Integrating Fuel Treatments into Comprehensive Ecosystem Management

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Abstract—*To plan fuel treatments in the context of comprehensive ecosystem management, forest managers must meet multiple-use and environmental objectives, address administrative and budget constraints, and reconcile performance measures from multiple policy directives. We demonstrate a multiple criteria approach to measuring success of fuel treatments used in the Butte North Strategic Placement of Treatments (SPOT) pilot project. Located in the Beaverhead – Deerlodge National Forests, Montana, the project addresses multiple issues: altered wildlife habitat affecting sensitive species, grassland conversion to forest, an insect epidemic, water resource concerns, wildland-urban interface development, and wildland fire management. Managers are working with researchers to develop dynamic landscape management strategies. They employ multiple modeling approaches to conduct an integrated assessment of ecological and resource issues relative to multiple management scenarios. Besides evaluating effects of proposed treatments on changes to fire behavior, they also evaluate effects on wildlife habitat, disturbance processes, water quality and economics of treatment alternatives. The intent is to effectively integrate fuel management with Forest Plan goals and comprehensive ecosystem management. This approach offers a structure to use multiple criteria to evaluate success of fuel management activities in the context of other resource objectives.*

Introduction

Recent dramatic increases in wildland fires triggered the commitment of substantial resources to reduce hazardous fuels. The Government Accounting Office (2002) calls for federal land management agencies to develop "consistent criteria to identify and prioritize" areas requiring treatment and "clearly defined outcome-oriented goals and objectives." The urgency to reduce forest fuels creates tension with expectations that forest management must address competing resource objectives while applying the best available ecosystem science. The Healthy Forest Restoration Act of 2003 established a framework to conduct hazardous fuels reduction projects on federal forested lands to protect key ecosystem components, reduce risk to communities and municipal water supplies, improve critical habitat for threatened or endangered species, restore vegetation structure to reflect historic variability, improve commercial value of forest biomass, and address insect infestation. How do managers effectively integrate the complexities of ecosystem science and multiple resource objectives into practical planning strategies?

The scientific basis for comprehensive ecosystem assessment is well established (Grumbine, 1997) and issues of applied ecosystem assessment have been thoroughly discussed (Haynes et al. 1996; Holt 2001; Jakeman and

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Letcher 2003; van der Sluijs 2002). Provisions for conducting environmental impact analysis and managing resources to meet multiple objectives were established in the National Environmental Policy Act of 1969 and National Forest Management Act of 1976, respectively.

Computer-based decision support systems evolved concurrently with ecosystem sciences. Numerous modeling systems seek to transfer ecosystem theory and knowledge into practical management solutions. Many modeling tools focus on resource specific issues such as water quality, wildlife habitat, wildland fire behavior, vegetation processes, management logistics, and economic resource assessment. Many modeling tools coevolved with geographic information systems (GIS) permitting spatially explicit model displays. The need to assess integrated ecosystem components drives development of the emerging field of Integrated Assessment Modeling (IAM) (Jakeman and Letcher 2003; van der Sluijs 2002). In principle, IAM accounts for ecological, social, and economic values where planning environmental and resource management activities. The objective of IAM is to integrate multiple, relevant modeling components into a unified framework to improve how complex environmental problems are analyzed and possible solutions identified.

This paper presents a conceptual framework for a modeling-based assessment and planning procedure that integrates forest fuel treatments with multiple resource objectives. The framework is an example of an IAM currently used for the Butte North Project, Beaverhead-Deerlodge National Forest, Montana. The project is as a pilot of the USDA Forest Service, Strategic Placement of Fuels (SPOT)program. The SPOT program is intended to guide development of a “consistent and systematic interagency approach” to identify and plan treatments on forested acres deemed most critically in need of fuel reduction (Bosworth 2005). The framework is presented in a structured, stepwise format, and provides insight into how integrated assessment modeling is practically implemented. We conclude by describing a “performance report card” for evaluating treatment success based upon multiple resource objectives.

