MAPPING VEGETATION AND FUELS FOR FIRE MANAGEMENT ON THE GILA NATIONAL FOREST COMPLEX, NEW MEXICO

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Abstract

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Fuels and vegetation spatial data layers required by the spatially explicit fire growth model FARSITE were developed for all lands in and around the Gila National Forest in New Mexico. Satellite imagery, terrain modeling, and biophysical simulation were used to create the three vegetation spatial data layers of biophysical settings, cover type, and structural stage. Fire behavior fuel models and vegetation characteristics needed by FARSITE were assigned to combinations of categories on maps developed from sampled field data and also from estimates by local fire managers, ecologists, and resource specialists. FARSITE fuels maps will be used to simulate growth of fires on the Gila National Forest aiding managers in the planning and allocation of resources for managing fire. An extensive accuracy assessment of all maps indicated surface and crown fuels layers are about 30 to 40 percent accurate. This methodology was designed to be replicated for other areas of the western United States.

Keywords: Gila National Forest, FARSITE modeling, fuels mapping, fire behavior fuel model, GIS, terrain modeling, satellite imagery classification, vegetation mapping, biophysical classification

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INTRODUCTION

Background

The movement toward holistic ecosystem management, coupled with the prolonged effects of 70 years of fire exclusion in the western United States, has necessitated the use of fire for returning ecosystem health and preventing disastrous wildfires (Mutch 1994, Mutch and others 1993). Fire managers must evaluate the potential size, rate, and intensity of a wildland fire to aid in short- and long-term wildland fire planning and resource allocation. Recent advances in computer software and hardware technology have enabled development of several spatially explicit fire behavior simulation models that predict the spread and intensity of fire as it progresses across the landscape (see Andrews 1989). Some of these computer programs have the ability to project future fire growth and compute possible parameters of wildland fires for planning applications or for real-time simulations (Campbell and others 1995, Richards 1990). One of the best spatially explicit fire growth models is the computer program FARSITE (Fire Area Simulator) available for most IBM-compatible personal computers (Finney 1995, 1998). FARSITE is currently used by many wildland fire managers in the United States and other countries to simulate characteristics of prescribed natural fires and wildfires (Finney 1998, Grupe 1998, Keane and others 1998a).

Realistic predictions of fire growth ultimately depend on the consistency and accuracy of the input data layers needed to execute spatially explicit fire behavior models (Keane and others 1998a, Finney 1998). FARSITE requires eight data layers for surface and crown fire simulations (Finney 1995). These data layers must be both precise and consistent for all lands and ecosystems across the analysis area. More importantly, the layers must agree with all other Geographical Information Systems (GIS) layers (i.e., spatially congruent). It is also helpful if these layers describe large land areas (e.g., greater than one million acres) so simulated fires will not encounter missing data at layer boundaries (Grupe 1998). Comprehensive development of these input data layers requires a high level of expertise in GIS methods, fire and fuel dynamics, field ecology, and advanced computer technology. It also requires abundant computer resources and field data. Unfortunately, many land management agencies do not have the computer resources or expertise to develop these complex spatial data layers.

So the FARSITE model, which is available for free to anyone, requires fuels layers that are quite costly and difficult to build (Keane and others 1998a). Since FARSITE has been selected by many federal land management agencies as the best model for predicting fire growth, many fire managers across the country are now learning how to use this tool and trying to obtain the input data layers for their land areas (Grupe 1998, Campbell and others 1995). Unfortunately, most fire and land managers do not have the fuels maps, or even base maps from which they could create the fuels maps, needed to run the FARSITE model for their area. Most existing vegetation layers and databases do not quantify fuels information to the level of detail or resolution needed by FARSITE. Moreover, some attempts to create FARSITE layers from existing maps have failed because of inexperience with fuels and vegetation modeling and mapping in the context of fire behavior. And those projects where suitable FARSITE layers were created, such as the Selway-Bitterroot Wilderness Complex, have been expensive and time-consuming, costing upwards of $0.10 per hectare and taking as long as one or two years (Keane and others 1998a).

Fire managers from the Gila National Forest and the Southwestern Regional Office of the USDA Forest Service had some unique fire management challenges. Areas in and around the Gila National Forest in southwestern New Mexico have a rich history of frequent fires, especially in the montane dry forests and grassland ecosystems (Abolt 1997, Boucher and Moody 1998, Gonzales and Maus 1992). However, effective fire suppression during the last 70 years coupled with intensive grazing has resulted in increased surface and crown fuels, thereby creating the potential for uncontrollable wildfires (Covington and others 1994). Moreover, intensive grazing in pinyon-juniper woodlands and grasslands had reduced fuel loads so much that conifer encroachment has proceeded unchecked by fires (Boucher and Moody 1998, Szaro 1989). Fire managers wanted to use the FARSITE computer program to simulate current and future fires for planning and real-time fire management, but they did not have the resources to construct the detailed FARSITE input layers needed for such a large area. Moreover, they wanted to develop spatially explicit, digital fuels maps useful for other fire management concerns, such as smoke generation and fuel consumption, to include in the fire planning process. We had just completed development of FARSITE input layers for 1 million ha (2.3 million acres) in the Selway-Bitterroot Wilderness Complex (SBWC) and had refined several new methods for mapping fuels and vegetation in mountainous terrain (Keane and others 1998a, 1998b). The Gila National Forest managers asked us to develop FARSITE data layers for their area using these new methods. They would then take the methods learned for their area to show other Forests in the Region how to map fuels on their areas.

This Gila fuels mapping project presented some challenging opportunities. First, there were no georeferenced ecological plot data for any part of the study area that were useful for mapping fuels and vegetation. In addition, we found very few GIS layers or paper maps available that were useful for FARSITE input mapping. To us, this meant that the development of vegetation and fuels classifications was unencumbered by existing classifications and data. Next, the fire managers wanted to use the layers for more than FARSITE fire behavior predictions. They needed spatially explicit data layers to predict smoke production, plan prescribed fire activities, and prioritize treatment areas. In addition, other resource groups besides fire management on the Gila National Forest needed vegetation layers to plan other management activities in wildlife and ecosystem restoration. This lack of spatial data and the inclusion of these additional objectives meant that we essentially had to start from "scratch" and could design every needed data layer around specific management objectives and FARSITE requirements, thereby minimizing translation problems with historical data and classifications. Moreover, the lack of field and spatial data meant that we did not have to follow existing classifications but could design efficient sampling methodologies and new vegetation and fuel classifications that would be meaningful to all mapping objectives. This was vastly different from our SBWC mapping effort where we encountered problems with translating existing georeferenced plot data to the vegetation classifications useful to fuel mapping, and incompatible existing and potential vegetation classifications that were rarely in agreement because they were developed independently (Keane and others 1998b).

The primary objective of this mapping project was ***to develop all input spatial data layers required by FARSITE to spatially simulate fire behavior on lands in and surrounding the Gila National Forest***. In addition, we agreed to develop several other vegetation and biophysical layers and relational databases useful for other phases of fire and natural resource management. In fact, the vegetation base layers developed for the primary objective of creating FARSITE input data layers provided a context to develop layers for the secondary objectives.

Some relevant terminology must be defined to avoid confusion for the reader. First, the term **polygon** describes a delineated area of similar environmental and vegetation conditions (Jensen 1986). In this paper, the terms "stand" and "polygon" have nearly identical meanings. Spatial data layers are either raster or vector layers. A **raster** layer is a grid of pixels over the geographic region of concern. Every **pixel** is square and its size defines the resolution of the layer. For the GNFC project, all pixels are 30 meters in width or

900 m^2 in area. A raster layer is defined as a georeferenced grid of pixels with each pixel assigned a value that describes a certain characteristics of the associated piece of ground. A **vector** layer is composed of georeferenced lines that define spatial objects—in this case, stands or polygons. **Georeferenced plot data** are field data collected within a fixed area plot whose center has been spatially referenced using a geographic coordinate system, often estimated using a Geographic Positioning System (GPS). In this study we used Universal Transverse Metacor (UTM) coordinates in UTM zone 12 with NAD 27 projection. **Fuels** are defined as the live and dead biomass that either contribute to the advancement of the fire front or are consumed after the flaming front has passed. Fuels are usually categorized as live or dead foliage and wood (Anderson 1982). Woody fuels are further stratified by four size classes based on their drying rates (Fosberg 1970). Two types of classifications are commonly discussed throughout this paper. A **vegetation classification** is a hierarchical list of categories that describe some characteristic of the vegetation referenced by a corresponding key to these categories. The three vegetation classifications used in this project are cover type, structural stage, and potential vegetation type. An **image classification** is the grouping of pixels based on similar spectral reflectance characteristics to map categories for a vegetation classification. A Glossary has been provided for terminology related to this project.

FARSITE Description

FARSITE requires eight spatial data layers for a comprehensive evaluation of surface and crown fire behavior. The first layer is called a Digital Elevation Model (DEM) where each pixel is assigned an **elevation**. **Slope and aspect** are also required FARSITE input layers and they can be easily derived from the DEM layer in a GIS using elevation values from surrounding pixels. The fourth layer is a **Fire Behavior Fuel Model** (FBFM) map. Pixels in this layer are assigned the Anderson (1982) fire behavior fuel model that best represents the surface fuel complex for the corresponding piece of ground. Pixels are assigned one of the 13 models of Anderson (1982) or assigned a customized fuel model (Finney 1995). We used seven of Anderson's (1982) 13 FBFMs and then built two customized fuel models for some unique conditions in the GNFC (Table 1). Average **canopy cover** is needed to compute hourly fuel moistures and reduce wind under the forest canopy. Canopy cover (percent) is the average vertically projected tree crown cover in the stand. These are the layers needed to simulate surface fire behavior and growth.

Table 1—Fire behavior fuel models (FBFM) used in this Gila project. All fuel models are discussed in detail in Anderson (1982) except for the pinyon-juniper (number 50), which we built specifically for this project.

