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Mapping Fuels Using Remote Sensing and Biophysical Modeling

a Proposal for the USDI-USDA Forest Service Joint Fire Science Plan

Executive Summary: The purpose of this study is to develop methods and protocols for mapping fuels and fire hazard across multiple-scale landscapes using a combination of remote sensing and spatially explicit biophysical modeling. This study is composed of 12 tasks that first coordinates fuels mapping research by organizing an international symposium, publishing electronic newsletters, and establishing a web site. Then active research will be conducted on fuels characterization linkages, comprehensive remote sensing fuels map classification, linking remote sensing to biophysical modeling, and assessment of experimental Lidar. Lastly, this information will be integrated into a set of publications and software that comprehensively describe methods of mapping fuels at different scales, accuracies, and costs. This study addresses issue 1 (fuel mapping and inventory) of the Joint Fire Sciences Plan (JFSP), and tasks 1 (inventory information), task 2 (survey of ongoing fuels mapping projects), task 3 (assess remote sensing), and task 4 (values at risk) of the JFSP Request For Proposals.

Principal Investigators:

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Leon Neuenschwander, College of Forest Resources, University of Idaho;

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Roger Ottmar, Ernesto Alvarado and David Sandberg, USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory;

Jan van Wagendonk, USGS, Western Ecological Research Center, Yosemite Field Station;

Jeff Eidenshink and Don Ohlen, US Geological Survey, EROS Data Center;

Lloyd Queen and Carl Seielstad, Numerical Terradynamics Simulation Group, School of Forestry, University of Montana, Missoula, MT

Schedule: This study starts October 1998 and ends September 2001 (3 years).

Year 1: Organize and conduct symposium, develop electronic mailing list and newsletter, initiate fuels characterization and EDC cluster map development, generate Lidar imagery.

Year 2: Link biophysical modeling with remote sensing, initiate field test sites, publish symposium proceedings, refine Lidar imagery, field sampling and data collection.

Year 3: Formalize fuels mapping protocols, develop fuels hazard and risk methods, publish research findings, generate comprehensive manual of fuels mapping.

Budget: This project requires **$576,671** over 3 years to successfully complete the 12 subtasks. This estimate includes salary ($353,053), travel and per diem ($60,500), computers and supplies ($32,400), overhead ($75,218), and publication and communication ($20,500). There is an estimated $123,230 in contributed dollars which brings the total cost for this project to $699,901. This project needs $350,000 in Year 1, $140,000 in Year 2, $88,671 in Year 3.

Individual Proposing work: _____
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Authorized Unit Representative: _____ Acting FUC
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Authorized Agency Representative: _____ 7/2/98
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Introduction

Background -- Comprehensive fuels mapping on federal and state lands is critical to modern fire management activities and several recent developments serve to emphasize the critical role fuels maps play in fire management. First, fire is now recognized as an essential natural process in many ecosystems and land managers are increasingly expected to use landscape-level fuels treatments to improve ecosystem health and to reduce likelihood of catastrophic fires. Second, an expanding urban interface and a highly litigious society have narrowed the margin for error in fire management decisions. As a result, fire managers are now required to use complex, data-intensive fire and smoke behavior models to support environmental assessments and burn plans. Moreover, fire managers must provide more accurate fire-behavior predictions for real-time support of suppression tactics and logistics decisions because of heightened concern for firefighter safety following the Storm King fire fighter fatalities. Maps of surface and crown fuels allow construction of fire hazard and risk maps for prioritizing and planning future fuels treatments.

Development of spatially explicit fire behavior and fire effects prediction models, such as FARSITE (Fire Area Simulator, Finney 1995), has revolutionized fire management prediction and decision support systems. These computer models allow managers to simulate the spatial and temporal characteristics of wildland fires on a computer to predict future wildland fire growth and direction so they can plan or fight it more efficiently. However, these models require detailed electronic maps of fuels and vegetation characteristics to generate accurate and consistent fire behavior predictions. Ironically, the FARSITE model, which is available for free to anyone, requires spatial vegetation and fuels layers that are quite costly and difficult to build (Keane et al. 1998). Fire managers across the country are rapidly trying to learn this tool and obtain the input data needed to run the model for their area. FARSITE requires eight data layers for a comprehensive treatment of spatial crown and surface fire growth -- elevation, aspect, slope, fuel model (Anderson 1982), canopy closure, stand height, crown base height, and crown bulk density. All eight data layers must be of high resolution and reasonably accurate to effectively predict fire growth.

The Problem -- Most fire and land managers do not have the fuels and vegetation maps needed to run the FARSITE model and other spatial fuel management decision support systems, and the existing vegetation and fuels maps and databases do not quantify the fuels or vegetation information to the extent, detail, or resolution needed by managers for fire behavior or effects prediction. Moreover, many attempts to create fuels layers from existing maps have failed because of inexperience with fuels and vegetation modeling and mapping in the context of fire behavior and fire effects. Those projects where suitable FARSITE layers were created, such as the Selway-Bitterroot Wilderness Complex (Keane et al. 1998) and Yosemite National Park (Van Wagtendonk 1998) have shown great promise but they are often costly and in need of refinement.