Study Area

The Butte North Project area, located in Silver Bow County, Montana, covers 38,600 ac, 80% of which is managed by the Beaverhead-Deerlodge National Forest (BDNF) (figure 1). In the lower elevations, shallow, highly erodible soils support grass and sagebrush lands. The forested lands above are dominated by lodgepole pine (*Pinus contorta*) with 2,800 ac of Douglas-fir (*Pseudotsuga menziesii*) in drier sites. The area was heavily impacted by mining throughout the late 19th and early 20th century (Lyden 1948). Most of the timber was removed to support mining operations. Commercial logging of lodgepole pine occurred most recently during the 1980’s. Many forest roads intersect stream channels. Over 80 residential structures occupy the wildland-urban interface. Small ranch operations run cattle on private lands and federal grazing allotments. The National Forest lands are highly valued for hunting and other recreation. A small municipal water supply reservoir is also located within the project area.

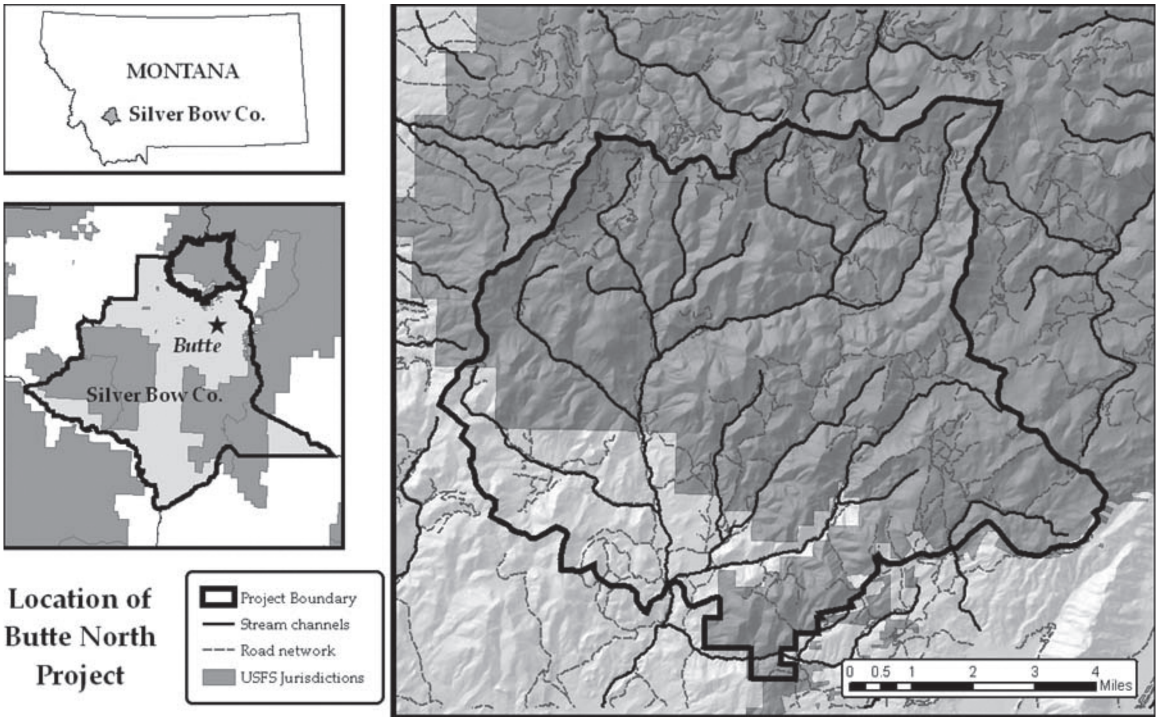


Figure 1—Location of study area within Silver Bow County, Montana.

Current Conditions and Management Issues

The land use history and current environmental conditions result in multiple management issues. Details follow by seven general resource topics as defined by the BDNF managers. These topics are repeated in major sections of the paper as we describe the integrated modeling process.

A. Vegetation: Dense seedling and sapling cohorts occupy stands commercially harvested 20-30 years ago. Conifers continue to encroach upon grass and sagebrush lands. Understory development within Douglas-fir stands increases acres of densely stocked, multi-story vegetation. There are few stands of large mature trees, limiting the potential development of more complex 'old-growth' type vegetation structure. Encroachment and increased vegetation density generally reduces landscape complexity.

B. Insects: Infestations of mountain pine beetles are present and threaten to spread rapidly throughout the conifer forests causing extensive mortality to lodgepole and Douglas-fir stands.