Fuel model[1]	Description	Fire behavior[2] Rate of spread	Flame length
		(*m/sec*)	(*m*)
1	Short grass (0.^{3} m)	0.436	1.22
2	Timber (with grass and understory)	0.196	1.83
5	Brush (shrubs and conifer regeneration, 0.8 m)	0.1^{0}	1.22
6	Dormant brush	0.17^{9}	1.83
8	Closed timber litter	0.0089	0.31
9	Ponderosa Pine duff	0.042	0.79
10	Timber (litter and understory)	0.044	1.46
50	Pinyon-juniper	0.004	0.15
98	Water	—	—
99	Non-vegetation (rock, mines, barren)	—	—

[1] From Anderson (1982).
[2] Fire behavior under the following conditions: windspeed 8 km/hr, dead fuel moisture 8%, and live fuel moisture 100%.

FARSITE can compute crown fire behavior if three other vegetation data layers are present. **Average stand height** (m) and **average crown base height** (m) data layers are needed to compute crown fire initiation based upon the Van Wagner (1977, 1993) crown fire model. Stand height is the average height of the dominant tree layer. Crown base height is the average height to the bottom of the tree crowns in the stand. A **crown bulk density** raster layer is used to compute crown fire spread, along with the previously mentioned crown cover map. Crown bulk density (kg m^{-3}) is the density of the combustible tree crown biomass above the shrub layer. We used vegetation characteristics based on cover types to guide our estimations of crown bulk density in the field since it is a difficult parameter to directly sample (Table 2).

FARSITE spreads fire across a landscape using the fire behavior routines found in the one-dimensional fire model BEHAVE (Andrews and Chase 1989, Andrews 1986, Burgan and Rothermal 1984, Rothermal 1972). FARSITE computes fire intensities and spread rates for numerous points along the existing fire line using the fire behavior algorithms of Albini (1976) and Rothermal (1972). Fire is then propagated across the landscape from these points using a series of eclipses based on Huygen's principle (Anderson and others 1982), which is a wave-type model (Richards 1990). Huygen's principle essentially states that a wave can be propagated from points on its edge that serve as independent sources of smaller waves (Richards 1990). Dimensions of the ellipses are computed from the fire behavior predictions. FARSITE then connects all points at the end of the smaller waves using topological algorithms

Table 2—Crown Bulk Density Assignments after Brown (1978) and Pollard (1971).

Crown Bulk Density (kg/m^3)			
	Canopy cover		
Species	**Low cover**	**Medium cover**	**High cover**
Ponderosa Pine			
Small	0.10	0.12	—
Medium/Large	0.09	0.14	0.20
Douglas-fir			
Small	0.10	0.12	—
Medium/Large	0.10	0.18	0.25
Aspen			
Small	0.10	0.01	—
Medium/Large	0.01	0.01	0.01
Gambel Oak			
Small	0.01	0.01	—
Medium/Large	0.01	0.01	0.01
Juniper			
Open Woodland	0.03	—	—
Closed Woodland	—	0.05	—
Piñon			
Open Woodland	0.03	—	—
Closed Woodland	—	0.05	—
Evergreen Oak			
Open Woodland	0.03	—	—
Closed Woodland	—	0.06	—
Subalpine Fir - Spruce			
Small	0.12	0.14	—
Medium/Large	0.12	0.20	0.27
Ponderosa Pine - Douglas-fir			
Small	0.10	0.12	—
Medium/Large	0.10	0.16	0.22
Pinyon - Juniper			
Open Woodland	0.03	—	—
Closed Woodland	—	0.04	—
Broadleaf Riparian Forest			
Small	0.01	0.01	—
Medium/Large	0.01	0.01	0.01
Broadleaf - Conifer Mix			
Small	0.12	0.14	—
Medium/Large	0.12	0.20	0.27
Conifer - Gambel Oak			
Small	0.10	0.12	—
Medium/Large	0.09	0.14	0.20
Conifer - Woodland Mix			
Small	0.10	0.12	—
Medium/Large	0.09	0.14	0.20
Mixed Woodland			
Open Woodland	0.03	—	—
Closed Woodland	—	0.04	—
Mixed Conifer - Mesic			
Small	0.10	0.12	—
Medium/Large	0.10	0.18	0.25
Mixed Conifer - Xeric			
Small	0.10	0.12	—

Canopy Cover Descriptions: Low = 21-50 percent overstory canopy cover; Medium = 51-80 percent overstory canopy cover; High = 81-100 percent overstory canopy cover

and this delineates a fire line at a given time. The fuels, weather and topography of areas within the fire line dictate fire intensity and spread rates. A complete discussion of FARSITE algorithms is presented in Finney (1998) and it is recommended that this document be read before FARSITE is used.

Weather data are not input as a spatial data layer, but rather as a set of generalized ASCII files composed of a stream (i.e., list) of hourly or daily temperatures, precipitation, and relative humidities (Finney 1995). Each weather file is assigned to a point on the ground and FARSITE extrapolates this weather across the landscape using adiabatic lapse rates and other algorithms. Wind is treated differently than other weather parameters in FARSITE. Wind speeds and directions are specified by time of day in a separate set of wind ASCII files. Each wind file is assigned to a portion of the simulation landscape using FARSITE protocols. A complete discussion of input layers and data files is present in the FARSITE users manual (Finney 1995). We included several weather files in the Gila FARSITE database for this project so fire managers wouldn’t have to obtain these data from complex sources.

FARSITE creates many raster and vector spatial data layers and tabular ASCII databases such as maps and summaries of computed fire intensity (kW m^{-1}), spread rates, and flame lengths stratified by space and time variables. Fire growth and intensity patterns can be interactively displayed on the computer screen overlaid on top of topography and fuels layers. FARSITE was developed primarily to be used as a tool in the management of prescribed natural fires so that maximum allowable perimeters could be predicted. However, its use has grown to many other phases of fire management including wildfire planning, prediction and real-time management. All FARSITE output layers can be imported into a GIS for additional analysis and display. Keane and others (1996b) linked FARSITE to a the forest succession model Fire-BGC to evaluate the effects of fire across a large landscape in the Bob Marshall Wilderness Complex, Montana.

Fuel Mapping Studies

There have been few studies where the sole objective was to map fuels for the prediction or description of fire behavior. Most studies map vegetation, then assign fuel models to the vegetation classification. However, Grupe (1998) used the Terrestrial Ecosystem Survey (TES) to quantify and map FARSITE input requirements for the Cibola National Forest, New Mexico, but found that, although TES contained sufficient data to quantify crown fuel information, there was not enough information to create or assign FBFM to land areas. Moreover, he found that small variations in fuel models significantly affected fire behavior predictions. De Vasconcelos and others (1998) mapped the Anderson (1982) fuel models over a 192,000 ha region in north-central Portugal using neural network pattern searching on elevation, land use, and satellite imagery layers. They found this method strongly differentiated between grassland and shrubland fuel models with accuracies between 33 to 75 percent depending on land cover type. Their study emphasized the importance of ground data to train, test, and validate the neural networks. And of course, Keane and others (1998a) specifically mapped fuels for FARSITE use and their work is referenced throughout this paper.

Most studies mapped vegetation first and then developed fuels layers from the vegetation layers for fire modeling. Jain and others (1996) intensively sampled fuels for all categories of a forest type map created from IRS LISS II (Linear Image Self Scanning) imagery to create a fuel map for Rajaji National Park in India. Fire fuel model maps of the North Cascades National Park were developed by Root and others (1985) from plant community maps created from 1979 Landsat MSS (Multi Spectral Scanner) imagery and environmental gradients. They assigned both the NFDRS (Deeming and others 1978) and the Northern Forest Fire Laboratory (NFFL) (Albini 1976) fuel models to each classified vegetation type. A similar approach was used by Miller and Johnston (1985) where they assigned NFDRS fuel models to vegetation classifications of MSS and AVHRR imagery. Mark and others (1995) assigned Anderson (1982) fuel models to combinations of timber size class, stocking level, crown density, crown texture, and vegetation type that were sampled or extrapolated attributes of photo-interpreted polygons in their timber stand atlases.

In Canada, Canadian Forest Fire Behaviour Prediction System fuel types were assigned to vegetation categories on maps created from Landsat MSS data for Wood Buffalo National Park (Wilson and others 1994), Quebec (Kourtz 1977), and Manitoba (Dixon and others 1985). Hawkes and others (1995) used an expert systems approach to assign Canadian Fire System fuel types to combinations of stand structure and composition information obtained from forest surveys. Taylor and others (1998) used a similar method to simulate the changes in fuel characteristics from stand conditions. In Taiwan, SPOT imagery and GIS were used to create land use types that were linked to NDVI greenness estimates to predict spatial changes in vegetation phenology (Hsieh 1996). Roberts and others (1998) used AVIRIS (Airborne Visible Infra-Red Imaging Spectrometer) satellite sensor imagery and spectral mixture analysis to classify vegetation fraction, cover, and water content which were then related to fuel loadings directly sampled on the ground. Yool and others (1985) used TM imagery to describe brushy fuels in southern California while Hardwick and others (1996) assigned Anderson (1982) fuel models to vegetation categories from the TM-derived CALVEG vegetation map to create a fuel map for the Lassen National Forest.

A major disadvantage of this approach is fuels are not always correlated with existing vegetation characteristics or land-use categories because stand history, biophysical setting, and vegetation structure are also significant factors governing fuel characteristics. They need to be incorporated into the fuel model assignment protocols. Another disadvantage is that vegetation layers are often composed of stands or polygons that may be too coarse for fine scale fire spread prediction. Homogeneity of the fine scale fuel mosaic may generate "smoothed" fire spread predictions which may not be realistic (Finney 1998). This indirect approach is often the easiest and quickest because many vegetation classifications and maps are available and most people can identify vegetation types with little trouble (Eyre 1980). The greatest benefit of this approach is the creation of a vegetation map that can be useful for other land management applications. Other attributes can be assigned to land use categories to create other useful maps. The ICBEMP (Interior Columbia River Basin Ecosystem Management Project) effort assigned wildlife habitat levels to the coarse scale cover type map to estimate historical to current declines in habitat value (Quigley and others 1996).