There are three main reasons why fuels map development is difficult and costly. First, most remotely sensed products used for mapping, such as aerial photos and satellite images, are unable to discriminate fuel types because the fuel bed is often obscured from view by the forest canopy. Second, the most important layer needed by fire management models, the fire behavior fuel model, is a generalization of fuel characteristics to just 13 categories that were then adjusted to predict realistic fire behavior. These fuel models rarely match actual fuel loadings (Anderson 1982), and as a result, many people who do not have experience in fire behavior or fuel model

mapping are unable to estimate fuel model accurately and consistently (Burgan and Rothermel 1984). Third, all data layers for fire behavior prediction must be developed and mapped simultaneously and consistently so they are spatially congruent. This means stand crown height should not be taller than stand height, for example. Obviously, the creation of these data layers requires a great deal of experience in ground-truthing, image processing, remote sensing, vegetation mapping, fuels modeling, and fire management.

One frustrating aspect of fuel mapping is there are three different fuel classifications used to describe the fuelbed of a stand for many different applications. Fire behavior computer programs, such as FARSITE and BEHAVE, use fire behavior fuel models such as the 13 described by Anderson (1982). Fire danger computer models use the 20 NFDRS fuel models (Cohen and Deeming 1985) to consistently predict fire potential. Fire effects prediction systems, such as FOFEM (Reinhardt et al. 1997) and CONSUME (Ottmar et al. 1997), require actual fuel loadings by fuel type and size class. Moreover, these three fuel classifications are comprised of different fuel categories. Therefore, fire behavior fuel models cannot be used for predicting fire effects, and vice versa; so two different maps must be made.

In summary, **land management agencies need a simple but specialized set of methods and standards to create fuels layers that are useful for fire management for their area.** And, since these layers cost a great deal of time and money, their development should produce also maps and databases useful to other fire and natural resource decision support systems.

Objectives

This fuels mapping project has one main objective~~s~~:

To develop methods for creating spatial fuels layers for fire behavior and fire effects prediction systems and hazard and risk assessment

The primary goal of this objective is to develop methods and protocols for creating high resolution fuels data layers for input to detailed fire management models. Secondary goals are to create fuels maps useful across all land management functions such as fire effects, site productivity, and smoke generation. This objective matches Principle Purpose 1 (Fuels Mapping) in the USDI-USDA Forest Service Joint Fire Science Plan. Development of procedures for creating multiple scale fire risk and hazard maps protocols matches Principle Purpose 2 and 3 (Fuels Evaluation and Scheduling) in the USDA Fire Science Plan.

Methods

This fuel mapping project will be accomplished in three simultaneously occurring phases linked together by 12 essential tasks. Information from all current fuels mapping efforts will be summarized in the **Coordination** phase. The **Research** phase will use the summarized information to develop new classifications, technologies, and methods to map fuels accurately. The **Implementation** phase synthesizes results from first two phases into a set of standardized protocols for use by fire and land managers for mapping fuels for fire hazard and risk prediction.

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Coordination Phase

This first phase involves coordinating and synthesizing all current and historical fuels mapping activities so information on mapping methods and technology is readily accessible. An extensive literature search will be conducted to identify current and past fuels mapping attempts. This

information will be synthesized into a research document. An international list of researchers and managers interested in fuels mapping and modeling will be developed. These people, and all others interested, will then be invited to attend **an international symposium** in Seattle, WA, Boise, ID, Spokane, WA, or Missoula, MT in winter 1998 or spring 1999 for the primary purpose of capturing the state-of-the-knowledge in the following four areas: 1) fuel, vegetation, and fire regime mapping, 2) fuel, fire behavior, and fire effects modeling, 3) fire hazard and risk modeling, and 4) fuel treatment technologies. This symposium will have a steering committee to structure the content of synthesis papers and topics and to decide on invited and solicited papers and posters. Jason Greenlee, publisher, and Mike Webber, editor of International Journal of Wildland Fire (IJWF), have agreed to publish the proceedings of this symposium as a special issue of this respected journal. The symposium will last for four days and will be tentatively organized into the following sessions:

outside non fire folks? clique of modelers synthesize or publish

Vegetation & Fuels Mapping and Inventory
Remote Sensing and Fuel Classification
Mapping Fire Regimes
Fire Hazard and Risk Assessment
Fuel Models and Fuels Dynamics
GIS Data Bases and Fuel Mapping
Spatial Fire Behavior and Effects Models
Planning & Implementing Fuels Treatments

In addition, **an electronic mailing list and bulletin board** will be created to continue dialog on current and future fuel mapping projects and research. Moreover, **a newsletter, called "The Fuels Mapper"**, will be created to pass along current information in a formal context to scientists and the fire management community. This newsletter will also be distributed via email, and also posted to a **Fuels Mapping home page,** also created as part of this proposal. This home page will be linked to two metadata bases developed specifically for this project. One meta database will describe the details and geographical extents of all fuels maps developed in the US and Canada. The second meta database will contain a listing of all georeferenced fuels data collected in the US and Canada that may be used in ground-truth or fuel modeling exercises. This phase will provide contacts and primary data that will be needed in the testing and validation of products generated from the next two phases.