C. Fire and forest fuels: Continuous stands with heavy fuel loading could provide conditions for rapid fire growth. Vegetation on over half of the managed area is classified as Fire Regime Condition Class 3 (FRCC3), indicating that conditions are departed from the historic range of variability and that significant management may be needed for restoration (Hann and Strohm 2003). Fuel loadings in beetle infested areas may increase in the future as infested trees senesce.

D. Watershed: Stream channels are over-widened and contain uncharacteristic volumes of fine sediments, probably from past mining activities and the extensive forest road network. Willow is regenerating poorly, in part due to conifer encroachment and over-grazing in riparian zones.

E. Wildlife habitat: The trend toward lower vegetation complexity probably limits habitat for species which historically inhabited the area. Plans for any proposed management activities must consider habitat for multiple aquatic and terrestrial sensitive species including red squirrel, *Tamiasciurus hudsonicus* (nesting, foraging), lynx, *Lynx canadensis* (den, foraging), black-backed woodpecker, *Picoides arcticus* (habitat), pileated woodpecker, *Dryocopus pileatus* (nesting, foraging), flammulated owl, *Otus flammeolus* (nesting, foraging), northern goshawk, *Accipiter gentilis* (nesting, foraging), fisher, *Martes pennanti* (den, foraging) and West Slope Cutthroat Trout (*Oncorhynchus clarki lewisi*).

F. Social: Dense fuel concentrations proximate to residential structures and within the municipal watershed could threaten lives, property, and a drinking water source should severe wildland fire occur.

G. Economics: Funds to conduct any management activities are limited. Proposed activities must be logistically and economically feasible.

Developing an Integrated Modeling Framework

The core Butte North assessment team consisted of specialists in silviculture, wildlife, GIS, fire and fuel management, hydrology, fisheries, and landscape modeling. Following background research, group discussions, and field reconnaissance, the team defined resource issues and developed a list of possible management objectives. The objectives were translated into landscape components and relationships that could be defined within a GIS and modeling applications. Rules were developed to adapt these components and relationships into assessment logic within the modeling framework. Modeling tools appropriate to resource issues were implemented addressing vegetation, insect spread, fuels and fire, wildlife habitat, and human uses. Modeling results were integrated into a final modeling system which assessed the feasibility and trade-offs associated with multiple objective scenarios. In summary, the IAM process was accomplished through the following steps:

Step 1: Translate Issues to Objectives
Step 2: Translate Objectives to Modeling Logic
Step 3: Build and Integrate Models
Step 4: Define Basis for Scenario Comparison
Step 5: Frame Alternative Scenarios

The IAM process permits visualization of possible consequences of multiple plausible alternatives which may help estimate and confirm anticipated benefits and conflicts. IAM may also reveal unanticipated opportunities and pitfalls. The intent is to provide spatially explicit comparison across a range of alternative scenarios.

Step 1: Translate Issues to Objectives

The core team developed a series of management objectives defined by specific activities, to address the seven identified landscape issues.

A. Vegetation: Implement pre-commercial thinning in stands commercially harvested over the past 2-3 decades. Restore grass and sagebrush lands using slashing and broadcast burning. Reduce Douglas-fir understory vegetation. Protect selected stands with larger stem sizes, passively managing for potential 'old growth' conditions. Monitor spatial arrangement of vegetation activities for changes to the mosaic of vegetation structure.

B. Insects: Thin beetle infested stands to reduce competition among the remaining trees and salvage value of some trees in infested areas.

C. Fire and forest fuels: Reduce forest fuels within stands with highest potential for extreme fire behavior. Reduce vegetation density in FRCC3 areas. Reduce vegetation density in beetle infested areas.

D. Watershed: Limit or prohibit management activities near stream channels, especially where sensitive species are present. Remove conifers encroaching into broadleaf riparian vegetation.

E. Wildlife habitat: Monitor and constrain management activities which alter potential habitat for species of concern. Minimize impacts to currently suitable habitat and favor change which increases suitable habitat.

F. Social: Reduce loading of forest fuel near structures and within the municipal water supply watershed.

G. Economics: Use commercial values from vegetation treatments which yield merchantable timber to generate revenues to fund other, non-commercial resource improvements.

