). Water quality in the Muddy Creek Watershed is forecasted to degrade under the Plan Trend and Moderate Conservation 2025 Future, with slight improvements shown under the High Conservation 2025 Future. The strategies imposed in the conservation-oriented futures were not effective in significantly improving water quality relative to current conditions.

Biodiversity. We tabulated the changing area percentages of habitat classes in the present, alternative futures, and past landscapes. The most obvious differences in the proportions of habitat classes were between the contemporary landscapes (present and alternative futures) and the past landscape. In the contemporary landscapes, conifer classes and grass seed dominated, whereas in the 1850s landscape, older age conifer, mixed forest, oak savanna, and prairie dominated. We reiterate, however, that there are several reasons for being cautious about these differences and the resulting effect on the biodiversity risk results. The spatial mapping resolution of the nineteenth-century land surveys almost certainly resulted in an underrepresentation of lowland riparian and marsh habitats. The lack of differentiation of forest age classes in the survey notes precluded use of the finer distinctions that we have in the contemporary data, with the result that all conifer forest in the 1850s landscape was assigned to the oldest age class as the most reasonable alternative. Lastly, some of the fine distinctions in floristic composition recorded by the land surveys were lost in our modeling because we did not have habitat association data for these distinctions.

All native species had at least some habitat in all alternative futures; three introduced species had no habitat in the past because of the absence of residential areas. However, if land use trends in the watershed continue unchanged (Plan Trend) or become more highly developed over the next thirty years, there is likely to be an increased risk to abundance of the 212 extant native species, particularly birds, mammals, and amphibians (Figure 11). The results for reptiles were counter to that for other taxa, primarily because most reptile species tended to have higher habitat suitability scores for prairie, oak savanna, deciduous forests, and pasture, classes that increased only slightly (prairie, oak savanna) or declined (deciduous forest, pasture) in extent along the gradient from high development to high conservation and that (except for pasture) were much more extensive in the past.

Locations within the watershed of species loss or gain compared to the present varied among alternative futures (Figure 12). There was a trend of largest total area of species habitat loss in the High Development

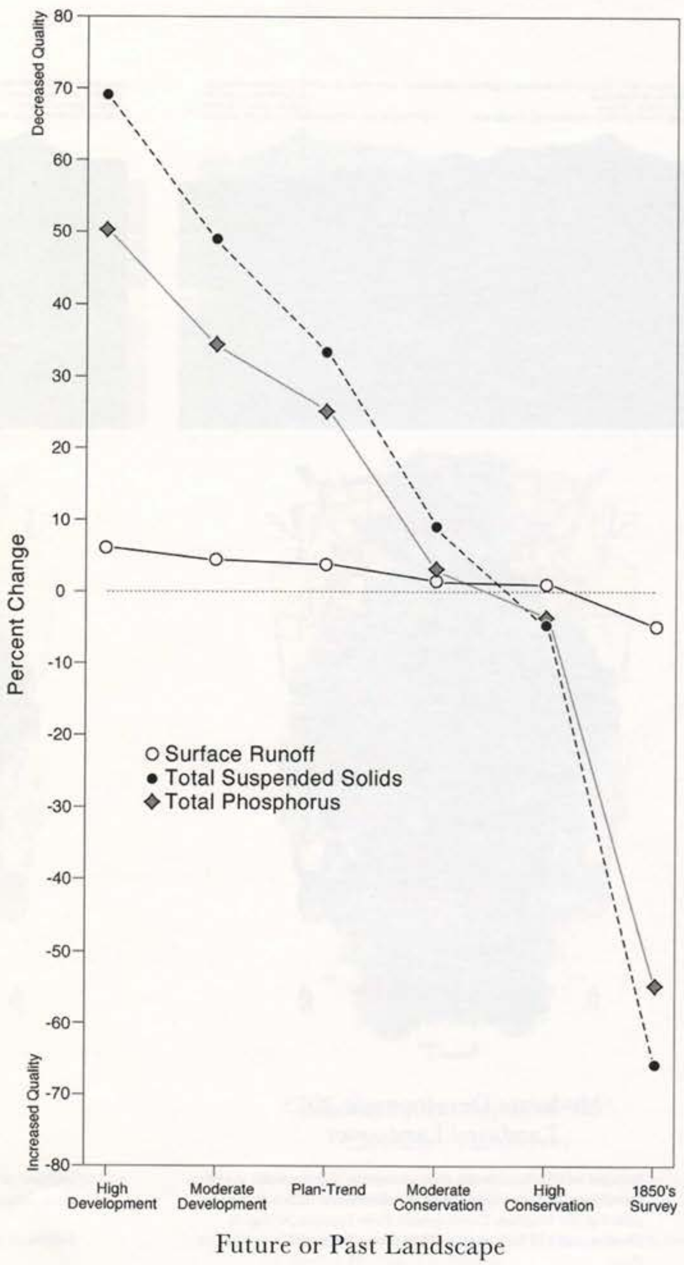
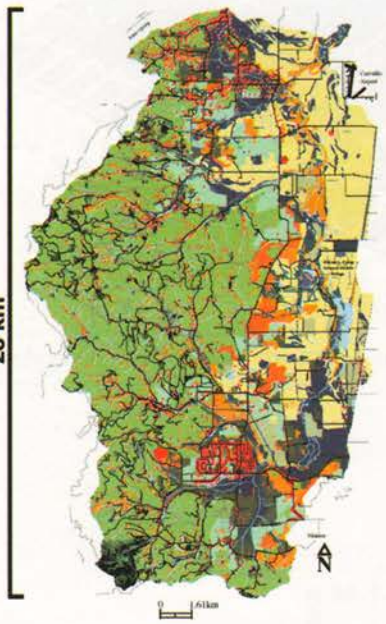


Figure 10: Overall water quality evaluative chart comparing each of the alternative futures for their effects on total discharge, total phosphorous and total suspended solids relative to 1990 conditions.

