United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

Research Note
PNW-RN-552
September 2006

Roads in Landscape Modeling: A Case Study of a Road Data Layer and Use in the Interior Northwest Landscape Analysis System

Marti Aitken and Jane L. Hayes [1]

Abstract

Roads are important ecological features of forest landscapes, but their cause-and-effect relationships with other ecosystem components are only recently becoming included in integrated landscape analyses. Simulation models can help us to understand how forested landscapes respond over time to disturbance and socio-economic factors, and potentially to address the important role roads play in these processes. The inclusion of roads as static or as process components of the landscape modeling, however, presents numerous challenges owing to a general lack of adequate road data and threshold effect information. Roads have been included in several recent landscape analysis efforts in the Pacific Northwest, but not as dynamic components. The Interior Northwest Landscape Analysis System (INLAS) developed a framework for simulation modeling of succession, disturbance, and management activities at the subbasin level. Roads were included in the INLAS project as a static landscape feature. We describe the data, analysis, and applications of road data in the INLAS project. Using the INLAS effort as a case study, we examine the challenges of incorporating roads into multidisciplinary landscape-level analyses. With an emphasis on data requirements, we identify practical and logistic barriers to dynamic modeling of road interactions, and propose a strategy for future studies.

Keywords: Road ecology, landscape analysis, simulation modeling, NETDISTANCE.

[1] **Marti Aitken** is an ecologist, Umatilla National Forest, 3502 Highway 30, La Grande, OR 97850; and **Jane L. Hayes** is a research biological scientist, Pacific Northwest Research Station, Forestry and Range Sciences Laboratory, 1401 Gekeler Lane, La Grande, OR 97850.

Introduction

The importance of roads in the landscape is receiving considerable attention by ecologists, particularly in the last decade (e.g., Forman 1998, 2000; Forman and Alexander 1998; Forman et al. 2002; Gelbard and Belnap 2003; Gucinski et al. 2001; Lugo and Gucinski 2000; Trombulak and Frissell 2000; Ritters and Wickham 2003). In these recent reviews, the direct and indirect impacts of roads on terrestrial and aquatic ecosystems have been discussed extensively and include transformation of the physical and chemical environment in both the immediate and extended area; increased mortality of animals and alteration of behaviors and habitats; and modification of plant communities, especially through the spread of exotic species. Development of road networks on the rural landscape has been largely influenced by socioeconomic considerations (Jaarsma 1997). Rural roads provide increased access for recreation, commodities extraction, and management activities. Roads also provide access for wildland fire suppression and serve as firebreaks (e.g., Gucinski et al. 2001). It has been widely acknowledged that there are ecological and economic tradeoffs associated with roads and that the true picture of those tradeoffs is best viewed at the landscape level (e.g., Gucinski et al. 2001, Lugo and Gucinski 2000).

That said, an important issue is how to appropriately depict roads in a landscape to accurately assess these tradeoffs. As tangible features in the landscape, roads can be considered as a current condition, much as a plant community or current vegetation structure can be modeled as a persistent fixed feature or state variable. However, roads also serve as disturbance agents and vectors, and thus are part of dynamic ecological processes. In some instances, roads may cause disturbance (e.g., soil erosion or habitat fragmentation) or facilitate disturbance (e.g., act as conduits for spread of weeds and other disturbance agents); in other instances, they may inhibit disturbance (e.g., creating a fuel break that stops progression of a fire). However, including roads in landscape-level analyses presents many challenges owing to a frequent lack of adequate attribute and effects data describing types of roads and their impacts, as well as a lack of accepted modeling methodology.

Methods have been developed to incorporate roads information beyond relatively simple road-density analyses in landscape-level analyses; however, none of these efforts explicitly addresses roads as a spatially and temporally dynamic entity within the study landscape. When roads are included in landscape-level analyses (e.g., Kline et al. 2003), typically data sources and methodologies are sparingly described, limiting opportunities to fully evaluate and build on these past efforts. In this paper, we describe many challenges of incorporating roads in multidisciplinary landscape-level analyses, and discuss the treatment of roads as a static feature in an example from a landscape analysis project at the subbasin level in northeastern Oregon (Interior Northwest Landscape Analysis System [INLAS]). We provide details of the road data, analysis, and application in this case study. Focusing on data gaps, we identify practical and logistic barriers to dynamic modeling of road interactions, and propose a strategy for future studies.

Roads in Landscape-Level Analyses

A number of recent landscape simulation efforts in the Pacific Northwest have attempted to incorporate roads in the assessment of forest management effects on landscape-level ecological processes. For the most part, these efforts have considered roads as persistent components in their examination of forest vegetation change and management issues at various landscape scales. At the broadest scale (around 58 million ha), the Interior Columbia Basin Ecosystem Management Project (ICBEMP; Keane et al. 1996) developed an ecosystem-based strategy for the management of U.S. Department of Agriculture Forest Service and the Department of Interior Bureau of Land Management lands within the basin. The ICBEMP established a framework for the assessment and management of the basin's ecological, bio-physical, social, and economic conditions. Roads data were compiled from National Forest Service and Bureau of Land Management databases and represented over 200 000 km of roads on these public lands. In this study, projections indicated 30 to 50 percent more kilometers of roads may not have been inventoried (Lee et al. 1997). Based on road density analyses, ICBEMP demonstrated significant influences of roads on aquatic and terrestrial ecosystem components in the basin (Hann et al. 1997, 2003; Lee et al. 1997; Wisdom et al. 2000).

The Coastal Landscape Analysis and Modeling Study (CLAMS; Spies et al. 2002) considered a smaller area (over 2 million ha) from Oregon's coast up the west slope of the Cascades including the fertile Willamette Valley. The CLAMS was designed to assess effects of land management policies in this relatively populous multiowner province. Roads data were obtained from 1:24,000 U.S. Geological Survey (USGS) digital linear grid data and treated as a fixed feature. These data were used in a variety of analyses of the area including the influence of roads in debris flows (Miller and Burnett, n.d.) and assessment of human modification of forest habitats (Wimberly and Ohmann 2004).

At still a finer scale, the Applegate River Watershed Forest Simulation Project encompassed approximately 250 000 ha of forest in southwestern Oregon. The objective of this project was to develop a model that included stochastic disturbance events to aid in evaluating potential effects of policies and management practices over time (Graetz 2000). Roads were included in the form of equivalent roaded acres (McGurk and Fong 1995), a measure used by some Forest Service units to track cumulative watershed effects or overall disturbance impacts at the planning watershed level 1215 to 4000 ha (Menning et al. 1996, Sessions et al. 1996). Equivalent roaded acre values were used to account for alteration of vegetation caused by management activities and fire that could result in increasing waterflows and sediment production (Bettinger et al. 2004, Graetz 2000).