Many of these objectives could be addressed simultaneously through activities within the same landscape area. For example, revenues from harvesting to reduce stand density within insect infested areas could help fund stream restoration projects. Conversely, activities to meet one objective could directly conflict with other resource objectives. For example, mechanical activity to reduce forest fuels could increase sedimentation to streams and alter sensitive wildlife habitat. The challenge of the IAM approach is to define resource relationships sufficiently well to illuminate benefits, trade-offs, and conflicts within the modeling environment.

Step 2: Translate Objectives to Modeling Logic

With objectives defined, the next step was to determine which resource components to model and to identify available data. Each objective was reviewed to determine which physical and landscape attributes best describe the features affected by the objective and how these features relate to the planning landscape. Implicit in these definitions is the requirement that spatial data be available. This is an iterative process which requires dealing with "chicken or egg" logic; prior knowledge of model input requirements may limit data that can be used, while available data may limit which modeling tools may be used (Mulligan and Wainwright 2004). Also, available data may not be sufficient; more data may need to be collected, parameters may need to be estimated from existing data, or alternative modeling approaches may be necessary.

The *minimum modeling unit*, the smallest land area identified as having unique characteristics, was also chosen at this step. The convention defining vegetation stands (hereafter "stands") as a minimum mapping unit logically translated to the minimum modeling unit. All computations and summaries are based upon the attributes of the minimum modeling unit. Attributes were assigned to stands as a single assignment assuming homogeneity for the entire unit or as a percentage of land area occupied by a given feature within the unit. An example of percentage is the portion of a vegetation stand occupied by a stream buffer. The stream buffer is also an example of a management *zone*. Zones may define common jurisdictions, areas with common management objectives, or other classifier useful for planning and analysis.

A. Vegetation: The GIS stands layer which established the minimum modeling unit was a composite of legacy Timber Stand Management Record System (TSMRS) with vegetation updates from Satellite Imagery Land Classification (SILC) data (Redmond and Ma 1996). Each stand was assigned a dominant plant/tree species, vegetation structure class, canopy density class, and habitat type.

B. Insects: The 2005 Aerial Detection Survey (ADS) GIS layer was used to identify stands and label with current beetle infestation (USDA Forest Service 2005).

C. Fire and forest fuels: In addition to assigning FRCC classifications a fire and fuels specialist used expert opinion to translate vegetation data into definitions of fuel characteristics required for fire behavior modeling. Topographic information required for fire behavior modeling was acquired from a digital elevation model and historical weather data was acquired from a nearby weather station.

D. Watershed: Stream buffers were delineated around perennial stream channels after the Inland Native Fish Strategy (INFISH) (USDA Forest Service 2006) guidelines. A riparian recovery zone was established at 50 ft and an activities monitoring/exclusion zone was established at 300 ft. The coincidence of the 300 ft zone was appended to the stands layer as a binary attribute and the portion of a stand occupied by the riparian buffer was assigned to each stand. Areas previously identified as high priority for recovery were assigned as a priority zone.

E. Wildlife habitat: Wildlife habitat modeling required vegetation characteristics acquired from the GIS stand layer.

F. Social: The locations of structures were approximated using the Montana parcel GIS layer (available at: http://nris.state.mt.us/nsdi/cadastral/) to generate a point layer representing building clusters. Points from the GIS were adjusted to match recent aerial photos provided by the BDNF. Stands within the municipal supply watershed were attributed based on a GIS layer provided by the BDNF.

G. Economics: Activity cost estimates were provided by the BDNF. Revenue estimates from potential commercial sales were derived from the transaction evidence appraisal (TEA) procedures of USDA Forest Service Region 1 (2005), explained further in the next section. Estimates of potential harvest volumes were derived from the basic vegetation attributes of the stands layer.

Step 3: Build and Integrate Models

The data describing landscape attributes and management effects were loaded into individual resource models, or sub-models. Using independent sub-models maintains model integrity, greater process transparency, and better description of errors and uncertainties inherent in all environmental modeling (Beven 2006; van der Sluijs 2002). Sub-models may be sophisticated computer programs or very simple rules developed from research or expert opinion. Respective model outputs were organized back into the base GIS and finally compiled into a final Integrated Assessment Model.