Figure 12: Summary maps showing change in species richness relative to 1990 conditions. Change in species richness maps for the alternative futures based on converting species habitat suitability scores into presence or absence using a threshold score of suitability 5 (> 5 means presence), then summing species present to obtain richness for each pixel, and then subtracting present richness from that of futures and past.

Simulation of 2025 High Development Landuse / Landcover
Muddy Creek Watershed
Benton County, Oregon
Looking Northwest from southern end of watershed



High Development 2025 Landuse / Landcover

Households increase by 1250, with 850 households added in the Southern Development Zone identified by stakeholders, 125 households added to the Northern Development Zone identified by stakeholders and 275 households added to the midlands (300-700ft in elevation) on suitable slopes with proximity to existing roads.

Major crops and practices not significantly different from 1990 conditions, except for conversion of some pasture and grassland areas to hybrid poplar based on suitable soils.

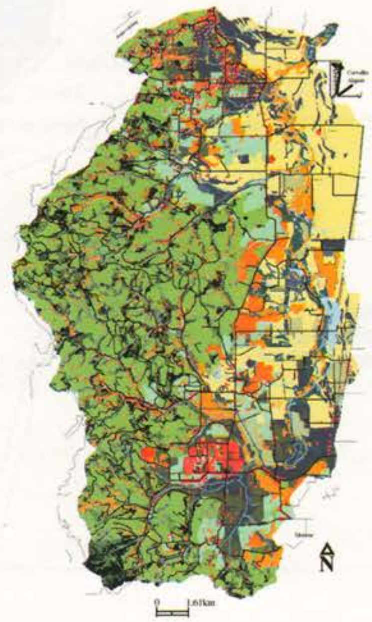
Hybrid poplar grown for pulp (short rotation) appears in suitable soils in low elevation former pastureland and grass seed as well as in some riparian wetlands.

All forest lands managed on 40 year rotation cycle with 50' riparian buffers. Approx. 10% in older age classes.

Landuse / Landcover of the Finley National Wildlife Refuge reflects an increase of grass seed production in former oak and upland deciduous/hardwood.

The Upper Hammer Creek is shown as becoming a municipal water supply for Alpine and grown 30 years.

Simulation of 2025 Moderate Development Landuse / Landcover
Muddy Creek Watershed
Benton County, Oregon
Looking Northwest from southern end of watershed



Moderate Development 2025 Landuse / Landcover

Increase of 950 households concentrated in Northern and Southern Development Zones identified by stakeholders. 825 households added in the Southern Development Zone between Alpine & Monroe and 125 households added to the Northern Development Zone.

Major crops and practices not significantly different from 1990 conditions, except for conversion of some pasture and grassland areas to hybrid poplar based on suitable soils.

All forest lands managed on 40 year rotation cycle with 100' riparian buffers. Approx. 17% in older age classes.

Landuse / Landcover of the Finley National Wildlife Refuge remains largely unchanged from 1990
with the exception of a decrease in upland oak acreage replaced by grass seed.

Simulation of 2025 Plan Trend Landuse / Landcover
Muddy Creek Watershed
Benton County, Oregon
Looking Northwest from southern end of watershed

Plan Tr
Landuse /

Increase of 475 households ac
Rural Residential 2-5 acre zo

Dominant agricultural uses m

Hybrid poplar appears in suit
pastureland.

Public lands follow the Presi
eligible lands uncut: 300' ripa
remaining "matrix" lands.

Private lands follow 1995 Or
stream buffers, with 50 year r

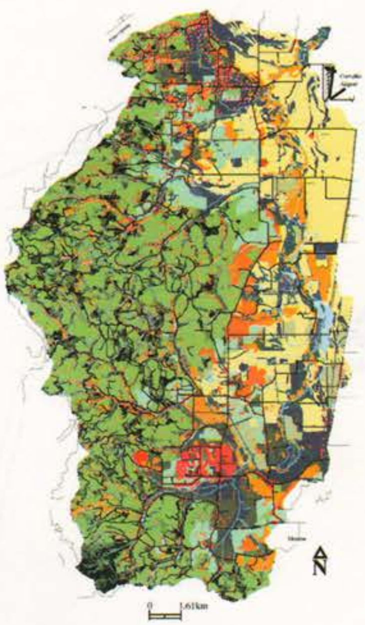
Late Successional Reserves o

Management of the Finley N
result in no change in Landus

Possible Futures for the Muddy Creek Watershed

Figure 8: The five alternative futures simulations, maps and summary assumptions. (High Development through High Conservation). Le

Simulation of 2025 Moderate Development Landuse / Landcover
Muddy Creek Watershed
Benton County, Oregon
Looking Northwest from southern end of watershed



Moderate Development 2025
Landuse / Landcover

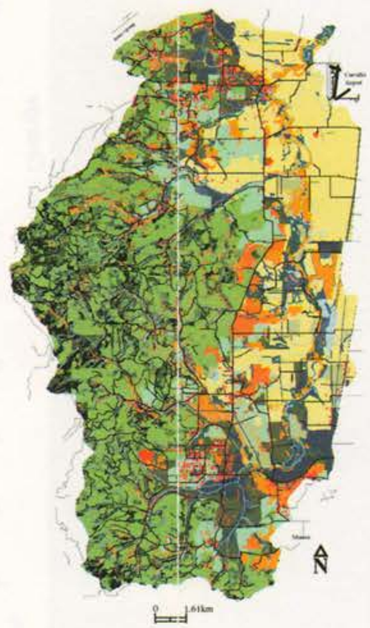
Increase of 950 households concentrated in Northern and Southern Development Zones identified by stakeholders. 825 households added in the Southern Development Zone between Alpine & Monroe and 125 households added to the Northern Development Zone.

Major crops and practices not significantly different from 1990 conditions, except for conversion of some pasture and grassland areas to hybrid poplar based on suitable soils.