Using a 6000-ha watershed (hydrologic unit code 5 [HUC5]) of the goals with aquatic habitat quality objectives. In this heuristic spatial model, decision choices included silvicultural prescriptions and logging systems as well as road management by modifications of standards (e.g., standard rock to road obliteration). In a subsequent study, Bettinger et al. (1998b) used data from this scheduling model to compare predictions of equivalent clearcut areas and other indices of aquatic habitat quality along with timber harvest volume over 100 years. Equivalent clearcut area (ECA) values, like equivalent roaded acre values are used to assess cumulative effects of land management activities (including roads) on stream habitats and fish populations by aggregating these effects and assigning a single measurement per watershed. Bettinger et al. (1998b) found ECA was a poor surrogate for stream sediment and temperature levels. (For a review of these two approaches, see Ager and Clifton 2005.)

Most recently, the INLAS project created an integrated framework for modeling landscape change (Barbour et al. 2004, in press a) that applied new and existing simulation models at the subbasin scale (approximately 180 000 ha) focusing on four contiguous HUC5 watersheds of the Upper Grande Ronde River. The purpose was to examine the long-term (≥60 years) relative effects of succession, disturbance, and resource management on terrestrial and aquatic conditions and thus enable decisionmakers to evaluate the short- and long-term risks and tradeoffs of policies and management actions (reviewed in Hayes et al. 2004). The importance of and need to include roads in this integrated landscape simulation effort was identified early in the development of INLAS. Unfortunately, efforts to address roads in the landscape in the INLAS study area assumed the road network was constant, and ultimately was limited to a static view.

To our knowledge, no integrated landscape analysis project considering both upslope interaction, as well as aquatic impacts, has included roads as a dynamic, spatially and temporally explicit feature. Yet, dynamic modeling could facilitate a myriad of insights. For example, resource managers could evaluate the effects of road modifications, such as changes in recreational impacts, economic consequences, dispersal of invasive species, and fire control, as well as aquatic efforts. Given the potential importance of roads in landscape-level analyses, clearly more effort will be needed to evaluate and account for the effects of roads in landscape-level processes. Greater discourse regarding the many challenges of incorporating roads and better documentation regarding data sources and how roads were examined will be necessary for significant advancement in how we deal with roads in multidisciplinary research.

Roads in the INLAS Study Area

The INLAS study area consists of four hydrologc unit code 5 (HUC5) watersheds within the Upper Grande Ronde watershed on the eastern slope of northeast Oregon's Blue Mountains, a predominantly rural area (fig. 1). With elevations ranging from 820 to over 2130 m, this complex topography of deeply dissected drainages supports numerous vegetation types from bunchgrass communities to mixed conifer and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). Decades of fire suppression and timber harvesting have influenced the current forest structure and composition in this disturbance-prone ecosystem (e.g., Jaindl and Quigley 1996, Starr et al. 2001). Outbreaks of native and nonnative forest insects over the past two to three decades have resulted in substantial, both widespread and patchy, tree mortality in and adjacent to the project area (Filip et al. 1996, Gast et al. 1991). In addition, wildfires burned about 8100 ha within and an additional 24 300 ha immediately adjacent to the project area during the last decade. Consequently, highly heterogeneous fuel loads exist throughout the project area.

Almost 70 percent of the lands within the study area are federally owned (table 1). Although no significant population centers occur within the study area, several towns (>750 people) within the region may derive benefits from the study area (table 2). Commodity extraction has primarily been through the timber and a few nontimber industries (e.g., mushrooms); however, other locally important commodities (e.g., fire wood, huckleberries) also exist. Diverse recreational opportunities include camping, hiking, fishing, snowmobiling, hunting, and skiing. Roads facilitate all of these activities.

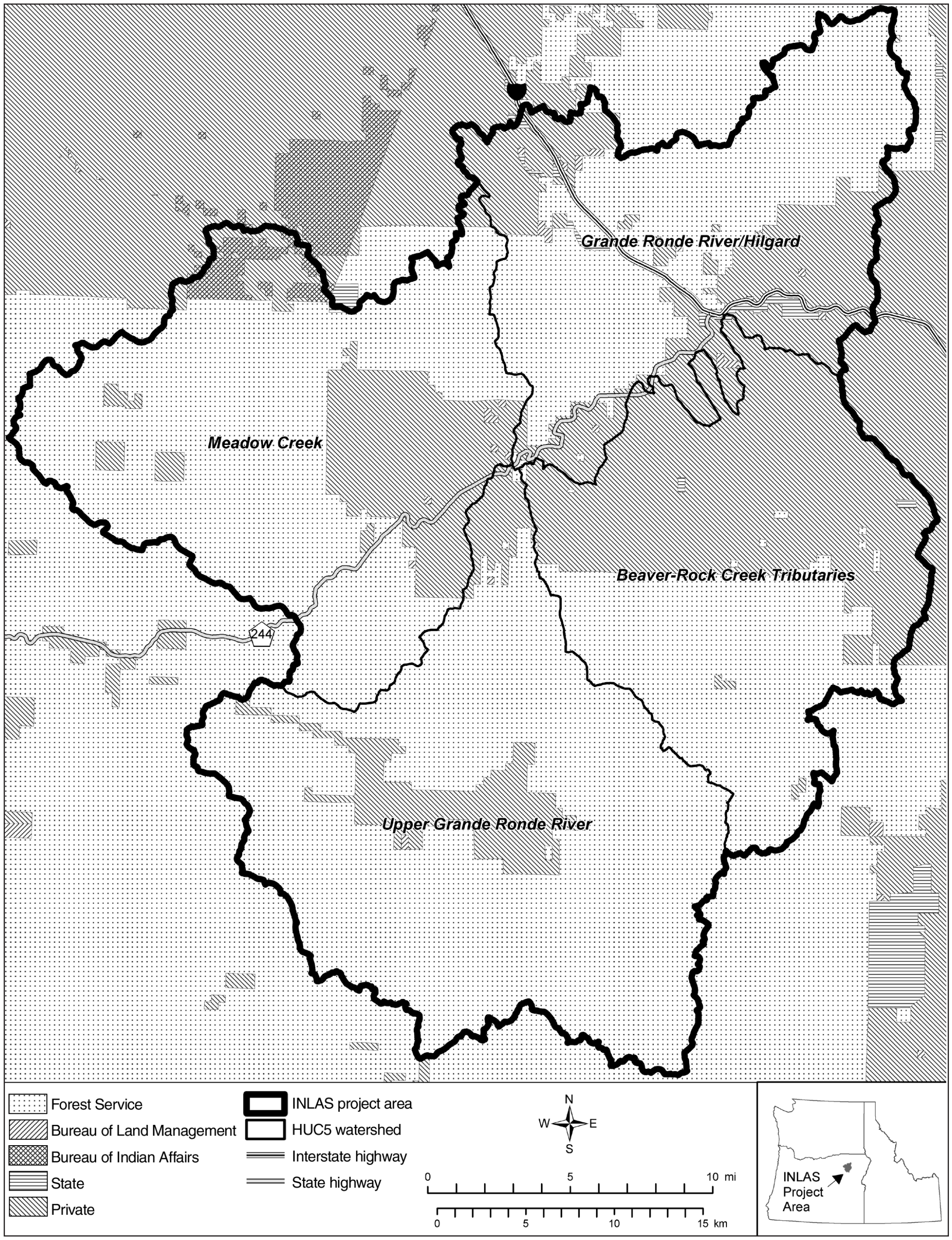

Figure 1—Land ownership in the Interior Northwest Landscape Analysis System (INLAS) project area. HUC5 = hydrologic unit code 5.