A. Vegetation—Successional pathways: Logic for successional pathways following disturbance and management activities was adopted as previously developed from research literature and expert opinion (Chew et al. 2004).

B. Insects—Infestation spread model: Based on current conditions defined by the ADS, the projected spread of the infestation was modeled using a GIS-based approach (Shore and Safranyik 1992) adapted to fit available data. Results of the insect spread modeling were used to construct a future landscape used in the fire behavior modeling to estimate fire behavior 20-30 years in the future assuming increased insect spread and increased fuel loading as dead and dying trees senesce.

C. Fire and forest fuels: Potential fire behavior was modeled using the Treatment Optimization Model (TOM) within the FLAMMAP modeling system (Finney 2002). TOM uses GIS data layers to analyze fire spread behavior assuming fixed ignition sources, and weather and wind conditions. The resulting map suggests the location, orientation, and size of fuel treatment polygons, or TOM polygons, which may most effectively and efficiently change large fire growth. Separate TOM runs were completed using 97-99th percentile weather conditions, prevailing winds from two directions, NW and SW, and two vegetation conditions, current and future bug-infested conditions created by the insect spread model. The GIS stands were attributed to indicate coincidence with TOM polygon.

D. Watershed—Specialist analysis: Watershed analysis was limited to specialist field assessments and GIS attribution of stream buffer zones previously described.

E. Wildlife Habitat—Model of wildlife habitat zones: Wildlife zones were determined by matching GIS vegetation data with the habitat requirements of the species (Hart et al. 1998; Pilliod 2005; Ruediger et al. 2000; Samson 2005). The zones were categorized on a 0-3 scale for habitat quality and the GIS stands were attributed with the suitability rank for each wildlife zone. The wildlife zones values were summed for an overall wildlife habitat quality index.

F. Social model: The wildland urban interface (WUI) was modeled by generating a buffer extending ½ mi from each building cluster point. Stands intersected by this buffer were assigned the WUI zone attribute.

G. Economic model: Timber value was estimated by the TEA method which predicts stumpage value adjusted for sale characteristics and market indicators. Polygons in the GIS vegetation layer were assigned a mechanical treatment method based on proximity to an existing road and mean slope within the polygon; this attribute adjusts the TEA values on a stand by stand basis. Estimates of forest product volumes from mechanical activities were derived by using Forest Inventory and Analysis (FIA) data in the Forest Vegetation Simulator model (FVS) (Dixon 2002) and the Fire and Fuels Extension of FVS (Reinhardt 2003). The modeling results were compiled into a "look-up" table which associates volume estimates from activities with the antecedent vegetation.

Model Integration—Results from each sub-model were compiled first in GIS then into a master IAM system called Multiple-resource Analysis and Geographic Information System (MAGIS). MAGIS is an optimization model designed to solve complex spatial and temporal scheduling problems in natural resource management (Zuuring et al. 1995). The MAGIS modeling system is based on mixed-integer mathematical programming that includes vegetation management and an optional roads component for analyzing access and associated costs and resource impacts (Weintraub et al. 1994). Generally, if a resource can be defined in a GIS and with rules relating the resource to management effects, the resource can be accounted for in MAGIS.

Figure 2 presents a schematic of the model integration structure. The MAGIS model was prepared for sub-model data by defining the attributes to import from the GIS layers. Other definitions were entered for management activities, costs, and rules for vegetation succession, activity outputs, and management activities. *Management regimes* were defined consisting of activities, alone or in series that could be applied to accomplish project objectives. Examples included slashing and broadcast burning to restore grass and sagebrush lands and mechanical thinning in the commercial management zones. With all definitions entered, the attributed GIS vegetation layer was imported to MAGIS.