All forest lands managed on 40 year rotation cycle with 100' riparian buffers. Approx. 17% in older age classes.

Landuse / Landcover of the Finley National Wildlife Refuge remains largely unchanged from 1990
with the exception of a decrease in upland oak acreage replaced by grass seed.

Simulation of 2025 Plan Trend Landuse / Landcover
Muddy Creek Watershed
Benton County, Oregon
Looking Northwest from southern end of watershed



Plan Trend 2025
Landuse / Landcover

Increase of 475 households accommodated entirely within existing Rural Residential 2-5 acre zones.

Dominant agricultural uses mostly unchanged from 1990.

Hybrid poplar appears in suitable soils in low elevation former pastureland.

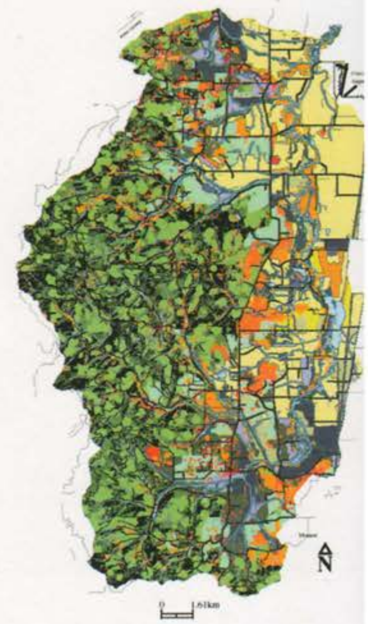
Public lands follow the President's Forest Plan with 15% of eligible lands uncut: 300' riparian buffers, 80 year rotation on remaining "matrix" lands.

Private lands follow 1995 Oregon Forest Practices Act: 100' stream buffers, with 50 year rotations across all age classes.

Late Successional Reserves on BLM land are aged by 40 years.

Management of the Finley National Wildlife Refuge is assumed to result in no change in Landuse / Landcover.

Simulation of 2025 Moderate Conservation Landuse / Landcover
Muddy Creek Watershed
Benton County, Oregon
Looking Northwest from southern end of watershed



Moderate Conservation 2025
Landuse / Landcover

Households increase by 225, all accommodated within Rural Residential 2-5 acre zoning.

An "Oregon Agricultural Practices Act" similar to the (tion Reserve Program is established.

The act requires 50' undisturbed areas adjacent to strea further 50' in cover crop or secondary forest products.

Hybrid poplar occurs in soils of low elevation formerly pastureland and grass seed. Approximately 1/2 of the l poplar will be grown for veneer (15 year rotation) and (7 year rotation).

100' hedgerows/windbreaks are introduced along all pa and line the edges of all grass seed fields. Wetlands ap the National Wetlands Inventory are incorporated near riparian buffers and hedgerows.

Public forestlands: managed in 120 year rotation cycle clearcuts (<5 acres) across all age classes. 300' riparia assumed to be no-entry zones and aged 30 years.

Private forestlands: managed in 80 year rotation cycle clearcuts (<5 acres) across all age classes. 100' riparia assumed to be no-entry zones and aged 30 years.

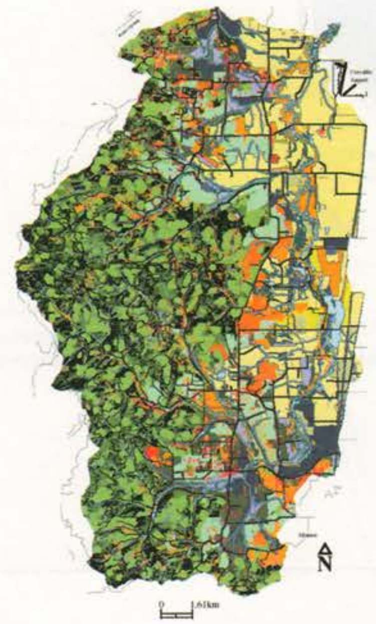
President's Forest Plan "Late Sucessional Reserves" ag Landuse / Landcover of the Finley changes with the co some grass seed to native prairie.

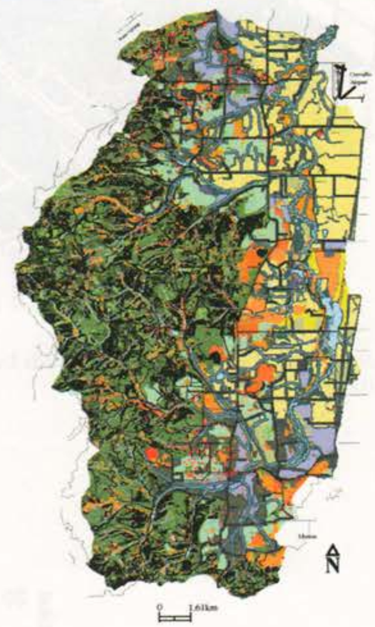
dy Creek Watershed

ps and summary assumptions. (High Development through High Conservation). Legend for these maps is same as figure 2 1990 land use/land cover.

Simulation of 2025 Moderate Conservation Landuse / Landcover
Muddy Creek Watershed
Benton County, Oregon
Looking Northwest from southern end of watershed

Simulation of 2025 High Conservation Landuse / Landcover
Muddy Creek Watershed
Benton County, Oregon
Looking Northwest from southern end of watershed





end 2025
Landcover

commodated entirely within existing
es.

ostly unchanged from 1990.

ble soils in low elevation former

ent's Forest Plan with 15% of
ian buffers, 80 year rotation on

gon Forest Practices Act: 100'
otations across all age classes.

n BLM land are aged by 40 years.

tional Wildlife Refuge is assumed to
/ Landcover.

Moderate Conservation 2025
Landuse / Landcover

Households increase by 225, all accommodated within existing Rural Residential 2-5 acre zoning.

An "Oregon Agricultural Practices Act" similar to the Conservation Reserve Program is established.