Projects where fuels were directly mapped from remotely sensed products such as aerial photos and satellite imagery have the highest success when estimating total living and dead biomass in grasslands and shrublands (Friedl and others 1994, Millington and others 1994), and have limited use for assessing surface fuels in forested ecosystems because of canopy obstruction of the forest floor. Principal components and NDVI calculated from AVHRR (Advanced Very High Resolution Radiometer) imagery composites of the western United States were classified directly to fuel classes that were based on vegetation for input to a Initial Attack Management System (McKinley and others 1985). The three images generated from the tasseled cap transformation on Thematic Mapper (TM) multispectral data have been used to classify chaparral shrub fuel characteristics across mid-scale landscapes in California (Cohen 1989, Stow and others 1993). Merrill and others (1993) estimated living grassland biomass in Yellowstone National Park using regression models on bands 4, 6, and 7 from MSS data. Salas and Chuvieco (1994) classified TM imagery directly to 11 of Anderson's (1982) fuel models, then assigned vegetation categories to each fuel model to compute fire risk on a large landscape in Spain. An Anderson (1982) fuel model map was directly classified from TM imagery of Camp Lejeune, North Carolina, for simulating prescribed fires with FARSITE (Campbell and others 1995). A special kriging technique called isarithmic analysis was used to interpolate sagebrush fuel loadings across a small Colorado landscape from field data (Kalabokidis and Omi 1995). At very fine scales, large scale aerial photography has been successfully used to estimate natural and slash fuel distributions in a variety of forested settings in Canada (Belfort 1988, Dendron Resource Surveys 1981, Morris 1970, Muraro 1970).

The use of environmental gradients to predict fuel characteristics has had mixed success. These gradients can be topographical (elevation, aspect, slope), vegetational (successional stages), biophysical (soils, landform), or biogeochemical (evapotranspiration, productivity, nutrient availability). Kessell (1979) used seven gradients based on topography and vegetation to predict fuel models and loadings in Glacier National Park, Montana. Habeck (1976) sampled fuels and vegetation in the Selway-Bitterroot Wilderness Area of Idaho and related fuel loadings to stand age and moisture-temperature gradients. Keane and others (1997b) developed an untested protocol for mapping fuels from several biogeochemical and biophysical variables using an extensive network of field plots. Kessell and Catellino (1978) used a form of gradient modeling to predict chaparral fuels in California.

One advantage of the gradient approach is that an expression of the surrounding environment provides a context in which to understand and predict fuel dynamics (Whittaker 1967). For example, low fuel loadings in a stand may be explained by low precipitation, high evapotranspiration, and shallow soils. Furthermore, environmental gradients that describe important ecosystem processes, such as biogeochemical cycles, correlate well with fuels dynamics and therefore provide a temporal and spatial framework for creating fuels maps. Climate change effects on spatial fuel loadings can be easily created by recomputing the environmental gradients under the new climate (Keane and others 1996b). Most environmental gradients are scale-independent which means that the same gradients may be used to predict fuel characteristics across many spatial scales regardless of pixel size (Kessell 1979, Whittaker 1967). A problem with this approach is that gradients do not provide a spatial description of existing conditions and remotely sensed data are often needed to portray vegetation-based gradients such as succession classes or cover types. Gradient information is best used to describe the potential of a landscape or stand rather than to compute existing conditions (Keane and others 1997b, Kessell 1979). Some fuel and vegetation mapping projects have merged combinations of the above approaches to map fuels. Keane and others (1998a) used terrain modeling to differentiate environmental gradients using potential vegetation types (Pfister and others 1977) and satellite imagery to differentiate vegetation types to create FARSITE fuel maps for several areas in the Rocky Mountains.

Study Area

FARSITE input layers were developed for all lands in and around the Gila National Forest with boundaries defined by the limits of the satellite imagery and Digital Elevation Model (DEM) coverage (see bold line in Figure 1). This study area will hereafter be referred to as the **Gila National Forest Complex or GNFC**. The Continental Divide winds its way through the GNFC, where elevations range from 1370 m in the low elevation grasslands to over 3000 m along the Mogollon Rim in the southwestern GNFC.

Figure 1—Boundaries of the Gila National Forest Complex (GNFC). Boundaries are set by the extent of the Digital Elevation Models (DEMs) and the extent of the 1993, 1996 Thematic Mapper satellite imagery.

Vegetation in the GNFC ranges from desert grassland and scrub at the lowest elevations to subalpine forest at the highest elevations. Mixed woodlands of pinyon (*Pinus edulis*), juniper (*Juniperus spp*.), and oak (*Quercus spp*.) and forests of ponderosa pine (*Pinus ponderosa*) interspersed with plains-mesa grasslands at mid elevations occupy large expanses of the GNFC. Upper elevations are dominated by montane coniferous forests of white fir (*Abies concolor*), blue spruce (*Picea pungens*), Douglas-fir (*Pseudotsuga menziesii*), and southwestern white pine (*Pinus strobiformis*) with the highest slopes and ridges dominated by subalpine coniferous forests of subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*). Broadleaf forests of quaking aspen (*Populus tremuloides*) and gambel oak (*Quercus gambelii*) also occur interspersed throughout the montane and subalpine forests (Kruse and others 1996, Dahms and Geils 1997).

GNFC climate is monsoonal with dry, mild winters and hot, dry summers punctuated by a monsoon season of about two months starting in mid-July. At Gila Hot Springs (elevation 1740 m), in the center of the Gila Wilderness area in the GNFC, average daily temperatures range seasonally from 1.7° C (35° F) to 21° C (70° F) and average daily precipitation ranges seasonally from .02 cm to .28 cm (McCurdy 1997). At higher elevations (2500 m), temperatures range from –5° C (22° F) to 14° C (57° F) (Dick-Peddie 1993). Precipitation ranges from less than 200 mm per year in the low elevation scrublands to over 1000 mm per year along the Mogollon rim.

The geology of the GNFC is regionally simple but locally complex. Marine sediments were deposited during much of the Paleozoic Era as seas covered most of the GNFC (Chronic 1995). As tension stretched the continental crust to the breaking point during the middle Cenozoic Era, composite volcanoes spewed lava and ash, eventually collapsing into large calderas in the western highlands of western New Mexico. More recently, geomorphic processes of erosion and mass wasting have created some unique and complex landforms that dictate vegetation composition and fuel dynamics. The GNFC landscape is highly dissected due to locally intense rainstorms contributing to highly variable erosion processes which create diverse topographic and biophysical settings. The dissected nature of the GNFC landscape affects the type and loading of fuels.

The GNFC had a rich and varied fire history (Boucher and Moody 1998). Low severity surface fires occurred every 3 to 27 years prior to 1900 in the ponderosa pine forests, and fires were more frequent in the grass and shrublands. Non-lethal surface fires and some stand-replacement fires occurred in the montane ecosystems at average fire intervals ranging from 10 to 50 years (Abolt 1997). Historically, the vast majority of GNFC landscape was composed of six fire behavior fuel models (Anderson 1982); the fast-moving grassland models 1 and 2, and the shrub models 5 and 6, and the slower-moving timber models 8 and 9 (Chronic 1995, Rixon 1905). However, over a century of livestock grazing and 60 years of active fire exclusion have dramatically altered fire regimes in the GNFC (Boucher and Moody 1998, Dahm and Geils 1997, Savage and Swetnam 1990). Stand-replacement fires are now more common because of the buildup of woody fuels and litter (Covington and Moore 1994). Conifer stands are denser and have more canopy layers that are more likely to result in crown fires (Covington and others 1994).

Tree densities have increased exponentially with the lack of fires because of abundant regeneration, and this has precipitated declines in tree vigor and forest health that has, in turn, caused increases in insect and pathogen infections (Abolt 1997, Covington and others 1994, Wilson and Tkacz 1996). Many stands that were historically described by low severity fire behavior fuel models (FBFM) 8 (closed timber low woody fuel loadings) and 9 (litter understory) have now succeeded to FBFM 10 (closed timber heavy fuel loading) which predicts severe fire behavior (Boucher and Moody 1998). Grasslands have been invaded by pinyon and juniper, which can create depauperate understories devoid of fine fuels. Now, fuel models for historical grasslands have gone from a FBFM 1 (grasslands) to some custom fuel model with much less fine fuels and less intense fire behaviors (FBFM 50 in Table 1). This anthropogenic modification of landscape fuels has made development of FARSITE fuels layers all the more imperative because these layers will be used to plan the prescribed fires that will help restore historical fire regimes and return ecosystem health.

METHODS

Framework

There are many reasons why FARSITE input data layers are difficult and costly to build. First and most important, most remotely sensed products used for fuel mapping, such as aerial photos and satellite images, are not particularly useful for discriminating different fuel types because the ground is often obscured from view by the forest canopy (Elvidge 1988, Lachowski and others 1995). Second, the most important layer needed by FARSITE, the fire behavior fuel model (FBFM) layer, is not so much a quantitative characterization of fuel loadings, but rather a description of expected fire behavior for the stand (Anderson 1982, Burgan and Rothermel 1984). Therefore, many people who do not have experience in fire behavior or fuel model classifications are often unable to estimate the FBFM accurately and consistently. Next, the characterization of all the types and sizes of fuel in a FBFM is very difficult to discern from remotely sensed imagery. In fact, wildland fire propagates primarily through the fine fuels (i.e., grasses, needles, and small woody material less than 1 cm in diameter), and the loadings of these small fuels are notoriously difficult to classify from imagery in timber environments (Jensen 1986). Fourth, the eight data layers needed to simulate fire growth must be developed and mapped simultaneously so they are spatially congruent. This means the crown height for a stand must not be taller than the stand height for the same stand, for example. The three topography layers (elevation, aspect, slope) are easily derived from DEM's (USGS 1987), but the surface fuel layer (FBFM) and the four crown fuel layers (closure, bulk density, stand height, and crown height) must be consistently quantified in an ecological context across large land areas (Finney 1998). Next, fuels are notoriously variable in time and space, and it is difficult to match their scale of measurement to the scale of mapping (Brown and Bevins 1986, Whittaker 1962). Last, fuel maps must be developed at fine resolutions (e.g., 30 meter pixels) for the accurate simulation of fire behavior, and many existing stand and vegetation classifications and maps are too coarse for use in FARSITE. So, since fuels are difficult to directly map or detect from imagery, we assumed that there must be a suite of biophysical or biological spatial data layers that are easy to map and yet correlate well with FBFMs and crown characteristics.