Research Phase

Active research into mapping fuels at multiple scales using remote sensing and biophysical modeling is critical because current technology is often inadequate, inappropriate, inaccurate, and expensive for fuels mapping (Keane et al. 1998). We propose to test and compare new remote sensing products and methods identified in Part One to accurately, comprehensively, and consistently map those ecosystem attributes useful to fire and fuels management and then develop the standard methodologies or protocols for using these tools to map fuels for other land areas. We will accomplish this objective by the linkage of the projects presented below.

Is it part of another proposal?

Fuel Characterization Scheme -- The first important project is to **develop a new national fuels characterization scheme that can be used to build fuel models for all land management applications**, especially fire behavior and fire effects prediction. Several scientists from the Intermountain Fire Science Laboratory and Pacific Northwest Research Station will develop this comprehensive fuel classification system using field data, simulation modeling, and photo series information. This project is **not** included as part of this proposal, but it is important because it provides the linkage from fuel classes to fuel map categories, which then provides the vehicle to

map fuels for many applications. The research and methods presented in this proposal will use current fire behavior fuel models to map and predict potential fire spread, but the integration of the new fuel characterization scheme from a parallel effort would greatly enhance our ability to accurately discriminate fuel loadings and fire behavior on the landscape. This study and the companion fuel characterization effort, will develop the linkage between the newly developed Fuel Characterization Classes (FCC) database and the old fire behavior and fire danger fuel models to the map elements needed to create spatial data layers of fuels. Colin Hardy, Don Latham, Roger Ottmar, David Sandberg, Ernesto Alvarado are responsible for this task.

EDC TM Cluster Map -- It is important to develop a basic data set from which a fire management agency in any part of the country can accurately and consistently prepare fuels characterization maps for input to fire management mapping and modeling activities such as FARSITE. For maps to be consistent on a nationwide scale there must be some conformity in the basic data used to produce the maps. We look to remote sensing data, specifically Landsat Thematic Mapper (TM) data, to provide information concerning the vegetation characteristics. Combining the TM data with ancillary data layers that describe soils, topography, potential vegetation, climate, and other data can provide a land characteristics data base from which national map of fuels characterization classes can be produced.

In the past, a major barrier to using Landsat TM data on a large scale was the cost of acquiring, processing, and merging the data. Moreover, land management agencies rarely have the expertise, computer facilities, or time to perform the initial processing of TM data including geo-rectifications, image corrections, and spectral classifications. Fortunately, the EROS Data Center (EDC) in cooperation with a consortium of federal agencies, including the Forest Service has initiated the Multi-Resolution Land Characteristics (MRLC) project. The MRLC project has produced a wall-to-wall nationwide data set of leaf-on and leaf-off 1991-1993 vintage Landsat TM data. The TM data are georegistered and corrected for terrain effects. The MRLC consortium will develop a second generation wall-to-wall data set using Landsat 7 data acquired in 2001-2002. As part of the MRLC activities, EDC is currently creating a 26 class land cover data set at 30 meter resolution for the conterminous US (**www.epa.gov/mrlcpage/index.html**). This data set is being developed using the Landsat TM data set in conjunction with ancillary data layers that describe soils, topography, and potential vegetation. Presently, the land cover data set is finished for most states on the eastern seaboard and the entire conterminous US is to be completed by the year 2000. The work in the western US will be expedited as part of this proposal. Purchasing and processing of data for Alaska will also be expedited. EDC has classified these scenes to spectral cluster classes for use in fuels mapping.

It was immediately apparent that the 26 land cover class information data set alone would not be adequate for mapping fuel characteristics at fine resolutions. However, the intermediate products from the land cover mapping process can provide in the information needed for mapping fuel characterization classes. In the land cover mapping process, a primary component is the vegetation characterization as depicted by the TM data. To capture these characteristics, spectral cluster classes from an unsupervised classification of the TM data are generated from large multi-scene TM mosaics. Generally 90 cluster classes were extracted from each mosaic. For land cover mapping, each cluster class is assigned to one or more land cover classes based on aerial photo interpretation. However, in most cases, individual cluster classes represent several land cover classes so these cluster classes were refined to 26 classes by constructing models that

use the appropriate ancillary spatial information.

For mapping fuels, EDC will provide the cluster class information in conjunction with other ancillary data in a land characteristics data base. The data base will include tabular summaries of ancillary data characteristics for each cluster class and the ancillary data layers. These summaries and the individual ancillary data layers will be used by field staff at the various land management agencies to derive the fuels characterization maps. A prototype methodology will be developed in the Pacific Northwest region to identify the capability of the land characteristics data base for mapping fuels. A key component of the development of a methodology will be based on the feedback of the field staff regarding the format and structure of the land characteristics data base. We will select one large landscape to perform much of the data analysis. Jeff Eidenshink and Don Ohlen at EDC will provide the land characteristics data base.