The act requires 50' undisturbed areas adjacent to streams, with a further 50' in cover crop or secondary forest products.

Hybrid poplar occurs in soils of low elevation formerly pastureland and grass seed. Approximately 1/2 of the hybrid poplar will be grown for veneer (15 year rotation) and 1/2 for pulp (7 year rotation).

100' hedgerows/windbreaks are introduced along all paved roads, and line the edges of all grass seed fields. Wetlands appearing in the National Wetlands Inventory are incorporated near (100') riparian buffers and hedgerows.

Public forestlands: managed in 120 year rotation cycle with small clearcuts (<5 acres) across all age classes. 300' riparian buffers assumed to be no-entry zones and aged 30 years.

Private forestlands: managed in 80 year rotation cycle with small clearcuts (<5 acres) across all age classes. 100' riparian buffers assumed to be no-entry zones and aged 30 years.

President's Forest Plan "Late Sucessional Reserves" aged 30 years. Landuse / Landcover of the Finley changes with the conversion of some grass seed to native prairie.

High Conservation 2025
Landuse / Landcover

Households increase by 125, all accommodated within existing Rural Residential 2-5 acre zoning.
An "Oregon Agricultural Practices Act" similar to the Conservation Reserve Program is established.

The act requires 100' undisturbed areas adjacent to streams, with a further 100' in cover crop or secondary forest products.

Hybrid poplar occurs in soils of low elevation formerly pastureland and grass seed. Approximately 3/4 of the hybrid poplar will be grown for veneer (15 year rotation) and 1/4 for pulp (7 year rotation).

200' hedgerows/windbreaks are introduced along all paved roads, and line the edges of all grass seed fields. Hedgerows also occur through grass seed fields to provide connectivity to wetlands.

Wetlands appearing in the National Wetlands Inventory are incorporated into hedgerow areas wherever possible.

Public forestlands: managed transition to pre-settlement forest species composition, age structure, patch distribution and disturbance processes.

Private forestlands: The 11 patches of Doug-fir >120 years old are preserved by either outright purchase or land swaps for other Federal lands. Other lands are managed on an 80 year uneven aged management regime with emphasis on ridges and flatter areas.

Landuse/Landcover of the Finley National Wildlife Refuge changes significantly with the conversion of some grass seed and upland oak to native prarie and oak savanna

gend for these maps is same as figure 2 1990 land use/land cover.

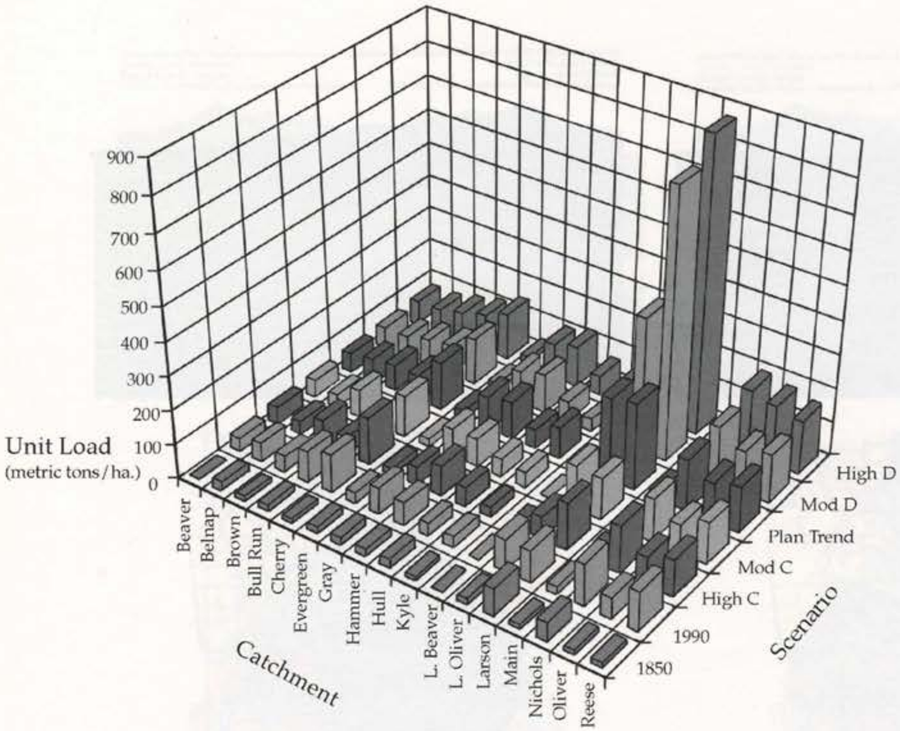
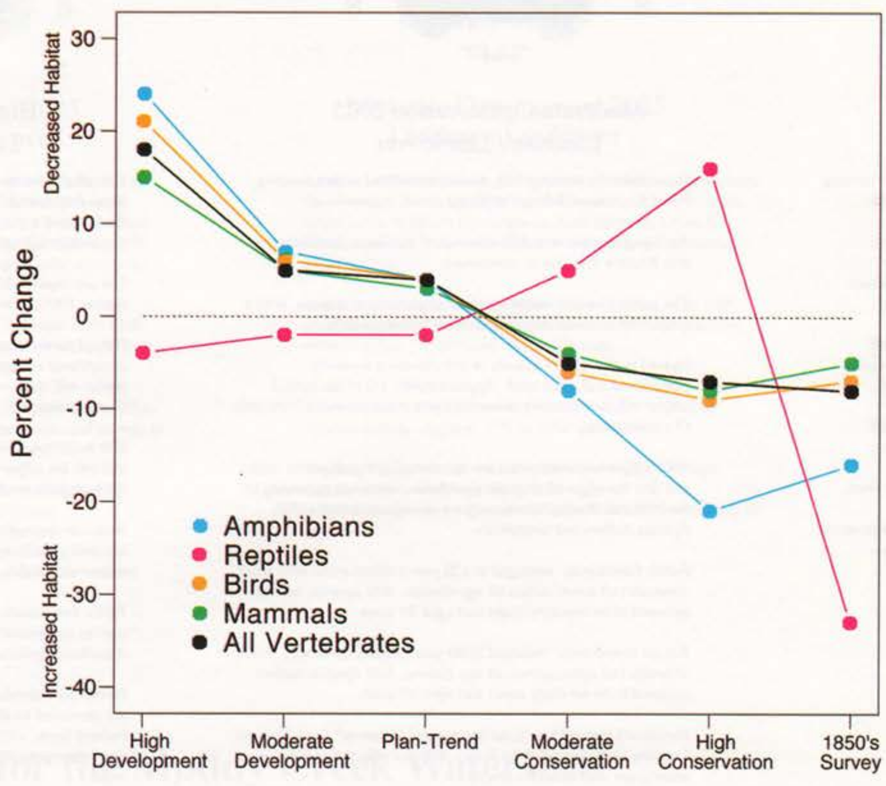