The methodology we used to develop the GNFC FARSITE input layers is based on the premise that most ecological characteristics, especially fuels, can be described from three commonly used ecological classifications of **site environment, species composition, and stand structure.** This assumes that many stand characteristics pertinent to land and fire management can be uniquely represented from a characterization of that stand's biophysical environment, dominant plant species, and vertical structure of the vegetation, called the vegetation triplet. The site environment is important because critical, site-dependent ecological processes such as productivity, decomposition, and fire regime often govern fuel loadings and fuel characteristics (Brown and Bevins 1986, Waring and Running 1998, Whittaker 1967). Species composition is important because branchfall and leaffall rates are unique to many forest and range communities. Moreover, the diverse fuel accumulation rates and varied species morphology of plant communities can create unique fuelbed characteristics (Brown and See 1981, Brown and Bevins 1986). Stand structure is critical because it describes the vertical arrangement of live and dead biomass above the ground surface (O'Hara and others 1996, Oliver and Larson 1990). The vertical arrangement of biomass, both on the ground and in the air, dictates the subsequent intensity and severity of a fire, especially a crown fire. The mapping protocol presented here is not the only way to map fuels for fire behavior prediction. There are many other methods for constructing fuel maps such as timber stand map assignments, direct satellite image classification, and photo interpretation (Grupe 1998, Mark and others 1995). But, we feel the methods presented in this paper provide for the most comprehensive and robust map products without exorbitant development costs.

This vegetation triplet concept has been successfully used to indirectly describe ecological characteristics for many applications. Arno and others (1985) classified successional plant communities from a description of habitat type (i.e., biophysical setting), cover type, and diameter structure. Keane and others (1996a) used this framework to simulate landscape succession at coarse, mid- and fine scales (Keane and others 1997a, Keane and Long 1998). Moreover, many hydrologic, wildlife, fire, and fuels characteristics were mapped for the Interior Columbia Basin Ecosystem Management Project (ICBEMP) scientific assessment from these three characteristics (see Quigley and others 1996). Shao and others (1996) used potential vegetation types to refine a cover type classification from satellite imagery for a natural reserve in China. Keane and others (1998b) detail four fuel mapping projects across the western United States where this approach was used.

The problem then is to select the set of three classifications that best describe environment, composition, and structure. For the GNFC project, we selected the classifications of **biophysical settings** to describe site environment, **cover type** to describe species composition, and **structural stage** to describe the vertical stand structure. Hereafter these three classifications will be referred to as the **base vegetation classifications** and maps. We assumed a myriad of ecosystem characteristics, including surface and crown fuels, can be quantified from this triplet based on past succession and ecological research (Arno and others 1985, Steele and Geier-Hayes 1989, Kessell and Fischer 1981). Classifications similar to these three were used successfully for the Selway-Bitterroot Wilderness Complex fuel mapping project and several other projects in the northern Rocky Mountains (Keane and others 1998a, Keane and others 1998b).

The biophysical settings layer was to be created from a **biophysical settings classification** of the GNFC landscape that integrated climate, hydrology, evapotranspiration, vegetation, and soils processes to spatially predict changes in the GNFC environment important to fuels mapping. We were going to use the mechanistic gradient model of Keane and others (1997b) to spatially predict biophysical settings by coupling topographic variables such as landform, elevation, and aspect to climate and biogeochemical process variables such as precipitation, evapotranspiration, and productivity to define GNFC biophysical settings categories. However, the simulation and mapping technology and expertise needed to perform this extensive task were not ready at the time. Instead, we decided to create the biophysical settings map from topographic rulebased terrain modeling based on potential vegetation type (see detailed description below). We did, however, test the applicability of the Keane and other (1997b) gradient model in creating the biophysical settings layer as presented in later sections.

Biophysical settings are inherently difficult to map because they represent the complex integration of long-term climatic interactions with vegetation, soils, fauna, and disturbance (Keane and others 1996a, Deitschman 1973). Moreover, selection of those biophysical processes critical to fuel dynamics is difficult because most are unknown or unquantifiable. Biophysical setting categories are hard to identify in the field because of their temporal aspect; many are quantified as a rate such as precipitation (mm year^{-1}). For example, one would need to place a weather station within each mapped polygon for several years to identify the biophysical setting categories described by climate. So, a vegetation-based classification was needed to easily identify biophysical settings on the ground. The biophysical classification can then be cross-referenced to the vegetation-based potential vegetation classification to directly identify biophysical settings from a plant key. Plant classifications that accurately identify the potential vegetation able to inhabit a site in the absence of disturbance provided the perfect linkage between biophysical settings and vegetation (Pfister and others 1977, Daubenmire 1966). Therefore, a **Potential Vegetation Type (PVT) classification** was used to identify biophysical settings in the field (Keane and others 1998b).

This linkage of the “bottom-up” PVT classification with the “top-down” biophysical settings classification (gradient model) will eventually provide a more robust approach to mapping site conditions. This strategy does not require the mapping of both PVT and biophysical settings, but rather uses each to improve the ultimate classification of site environment. The great utility of this approach is that these two site classifications can be used alone or in tandem.

The biophysical settings layer can be used if field data and ecological expertise are limited, while the PVT settings can be used if weather, soils, simulation model input data are unavailable. And the PVT and biophysical settings layers can be linked to improve the overall site descriptions. For example, the mapping of PVT categories from terrain data (topography) can be enhanced if the data layers of annual rainfall, solar radiation, and net primary productivity are used to refine the topographic ruleset (Keane and others 1997b).

A PVT describes the composition of near-climax communities at the endpoint of succession (Daubenmire 1966). Theoretically, a PVT supports a stable, self-perpetuating plant community in the absence of disturbance (Pfister and others 1977). This community exists within a unique set of environmental conditions that can serve as a surrogate for classifying environmental site conditions (Arno and others 1985, Pfister and others 1977, Steele and Geier-Hayes 1989, see Jensen and others 1993). Habitat types and habitat type phases (Pfister and others 1977) are roughly equivalent to PVTs at fine spatial scales, while habitat type groups (Reid and others 1995), fire groups (Fischer and Bradley 1987), or topographic settings (Barrett and Arno 1992, Brown and others 1994, Keane and others 1997b) can be used as PVTs at mid scales, which is the scale of reference for most fuel mapping studies. The ICBEMP created a biophysical settings layer from temperature and moisture variables to classify and delineate coarse scale PVTs across the Interior Columbia River Basin (Reid and others 1995). Methods used to create the biophysical settings layer and the PVT classification for this GNFC project are discussed in detail in later sections.

Species composition is roughly characterized from **cover types** with categories that generally describe the dominant plant species based on a plurality of basal area and canopy cover for forest types or based on vertically projected plant cover for rangelands. Examples of coarse and mid scale cover type categories are presented in Shiflet (1994) for range types and Eyre (1980) for forest types. Differences in cover types can be successfully discriminated from satellite imagery and remote sensing but with a limited accuracy (see Greer 1994, Lachowski and others 1995, Redmond and Prather 1996, Shao and others 1996). Cover type maps can be created from a multitude of remotely sensed products including aerial photo interpretation, digitized stand maps, videography, and satellite imagery (Lachowski and others 1995, Keane and others 1997b, Kessell 1979). Both cover type and structural stage maps for the GNFC project were created from Landsat 5 Thematic Mapper (TM) satellite imagery using image processing techniques.

Plant community structure is the vertical arrangement of dead and live plant biomass above the ground and mostly describes the vertical characteristics of canopy layers and stem material. Stand structure was described in the ICBEMP by a process-based classification of **structural stage** which describes the vertical succession of tree and rangeland structures during stand development (O'Hara and others 1996, Oliver and Larsen 1990). However, preliminary field investigations on the GNFC revealed many process-based structural stages could not be accurately and consistently assessed in the field or adequately discriminated with satellite imagery because of past disturbance history. Therefore, we simplified our forest structural stages categories by relating them to tree diameter size-classes and the rangeland stages by stratifying them by lifeforms and site type.

There are many advantages of using this "vegetation triplet" approach to mapping fuels. First, the concept can be used across many spatial scales because the categories in each of the three classifications are easily scaled to the appropriate level of application. For instance, a cover type category at a coarse scale may be "needleleaf conifer" whereas the same cover type at a mid or fine scale might be "ponderosa pine." Second, many land management agencies already use some form of these classifications in their every day management activities, and these classifications can be easily developed if they do not exist for some areas. There is also a large body of research available on these types of classifications and their mapping (Arno and others 1985, Steele and Geier-Hayes 1989). Many National Forests have existing classifications for these three attributes, and many of their databases contain fields for these classifications, but very few have accurate maps of these attributes across large land areas as yet. Fourth, this vegetation triplet provides a context in which to interpret fuels maps. For example, it is useful to know that a stand received a closed conifer FBFM because it is a high elevation, northfacing site with a spruce-fir cover type in the pole stage. Next, many types of georeferenced field data can be used to identify categories of these classifications in the field. Numerous historical plot data contain plant species lists that can be keyed to cover type and PVT. These layers can easily be updated and refined, and new categories can be added as additional field data become available. Lastly, and probably most importantly, these layers can be used to map, not only the FARSITE input data layers, but also many other ecosystem characteristics such as hiding cover, coarse woody debris, and erosion potential useful to wildlife, fuels, and hydrology issues.