Table 1—Land administration within the Interior Northwest Landscape Analysis project area

Landowner or administrator	Area
Forest Service	122 115 ha
Private	53 551 ha
Confederated tribes	1 373 ha
State of Oregon	885 ha
Bureau of Land Management	479 ha

Source: U.S. Department of Agriculture, Forest Service 2004.

Table 2—Population centers (>750 people) within the region of the study area

Population center	Population
Baker City	9,860
Elgin	1,654
Enterprise	1,895
Joseph	1,054
La Grande	12,327
Pilot Rock	1,532
Pendleton	16,354
Union	1,962

Source: U.S. Census Bureau 2002.

Approximately 4071 km of roads exist within the study area, including 102 km of interstate and state highways (fig. 2). Most (3217 km) roads consist of native material ("dirt" or "improved dirt") and aggregate material ("gravel"). Of these local roads, 1592 km (49 percent) are closed to vehicular traffic during at least part of the year, but may continue to provide recreational access (e.g., all-terrain vehicles, snowmobiles, and equestrian and pedestrian traffic). Estimated use throughout the project area averages less than five vehicles per week annually with wide seasonal fluctuations (LeBold 2004).

Road density over the entire study area (2.28 km/km^2) exceeds both the national average (1.21 km/km^2) and the suggested maximum for maintaining large predator populations (0.6 km/km^2) (Forman and Alexander 1998). Roads in this landscape can create resource management challenges. For example, directly and indirectly roads pose significant threats to the status and abundance of some salmonid species (Baxter et al. 1999, Rieman et al. 1997) and to the viability of rare plant populations (Croft 2001). The study area provides habitat or potential habitat for 3 salmonids, 3 terrestrial vertebrates, 15 insects, and 1 plant species that

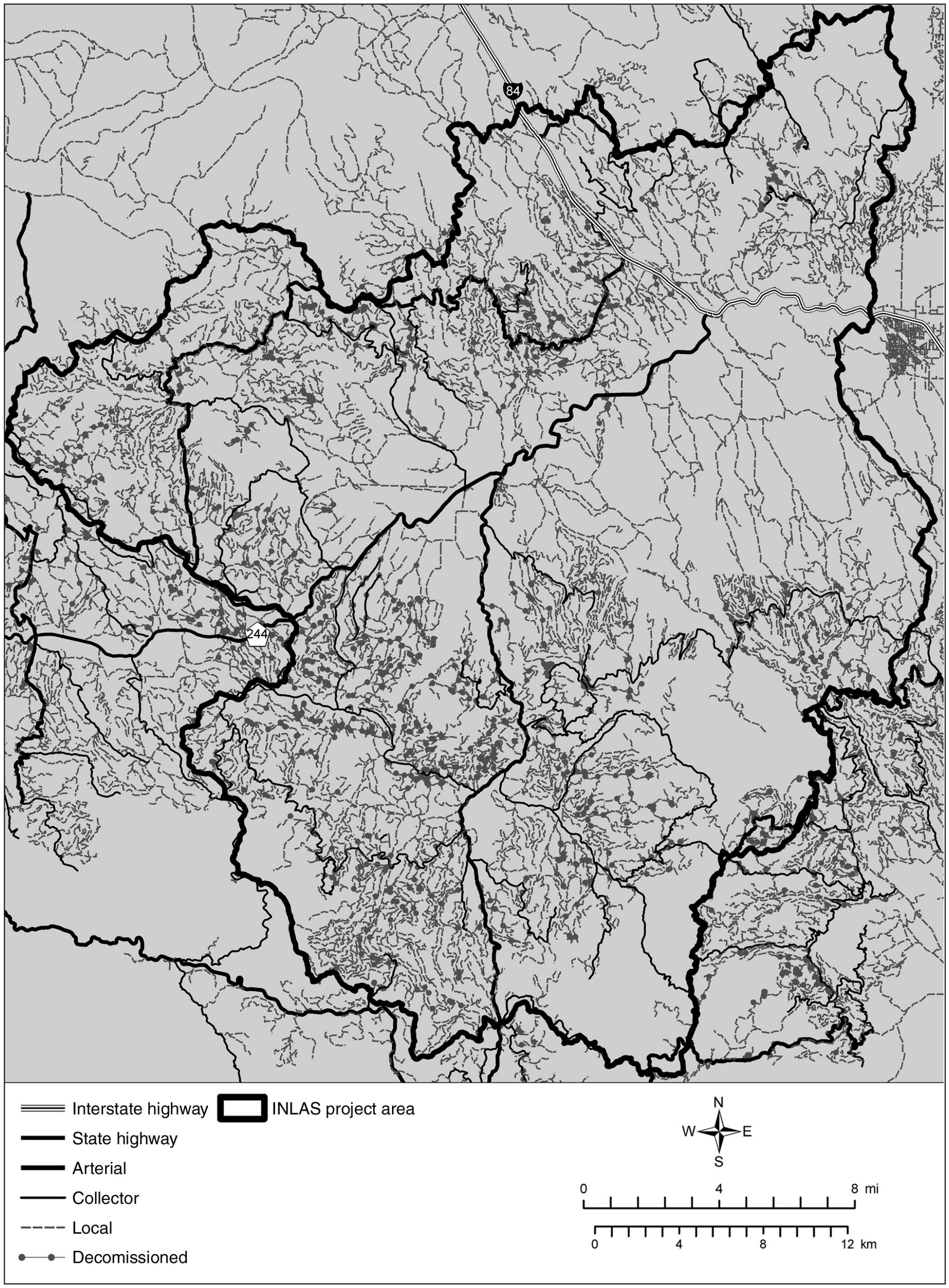

Figure 2—Transportation network in the Interior Northwest Landscape Analysis System (INLAS) project area.