Figure 9: Unit loads of total suspended solids by sub-basin catchment and alternative future. Units are metric tons/ha.



Future or Past Landscape

Figure 11: Summary graph of biodiversity risk relative to 1990 conditions by taxonomic group. Risk to habitat area (adjusted by suitability), compared to the present, for taxonomic groups of native species, excluding introduced (I) and extirpated (E) species.

Future, decreasing to smallest total area of species habitat loss in the High Conservation Future. There was also an opposing trend of smallest total area of species habitat gain in the High Development Future, increasing to largest total area of species habitat gain in the High Conservation Future. In the Moderate Conservation Future, the total area of species habitat loss was roughly equal to the total area of species habitat gain.

Of the 220 species native to the watershed throughout its recent history, twenty-six species have lost more than half of their habitat since 1850. Under the High Development Future, twelve species are estimated to lose more than half of their present habitat in the next thirty years. Only two species—the California Condor (*Gymnogyps californianus*) and the Marbled Murrelet (*Brachyramphus marmoratus*)—are common to both lists. This acceleration and shifting of risk from one set of species to another suggests that the kinds of habitat changes from 1850 to 1990 are different than those envisioned in the alternative futures, and may indicate a cultural disturbance regime operating outside the range of natural variability of the disturbance regimes at work in the watershed prior to Euro-American settlement. We concur with Bradshaw (1998) who argues that such risk shifts can help guide well-informed monitoring plans.

If the residents of the Muddy Creek Watershed desire a future presenting no greater risk to biodiversity than the present pattern of land use, then they should plan toward a future with a land use pattern somewhere between the Moderate Conservation Future and the Plan Trend Future. The Plan Trend 2025 Future is forecasted to result in a decrease of biodiversity as defined in this project for all taxonomic groups except reptiles (Figure 11).

Discussion

The Muddy Creek project is an example of how science, policy, and citizen-based planning can interconnect to create a choice of possible future landscape configurations, each varying in its consequences. Although further refinement is required, linking landscape planning with modeling through approaches such as those presented here can begin to discriminate the effects of potential landscape change and help inform decision-making processes. Our approach has been useful for developing and engaging local support for land use planning based on a broadened set of considerations. It provides a quantitative ranking of landscape alternatives using a methodology that is relatively simple with few parameters and is adaptable to different descriptors of biodiversity and water quality. The approach is sufficiently generic that it can be applied to other spatial and temporal scales and to other regions using data of different levels of resolution (Santelmann et al. 1996). As such, it can facilitate a more comprehensive and hierarchical approach to the development of land use plans for the proactive conservation of biological diversity and water quality. It is worth noting that this process becomes merely a technical and technocratic exercise, when it is applied in such a way that the understandings produced in each step remain separate from the other steps or understandings remain known primarily to project investigators with little opportunity for the sharing of lessons learned from scientific evaluation of publicly-articulated visions. We address below the lessons and limitations that we learned from this project, using the four questions outlined previously.

1) Defining trajectories of change. The end aim of defining trajectories of change may be to determine whether or not the cultural processes currently at work in a landscape are operating beyond the historic range of variability of the natural processes that have shaped the native biota there over millennia. Rarely will information or understanding be sufficient to definitively answer this question. Thus the alternative futures approach requires those applying it to explicitly represent landscape changes in space through time, in less than perfect ways. This requires attention to the grain/extent and frequency/duration of the GIS representational models that form the basis of the alternative futures. The extent and grain of these maps limit how much territory is represented as well as the terms (i.e., the map legends) used to represent it. Perhaps more significantly for efforts where the planning horizon spans decades to centuries and the study area encompasses more than one major land use type, the grain and extent of these representational models are strongly correlated with their ability to capture the frequency and duration of change among the several land use types. Agricultural land cover conditions may vary annually, or a sequence of crops may be regularly rotated on a biannual or triennial cycle. Forest land uses may employ harvest cycles in the forty to ninety year range, while urban and suburban land uses can change in more punctuated, persistent ways. The time step between the present (1990 in our study) and the next represented time slice (2025 in our study) may be of a duration too short to capture certain landscape change processes, and too long for others. Representing landscapes with more frequent time slices and shorter time steps can help here, as can determining early in a project the periodicity of major drivers of landscape change in a study area, and designing representational models (i.e., GIS maps and their legends) and alternative future time steps accordingly.

This approach applies equally to representational models of past landscapes. In the Muddy Creek project, we would have benefited from having not only a map of landcover from presettlement times, but also from having a map of land use/land cover as far into the past as we were planning into the future. In our case, this would have meant having a map of conditions in 1955 of equal grain, extent, and articulation to those we had for 1990 and eventually for 2025. This is useful not only for adding to planners' and researchers' understandings of more recent trajectories of landscape change, but also in helping stakeholders understand in detail just how much change is possible over the planning horizon of the study. This also underscores the value of tracking spatial change over time as a meta-indicator of landscape conditions.