Mapping Approach

This mapping project required many tasks to be done simultaneously so that it could be completed in less than three years with two years of field sampling. This means that many critical steps needed to be initiated without critical products from other steps. For example, we could not afford to wait for the first year's field data to be collected to develop the vegetation classifications. Figure 2 generally describes the steps (listed vertically) in each phase

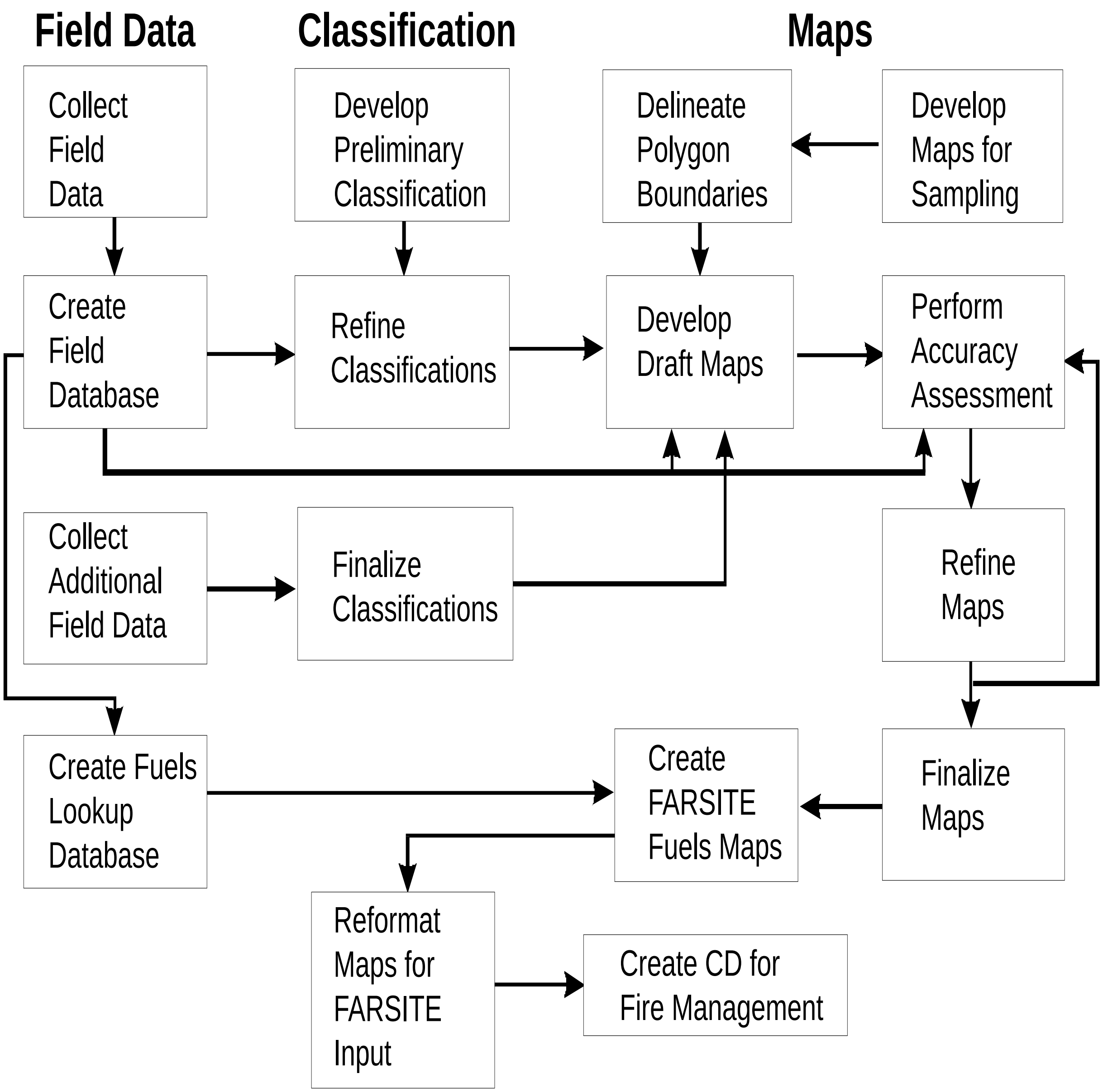

Figure 2—Steps involved in this fuel mapping process. To save time, many steps needed to be simultaneously.

(listed horizontally) of the project (Field data collection, classification, and mapping). In summary, preliminary vegetation and fuels classifications were developed and an unsupervised cluster layer of tentative polygons was created to aid in collection of the first year of field data and the first draft version of the FARSITE fuels maps (Figure 2). Extensive field data were collected and organized into a database that was then used to refine classifications. Polygon boundaries were delineated for all areas of the GNFC using textural classification algorithms and then a supervised classification of the same TM imagery was used to assign vegetation categories to each delineated polygon. Field data were used to iteratively refine and improve both the supervised classification and polygon assignments. Categories for each base vegetation classification were finally assigned to each delineated polygon and then a fuels lookup table was created from the field data to assign FARSITE fuel parameters to each base vegetation triplet combination. These maps were then reformatted to FARSITE format and written to a Compact Disk (CD) for fire management.

Implementation of this vegetation-based strategy to create the FARSITE layers involved the complex integration of field sampling, image processing, GIS, and fuel modeling tasks as illustrated in Figure 3. In short, maps of PVT, cover type, and structural stage were created from terrain modeling, gradient modeling, and satellite imagery using an extensive georeferenced field data set. Then, the three layers were overlaid to identify all combinations of PVT, cover type, and structural stage for every polygon. Illogical combinations were discovered and fixed using the field data and ecological knowledge of the area as criteria. Field data were then summarized by every PVT-cover type-structural stage combination to assign an FBFM, crown height, stand height, crown closure, and crown bulk density to each combination (right side of Figure 3). Field data were also used to assign other ecological parameters discussed later to each combination. Lastly, raster maps of the eight FARSITE layers were constructed and imported into the FARSITE landscape format along with weather databases and other cartographic raster layers (Finney 1995).

Field Sampling

Collection of field data is the most critical task in the mapping of fuels, even though it is often the most costly and time-consuming part of any mapping effort. It would be difficult to overemphasize the importance of obtaining ground-based data to guide fuel mapping projects. As mentioned, it is nearly impossible to accurately describe fuels characteristics important to fire behavior from remotely sensed imagery because the canopy obscures fuels

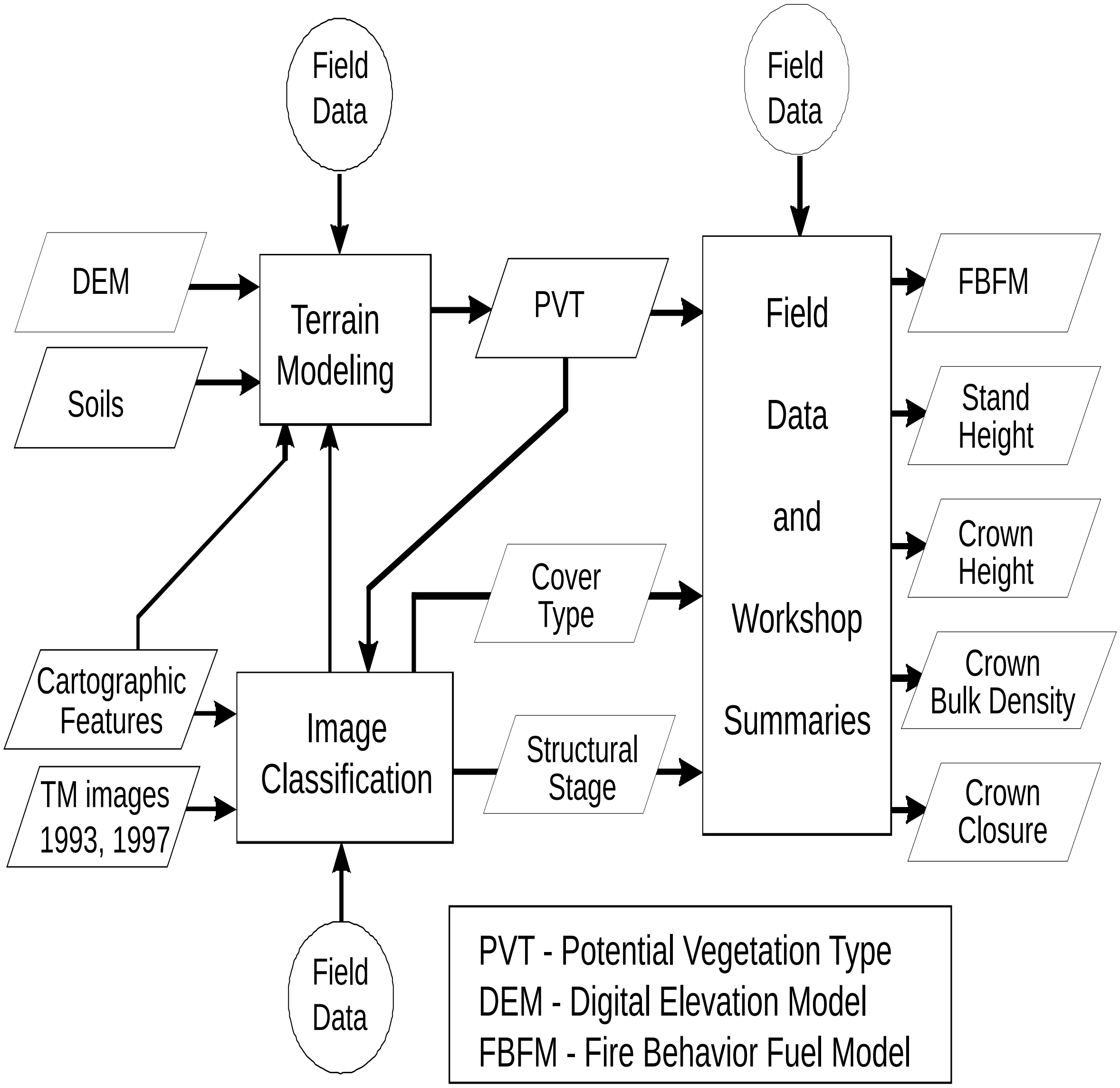

Figure 3—Flow diagram illustrating the general procedure used to create the FARSITE input fuel maps for the Gila National Forest Complex (GNFC) area.

characteristics and the important fine fuels are too small to detect. Therefore, plot data with georeferenced coordinates are the only source available to accurately describe fuelbed characteristics for mapping and relating these characteristics to other mappable entities that correlate closely with fuels. Field sampling is literally the only way as yet to adequately describe fuel characteristics for fire modeling for all situations. It would be folly to attempt to map FARSITE input layers without adequate field sampling.