Table 3—Attributes of National Forest System roads data as defined by the agency[a]

Attribute	Categories
Administrative organization (The unit where the route segment physically resides)	061606—La Grande Ranger District
Access and travel management strategy	PLC–primary roads system suitable for passenger car clearance SHC–secondary road system suitable for high clearance SLC–secondary road system suitable for high-clearance vehicles OTHR- other ATM status, road not maintained
Critical traffic (The vehicle, normally the largest [by weight, size, or unique configuration] whose limited use on the road is necessary to complete the planned activity)	4WD–four-wheel drive Bus Bus (40)–40 passenger tour bus Car–passenger car Flatbed H15 truck (tandem axle bob-tail) Garbage–garbage truck LOGT–logging truck LOWBOY–lowboy tractor trailer MTRHOME–motorhome OHH–off-highway haul vehicle PICKUP–pickup truck, high-clearance vehicle S4WD–short base four-wheel drive SEMI–semi truck (tractor trailer) SERVICE–service vehicle TRLR–car or truck with camper-boat trailer TRUCK–straight truck (H-load) YARDER–yarder-cable logging equipment
Design traffic	4WD–four wheel drive Bus Bus (40)–40-passenger tour bus Car–passenger car Flatbed–H15 truck (tandem axle bob-tail) Garbage–garbage truck LOGT–logging truck LOWBOY–lowboy tractor trailer MTRHOME–motorhome OHH–off-highway haul vehicle PICKUP–pickup truck, high-clearance vehicle S4WD–short base four-wheel drive SEMI–semi truck (tractor trailer) SERVICE–service vehicle TRLR–car or truck with camper-boat trailer TRUCK–straight truck (H-load) YARDER–yarder-cable logging equipment

Table 3—Attributes of National Forest System roads data as defined by the agency[a] (continued)

Attribute	Categories
Functional class (Character of service provided)	Arterial–service to large land areas and usually connects with other arterial roads or public highways Collector–provides service to smaller land areas than arterial roads, and usually connects forest roads to local roads Local–connects terminal facilities with forest collector roads
ID	Road ID
Jurisdiction (The legal right to control or regulate the use of a transportation facility. This requires authority, but not necessarily ownership)	BLM–Bureau of Land Management C–county FS–Forest Service L–local OFS–other Forest Service P–private S–state
Objective maintenance level (Maintenance level considering future road management objectives, traffic needs, budget constraints, and environmental concerns)	Basic custodial care (CLOSED) High-clearance vehicles Suitable for passenger cars Moderate degree of user comfort High degree of user comfort
Lanes	Single- or double-lane road
Operational maintenance level (Maintenance level currently assigned to the road considering today's needs, road condition, budget constraints, and environmental concerns)	Basic custodial care (CLOSED) High-clearance vehicles Suitable for passenger cars Moderate degree of user comfort High degree of user comfort
Primary maintenance (Agency or party having primary [largest share] financial responsibility for maintenance)	C–county CU–commercial user FS–Forest Service P–private S–state
Route status (Current physical state of being of the route segment)	Decommissioned–road surface has been significantly altered to deter vehicle use Existing–road surface exists
Surface type (The wearing course)	Asphalt Aggregate/gravel Bituminous Improved native material Native material Paved Unknown

Table 3—Attributes of National Forest System roads data as defined by the agency[a] (continued)

Attribute	Categories
System (Network of travel ways serving a common need or purpose, managed by an entity with the authority to finance, build, operate and maintain the routes)	C–county I–interstate highway NFSR–National Forest System road OF–other federal agency P–private SH–state highway US–U.S. highway
Traffic service level (Description of the road's significant traffic characteristics and operating conditions)	Free-flowing mixed traffic Congested during heavy traffic Flow interrupted–use limited Slow flow or may be blocked

[a] This table does not include fields that are the same for the entire study area (such as congressional district) or that relate solely to database management.

are federally listed as threatened, and 40 terrestrial vertebrate (Wisdom et al. 2000) and 9 plant species (USFWS 2002) that are of conservation concern. With over 65 exotic plant species documented within the Blue Mountains (Harrod et al. 1996), the role of roads in facilitating nonnative plant invasions (Gelbard and Belnap 2003, Parendes and Jones 2000) raises additional concerns.

INLAS Roads Data Sources

The INLAS modules used existing roads data from the Wallowa-Whitman National Forest geographical information system (GIS) database, with one exception. What follows is a brief outline of the roads data compiled for these analyses. The exception was the land use analysis module, which used data obtained from the Bureau of Land Management ground transportation layer and included only paved roads (Kline et al., in press); these data and analyses are not included here. For purposes of this discussion, we distinguish roads as either on-forest (within the Forest Service boundary) or off-forest (outside the Forest Service boundary).

On-forest roads originated from cartographic feature files. In 1992, the cartographic feature files were transferred to a GIS database and aligned to digital orthophoto quadrangles. Roads not visible on digital orthophoto quadrangles were field recorded with class 2 and class 3 global positioning system equipment. Attributes (e.g., type and use) were then added to the line data and calibrated to odometer measurements. These data came from numerous sources including USGS

Table 4—Number of records/segments by number of data fields containing an attribute

Number of attributes	Number of records/segments
1	1,205
5	1
6	2
7	15
8	30
9	2
10	7
11	40
12	313
13	5,436

7.5 minute quadrangle hardcopy maps, internal hardcopy road logs, reports, historical documents, and computer-aided design (CAD) files. Attribute collection and application followed Forest Service core data management specifications. Attributes are summarized in table 3. As is typical of Forest Service roads data (Gucinski et al. 2001), these data emphasize the transportation aspect of roads (vs. impacts to natural resources).

Off-forest roads were also based on cartographic feature files but generally did not receive the extensive alignment and correction processes of the on-forest roads, as they are outside the agency's jurisdiction. For similar reasons, and with few exceptions (e.g., state and federal highways), these roads lacked attribute data collected for the on-forest roads (see table 3). These roads occurred on state, county, industrial, and nonindustrial private, and tribal lands.

All spatial data obtained from the Wallowa-Whitman National Forest were mapped at 1:24,000, comply with National Map Accuracy Standards (precision and accuracy ± 12.192 m) to the extent possible, and were assumed to be complete. The INLAS roads database was derived from a forest-wide coverage that was updated in August 2003.

The database consisted of 7,051 records, each representing a road segment and associated attributes (fig. 2). A segment is defined as the portion of road between an intersection and either an endpoint or another intersection. Together these segments form a transportation network. Record completeness (columns with data) varied tremendously within the data set. For example, no records were complete, and 17 percent of the records were missing more than half of the attribute data (table 4). Furthermore, records with missing data were not necessarily missing the same data. These variations in the composite database occurred as the result of aggregating records from different projects with different objectives, funding, and staffing. As the agency's organizational emphasis continues to change, databases with comparable variation may become more common. Although many nonforest administrative entities maintain databases of roads within their jurisdiction, no common standards exist. No additional data were collected specifically for the INLAS project. Although we cannot know how many uninventoried roads may exist in the study area, Bate et al. (in press) estimated the percentage of uninventoried roads within this area to be 20 percent, which is significantly lower than reported for the ICBEMP (Lee et al. 1997) mentioned earlier.

The INLAS project assumed private roads were open and accessible. Closed (access controlled with signage, gate or barricade) and decommissioned (physically altered to prevent use) roads were included in the analysis with the assumption that closed roads could be reopened. Closed roads were considered closed regardless of duration of closure (continuous, temporary, or seasonal). Although construction of new roads in the study area was considered unlikely at the time, the project included closed and decomissioned roads to allow for some flexibility in the roads network.

Application of Roads Data in INLAS Modules

The detailed road GIS data layer described above was used in the INLAS study in two specific ways: (1) to help determine the feasibility of forest product utilization throughout the study area based on road access and (2) to account for the influence of roads on wildlife habitat conditions.