2) Depicting alternative futures. There are two general approaches in this kind of project to depicting specific locations of future land use activities: deterministic and probabilistic (Costanza and Sklar 1985). In deterministic approaches, a single set of inputs, expressed as map layers or land use siting rules, lead to a single conclusion about the siting location of the land use in question. In probabilistic approaches, land use siting decisions represent the likelihood of land uses occurring in a location, but multiple attempts of the same approach to siting land uses will produce a range of locations for the same land use, with sites of high probability receiving the land use more frequently than sites of low probability, thus reflecting the probabilistic nature of the approach.

For example, in examining the forested portions of the 1990 land use / land cover map of the watershed, it became clear that a simple deterministic description of industrial forestry in terms of average clear-cut size and frequency could not adequately describe the current state of the landscape. When deterministic algorithms were applied in describing the future landscape, the discrepancy became even more apparent: the landscape pattern which emerged was strikingly more regular than the stakeholder group thought reasonable or than has been produced by the past century of forest management in the watershed.

We thus worked with stakeholders to specify both standard practices and the leakage or noncompliance factor. As employed, the leakage factor was higher, for example, for the small private forest land owners than for the large industrial private forest land owners in all scenarios. That is, a smaller percentage of small private forest land owners were expected to employ the standard practice assumptions in a given year than were the large industrial private forest land owners. In our experience, this led to a more accurate characterization of the current landscape condition, and we believe the same holds true for the alternative futures.

Similarly, land use information alone is sometimes insufficient to assess the effects of land use practices on water quality. For example, much of the eastern portion of Muddy Creek Watershed is flat agricultural land currently used for grass seed production. Recent restrictions on crop residue burning have led grass seed farmers to use greater quantities of herbicides to maintain crop quality. In addition, the farmers have continued to install tile drains to further enhance crop production. These practices promote use of pesticides and may increase surface water transport from the fields without any apparent change in land use. The water quality modeling effort did not address pesticide use nor would it be sensitive enough in its current form to evaluate the hydrologic changes in intensification of a given land use.

Our analysis indicates that two intertwined factors, land ownership patterns and land use zoning, have most strongly conditioned the relationship between the human use of land and its effects on biodiversity and water quality in the Muddy Creek Watershed. These two factors and their associated mandates and incentives have led to a more spatially consolidated landscape in which patches of forest, agricultural, and rural residential land have been gathered into contiguous groups. As intended by the creators of Oregon's land use planning system, this has constrained change in use and development across the watershed during the past twenty years. The alternative futures, to the extent that they bracket a plausible range of what may be expected to happen in the watershed, show that the kinds of change anticipated by the extremes of development and conservation may overwhelm the ability of land ownership and zoning to constrain landscape change in the next thirty years as powerfully as they have during the past twenty years. We expect that seminal landscape-shaping practices, comparable in effect to these two factors in Muddy Creek, exist in other inhabited landscapes and may be equally influential in mediating the effects of human activities on biodiversity and water quality.

3. Evaluating alternative futures. The biodiversity assessment based on habitat (weighted by suitability) in this study is an approximation of a more complete assessment of population viability for the species of concern. Our approximation is based on findings that population viability is often related to area of suitable habitat and to population size, and population size is often a function of habitat area (Ehrlich 1995). In future studies we hope to augment this approach with population viability analysis (PVA) to improve the assessment of risk. For example, efforts are underway to apply PVA to all native birds and mammals in a comparable study for the Willamette River Basin (N. Schumaker, personal comment) and to mammals in agricultural watersheds in Iowa (B. Danielson, personal comment). Augmenting the approach with PVA will improve the assessment of risk by incorporating the persistence probability of species within landscapes.

As in White et al. (1997), we made a number of simplifying assumptions in the biodiversity model. We did not consider area requirements for species, nor the shape or context of a habitat patch, except for proximity to water, and upland versus lowland occurrence of water and roads. Many factors may complicate the use of species-habitat associations, including biotic interactions (e.g., predation and competition), disturbances, stochastic demographic events, suitability of edge versus interior habitat, habitat configuration, and the ability of land cover data to represent animal habitat (Wolff 1995). Studies we have in progress indicate, in particular, the need for refinements to the initial model to include a more restrictive definition of suitable habitat in relation to area sensitivity and interior/edge habitat preferences for at least some forest bird species (Santelmann et al. in review). Furthermore, many species do not occupy the entire amount of habitat available, even the most desirable habitat (Robbins et al. 1989). Thus, it is important to assess error in species-habitat models (Hansen et al. 1993, Block et al. 1994).

In addition to these assumptions, other limitations of this study include possible errors in the land cover maps. To the extent that errors in the land cover maps or in the species-habitat matrix are of similar type and magnitude across all landscapes, the errors could be partially cancelled by the model formulation as ratios of performance in the future or past to performance in the present. Furthermore, the averaging of performance across a number of species may help to smooth out errors in the representation of habitat for any particular species.

Species richness (total number of species) did not change in any of the alternative futures, because our definition of species loss was zero pixels of habitat, implying that as long as one pixel of habitat existed, a breeding unit of the species could be supported. Without considering minimum area requirements and intraspecific demographic effects, the loss of a species would require complete elimination of habitat, rather than habitat loss sufficient to reduce populations below sustainable levels. Thus there is a discrepancy between the model results (no loss of species) and reality (eight permanently extirpated species, and nine rare or locally extirpated species). This discrepancy suggests that: (1) some species may not have enough habitat to sustain a viable population and/or (2) some of the habitat associations are not accurately reflecting actual habitat use; and/or (3) the extirpations are due to factors other than habitat loss or habitat alteration (e.g., extermination of undesirable species, competition with introduced species, sensitivity to disturbance, pollution).