Georeferenced plot data are important for many reasons. First, field data provide important **ground-truth** information or an accurate description of what is being sensed from imagery. This means sampled polygons can be used as **training areas** that define classification categories for controlling image classification procedures and techniques (i.e., supervised approaches) (Jensen 1986). In addition, field data can be used to describe a polygon classified from unsupervised clustering techniques (Verbyla 1995). Field data also provide a means for quantifying accuracy and precision of developed spatial classifications. These data are also useful for designing and improving keys for the vegetation classification categories that are being mapped with imagery. But most importantly, field data provide a means for interpreting image classifications. Reasons for inaccuracies in an image classification can be explored using detailed plot data. For example, an inaccurate shrub-herb classification category can often be improved if the cover of bare soil and rock was sampled at each plot.

Sampling Strategy — We used a fixed-area plot sampling technique to describe ecological characteristics within each map unit (i.e., polygon). Each plot was circular in shape and 405 m^2 (1/10th acre) in size. Plot centers were subjectively located in a representative portion of selected polygons without preconceived bias (Mueller-Dombois and Ellenburg 1974, Arno and others 1985). Representativeness was determined from disturbance history, plant species composition, and site environment (Pfister and others 1977). It was assumed conditions within the circular plot were indicative of the stand or polygon as a whole. Each plot was georeferenced using a Global Positioning System (GPS) and its coordinates were entered into a database that was later imported into the GNFC GIS. We gathered all GNFC field data during the spring and summers of 1997 and 1998.

Information collected at each plot was measured using modified ECODATA methodology (Keane and others 1990, Jensen and others 1993). ECODATA is a set of standardized methodologies designed to measure common ecological characteristics using flexible procedures. ECODATA sampling techniques provided the desired level of detail 1) to develop vegetation classifications, 2) to map vegetation and fuels using satellite imagery, and 3) to understand and interpret each classification with ecological parameters. We modified ECODATA forms and methods so that the inputs required by FARSITE were directly measured on all field plots. Plot forms used in this effort are presented in Appendix A. ECODATA methods are explained in detail in Hann and others (1988), Keane and others (1990), and Jensen and others (1993) so we will not discuss those methodologies here, except to describe the modifications specifically implemented for this study presented in later sections.

Sampling Stratification — A preliminary map of GNFC polygons was developed from an unsupervised classification of satellite imagery data obtained for this study to temporarily stratify the landscape for field sampling (Jensen 1986, Lachowski and others 1995). These tentative polygons were used to find map units to sample on the ground. Their boundaries were improved as more refined image classifications were completed later in the study. Paper copies of these preliminary polygon layers, made at the same scale as a USGS 7.5 minute quadrangle map, were brought into the field for navigation to the polygons selected for sampling.

Polygons were selected for sampling based on a geographic and topographic hierarchical sampling stratification where the GNFC was divided into ecological regions, then important environmental gradients within each region dictated the sampling locations (Dicke-Peddie 1993). The GNFC study area was divided into five ecological zones based on vegetation, climate, and topographic diversity (Figure 4). The first zone, the Black Range zone, occurs on

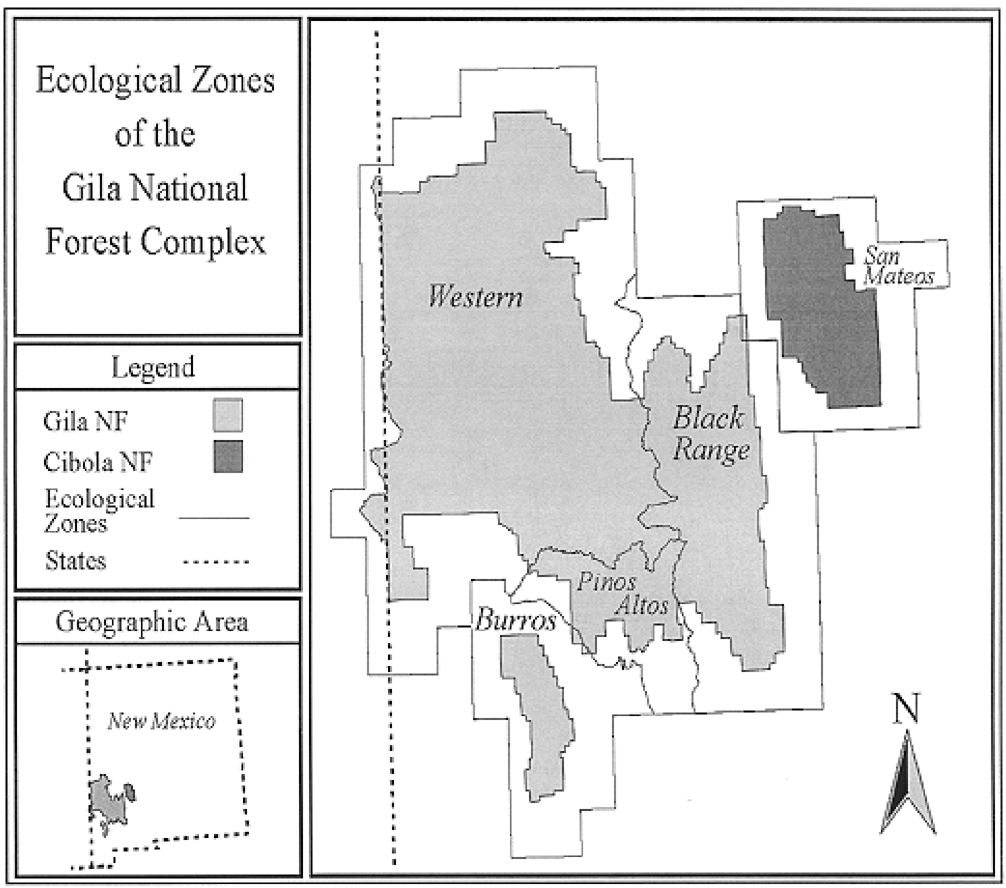

Figure 4—The five ecological zones within the Gila National Forest Complex. These zones geographically stratified major GNFC ecological types for sampling stratification, image classification, and terrain modeling.

the eastern border of the GNFC and includes the Black and Mimbres mountains. The second zone is the Pinos Altos zone, located north of Silver City, New Mexico, where the absence of white fir differentiates this mountain range from others with similar elevation ranges within the GNFC. The third zone, the Burro Mountains Zone, includes the Burro Mountains, located to the southwest of Silver City, New Mexico, where vegetation ranges from desert scrub at the lower elevations to ponderosa pine and gambel oak in the higher elevations. The fourth zone, the San Mateo zone, includes the San Mateo Mountains, a portion of the Cibola National Forest, located to the southwest of Socorro, New Mexico. The fifth zone, the Western zone, includes the Mogollon Mountains and the remaining lands of the study area and is characterized by woodlands and montane and subalpine coniferous forest (Dick-Peddie 1993). These zones were partially created from a classification of watersheds based on soils, topography, and geographical locations performed in the GNFC GIS. We refined the zones as sampling progressed and as additional plot data became available for evaluation (Figure 4). A consistent and comparable sample size was imposed for each zone weighted by area.

We used these ecological zones not only to stratify plot sampling, but also to refine and constrain the cover type and PVT base layers needed to map fuels. This zonation allowed us to key certain cover type and PVT categories to those areas where they occurred. For instance, white fir does not occur in the Pinos Altos Zone, so we did not map white fir cover types and white fir PVTs in the Pinos Altos Zone. This zonation also allowed us to stratify the imagery classification by broad ecosystem types so that we could constrain the unique list of possible cover types and structural stages to each zone and minimize image classification categories by geographical region.

We originally divided each ecological zone by watershed using the 6th code Hydrologic Unit Code or HUC (Seaber and others 1987, USGS 1990) to delineate mid-scale areas to sample based on the following criteria: accessibility, representation of ecological zone, full elevational range, and watershed size (20,000 to 40,000 ha). The selected sample watersheds (HUCs) were further divided into polygons generated from the unsupervised satellite image classification discussed above. However, because of limited time and sampling crews, we had to abandon the HUC sampling stratification and instead sample based on accessibility, ecological zone, and elevation range.

Selection of the polygons to sample was based on several factors. First, it was important to establish plots along important environmental gradients within each zone to ensure all combinations of vegetation and environments are represented in the field data. Since the direct gradients of climate, soils, and disturbance are often difficult to identify in the field, we needed a set of easily measured surrogates that correlate well with these direct environmental factors (Keane and others 1997b). We selected the indirect topographic gradients of elevation, aspect, and slope as important indicators of environmental gradients to guide polygon selection. These gradients served as guidelines for plot establishment and were not absolute requirements. We tried to establish at least one plot in each major topographic settings within each zone, but this wasn't always possible because of inaccessibility and time constraints. We also tried to sample all cover type and structural stage combinations within a topographic gradient, but this was also difficult because the combinations were not known prior to going into the field. Obviously, a great deal of field experience was needed to guide the selection of sample polygons to ensure a robust data set because of the somewhat subjective nature of polygon selection.

Plot Measurement Detail — It would have been nearly impossible to adequately sample the entire 2.3 million ha GNFC study area to the appropriate level of intensity and detail needed to accurately describe fuels for all project objectives because of time, money, and access constraints. There was not enough time or money to hire, train, and mobilize the field crews needed to extensively sample all ecosystems and topographical situations in the GNFC study area. And, there were many private lands where we could not gain access for sampling. Moreover, the level of detail needed from each plot could take several hours to measure which would prohibit large sample sizes needed for image classification and accuracy assessment. In other words, the wide array of ecological characteristics specified for measurement at each plot (e.g., tree sizes, plant species coverages, fuel loadings) would have exhausted the time that could be used to sample more plots. As a result, we needed to design a sampling strategy that would balance measurement detail with sampling intensity and available resources.