To support the forest product utilization and wildlife habitat components of INLAS, we needed to be able to calculate the shortest distance between specified points within the project area by using the existing transportation network. The analyses were done in Arc/INFO[2] and Arc/GRID with NETDISTANCE (Hatfield 2002), an Arc Macro Language script that calculates the shortest distance from any point or polygon centroid ("approximate center") on or near any specified linear network (e.g., transportation, streams, etc.), and then the distance along that network to another point on that network (a network center). This program allowed us to calculate (1) the distance from the centroid of each of the 27,557 mapped vegetation stands (polygon centroids) to the nearest road (part of a linear network), and (2) the shortest distance within the transportation network from that point to a

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

specified end point such as a town ("network center"). Unlike other Arc/INFO program functions, such as COSTDISTANCE, which returns a cost (e.g., time) on a case-by-case basis, NETDISTANCE returns distances within a network and can evaluate multiple cases, such as our large data set. Although NETDISTANCE was developed specifically for INLAS, the tool can be applied to any network and may have great utility to those working with stream networks.

The forest product utilization component of INLAS examined the forest product potential as part of planning ecological restoration treatments of forested landscapes. Barbour et al. (in press b) developed a composite utilization index based on the concept that the probability that harvest activities will occur on a site is a function of the site accessibility, treatment implementation cost, and removed material value. They employed NETDISTANCE and the roads data for two purposes: first, to estimate potential physical access to vegetation stands for harvesting; and second, to compute mileage from those accessible vegetation stands to an existing mill in Elgin, Oregon (table 2). Any stand for which the minimum distance to an open or closed road was no more than 90 m was considered accessible for harvest operations. Mileage values were used to calculate approximate hauling costs for economic evaluation of potential harvesting prescriptions (Barbour et al., in press b).

The wildlife component of INLAS used roads data to evaluate the influence of roads on certain habitat conditions (Bate et al., in press). Snags and logs provide critical habitat for many terrestrial vertebrates and invertebrates. The existence of a road, open or closed, was an important factor for modeling snag density in wildlife analyses (Bate et al., in press). Studies have shown that snag and log densities decrease as distance to roads decreases (Hann et al. 1997, Reed et al. 1996, Trombulak and Frissell 2000). Bate et al. (in press) created two distance variables to evaluate relationships of roads with snag/log densities. As with the utilization component, distances were calculated by using NETDISTANCE from each stand or plot to the nearest open or closed road. Bate et al. (in press) also used distances to categorize each stand or plot according to the adjacent road status: (1) primary road (open seasonally or year round), (2) secondary (gated, controlled, or closed), or (3) no adjacent road. NETDISTANCE was also used to compute a mileage estimate from each sample stand or plot to the nearest network center. In this case, network centers were the towns of La Grande, Pilot Rock, and Elgin (table 2).

Note that the shortest distance analyses, such as used here, assume the shortest route is the optimal route. In reality, the shortest route may not be optimal. For example, topographic constraints (e.g., a sheer cliff, river, etc.) between the polygon centroid and the road may render a route undesirable. Within the transportation or road network, engineering and ownership constraints may prohibit certain traffic. Also, a slightly longer route may have higher travel speeds and thus be preferable owing to shorter travel time. To develop an analytical tool that yielded optimal NETDISTANCE calculations would require the consistent availability of attribute and use data on which to build reasonable assumptions about ideal travel routes, and these data were unavailable.

Challenges for Future Landscape Analysis Efforts

Roads data developed for INLAS contributed to forest product utilization and wildlife habitat components. Nevertheless, despite the high quality of the data (i.e., an estimated 80 percent of the roads were represented), those contributions were based on a snapshot of the INLAS roads data. Unfortunately, snapshots are the case to date for other landscape modeling efforts as well. Although theoretically possible, a dynamic modeling effort required data that are not presently available. A dynamic method of modeling roads may allow better understanding of the impacts of roads on ecosystem processes and on management activities and resource goals. For example, the ability to simulate road construction could have contributed substantially to projections of forest product utilization, aligning it with prescribed treatments and in keeping with nontimber resource management. However, simulating ecological impacts of road treatments requires not only the ability to add, modify, and remove roads on the landscape, but also to assign accurate parameters for effects. These assignments pose potentially significant challenges, given existing data and research gaps. These knowledge gaps occur primarily in the availability of spatially explicit baseline attribute and use data and of data documenting resource effects, especially threshold levels (Lugo and Gucinski 2000, Miller et al. 1996).

In the INLAS project, spatial data were collected at appropriate and comparable scales for most analysis modules, and were detailed and current. However, this may not be the case for all projects, and supplementary data acquisition can be a major task. Numerous sources for roads data exist (e.g., commercial data, U.S. Census Bureau TIGER data, etc.), but these data may have been collected at a scale inappropriate for the analysis. Within interdisciplinary analyses the appropriate scale may vary among disciplines. For example, the vegetation and other biophysical components of INLAS used local data, whereas the land use analysis component of INLAS was carried out on a regional scale reflecting the potentially substantial influence of regional factors on forest and rangeland development. In addition to scale issues, data from these different sources do not necessarily follow standard mapping guidelines or provide adequate metadata. Consequently, quality cannot always be determined (e.g., data age, spatial accuracy) and in some instances, existing data may be outdated. For example, USGS digital line data (vector) are available for our study area but are derived from data that are 20 or more years old. Hawbaker and Radeloff (2004) compared available sources of digital roads data and concluded that road density is substantially underestimated and that fragmentation may be significantly underestimated as well. In the case of the INLAS project, other data sources lacked representation of minor roads that make up the majority of the road network and often play a significant ecological role in many forest and range landscapes.

In addition to the spatial representation, complete and pertinent attribute data are also needed. Incomplete attribute data may result in the elimination of minor roads and underestimation of road density (e.g., ICBEMP, Keane et al. 1996). Even when data sets are complete, the attribute data typically reflect the interests of the collecting entity, which may be insignificant or unsuitable for ecological analysis. For example, attributes of TIGER data (U.S. Census Bureau 2002) consist primarily of addresses, which may not be useful for ecological analysis of rural landscape. Similarly, the preponderance of data collected for forest roads inventories relates to transportation (Gucinski et al. 2001) and engineering needs, not ecological modeling efforts.

Given the opportunity to collect additional data, a project like INLAS might consider traffic count data. Strategically placed counters can yield valuable information about when roads are used (e.g., do traffic peaks occur during hunting seasons, during spring mushroom harvests, etc.) and by what types of traffic (e.g., a logging truck, a passenger car, or an all-terrain vehicle). Limited traffic count data existed for the study area, and these data were nearly two decades old. More recent and extensive traffic count data exist for the Starkey Experimental Forest and Range (Rowland et al. 1997, Wisdom et al. 2005), a 10 285-ha research facility located entirely within the INLAS project area. Traffic within the facility is controlled for research purposes, and it is not necessarily appropriate to extrapolate numbers throughout the project area. Road use data could contribute to and connect multiple components of INLAS. For example, traffic can influence elk ranges and movement (e.g., Rowland et al. 2005). Traffic data may be used to model elk movement patterns, which may influence herbivory, and subsequently vegetation patterns. Road use data could also enable more effective use of existing road modeling tools such as ROADMOD (Anderson and MacDonald 1998), which provides spatially-explicit estimates of road surface erosion based on the upslope road drainage area and the road gradient. They suggest that additional data such as road surface characteristics and road use would likely increase the model's predictive accuracy. Because most roads in the study are constructed from "native materials," these data are likely to be very important (Miller et al. 1996).