Biophysical Modeling -- As mentioned, spectral imagery alone is not a sufficient tool for mapping fuel classes because of canopy obstruction. Spectral clusters, such as those in the EDC TM product, need ancillary data describing the biophysical environment to accurately discriminate between fuel classes. Many ancillary spatial data layers can be used to quantify biophysical attributes such as the STATSGO soils maps, digital elevation models (DEM), and annual precipitation maps, but these variables do not directly describe the environmental processes governing fuel dynamics such as climate, ecosystem productivity, decomposition, and litterfall. What is needed is a method to generate layers that represent the important biophysical, ecophysiological, and vegetational processes that dictate fuel characteristics. These maps can then be used in conjunction with spectral imagery to map fuels.

We have been developing a biophysically-based gradient model to spatially map ecosystem characteristics for the past three years (Keane et al. 1997). This model synthesizes field data into environmental gradients that can be used to predict those entities important to land management such as cover type, productivity, fire regime, and in this case, fuels. We do this by linking field data to an extensive set of ecosystem process models that simulate and compute important ecosystem attributes, such as net primary productivity, transpiration, decomposition, and respiration, across multiple temporal and spatial scales. These simulated attributes are then added to the biophysical gradient model for use in mapping ecosystem characteristics. We will use this gradient model to generate the appropriate biophysically-based ancillary data layers needed for fuels mapping. We will link the biophysical approach with the EDC TM cluster map to develop protocols for FCC mapping.

EMAP data

This gradient model approach has many advantages. First, since field data are taken along biophysical gradients, the model can be used at any scale, from site to project to watershed to region, as long the same gradients are represented within that spatial scale. Second, data collected for this model never become obsolete because they quantify environmental gradients, and do not represent static conditions on a piece of ground. Lastly, other important fuel and vegetation characteristics can be mapped using the gradient approach. Many ecosystem characteristics such as tree densities, hiding cover, and leaf area, were measured along with fuels at each field plot, so these data are available to be used as dependent variables in the gradient model to predict their occurrence across the landscape. Such ancillary data may prove to be critically important for prioritizing fuel treatments and evaluating effects of fuel treatments.

Extensive field data collected on the Kootenai and Nez Perce National Forests in Montana and Idaho (Keane et al. 1997) and the Gila National Forest in New Mexico will be used

to test and refine the biophysical gradient model for this project. We will generate biophysical data layers for these Forests and then link them with the EDC TM cluster map to predict fuel characterization classes. We will then develop protocols to repeat this process for any part of the United States. Bob Keane is responsible for this task.

Validation -- We have tentatively identified six sites where the protocols and maps generated from above tasks will be independently tested. Each site is composed of a mosaic of land ownership that includes private, state, and federal (USDA Forest Service, USDI National Park Service, Bureau of Land Management, Bureau of Indian Affairs). There is a management cooperator at each site who will aid in our project. These sites run the gamut of data availability, size, topography, and ecosystems. They are listed in order of the quality and quantity of spatial and field data critically needed for the validation process.

Yosemite National Park (California) -- This area has extensive spatial data layers and an intensive network of over 8,000 field plots. In addition to the single-scene satellite image map developed by van Wagtendonk (1998) for the entire Park, new maps using a temporal sequence of TM scenes are in preparation by van Wagtendonk (1998). Coupled with very high resolution imagery, these maps will provide the basis of comparison with a classified fuel model map created from EDC TM Cluster Map and biophysical gradient model for the entire Yosemite National Park. Jan van Wagtendonk will compare these existing fuels maps to the classified EDC TM map and then interpret the differences from other fuel model maps, ancillary data layers, and field data. Yosemite National Park fire staff will be used extensively for the field sampling and spatial analysis in this validation effort.

Nez Perce National Forest (Idaho) -- This area was selected because it was extensively sampled for the Keane et al. (1996) gradient modeling project and it has a comprehensive GIS of the entire complex and an extensive ground-truth collection. No fuels layers yet exist for this area. Bob Keane will test the EDC methodology and map for the Nez Perce using a combination of the gradient modeling techniques presented above and the EDC cluster map methodologies. Protocols and methods will be refined from this effort. Keane will work with Pat Green, Ecologist on the Nez Perce National Forest, and Dan Leavell, Ecologist on the Kootenai National Forest in this effort to prepare a quality and useable map for the area for the fire management staff.

Tenderfoot Experimental Forest (Montana) -- This 3,000 ha area was intensively sampled for fuels and vegetation on a 300 meter grid so the spatial and temporal distribution of ground truth is extensive. This area will also be treated as part of an ecosystem management project which will allow these methods to be tested across two time periods to quantify change in fuel dynamics which provides a test of the sensitivity of fuels mapping methodologies. Bob Keane will generate the biophysical data layers from the gradient model for this area. Colin Hardy will perform the majority of this validation and he will work with Fire Management Staff on the Lewis and Clark National Forest.

Gila National Forest Complex (New Mexico) -- Fuels for this 1.2 million ha area are currently being mapped using Landsat TM imagery and potential vegetation types by Bob Keane and staff

at the Intermountain Fire Sciences Laboratory. This provides an excellent comparison with the EDC cluster map because Keane used the same TM data but generated spectral clusters with different parameters and techniques. Over 2,000 plots comprise and extensive ground truth layer. Lindon Weibe and Gary Benevitez on the Gila National Forest, and Ron Moody of the Regional office offer support in this effort.