Three levels of measurement detail were utilized in this field approach. The most intensive sampling methodology was used to quantify the myriad of ecological attributes and stand characteristics (e.g., fuel loadings, tree size distributions, plant species compositions) important to understanding the ecological interrelationships that influence vegetation and fuel dynamics in and around the Gila National Forest. The next level of sampling detail was used to quantify ecological attributes and stand characteristics used in all map layers and vegetation classifications. The least intensive measurement methodology was used to quickly assess accuracy of developed layers.

The most intensive measurements were taken on the **Ecosystem Characterization (EC) plots** that were semi-permanently located within representative portions of unsupervised polygons using a wooden stake (See Appendix B for EC plot establishment details). The primary purpose of this sampling scheme was to collect the detailed information needed to characterize and describe all ecosystem attributes, especially actual fuel loadings, for assigning important attributes to base vegetation (PVT-cover type-structural stage) categories. In addition, these plots were used to describe the context and relationships of the mapped entities with other ecological characteristics such as plant cover, slope position, and ground cover. EC plots were essential for understanding the interrelationships between fuels, climate, fire and vegetation, and they also provided baseline data for the calculation of many other ecological characteristics useful to land management including timber biomass, hiding cover, and thermal cover.

General site information including lifeform plant cover, ground cover, geology, topographic features, fuels descriptions, and fire behavior models (FBFM) were estimated on the EC plots from the General ECODATA methodologies described by Hann and others (1988) and these data were recorded on a modified General Form (GF) shown in Appendix A. We also recorded the eight FARSITE input parameters specially added fields on this General form. Plant composition measurements (species, percent cover, height) were recorded on the ECODATA Plant Composition (PC) form with tree and shrub cover stratified by six size classes (Appendix A). Fuels data were recorded using the line intersect technique of Brown (1974) described in Appendix C which was taken from the ECODATA Downed Woody (DW) Fuels method (form in - Appendix A). Tree health, species, diameter at breast height (DBH), crown height, and total height were recorded for all trees within the plot boundaries using the modified ECODATA Tree Data (TD) methods presented in Appendix D (TD form presented in Appendix A). The position of each EC plot was georeferenced to UTM coordinates in UTM zone 12 using Global Positioning System (GPS) units and recorded on the ECODATA Location Linkage (LL) form (see Appendix A for LL form, Appendix B for GPS procedures). Differential correction of locations was completed in the office and recorded on the LL form (see Keane and others 1998b). Approximately 10 percent of the field plots were targeted to be EC plots. It took from one to two hours to complete measurements on the EC plot.

Estimating the FARSITE input layer values for each plot was difficult because of the high variability observed in each ecosystem. Stand and crown base heights were ocularly estimated to the nearest meter. Canopy cover was assessed in the same way used to assess cover for each plant species from the ECODATA PC methods. Crown bulk density values was assessed from the canopy cover-cover type-structural stage combinations (Table 2). Values from Table 2 were reduced proportionally for medium and low canopy cover classes (30 and 60 percent, respectively) (Pollard 1972, Brown 1978). Seedling/sapling stands will be assigned a crown bulk density for the low cover class and increased by 15 percent for the medium cover class. Bulk densities for woodland types were calculated from the Leaf Area Index measurement device (LiCor LAI-2000) readings measured on woodland-type plots. The leaf area was converted to crown biomass using specific leaf areas (kg m-2).

The next level of measurement detail was captured by the **Ground Truth (GT) plot** and this was the primary method used to collect field data for this study. The purpose of this sampling level was to collect the data needed to develop biophysical settings, cover type, and structural stage classifications, and also to collect the georeferenced data needed as training areas and accuracy assessments for satellite image classifications. This plot sampling method also gathered all data needed for direct estimation of all FARSITE input layer variables, for development of all base vegetation map classifications (PVT, cover type, structural stage), and for computation of all the variables needed to key or compute and validate the FARSITE and base map classifications. Forms completed at each GT sample site included modified General Forms (GF), Location Linkage (LL), and Plant Composition (PC) (Appendix A). The GT plot center coordinates were also determined from GPS units (See Appendix B for GT plot establishment details). Approximately 40 percent of all sample plots were targeted to be GT plots for this study and it took about 40 minutes to complete all GT forms.

The least intensive sample plot was the **Polygon Validation (PV) plot**. This sampling method was only used to assess accuracy and precision of the developed vegetation base layers and the FARSITE input layers. Only the PVT, cover type, structural stage, FBFMs, canopy cover, crown base height, stand height, and crown bulk density were assessed at these plots. Paper maps, identical in size and scale with USGS quadrangle maps, were created with the boundaries of the spectrally classified polygons overlaid on roads, trails, streams, and contour lines. A unique polygon identification number (ID) was printed inside each polygon on the map. These maps were taken into the field and used to navigate to selected polygons in the sample watersheds. Most sampled polygons were along roads and trails because they transacted the topographic gradients, and also, they were more efficient to sample because of accessibility. Once we verified the polygon location with either GPS readings or map reference points (e.g., confluence of streams, road intersections, unique topographic settings), we visually estimated the eight base parameters mentioned above. These data were written onto the PV form shown in Appendix A along with the unique polygon ID number printed on the paper map. It took less than 10 minutes to sample a polygon using PV plot methods but the information content of these measurements was very limited. This method was only used during the second sampling season of 1998.

All field data collected for the Gila fuels mapping project were entered into Paradox databases and double-checked for errors by scanning all entries and then performing logic checks via database queries (Jensen and others 1993). These databases were structured so that they were easily transportable to the GNFC ArcInfo GIS spatial database and various statistical programs. DBF (database format) files of all field data are stored on the CD in the directory *CD\DATABASE* with each subdirectory named for the two-letter form name (e.g., GF contains all data recorded on the General Form shown in Appendix A). The formats of these DBF data sets are in *CD\DATABASE\FORMATS* and presented in Appendix G.

Vegetation Classifications

We created robust, comprehensive, and flexible vegetation classifications of PVT, cover type, and structural stage from the data collected in the field. This proved to be one of the most demanding tasks of the project because the classifications for the vegetation triplet are the heart of the image classification and fuel mapping procedure, so the resolution of the categories of each vegetation map needed to match the resolution of FARSITE input layer categories and the resolution of the digital maps. For example, cover type categories needed to be fine enough to identify major changes in surface FBFMs and crown fuel characteristics at a 30 meter pixel resolution, but broad enough to minimize classification and sampling complexity (Finney 1998). Broad categories could "smooth" the spatial distribution of fuels, while many fine categories could overwhelm the satellite image classification process and require inordinately large field data sets (Jensen 1986, Schowengerdt 1997). And most importantly, we needed to design the vegetation classification categories so that they would be useful to other facets of land management, and not only fire management (Keane and others 1998b). This was difficult since most cover types and structural stages commonly used in land management are difficult to accurately discriminate using satellite imagery (Keane and others 1998b, Lachowski and others 1995). Lastly, the categories of the base maps needed to be consistent across the three classifications to allow a unique set of cover types and structural stages for each PVT. Keys for the base vegetation classifications are presented in Appendix E.

PVT Classification —The existing plant association classification for the GNFC (USDA Forest Service 1997) was not useful for this study for several reasons. First, the level of classification was too fine for fuel mapping, and it was difficult to aggregate plant associations to the coarser categories needed for this mapping effort. This was partially because many associations were not true PVTs but rather plant communities defined by disturbance processes and therefore did not consistently represent unique site conditions. It was difficult to hierarchically aggregate associations with the existing classification system and relate the composite types to dynamic site descriptors such as climate or soils. So instead, we created our own PVT classification based on the synecology of existing tree species in the GNFC.

First, the field data were analyzed using database queries to identify similar groups that describe biophysical conditions appropriate for mapping fuels. We used the existing classification as a starting point, and then refined, deleted, and added classified types in accordance with our project objectives. We then created a working list of draft PVTs and an associated key to their classification. Next, this draft PVT key was refined by reclassifying the field data and also by soliciting help from regional experts.

A tentative list of PVTs along with a corresponding key was developed after analysis of the 1997 vegetation database of 1000 plots. Only 1 percent of field plots were not classified to PVT by the tentative key; those plots were assigned the most plausible PVT from an assessment of the original plot data sheet. This tentative PVT key was then refined and used for the 1998 field season to determine PVT for the Polygon Validation sampling effort. Following the 1998 field season, several PVT classes were combined or reclassified because they could not be adequately mapped using the terrain model methodology even though the key and associated classes worked well in the field. For example, pinyon, juniper, and oak PVTs were combined into one class since differences in ecological, vegetation, and fuel characteristics among these types are better defined at the cover type level and these three PVTs were notoriously difficult to map using topographical rules because of the wide environmental ranges of the species (Appendix E). The final list of PVT categories is presented in Table 3.

Table 3—The Potential Vegetation Types (PVTs) created and used in this study.