Step 4: Define Basis for Scenario Comparison

The final step for building an integrated model was to define e*ffects functions*. These establish resource characteristics to be monitored and compared between alternative management scenarios run in MAGIS. These are constructed so that the output of each effects function specifically relates to a project objective. Effects functions commonly summarize acres affected by management actions. They may be viewed as an *accomplishment* meeting an objective (e.g. sum of stream project acres treated), or an *indicator* to be monitored or perhaps constrained (e.g. change in wildlife habitat index or number of acres impacted within the 300 ft stream buffer). Virtually any number of effects functions can be defined limited by project objectives and common sense. Effects functions defined for the Butte North Project include:

A. Vegetation

– Acres of lodgepole plantation thinned (accomplishment)
– Acres of grass/sagebrush restoration candidates treated (accomplishment)
– Acres of multi-story Douglas-fir treated (accomplishment)
– Acres of potential old growth affected (indicator)

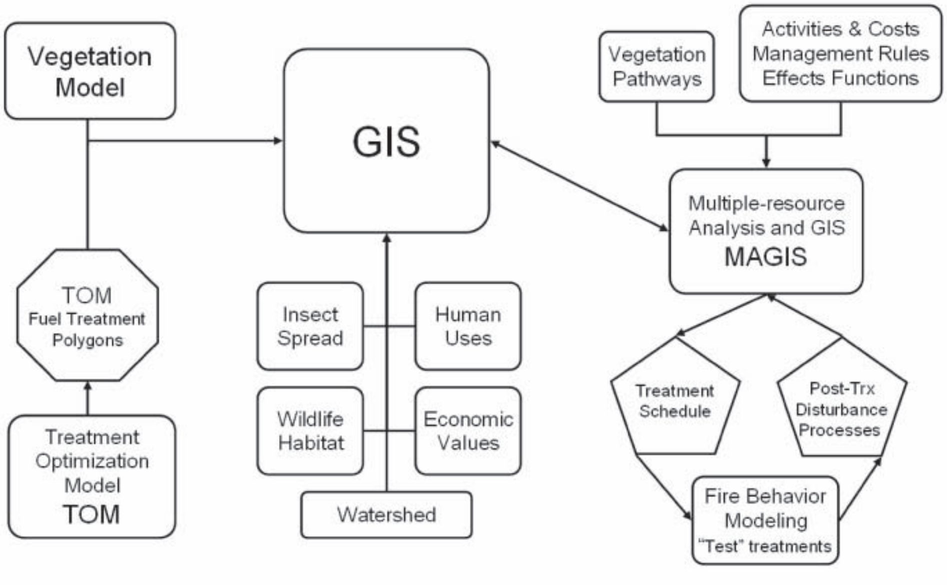


Figure 2—Schematic of model relationships and integration structure.

B. Insects

- Acres treated intersected by TOM polygons in areas of projected insect spread (accomplishment)

C. Fire and fuels

- Acres treated intersected by TOM given modeled fire behavior based on current vegetation (accomplishment)
- Acres treated classified as fire regime condition class 3 (accomplishment)

D. Watershed

- Acres of priority riparian project treated (accomplishment)
- Acres of stands treated containing any 300 ft stream buffer (indicator)

E. Wildlife habitat

- Acres treated containing habitat of key species (accomplishment or indicator depending upon associated affects)
- Index of wildlife habitat value (indicator)

F. Social

- Acres treated containing WUI buffer (accomplishment)
- Acres treated around reservoir (accomplishment)

G. Economics: These effects functions are either accomplishments or indicators depending upon other associated resource effects