In addition to the data described above, there is a need for "threshold data" that would identify the point(s) at which the effect(s) from roads become detectable for the resource in question (Lugo and Gucinski 2000, Miller et al. 1996). Threshold data for populations or species are complex because, over the landscape, they vary temporally and by resource. Lugo and Gucinski (2000) pointed to the challenges of evaluating effects of roads with regard to fragmentation, because the road types and use patterns represent different barriers to different species, and the fragment size threshold for a normally functioning population or community is likely to differ. For example, elk and deer respond differently to roads, and these responses differ with the level and type of traffic, but the precise levels of disturbance that elicit responses are unknown (Wisdom et al. 2005). Ideally, threshold data would not only be collected for functioning roads, but for closed and decommissioned roads as well. Trombulak and Frissell (2000) found ecological benefits from the selective removal, relocation, or remediation of roads may also have thresholds. Road effects often continue over an extended period and impact resources in many ways, such as through the continued harvest of snags by woodcutters along roads closed to vehicular traffic (e.g., Bate et al., in press). Thus, the threshold at which an effect from a management activity occurs (such as a road closure) may be spatially and temporally deferred.

Although some resource impacts data exist and the number of studies is increasing, these data are often specific to a species and locality. In watershed contexts, road effects are rarely distinguished from other landscape disturbances such as logging and the site preparation that accompanies road construction. Consequently, the ability to model the effects of roads on the landscape over time is limited. Relatively few studies of road manipulations have considered multiple ecological or resource impacts or been carried out over sufficient timeframes to provide temporal "threshold data" for these activities. Currently, the general lack of research and information regarding the ecological impacts of roads ultimately limits the relevance of roads data in landscape-level analyses.

Although collection of new data exceeded the scope of INLAS and road data requirements for future efforts may be daunting, projects with similar data issues may consider implementing a stratified sampling approach. For example, the study area could be divided into areas based on predominant types of use. Roads could be stratified by surface type and functional class for traffic count data collection. Subsequent stratifications might include topographic qualities (i.e., slope, aspect, elevation), ownership, and surficial geology.

Given these data, one approach toward dynamic modeling of roads in landscape analyses may be to treat roads as both a static condition (a "state") and a process (a "transition") occurring on the landscape. This would allow incorporation into existing and accepted landscape modeling software, such as the Vegetation Dynamics Development Tool (VDDT; Beukema et al. 2003) and the Tool for Explanatory Landscape Scenario Analysis (TELSA; Kurz et al. 2000), which were backbone tools for several INLAS modules including vegetation (Hemstrom et al., in press), herbivory (Vavra et al., in press), wildlife (Wales et al., in press), and riparian (Wondzell et al., in press). VDDT is a nonspatial model used to build and test state and transition models for a set of environmental strata. TELSA allows assignment of state transition probabilities, assignment of contagions to polygons, preferential flow between polygons, and neighborhood checks. With this flexibility, it may be possible to model a variety of processes such as changes in road use, the spread of noxious weeds along the road corridor and into adjacent vegetation stands, and changes in traffic flow, by modeling roads as both a state and a process (or transition). Linear road data could be used to generate road polygons identifying both the road and the "impact zone." Application of these tools to "linear" features builds on the approach taken by Wondzell at al. (in press) in modeling stream and riparian habitat. However, unlike the stream and riparian modeling where disturbance typically propagates in one direction (downstream), disturbances associated with roads are at least bi-directional. Incorporating these data with other existing resource data may significantly increase the data set size. For example, with INLAS data, incorporation of preliminary road polygon data with the vegetation data (27,557 features) more than tripled the number of polygons for analysis. We estimate the increase in polygons would double the already considerable processing time for TELSA analysis.

Considering the complexity of the roads resources, multidisciplinary projects such as INLAS may be better able to incorporate roads data by the early and continued commitment of resources specifically for acquisition of necessary data and analyses. The development of a dynamic road ecology component for similar landscape analyses might require the following skills: a working knowledge of GIS applications including network modeling; first-hand knowledge of the study area; knowledge of engineering, ecology, policy, and socioeconomics; and skills in developing relationships among research disciplines. These considerations, along with the realization that this will not be a simple effort, should be in place before the project start.

Acknowledgments

Financial support for this project was received from the USDA Forest Service, Pacific Northwest Research Station, Managing Disturbance Regimes and Focused Sciences Delivery Programs. We thank Sue Cothren, and Brian Fischer for roads data, and technical expertise. We thank Chuck LeBold for information regarding road use in the Upper Grande Ronde watershed, and David Hatfield for analytical support. We thank Mary Rowland, Miles Hemstrom, and three anonymous reviewers for helpful comments.

English Equivalents

When you know:	Multiply by:	To find:
Centimeters (cm)	0.394	Inches
Meters (m)	3.28	Feet
Square meters (m^2)	1.20	Square yards
Hectares (ha)	2.47	Acres
Kilograms per hectare (kg/ha)	.893	Pounds per acre
Liters (L)	1.057	Quarts
Celsius (°C)	1.8 and add 32	Fahrenheit

References

Anderson, D.M.; MacDonald, L.H. 1998. Modeling road surface sediment production using a vector geographic information system. Earth Surface Processes and Landforms. 23: 95-107.

Ager, A.A.; Clifton, C. 2005. Software for calculating vegetation disturbance and recovery by using the equivalent clearcut area model. Gen. Tech. Rep. PNW-GTR-637. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 11 p.

Barbour, R.J.; Ager, A.A.; Hayes, J.L. 2004. A framework for the development and application of INLAS: the Interior Northwest Landscape Analysis System. In: Hayes, J.L.; Ager, A.A.; Barbour, R.J., tech. eds. Methods for integrating modeling of landscape change: Interior Northwest Landscape Analysis System. Gen. Tech. Rep. PNW-GTR-610. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 1-16.

Barbour, R.J.; Hemstrom, M.; Hayes, J.L. [In press a]. The Interior Northwest Landscape Analysis System: a step toward understanding integrated landscape management planninig. Landscape and Urban Planning.

Barbour, R.J.; Maguire, D.A.; Singleton, R. [In press b]. Evaluating forest product potential as part of planning ecological restoration treatments of forested landscapes. Landscape and Urban Planning.

Bate, L.J.; Wales, B.; Wisdom, M.J. [In press]. Snag densities in relation to human access and associated management factors in forests of northeastern Oregon. Landscape and Urban Planning.