4) Sensitivity analysis/risk assessment. This is the portion of the alternative futures approach that is least developed and where the most work remains to be done. Current institutional frameworks for land use planning in the United States, even in states with comparatively progressive land use programs, are poorly equipped to accommodate the use of spatially-explicit sensitivity analyses in the politically-charged context of planning for landscape change. While geographic information systems are increasingly widespread in county and metropolitan planning departments, their use for tasks other than spatial record-keeping remains the exception. Our experience in the Muddy Creek study was that the appeal of such tools to the public is precisely their capacity to pose and answer "what if" questions, when used in the context of exploring plausible alternative futures. Although we were not able to explore more than a small fraction of the sensitivity analyses we considered, one will serve for example: the construction of species richness change maps for future and past landscape representations.

One way to assess the risk to biodiversity inherent in any future pattern of land use is to measure the increase or decrease, relative to the present, in the number of species per unit area of each alternative future. The species richness change maps we constructed (Figure 12) aided in the identification of landscape changes that contributed most to changes in species richness in the futures, thus helping to determine the spatial sensitivity of effects from the biodiversity model.

We argue that by demonstrating such sensitivity analyses in public venues, using alternative futures prescribed by representative public groups, awareness of such approaches grows among larger audiences and support increases to improve the information on which the analyses are based. Ultimately the political and financial support required for such efforts are intertwined. A comparatively small set of such studies exists in the United States, although their influence to date has been substantial among several federal regulatory and land management agencies, most notably the United States Environmental Protection Agency (Baker et al. 1995 (Santelmann et al. 1996) and the Department of Defense (Fittipaldi and Wuichet 1997; Mouat et al. 1998; Steinitz et al. 1996). Transferring these approaches to county and metropolitan levels may enhance planning of non-federal lands in the United States.

Acknowledgments

The authors wish to thank Muddy Creek team members Steve Radosevich, Michael Flaxman, Joe Bernert, Kellie Vache, Hilary Dearborn, Kate Kirsh, Ed Armstrong, Lisa Goorjian, David Richey, and Allan Branscomb. The authors gratefully acknowledge the assistance of Jean Baker, Rich Sumner, David Richey and David Diethelm in preparing this article. Additional information can be obtained via the Internet at http://ise.uoregon.edu.

This work was funded by cooperative agreement CR822930 between the U.S. Environmental Protection Agency and the University of Oregon; cooperative research agreement PNW 92–0283 between the U.S. Forest Service and Oregon State University; interagency agreement DW12935631 between the U.S. Environmental Protection Agency and the U.S. Forest Service, and the U.S. Department of Defense Strategic Environmental Research and Development Program Project #241-EPA. This manuscript has been subjected to U.S. Environmental Protection Agency review and approved for publication. The conclusions and opinions are solely those of the authors and are not necessarily the views of the Environmental Protection Agency.

References

Anderson, P. July 1998. *GIS Research to Digitize Maps of Iowa 1832–1859 Vegetation from General Land Office Township Plat Maps*. Departments of Landscape Architecture and Agronomy Iowa State University. http://www.public.iastate.edu/~fridolph/dnrglo.html

Baker, J., et al. 1995. *Ecosystem Management Research in the Pacific Northwest: Five-year Research Strategy*. Corvallis, OR: Regional Ecology Branch/Western Ecology Division, U.S. Environmental Protection Agency.

Block, W.M., et al. 1994. "Assessing Wildlife-habitat-relationships Models: A Case Study with California Oak Woodlands." *Wildlife Society Bulletin* 22:549–561.

Boag, P.G., 1992. *Environment and Experience : Settlement Culture in Nineteenth-century Oregon*. Berkeley : University of California Press.

Bowen, W.A. 1975. "Mapping the American Frontier Oregon in 1850, Map F Oregon Population." Map Supplement #18. *Annals of the Association of American Geographers* 65:1.

———. 1978. *The Willamette Valley—Migration and Settlement on the Oregon Frontier*. Seattle: University of Washington Press.

Bradshaw, G.A. 1998. "Defining Ecologically Relevant Change in the Process of Scaling Up: Implications for Monitoring at the 'Landscape' Level." *Ecological Scale: Theory and Application*. New York: Columbia University Press.

Costanza, R., and F.H. Sklar. 1985. "Articulation, Accuracy and Effectiveness of Mathematical Models: A Review of Freshwater Wetland Applications." *Ecological Modeling* 27:45–68.

Ehrlich, P.R. 1995. The Scale of the Human Enterprise and Biodiversity Loss. *Extinction Rates*. Oxford: Oxford University Press..

Eilers, J.E. and J. A. Bernert. 1995. *Nonpoint Source Pollution in the Pudding River Subbasin of the Willamette River. Final Report. Phase II. Willamette River Basin Water Quality Study*. Submitted to Oregon Department of Environmental Quality.

Fittipaldi, J.J. and J.W. Wuichet. 1997. *Army Ecosystem Management Study*. Army Environmental Policy Institute. AEPI-IFP-397. U. S. Department of the Army.

Freemark, K. 1995. "Assessing Effects of Agriculture on Terrestrial Wildlife: Developing a Hierarchical Approach for the U.S. EPA." *Landscape & Urban Planning* 31(1–3): 99–115.

———, et al. 1996. *Modeling Risks to Biodiversity in Past, Present and Future Landscapes*. Technical Report No. 268. Ottawa: Canadian Wildlife Service.

Gray, D.M. (ed.). 1973. *Handbook on the Principles of Hydrology*. Port Washington, NY: Water Information Center.

Habeck, J.R., 1961. "The Original Vegetation of the Mid-Willamette Valley. *Northwest Science* 35: 65–77.

Hansen, A.J., et al. 1993. "An Approach for Managing Vertebrate Diversity Across Multiple-use Landscapes." *Ecological Applications* 3:481–496.

Henderson, F.M. and R.A. Wooding. 1964. "Overland Flow and Groundwater Flow from a Steady Rainfall of Finite Duration." *Journal of Geophysical Research* 69:114–121.