Frostfire (Alaska) -- This small land area will be extensively sampled for fuels and vegetation during the summer of 1998. An EDC cluster map will be linked to the GIS and ground truth data for this site to validate and refine fuel mapping methodologies. Dave Sandberg, Roger Ottmar, and Ernesto Alvarado will perform this validation task.

Southern Utah (Utah) -- Fuels maps for the entire southern half of Utah will be developed from the methods described here. This study will be linked to another proposed study "Southern Utah Fuels Management Demonstration Project" where they will build the fuels maps using techniques presented here and we will validate the maps. This area was selected because there are few ground-truth sources, spatial data layers, and fuel maps available so the fuels mapping project would essentially start from the beginning. Secondly, this area is managed by a melange of government agencies including USFS, BLM, NPS, and state. Lastly, this is a good test of the methods over a very large area, approximately 9 million hectares. Colin Hardy and Bob Keane will work with Kevin Ryan and the staffs of BLM, the three USFS National Forests, and the four National Parks to successfully complete this task.

Lidar Fuel Mapping -- The inability of current optical sensors, including the TM sensor mentioned above, to "see" below the forest canopy is a major shortcoming for mapping fuels. This usually results in low map accuracies and inconsistent class assignments (Keane et al. 1997), but these sensors are the best available now and in the near future. However, there are new remote sensing technologies from satellite and airborne platforms that have applications in mapping fuel characteristics, and **Lidar** seems to show the greatest promise.

Lidar is an active remote sensing technique that can provide relatively precise measurements of canopy top height, vertical canopy distribution, surface roughness, and ground surface elevation (Nelson et al. 1988a, Nelson et al. 1988b, Ritchie et al. 1992, Weltz et al. 1994, Nelson 1996, Naesset 1997, Nelson 1997, Nelson et al. 1997). A lidar uses light emissions to measure ranges between itself and a reflective surface. Airborne or spaceborne lidar instruments emit pulses of electro-magnetic radiation toward the earth and collect the backscatter using nanosecond-resolution clocks to the roundtrip propagation of each pulse (Bufton 1989). The speed of light is then used to calculate the distance from sensor to target. The intensity and temporal distribution of returned pulses (backscatter radiation) are used to determine earth surface parameters such as vegetation height and slope. The interaction of the light pulse with the earth surface (leaves, rocks, twigs, soil) alters its timing and intensity which creates a unique signal for mapping terrestrial characteristics like soils. The primary goal of earth surface lidar remote sensing is to quantitatively link this distorted return signal to surface structural variables.

Although lidars have been used for almost three decades in the space and atmospheric sciences to map topographic and atmospheric characteristics of planets (including earth), it is only recently that research has turned toward the earth's surface with the goal of accurately measuring vegetation structure. To date, most lidar studies of the earth have utilized airborne or

ground-based sensors over relatively small land areas at inordinately high prices relative to land management. However, Earth Systems Science Pathfinder's (ESSP) Vegetation Canopy Lidar (VCL), a multi-laser spaceborne system to be launched in February of 2000, promises to provide systematic, high-spatial resolution global coverage for the first time (Dubayah et. al. 1997). The launch of VCL will be the first opportunity for land management agencies to acquire high-quality vegetation structure information remotely for large land areas. It is believed that this sensor will allow detailed characterization of vertical and horizontal forest fuel distributions at high spatial resolution. Furthermore, lidar-derived fuels data will serve as inputs into spatially explicit fire behavior models like Finney's (1995) FARSITE. Lidar will improve the accuracies of fuels maps but at a significant cost. Its use in fuel mapping might be initially confined to the highly sensitive urban-interface because high fuel mapping accuracies are essential for defensible and scientifically-base fire management.

We propose to obtain lidar data for three sites in Montana and Idaho: the Tenderfoot Experimental Forest, Lewis and Clark National Forest (65 km^2); Lubrecht Experimental Forest, MT (93 km^2); and the Lower Salmon Watershed, Nez Perce National Forest, ID (6000 km^2) . These sites span a diverse array of fuel types, are easily accessible, and contain dense networks of spatial forest structure and fuels data, thereby facilitating accomplishment of the following specific objectives:

1. *Define the relationships between lidar return data and forest/fuel structure.*
2. *Develop a methodology to accurately characterize canopy, transition (ladder), and surface fuels using multi-return lidar data.*
3. *Determine the ability of lidar to measure biomass density for smoke emissions models.*
4. *Validate the belief that lidar will provide significantly better discriminatory power for fuels mapping than existing remote sensing techniques.*
5. *Evaluate the potential cost-effectiveness of lidar for large-scale fuels mapping.*

Lidar data will be preprocessed to maximize the signal to noise ratio. The data will then be spatially partitioned into units compatible with common spectral sensors (20m, 30m, 100m, 1km). The statistical package SAS will be used to generate statistics for each unit of lidar data. These statistics will be evaluated to determine which statistics describe specific fuels variables. The resulting algorithms linking lidar returns to fuels will then be used to classify each study site (figure 1). Spectral data will be incorporated if necessary to refine the classification. The final product will be a set of protocols for using lidar for mapping fuels that will detail when to use lidar and how to create the FARSITE input map layers. Lloyd Queen and Carl Seielstad of the Numerical Terradynamics Simulation Group (NTSG) Remote Sensing Laboratory at the University of Montana School of Forestry will perform all of the Lidar analysis.