Baxter, C.V.; Frissell, C.A.; Hauer, F.R. 1999. Geomorphology, logging roads, and the distribution of bull trout (*Salvelinus confluentus*) spawning in a forested river basin: implication for management and conservation. Transactions of the American Fisheries Society. 128: 854-867.

Bettinger, P.; Johnson, K.N. 1998a. Evaluating the association among alternative measures of cumulative watershed effects on a forested watershed in eastern Oregon. Western Journal of Forestry. 13: 15-22.

Bettinger, P.; Graetz, D.; Ager, A.A.; Sessions, J. 2004. The SafeD forest landscape planning model. In: Hayes, J.L.; Ager, A.A.; Barbour, R.J., tech. eds. Methods for integrating modeling of landscape change: Interior Northwest Landscape Analysis System. Gen. Tech. Rep. PNW-GTR-610. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 41-63.

Bettinger, P.; Sessions, J.; Johnson, N.K. 1998b. Ensuring the compatibility of aquatic habitat and commodity production goals in eastern Oregon with a Tabu search procedure. Forest Science. 44: 96-112.

Beukema, S.J.; Kurz, W.A.; Pinkham, C.B.; Milosheva, K.; Frid, L. 2003. Vegetation Dynamics Development Tool, user's guide version 4.4c. Vancouver, BC: ESSA Technologies Ltd. 239 p.

Croft, L.K. 2001. Rare plants of eastern Oregon and Washington. Northwest Science. 75 (Spec. issue): 149-156.

Filip, G.M.; Torgersen, T.R.; Parks, C.A.; Mason, R.R.; Wickman, B. 1996. Insects and disease factors in the Blue Mountains. In: Jaindl, R.G.; Quigley, T.M., eds. Search for a solution: sustaining the land, people, and economy of the Blue Mountains. Washington, DC: American Forests: 169-202.

Forman, R.T.T. 1998. Road ecology: a solution for the giant embracing us. Landscape Ecology. 13: iii-v.

Forman, R.T.T. 2000. Estimate of the area affected ecologically by the roads system in the United States. Conservation Biology. 14: 31-35.

Forman, R.T.T.; Alexander, L.E. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics. 29: 207-31.

Forman, R.T.T.; Sperling, D.; Bissonette, J.A.; Clevenger, A.P.; Cutshall, C.D.; Dale, V.H.; Fahrig, L.; France, R.; Goldman, C.R.; Heanue, K.; Jones, J.A.; Swanson, F.J.; Truentine, T.; Winter, T.C. 2002. Road ecology: science and solutions. Washington, DC: Island Press. 481 p.

Gast, W.R., Jr., Scott, D.W.; Schmitt, C.; Clemens, D.; Howes, S.; Johnson, C.G., Jr., Mason, R.; Mohr, F.; Clapp, R.A., Jr. 1991. Blue Mountains forest health report: new perspectives in forest health. [Place of publication unknown: [Unconventional pagination]. U.S. Department of Agriculture, Forest Service, Malheur, Umatilla, and Wallowa-Whitman National Forests.

Gelbard, J.L.; Belnap, J. 2003. Roads as conduits for exotic plant invasions in a semiarid landscape. Conservation Biology. 17: 420-432.

Graetz, D.H. 2000. The SafeD model: incorporating episodic disturbances and heuristic programming into forest management planning for the Applegate River watershed, southwestern Oregon. Corvallis, OR: Oregon State University. 344 p. M.S. thesis.

Gucinski, H.; Furniss, M.J.; Ziemer, R.R.; Brookes, M.H., eds. 2001. Forest roads: a synthesis of scientific information. Gen.Tech. Rep. PNW-GTR-509. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 103 p.

Hann, W.J.; Jones, J.L.; Karl, M.G.; Hessburg, P.F.; Keane, R.E.; Long, D.G.; Menakis, J.P.; McNicoll, C.H.; Leonard, S.G.; Gravenmire, R.A.; Smith, B.A. 1997. Landscape dynamics in the basin. In: Quigley, T.M.; Arbelbide, S.J., eds. An assessment of ecosystem components in the Interior Columbia basin and portions of the Klamath and Great Basins. Gen. Tech. Rep. PNW-GTR-405. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 337-1077. Vol. 2.

Hann, W.J.; Wisdom, M.J.; Rowland, M.M. 2003. Disturbance departure and fragmentation of natural systems in the interior Columbia basin. Res. Pap. PNW-RP-545. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 19 p. (Quigley, T.M., ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

Harrod, R.J.; Taylor, R.J.; Gaines, W.L.; Lillybridge, T.; Everett, R. 1996. Noxious weeds in the Blue Mountains. In: Jaindl, R.G.; Quigley, T.M., eds. Search for a solution: sustaining the land, people, and economy of the Blue Mountains. Washington, DC: American Forests: 107-117.

Hatfield, D.C. 2002. NETDISTANCE. http://www.fs.fed.us/digitalvisions/tools/index.php. (March 21, 2005).

Hawbaker, T.J.; Radeloff, V.C. 2004. Roads and landscape pattern in northern Wisconsin based on a comparison of four road data sources. Conservation Biology. 38: 1233-1244.

Hayes, J.L.; Ager, A.A.; Barbour, R.J., tech. eds. 2004. Methods for integrating modeling of landscape change: Interior Northwest Landscape Analysis System. Gen. Tech. Rep. PNW-GTR-610. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 218 p.

Hemstrom, M.; Merzenich, J.; Reger, A.; Wales, B. [In press]. Integrated analysis of landscape management scenerios using state and transition models in the Upper Grande Ronde River subbasin, Oregon, USA. Landscape and Urban Planning.

Jaarsma, C.F. 1997. Approaches for the planning of rural road networks according to sustainable land use planning. Landscape and Urban Planning. 39: 47-54.

Jaindl, R.G.; Quigley, T.M. 1996. Finding a solution. In: Jaindl, R.G.; Quigley, T.M., eds. Search for a solution: sustaining the land, people, and economy of the Blue Mountains. Washington, DC: American Forests: 285-299.

Keane, R.E.; Long, D.G.; Menakis, J.P.; Hann, W.J.; Bevins, C.D. 1996. Simulating coarse scale vegetation dynamics using the Columbia River basin succession model–CRBSUM. Gen. Tech. Rep. INT-GTR-340. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 50 p.

Kline, J.D.; Azuma, D.L.; Moses, A. 2003. Modeling the spatially dynamic distribution of humans in the Oregon (USA) Coast Range. Landscape Ecology. 18: 347-361.

Kline, J.D.; Moses, A.; Lettman, G.; Azuma, D.L. [In press]. Modeling forest and rangeland development in rural locations, with examples from eastern Oregon. Landscape and Urban Planning.

Kurz, W.A.; Beukema, S.J.; Klenner, W.; Greenough, J.A.; Robinson, D.C.E., Sharpe, A.D.; Webb, T.M. 2000. TELSA: the tool for exploratory landscape scenario analysis. Computers and Electronics in Agriculture. 27: 227-242.

LeBold, C. 2004. Personal communication. Civil engineering technician. Wallowa-Whitman National Forest, 3502 Highway 30, La Grande, OR 97850.