Holtan, H.N. and N.C. Lopez. 1973. USDAHL-*73 Revised Model of Watershed Hydrology*. Report # 1. Washington, D.C.: U.S. Department of Agriculture, Agriculture Research Service, Plant Physiology Institute.

Hulse, D., et al. 1997. *Possible Futures For The Muddy Creek Watershed, Benton County, Oregon*. Eugene, OR: Institute For A Sustainable Environment

Johnson, K. N., et al. 1999. *Bioregional Assessments: Science at the Crossroads of Management and Policy*. Washington, D.C.: Island Press.

Kiester, A.R., et al. 1996. "Conservation Prioritization Using GAP Data." *Conservation Biology* 10(5): 1332–1342.

Montgomery, D.R., et al. 1995. "Watershed Analysis as a Framework for Implementing Ecosystem Management." *Water Resources Bulletin* 31(3): 369–386.

Moore, I.D. and G.J. Burch. 1986. "Physical Basis of the Length-slope Factor in the Universal Soil Loss Equation. *Soil Science Society American Journal* 50: 1294–1298.

Mouat, D., et al. 1998. *Analysis and Assessment of Impacts on Biodiversity: A Framework for Environmental Management on DoD Lands within the California Mohave Desert: A Research Plan*. Corvallis, OR: Regional Ecology Branch/Western Ecology Division, U.S. Environmental Protection Agency.

Novotny, V. and H. Olem. 1994. *Water Quality*. New York: Van Nostrand-Reinhold.

Portland State University Center for Population Research and Census (PSUCPRC). July 1993. *Provisional Projections of the Population of Oregon and its Counties*. Portland, Oregon.

Ports, M.A. 1973. "Use of Universal Soil Loss Equation as a Design Standard." Water Resources Engineering Meeting, ASAE, Washington, DC.

Robbins, C.S., et al. 1989. "Habitat Area Requirements of Breeding Forest Birds of the Middle Atlantic States." *Wildlife Monographs*, No. 103.

Roth, N. E., et al. 1996. "Landscape Influences on Stream Biotic Integrity Assessed at Multiple Spatial Scales." *Landscape Ecology* 11(3): 141–156.

Santelmann, M.V., et al. In Review. *Modeling Relative Risks of Local Extinction in Future Landscape Scenarios*.

———, et al. 1996. *Modeling Effects of Alternative Landscape Design and Management on Water Quality and Biodiversity in Midwest Agricultural Watersheds*. A research plan for Environmental Protection Agency grant # R825335–01. Washington, D.C.: U.S. Environmental Protection Agency/National Science Foundation Partnership for Environmental Research, Water and Watersheds Program.

Schoonenboom, I.J. 1995. "Overview and State of the Art of Scenario Studies for the Rural Environment." *Scenario Studies for the Rural Environment* Proceedings of the Symposium Scenario Studies for the Rural Environment, Wageningen, The Netherlands, 12–15 September 1994. Dordrecht: Kluwer Academic Publishers.S

Schumaker, N.H. 1996. "Using Landscape Indices to Predict Habitat Connectivity." *Ecology* 77(4): 1210–1225.

Scott, J.M., et al. 1993. "Gap Analysis: A Geographic Approach to Protection of Biodiversity. Wildlife Monographs No. 123. Supplement, *Journal of Wildlife Management* 57.

Steinitz, C. 1990. "A Framework for Theory Applicable to the Education of Landscape Architects (and other Environmental Design Professionals)." *Landscape Journal* 9(2): 136–143.

———, et al. 1996. *Biodiversity and Landscape Planning: Alternative Futures for the Region of Camp Pendleton, California*. Cambridge, MA: Harvard Design School. http://www.gsd.harvard.edu/brd/brc.html

Stewart, B.A., et al. 1975. *Control of Pollution from Cropland*. Washington, D.C.: U.S. Environmental Protection Agency Report No. 600/2–75–026 or USDA Rep. No. ARS–H–5–1. (as cited in Novotny and Olem 1994)

Swanson, F.J., et al. 1982. *Land-Water Interactions: The Riparian Zone*.Stroudsburg, PA: I Hutchinson Ross Publishing Company.

Towle, J.C. 1983. "Changing Geography of the Willamette Valley Woodlands." *Oregon Historical Quarterly* 1: 66–87.

United States Census Office. 1854. "Statistical View of the United States, embracing its territory, population—white, free colored, and slave—moral and social condition, industry, property, and revenue; the detailed statistics of cities, towns, and counties; being a compendium of the seventh census, to which are added the results of every previous census, beginning with 1790, in comparative tables, with explanatory and illustrative notes, based upon the schedules and other sources of information." Compiled by J. D. B. DeBow, Washington, D.C.

United States Department of Agriculture, Soil Conservation Service. 1972. "Hydrology." *National Engineering Handbook*. Washington, DC.

White D., et al. 1997. "Assessing Risks to Biodiversity from Future Landscape Change." *Conservation Biology* 11(2): 349–360.

———, et al. 1999. "A Hierarchical Framework for Conserving Biodiversity." *Landscape Ecological Analysis: Issues and Applications*. New York: Springer-Verlag.

Williams, J.R. and H.D. Berndt. 1977. "Sediment Yield Prediction Based on Watershed Hydrology." *Trans. ASAE* 20(6): 1100–1104.

Wischmeier, W.H. 1972. *Estimating the Soil Loss Equation's Cover and Management Factor for Undisturbed Areas*. Proceedings of the Sediment-Yield Workshop. Oxford, MS: U.S. Dept. of Agriculture Sedimentation Lab.

——— and D.D. Smith. 1965. *Predicting Rainfall-Erosion Losses from Cropland East of Rocky Mountains*. Washington, D.C.: U.S. Department of Agriculture, Agriculture Handbook # 282.

Wolff, J.O. 1995. "On the Limitations of Species-habitat Association Studies." *Northwest Science* 69: 72–76.