- Total costs of activities
- Total product volume
- Total present net revenue

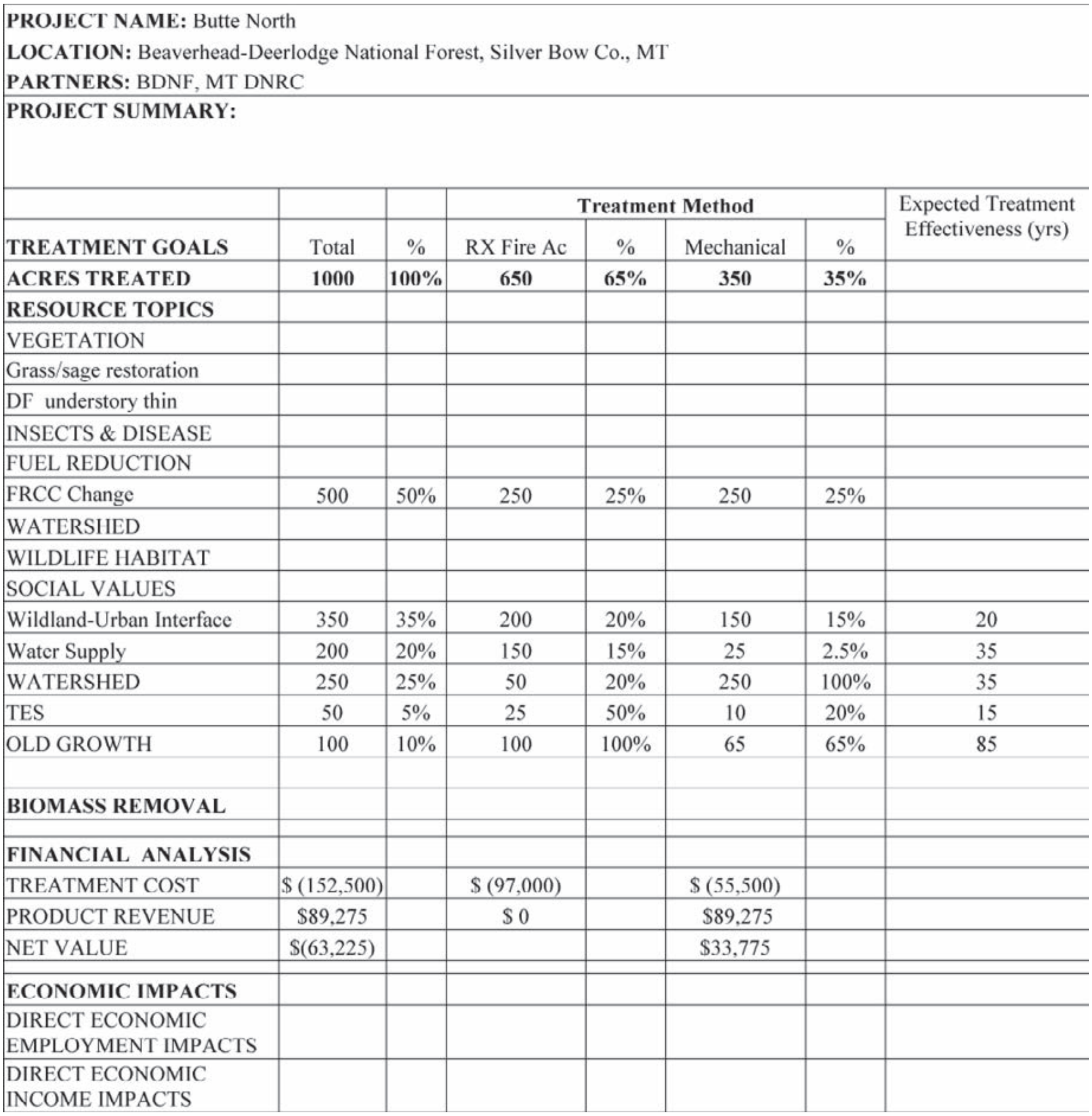
Step 5: Frame Alternative Scenarios

The process of using IAM to define alternative scenarios is similar to developing alternative land management proposals. Different combinations of desired outcomes are compiled, each emphasizing a particular set of resource objectives. A primary scenario goal or *objective function* is determined. Boolean logic is then applied to effects functions to set specific goals and apply constraints. For example, an objective function might be to maximize acres of WUI treated to reduce fuels. Constraints might be set to simultaneously limit impact in the stream protection zone, acres of mechanical treatment in the WUI zone, and budget. The mathematical solver in MAGIS first determines the feasibility of meeting the objective function within the constraints set and then calculates related impacts and outcomes defined by each effects function. Defining scenarios is an iterative and cumulative process. Results from one scenario are analyzed, adjusted, and fed into the next. This process continues until the users believe they have reached an optimal spatial and temporal schedule of treatments to meet objectives. Work on the Butte North modeling continues. Examples of basic scenarios which will be used for the Butte North analysis will include a fire threat reduction option, a wildlife option, and an economic option.

Forest Health Restoration Report Card

The IAM outlined for the Butte North Project demonstrates application of multiple modeling tools for multi-objective, multi-resource analysis. The single issue of fuel reduction does not drive the analysis. Fuels and fire threats are addressed in the context of the other significant environmental and management concerns. The opening assessment question is not, “What is the problem fire?" Instead this approach asks, "What role does fire play as one component of a complex system?" and "What management actions are warranted to address overall forest health?"