Lee, D.C.; Sedell, J.R.; Rieman, B.E.; Thurow, R.F.; Williams, J.E.; Burns, D.; Clayton, J.; Decker, L.; Gresswell, R.; House, R.; Howell, P.; Lee, K.M.; MacDonald, K.; McIntyre, J.; McKinney, S.; Noel, T.; O'Conner, J.E.; Overton, C.TK.; Perkinson, D.; Tu, K.; Van Eimeren, P. 1997. Broadscale assessment of aquatic species and habitats. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 1057-1713. (Quigley, T.M., ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

Lugo, A.E.; Gucinski, H. 2000. Function, effect, and management of forest roads. Forest Ecology and Management. 133: 249-262.

McGurk, B.J.; Fong, D.R. 1995. Equivalent roaded area as a measure of cumulative effect of logging. Environment Management. 19: 609-621.

Menning, K.; Erman, D.C.; Johnson, K.N.; Sessions, J. 1996. Modeling aquatic and riparian systems, assessing cumulative watershed effects, and limiting watershed disturbance. In: Sierra Nevada Ecosystem Project: final report to Congress. Addendum. Davis, CA: University of California, Centers for Water and Wildland Resources.

Miller, J.R.; Burnett, K.M. [N.d.]. Debris flow model. Manuscript in preparation. On file with: K. Burnett, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331.

Miller, J.R.; Joyce, L.A.; Knight, R.L.; King, R. 1996. Forest roads and landscape structure in the southern Rocky Mountains. Landscape Ecology. 11: 115-127.

Parendes, L.A.; Jones, J.A. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the H.J. Andrews Experimental Forest, Oregon. Conservation Biology. 14: 64-75.

Reed, R.A.; Johnson-Barnard, J.; Baker, W.L. 1996. Contribution of roads to forest fragmentation in the Rocky Mountains. Conservation Biology. 10: 1098-1106.

Rieman, B.E.; Lee, D.C.; Thurow, R.F. 1997. Distribution, status, and likely future trends of bull trout within the Columbia River and Klamath River Basins. North American Journal of Fisheries Management. 17: 1111-1125.

Ritters, K.H.; Wickham, J.D. 2003. How far to the nearest road? Frontiers in Ecology and Environment. 1(3): 125-129.

Rowland, M.M.; Bryant, L.D.; Johnson, B.K.; Noyes, J.H.; Wisdom, M.J.; Thomas, J.W. 1997. The Starkey project: history, facilities, and data collection methods for ungulate research. Gen. Tech. Rep. PNW-GTR-396. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 62 p.

Rowland, M.M.; Wisdom, M.J.; Johnson, B.K.; Penninger, M.A. 2005. Effects of roads on elk: Implications for management in forested ecosystems. In: Wisdom, M.J., tech. ed. The Starkey project: a synthesis of long-term studies of elk and mule deer. Lawrence, KS: Transactions of the North American Wildlife and Natural Resources Conference, Alliance Communication Group: 42-52.

Sessions, J.; Johnson, K.N.; Sapis, D.; Bahro, B.; Gabriel, J.T. 1996. Methodology for simulating forest growth, fire effects, timber harvest, and watershed disturbance under different management regimes. In: Sierra Nevada Ecosystem Project: final report to Congress. Addendum. Davis, CA: University of California, Centers for Water and Wildland Resources: 115-142. Chapter 5.

Spies, T.; Reeves, G.; Burnett, K.M.; McComb, W.C.; Johnson, K.N.; Grant, G.; Ohmann, J.L.; Garmen, S.L.; Bettinger, P. 2002. Assessing the ecological consequences of forest policies in a multi-ownership province in Oregon. In: Liu, J.; Taylor, W.W., eds. Integrating landscape ecology into natural resource management. Cambridge, United Kingdom: Cambridge Press: 179-207.

Starr, G.L.; Hayes, J.L.; Quigley, T.M.; Daterman; G.E.; Brown, S. 2001. A framework for addressing forest health and productivity in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 1-10.

Trombulak, S.C.; Frissell, C.A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology. 14: 18-30.

U.S. Census Bureau. 2002. Census 2000 data for the state of Oregon http://www.census.gov/census2000/states/or.html. (July 8, 2005).

U.S. Fish and Wildlife Service [USFWS]. 2002. Letter to Forest Supervisor listing species of concern for the La Grande Ranger District, Wallowa-Whitman National Forest. Species list No. 1-4-02-SP-912, File No. 118.0000 of September 2002. On file with: La Grande Ranger District, 3502 Hwy. 30, La Grande, OR 97850.

U.S. Department of Agriculture, Forest Service. 2004. Data on file with: Wallowa-Whitman National Forest, 1550 Dewey Ave., Baker City, OR 97814.

Vavra, M.; Hemstrom, M.; Wisdom, M.J. [In press]. Modeling the effects of herbivores on the abundance of forest overstory states using a state-transition approach in the Upper Grande Ronde River Basin, Oregon, USA. Landscape and Urban Planning.

Wales, B.; Suring, L.; Hemstrom, M.A. [In press]. Modeling potential outcomes of fire and fuel management scenarios on the structure of forested habitats in northeastern Oregon, USA. Landscape and Urban Planning.

Wimberly, M.C.; Ohmann, J.L. 2004. A multiscale assessment of human and environmental constrains on forest land cover change on the Oregon (USA) coast range. Landscape Ecology. 19: 631-646.

Wisdom, M.J.; Cimon, N.J.; Johnson, B.K.; Garton, E.O.; Thomas, J.W. 2005. Spatial partitioning by mule deer and elk in relation to traffic. In: Wisdom, M.J., tech. ed. The Starkey project: a synthesis of long-term studies of elk and mule deer. Lawrence, KS: Transactions of the North American Wildlife and Natural Resources Conference, Alliance Communication Group: 53-66.

Wisdom, M.J.; Holthausen, R.S.; Wales, B.C.; Hargis, C.D.; Saab, V.A.; Lee, D.C.; Hann, W.J.; Rich, T.D.; Rowland, M.M.; Murphy, W.J.; Eames, M.R. 2000. Source habitats for terrestrial vertebrates of focus in the interior Columbia basin: broad-scale trends and management implications. Volume 1–Overview. Gen. Tech. Rep. PNW-GTR-485. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 529 p. (Quigley, T.M., ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

Wondzell, S.M.; Hemstrom, M.A.; Bisson, P.A. [In press]. Simulating riparian and aquatic habitat dynamics in response to natural and anthropogenic disturbance regimes in the Upper Grande Ronde River, Oregon, USA. Landscape and Urban Planning.

Pacific Northwest Research Station

Web site	http://www.fs.fed.us/pnw
Telephone	(503) 808-2592
Publication requests	(503) 808-2138
FAX	(503) 808-2130
E-mail	pnw_pnwpubs@fs.fed.us
Mailing address	Publications Distribution Pacific Northwest Research Station P.O. Box 3890 Portland, OR 97208-3890