Implementation Phase

The third part of this project will distribute a standardized set of protocols for fuels mapping to fire management in the form of computer programs, publications, and training sessions. These methods will be designed so fire management personnel can match the characteristics of their project area with the correct or most appropriate fuels mapping methods. Each set of methods will be sufficiently detailed so management agencies can perform the selected tasks on their own. but consultation would be available from the extensive network set up in Phase One. Fuels maps created from standardized methods can be combined to increase the effective area. **Included in the standardized mapping methods is a hierarchically structured standardized field**

sampling methodology for collecting data to validate and test created fuels maps. There will be a key to match the sampling methods to project area attributes. Other methods detailing the creation of vegetation attributes and fire effects fuel models will also be developed. A centralized database for field data storage will be designed to allow access to everyone.

A vital outgrowth of this fuels mapping effort is to develop of standards, protocols, and methods for application of these maps to other fuels management purposes besides predicting fire growth in FARSITE. And, perhaps the most critical need in fuels treatment planning and implementation is the creation of **fire hazard and risk maps** that identify those areas where wildland fire can cause significant damage. This will serve as a vehicle to prioritize and schedule fuels treatments in space and time. We will develop methods to create spatial data layers of fire hazard and risk at multiple scales that integrate surface and crown fire behavior, weather, land-use, ignition, and topography into simple indices that express the probability or subsequent effects of a fire on various ecosystem and social components. These methods will be designed for use across multiple spatial and temporal scales so that planning can prioritize regions, zones, watersheds, sites, and down to stands for one year or a set of years spanning the range of weather conditions. Leon Neuenschwander, Bob Keane, and Neil Sampson will develop these methods.

Schedule and Budget

This is a three year project with important tasks scheduled in Table 1. Many tasks are done simultaneously but will be actively coordinated so that desired products will link into a cohesive application. We will start this project on October 1, 1998 and finish on September 30, 2001.

The cost of the project is **$576,671** over the entire three years which includes $75,218 overhead. Contributed cost is $123,230 or 22 percent. The detailed budget for all three years is presented in Table 2. This project requires $350,000 in Year 1, $140,000 in Year 2, $88,671 in Year 3. We designed this study so that it could be funded at lower levels by eliminating the tasks specified in Tables 1 and 2. We could include more validation test sites in this study for the cost of $25,000 each providing each site has an intact GIS and extensive spatially explicit ground truth sample data base.

Research Team

Dr. Robert E. Keane is a research ecologist 15 years studying and modeling fire's effect on ecosystems. Currently he has successfully mapped fuels in the Selway Bitterroot Wilderness Complex (Keane et al. 1998), Gila National Forest, and the Salmon-Challis National Forest using TM imagery and biophysical modeling (Keane et al 1999). He has published over 12 articles on fuels and ecosystem mapping.

Colin Hardy is a research forester with the Rocky Mountain Research Station at the Intermountain Fire Sciences Laboratory in Missoula, MT. His area of expertise is fuels and smoke management.

Dr. Don Latham is Project Leader of RWU INT-4401, Fire Behavior Research Project. He has worked in the fields of fire physics, ignition by lightning, decision support systems, artificial intelligence, and geophysical fluid dynamics for the past 30 years.

Robert Burgan is leader of the Applications Team in the Fire Behavior Work Unit. He has over 25 years of experience in fire danger and fire behavior research. Currently, he has mapped fire danger fuel models nationally and has brought satellite observation of vegetation to operational use.

Dr. Leon Neuenschwander is a full professor at the University of Idaho College of Forest Resources in Moscow, Idaho. He has published over 150 articles on fuel and fire sciences related topics.

R. Neil Sampson is President of the Sampson Group, Inc., a natural resources consulting firm in Alexandria, Virginia. He has written and edited several books and dozens of papers on forestry and wildfire topics, and

organized five workshops to develop inter-disciplinary approaches and publish proceedings on complex resource management questions.

Jeff Eidenshink is a remote sensing scientist with the USGS EROS Data Center (EDC). He has experience in the use of AVHRR data for fire danger assessment and has completed numerous land cover classifications using Landsat data. He is the manager of all digital data production activities at EDC.

Don Ohlen is a Senior Scientist in the Science and Applications Branch of the EROS Data Center. He has over 20 years of experience in using remotely sensed data for land cover mapping. He has most recently been developing the Global Land Cover Characteristics Data Base and the conterminous US Regional Land Cover Data Set.