Expecting that management accomplishments must be accounted for based on standard performance criteria, the systematic assessment of key resources through the preceding analysis presents a logical foundation for a multiple criteria performance reporting tool. Given that fire and forest fuel will drive budgets for the foreseeable future and that the Healthy Forest Restoration Act establishes the management directives, the prospective tool is entitled: Forest Health Restoration Report Card. Figure 3 presents a working draft concept. The intent is to account for and acknowledge multiple costs and benefits from management activities, to concisely report expected treatments objectives, and to convey this information simultaneously to several audi-



PROJECT NAME: Butte North
LOCATION: Beaverhead-Deerlodge National Forest, Silver Bow Co., MT
PARTNERS: BDNF, MT DNRC
PROJECT SUMMARY:

			Treatment Method				Expected Treatment Effectiveness (yrs)
TREATMENT GOALS	Total	%	RX Fire Ac	%	Mechanical	%	
ACRES TREATED	**1000**	**100%**	**650**	**65%**	**350**	**35%**	
RESOURCE TOPICS							
VEGETATION							
Grass/sage restoration							
DF understory thin							
INSECTS & DISEASE							
FUEL REDUCTION							
FRCC Change	500	50%	250	25%	250	25%	
WATERSHED							
WILDLIFE HABITAT							
SOCIAL VALUES							
Wildland-Urban Interface	350	35%	200	20%	150	15%	20
Water Supply	200	20%	150	15%	25	2.5%	35
WATERSHED	250	25%	50	20%	250	100%	35
TES	50	5%	25	50%	10	20%	15
OLD GROWTH	100	10%	100	100%	65	65%	85
BIOMASS REMOVAL							
FINANCIAL ANALYSIS							
TREATMENT COST	$ (152,500)		$ (97,000)		$ (55,500)		
PRODUCT REVENUE	$89,275		$ 0		$89,275		
NET VALUE	$(63,225)				$33,775		
ECONOMIC IMPACTS							
DIRECT ECONOMIC EMPLOYMENT IMPACTS							
DIRECT ECONOMIC INCOME IMPACTS							

Figure 3—Working prototype for a Forest Health Restoration Report Card. Some cells are intentionally left empty to reflect how the single card can capture the unique character of each project.

ences. The report card should directly reflect the project purpose and need. It should document the expected resource effects, both positive and negative, expected duration of treatment effectiveness, the economic benefits and costs, and any other social effects that have been analyzed. The tool provides a valuable qualitative and quantitative summary of project goals, merits, impacts, and costs; accounts for annual accomplishments comparing treatment targets to actual acres treated; and provides a basis for future project monitoring and outcome-based performance reporting. This tool sets the foundation for measuring success beyond simply reporting acres treated and more robustly captures the value and intent of undertaking fuel and forest restoration treatments.

The report card system may be one tool to help restore public trust, because it clearly demonstrates that multiple resource and environmental concerns were addressed and acted upon. Furthermore, the report card system may provide a basis for more consistent multi-objective planning and monitoring of future projects with a forest health emphasis. Modeling results may be validated and the degree to which intentions are realized is transparent.

Future of Modeling and Performance Measures

Models may help guide decisions, not make them. Models are limited by errors and uncertainty and, as such, are never a substitute for professional judgment and ground verification of planning data. For all the error and uncertainties within the models and modeling processes themselves, we cannot hold off decisions until we have perfect systems. Models provide some measure of simplicity with the hope of greater clarity as we wrestle with inherently and intractably complex systems. Reasonably enough, management of complex systems requires tools that adequately represent this complexity. IAM is one such tool. Our current abilities to integrate resource modeling systems are coarse but will only improve with practice (Jakeman and Letcher 2003) and development of improved IAM tools and logic.

We have outlined a practical procedure for integrating fuel treatments into comprehensive ecosystem management through integrated assessment modeling. This framework provides a tool for systematic analysis of multiple resource objectives within a common planning area. Rather than fire and fuels issues driving the process, this framework provides insight into the relationship between fire, forest fuels, and other resources. The results from this integrated assessment modeling approach offer a structure to develop a multi-criteria performance report card. The outcome may be planning protocols that make better use of ecosystem science and more defensibly meet land management directives.

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