Roger Ottmar is a Research Forester with the Pacific Northwest Research Station at the Seattle Forestry Sciences Laboratory. He has been involved with fuels, fire, and smoke research for over 20 years and is leading efforts to 1) develop a natural fuels photo series, 2) assess fuel loading, fire behavior, and emissions for different management scenarios for the Interior Columbia Basin Ecosystem Management Project. 3) develop fuel consumption models, 4) develop a new fuel characterization system for the contiguous United States and Alaska, and 5) assess wildland firefighter exposure to smoke and the associated health risk. He has authored over 50 research publications and final reports, and has served as principle investigator on more than 60 grants, agreements, and coops between other USDA Forest Service Stations, government agencies, private corporations, and Universities.

Dr. David Sandberg is a Supervisory Research Biologist, USDA Forest Service, Pacific Northwest Research Station, Corvallis Forestry Sciences Laboratory. He has done extensive research in fire, fire effects, global climate change, and smoke.

Dr. Ernesto Alvarado is a Research Scientist at the University of Washington, Seattle. His expertise is in ecological modeling, landscape ecology, forest flammability, statistical modeling of large wildfires, and fire effects at different spatial scales. For the last five years he as collaborated with the Pacific Northwest Research Station on the Eastside Health Assessment and the Interior Columbia Basin Ecosystem Management Project.

Dr. Jan van Wagendonk is a Research Forester with the USGS Western Ecological Research Center stationed at Yosemite National Park. He has been involved with fire and fuels research in the Sierra Nevada for over 25 years and has developed a preliminary fuels map for Yosemite NP using satellite imagery and ancillary data.

Dr. Lloyd Queen is an associate professor of remote sensing in the University of Montana's School of Forestry. He has published over 25 research articles in peer-reviewed scientific journals and an additional 30 technical reports in other forums. He has obtained outside research funding exceeding $3 million for 30 sponsored proposals.

Carl Seielstad is pursuing a PhD in Forestry at University of Montana. His masters thesis incorporated elements of geology, ecology, and remote sensing to reconstruct landscape-level change on the Coastal Plain of Georgia. At UM he is exploring new fuels mapping techniques and examining spatial distributions of fuels. He has worked seasonally for the Forest Service over the past 8 years in fire suppression as a firefighter, hotshot, and smokejumper.

References

Anderson, Hal E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forestry and Range Experimental Station. 22 p.

Bufton, J.L., 1989, Laser altimetry measurements from aircraft and spacecraft, Proceedings of the IEEE, 77: 463-477.

Burgan, Robert E. And R.C. Rothermel. 1984. BEHAVE: Fire behavior prediction and fuel modeling system -- FUEL subsystem. USDA Forest Service General Technical Report INT-167. 126 pages.

Cohen, J.D. and J.E. Deeming. 1985. The National Fire Danger Rating System: basic equations. USDA Forest Service General Technical Report PSW-82. 16 pages.

Dubayah, R. and 8 others, 1997, The Vegetation Canopy Lidar mission, ASPRS conference 'Land Satellite Information in the Next Decade', 12 pp.

Finney, Mark A. 1994. Modeling the spread and behavior of prescribed natural fires. In: 12th Conference on Fire and Forest Meteorology, October 26-28, 1993, Jekyll Island, Georgia. Pages 138-144. Society of American Foresters, Washington D.C. 796 p.

Keane, R.E., J.L. Garner, K.M. Schmidt, D.G. Long, J.P. Menakis, M.A. Finney. 1998. Development of the input spatial data layers for the FARSITE fire growth model for the Selway-Bitterroot Wilderness complex, USA. USDA Forest Service General Technical Report RMRS-GTR-3.

Keane, R.E., D.G. Long, K.M. Schmidt, S. Mincemoyer, and J.L. Garner. 1999. Mapping fuels for spatial fire simulations using remote sensing and biophysical modeling. In: J.D. Greer, editor, Proceedings of the seventh Forest Service remote sensing applications conference. American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland. (In review).

Keane, Robert E., Cecilia H. McNicoll, Kirsten Schmidt and Janice L. Garner. 1996. Spatially explicit ecological inventories for ecosystem management planning using gradient modeling and remote sensing. In: J.D. Greer, editor, Proceedings of the sixth Forest Service remote sensing applications conference April 29-May 3, 1996. American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland. Pages 135-146.

Naesset, E., 1997, Estimating timber volume of forest stands using airborne laser scanner data, Remote Sensing of Environment, 61: 246-253.

Nelson, R. and five others, 1998, Canopy height models and airborne lasers to estimate forest biomass, International Journal of Remote Sensing, in press

Nelson, R., 1997, Modeling forest canopy heights: the effects of canopy shape. Remote Sensing of Environment, 60: 327-334.

Nelson, R., R. Swift, and W. Krabill, 1988, Using airborne lasers to estimate forest canopy and stand characteristics. Journal of Forestry, 86: 31-38.

Ritchie, J.C., and 8 others, 1992, Airborne laser measurements of rangeland canopy cover and distribution, Journal of Range Management, 45: 189-193.

Reinhardt, E., R.E. Keane, and J.K. Brown. 1997. First Order Fire Effects Model: FOFEM 4.0 User's Guide. USDA Forest Service General Technical Report INT-GTR-344. 65 pages.

Van Wagtendonk, Jan W. 1998. Use of Thematic Mapper imagery to map fuel models. In: Proceedings of the 13th Conference on Fire and Forest Meterology. Lorne, Australia.

Van Wagtendonk, Jan W., J.M. Benedict, W.M. Sydoriak. 1998. Fuel bed characteristics of Sierra Nevada conifers. Western Journal of Applied Forestry (in press).

Vogelmann, J.E., T.L. Sohl, and S.W. Howard. 1998. Regional characterization of land cover using multiple sources of data. Photogrammetric Engineering and Remote Sensing. 64(1):45-57.

Weltz, M.A., J.C. Ritchie, and H.D. Fox, 1994, Comparison of laser and field measurements of vegetation height and canopy cover, Water Resources Research, 30: 1311-1319.

Table 1. Schedule for fuels mapping project.

Phase	Oct 1998	April 1999	Oct 1999	April 2000	Oct 2000	April 2001	Oct 2001	Lead Team Member
Coordination Phase	|<-- Fuels symposium --->			|<-- Proceedings -->				Neuenschwander/Sampson
		|<---------- Electronic mailing list ---------->						Hardy
	|<---------- Publish newsletter ---------->							Keane
Research Phase	|<---- Fuel Characterization Linkage -------->							Hardy, Latham
	|<------- EDC TM Cluster Map ------->							Ohlen, Eidenshank
	|<---- Biophysical gradient model development ---->							Keane
	|<-- Link/test biophysical/ remote sensing approaches -->							All scientists
		|<------ Yosemite field test ---------->						Van Wagendonk
		|<------ Gila, Nez field test ---------->						Keane
		|<------ Frostfire field test ---------->						Ottmar, Sandberg, Alvarado
		|<------ Tenderfoot, Utah field test ----->						Hardy
	|< ---------- Lidar fuels map development ---------->							Queen/Seielstad
Implementation Phase	|<---- Formalize fuel mapping protocols and methods ----->							Hardy/Keane
		|< ----- Develop fuel hazard risk protocols ----->						Neuenschwander/Sampson
	|<---- Design and develop fire risk map protocols ------->							Burgan/Keane
				Release methods October 1, 2001---->				All scientists

Table 2. Budget of each task with direct costs and contributed costs. Applicable overhead computed at either 10% or 15% of sub-total, as indicated in column headers.

Item	Symposium and Proceedings		Mailing list, newsletter, and Web page		EDC TM Cluster map		Biophysical Gradient model and Linkages		Yosemite Park test		Gila and Nez Perce NF tests	
	Cost	Contrib	Cost	Contrib	Cost	Contrib	Cost	Contrib	Cost	Contrib	Cost	Contrib
Salary - PI	0	1,000	0	2,000	69,460	34,730	0	5,000	0	25,000	0	2,000
Salary - Asst	27,000	3,000	2,000	1,000	0	0	50,000	1,000	20,000	0	20,000	0
Fringe	0	0	0	0	0	0	0	0	0	0	0	0
Computers	500	500	500	500	10,000	5,000	1,000	1,000	0	0	1,000	1,000
Supplies	1,000	200	100	100	1,500	1,000	2,000	1,000	0	0	500	500
Travel	10,000	0	0	0	8,000	4,000	2,000	1,000	10,000	0	1,000	500
Commun.	5,000	0	0	0	0	0	0	0	0	0	0	0
Publication	10,000	0	500	500	0	0	1,000	1,000	0	0	0	0
Subtotal	53,500	4,700	3,100	4,100	88,960	44,730	56,000	10,000	30,000	25,000	22,500	4,000
Overhead (15%)	8,025	0	465	0	13,344	0	8,400	0	4,500	0	3,375	0
Totals	61,525	4,700	3,565	4,100	102,304	44,730	64,400	10,000	34,500	25,000	25,875	4,000

Item	Tenderfoot and Southern Utah field test		Frostfire field test		Lidar fuels map development		Fuel map protocols publication		Hazard map protocols		Fire risk map protocols	
	Cost	Contrib	Cost	Contrib	Cost	Contrib	Cost	Contrib	Cost	Contrib	Cost	Contrib
Salary - PI	0	5,000	0	5,000	11,374	0	0	5,000	2,000	0	0	5,000
Salary - Asst	20,000	1,000	20,000	5,000	70,000	0	2,000	500	26,000	0	9,000	0
Fringe	0	0	0	0	4,219	0	0	0	0	0	0	0
Computers	1,000	1,000	1,000	1,000	0	0	100	100	0	0	500	0
Supplies	500	500	1,000	1,000	10,000	0	200	100	0	0	0	0
Lidar Flights	0	0		0	35,000	0	0	0	0	0	0	0
Travel	1,000	0	5000	500	12,000	0	1,000	0	10,000	0	500	0
Commun.	0	0	0	0	4,000	0	0	0	0	0	0	0
Publication	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	22,500	7,500	27,000	12,500	146,593	0	3,300	5,700	38,000	0	10,000	5,000
Overhead (15%)	3,375	0	4,050	0	21,989	0	495	0	5,700	0	1,500	0
Totals	25,875	7,500	31,050	12,500	168,582	0	3,795	5,700	43,700	0	11,500	5,000