PVT code	PVT name	Site description	Mapped percent GNFC landscape (%)
1	Riparian	all broadleaf trees, shrubs, and herbaceous riparian and wetland types	1.4
2	Spruce-Fir	subalpine fir and Engelmann spruce habitat types	0.6
3	Mixed Conifer	white fir and Colorado blue spruce habitat types	4.1
4	Douglas-fir	Douglas-fir habitat types	7.6
5	Ponderosa Pine	ponderosa pine and Chihuahuan pine habitat types	18.8
6	Pinyon-Oak-Juniper	pinyon, Emory oak, gray oak, alligator juniper, one-seed juniper, Utah juniper habitat types	39.2
7	Scrub-Grassland	all non-riparian shrub and grassland types occurring below the P-O-J zone	10.6
8	Nonvegetated	rock, tailings, barren or **developed land, water**	17.7

Cover Type Classification — The cover type classification key was primarily driven by data collected in the field. Because we found no adequate cover type classification existed for the project area, we sampled our first field season without an a priori classification. This allowed us to develop a classification that was ecologically based and also useful to fuel mapping. The cover type classification key was constructed by first specifying the target number of cover types we wanted to include in the mapping effort. This number could not be so great that many plots were needed for their description, or so few that fuels weren't adequately differentiated. The cover type classification also had to include all land cover types not related to vegetation such as rock, soil, water, and so on. We decided that there should be between 10 to 30 cover types based on a review of the literature and discussions with National Forest personnel (Eyre 1980, Shiflet 1994, USDA Forest Service 1997). Next, we specified the list of potentially important cover types on the GNFC. The first year's field data, coupled with our knowledge of the area and its ecosystems, were used as guides in devising this list (USDA Forest Service 1997). The list of cover types were developed in a hierarchy where similar cover types could be aggregated in case the list needed to be reduced later. We then tried to rectify the number in the cover type list to the target number by eliminating cover types that could be easily aggregated with similar types, or cover types that had small aerial extents.

Classification categories for both cover type and structural stage were created in cooperation with the Gila National Forest resource personnel (Table 4 and Table 5). These categories were designed to mesh with current management-oriented landscape analyses along with FARSITE fuel mapping. However, we mostly used sampled field data to guide the classification criteria for each category and to assess the value of each category to the overall classification and mapping effort in a spatial context. We also made sure that our classification categories agreed with National vegetation mapping standards and protocols (Anderson and others 1998, Grossman and others 1998) (Appendix E).

Table 4—The Gila National Forest Complex cover types used in this study.

Cover type code	Cover type name	Description	Mapped percent GNFC landscape (%)
100	Water	lakes, ponds, reservoirs	0.1
201	Rock	rock, gravel, scree	17.0
202	Barren Ground	dominated by bare soil with <10% vegetation cover	12.3
203	Mine-Quarry	mines, quarries, tailing piles	0.4
205	Urban	urban and urban-interface areas	0.2
310	Herblands	grass and/or forb dominated communities	23.0
321	Xeric Shrublands	desert scrub, mountain mahogony or other commuities dominated by sclerophyllous shrubs	6.0
322	Mesic Shrublands	riparian shrub(willows) or high elevation deciduous shrub communities	0.9
401	Broadleaf Riparian Forest	cottonwood, alder, boxelder, sycamore or other broadleaf riparian communities	1.0
402	Broadleaf/Conifer Forest	ponderosa pine mixed with broadleaf riparian trees or aspen mixed with conifers	0.7
403	Conifer-Gambel Oak Forest	conifers mixed with gambel oak	1.5
404	Conifer Forest-Woodland Mix	ponderosa pine and/or Douglas-fir mixed with pinyon, juniper and/or evergreen oaks	2.2
405	Mixed Woodland	pinyon and/or junipers mixed with evergreen oaks	3.9
406	Mesic Mixed Conifer	stands dominated by white fir and/or blue spruce usually mixed with other conifers	3.4
407	Xeric Mixed Conifer	stands dominated by mix of ponderosa pine, douglas-fir and/or southwestern white pine	2.6
410	Aspen	stands dominated by aspen	0.2
411	Gambel Oak	stands dominated by gambel oak	0.3
412	Juniper	juniper dominated communities	5.0
413	Pinyon	pinyon dominated communities	6.2
414	Evergreen Oak	Emory, gray, netleaf and/or silverleaf oaks	3.4
415	Ponderosa Pine	stands dominated by ponderosa pine	5.7
416	Douglas-fir	stands dominated by douglas-fir	0.5
421	Pinyon-Juniper	pinyon mixed with any species of juniper	3.0
424	Spruce-Fir	stands dominated by subalpine fir and/or Engelmann spruce	0.3

Table 5—The structural stage categories used in this GNFC study.

Structural stage code	Structural stage name	Description	Predominant vegetation	Mapped percent GNFC landscape (%)
1	Closed Herbland	≥55 percent herbaceous cover	grasses, forbs	8.8
2	Open Herbland	<55 percent herbaceous cover	grasses, forbs	14.2
3	Closed Shrubland	≥55 percent shrub cover	shrubs	1.6
4	Open Shrubland	<55 percent shrub cover	shrubs	5.3
5	Closed Woodland	≥55 percent woodland cover	pinyon, juniper, oak	8.3
6	Open Woodland	<55 percent woodland cover	pinyon, juniper, oak	13.1
7	Small Tree	trees <5.0 inch DBH	broadleaf & coniferous forests	0.8
8	Medium Tree	trees 5.0 - 21.0 inch DBH	broadleaf & coniferous forests	17.6
9	Large Tree	trees > 21.0 inch DBH	broadleaf & coniferous forests	0.1
96	Urban	developed areas	—	0.2
98	Water	water	—	0.1
99	Rock	rock, barren or mining related areas	—	29.7

We coded all vegetation classifications into Paradox database queries that use plant species and canopy cover information along with other relevant site descriptions to key each plot to PVT, cover type, and size class. We did this as a test of the classification keys and because it was easy to update classification criteria to refine and improve classification accuracy. Moreover, the database queries were used to assign classification categories to each plot for use in satellite image classifications. The coded plots were then used to assign the FARSITE fuel and crown characteristics parameters to each layer to finally create the FARSITE input layers.

Structural Stage Classification — The initial structural stage classes used during the 1997 field season were based on stand developmental processes and included seven forested types and eight rangeland types as described by O'Hara and others (1996). We then added six woodland classes to describe structure of pinyon, juniper, and oak. After the 1998 field season, it was determined that this fine level of structural differentiation was not needed to describe the changes in fuels as related to vegetation structure. We found very few stands dominated by seedlings, saplings or large trees within the GNFC, so we lumped the seven forested structure types were into three broad classes based on tree diameter at breast height (DBH) (Table 5). Woodland, shrub, and herbaceous communities were each grouped into two structural stages based on projected canopy cover. These seven structural stages plus two more for non-vegetated types were used as the final set of categories for the key to stand structure (Appendix E).

Fuels Classification — FARSITE does not restrict the characterization of fuels to only the 13 FBFMs described by Anderson

(1982). In fact, FARSITE has options that allow over 80 user-defined or “custom” FBFMs in a spatial fire simulation. Most people use the standard 13 FBFMs because it requires a great deal of expertise to develop a custom FBFM (Burgan and Rothermel 1984). The FBFM includes many other characterizations besides fuel loading by size class, such as bulk density, surface area-to-volume ratios (cm^{-1}), and heat content ($kW\ kg^{-1}$). The inherent complexity of the mechanistic fire behavior models of Albini (1976) and Rothermel (1972) make it difficult to predict realistic fire behavior from actual fuel loadings (Burgan and Rothermel 1984). As a result, a somewhat complicated procedure must be done each time a fire manager wants to create a new fuel model for a local situation. This procedure involves altering actual fuel characteristics to generate realistic fire behavior observed for the new situation using the fire behavior models (Burgan and Rothermel 1984). Therefore, many people who do not have experience in fire or fuels modeling find it difficult to accurately and consistently create new fuel models (Root and others 1985, Hardwick and others 1996).

We developed two new FBFMs for the GNFC project by following the procedures detailed in Burgan and Rothermel (1984). The first FBFM was for surface fires in the pinyon-juniper understory. There are very little fine fuels on the floor of a pinyon or juniper stand, probably due to excessive droughty conditions, allelopathic influences by the pine and juniper foliage, heavy grazing pressure, and excessive root competition (Moody and Boucher 1998). Therefore, fires that occur in these ecosystems have exceptionally low intensities and do not spread very well, unless there is a wind strong enough to spread the fire through the crowns. No FBFM in Anderson (1982) could adequately describe this unique situation, so we decided to build our own FBFM. We estimated fuel loadings in the standard size classes for this ecosystem based on measured fuel data (EC plots) and ocular estimates (GT plots). We then entered these fuel loadings in a custom fuel model option in the fire behavior program BEHAVE (Andrews 1986). Extensive documentation of fire behavior in pinyon-juniper was obtained from historical fire reports from Gila National Forest fire managers and from the available literature. Once the pinyon juniper FBFM was quantified, it was then coded into a file for input into FARSITE (see Table 1). The other new FBFM was for rock, bare soil, and water where fuel loadings were set to zero so no fire could spread on this area (Table 1). The details for the custom fuel models are stored on the CD in the directory *CD\CUSTOM* for input to FARSITE and in Appendix G.

Only seven of the 13 Anderson (1982) FBFMs were used in this study (Table 1). Timber harvesting is rare in the GNFC so the activity fuel models 11, 12, and 13 were deemed unnecessary. The sawgrass model (FBFM 3) was not applicable to any area in the GNFC because of the high loadings for perennial grasses. The high intensity shrub model (FBFM 4) is also rare on the GNFC because shrub fields rarely become tall and dense enough to generate fire behavior typical to FBFM 4. A reduced list of possible FBFMs can often increase layer accuracy and simplify fuels assignments to vegetation triplets as described later (Keane and others 1998a). However, a limited number of FBFMs may not adequately describe fuel variablility in diverse landscapes like the GNFC.An advantage of using the vegetation-triplet methodology presented here is that new FBFMs can be added or substituted later as more fire behavior data become available.

Two fire behavior fuel model (FBFM) GIS layers were developed for this project. Apparently, some plant communities can exhibit drastically different fire behavior after prolonged drought or under severe winds, and the standard fire behavior fuel models do not account for the contribution of deciduous shrubs to subsequent fire behavior. For example, montane shrub communities are often assigned the Anderson (1982) FBFM 5 (live shrub fuel model) because of their high summer moisture contents. However, these same communities can exhibit the fire behavior typical of the FBFM 6 (xeric shrub, high fire behavior model) under extreme drought conditions because of their very low live fuel moisture contents. To represent these situations in the FARSITE input maps, we developed two FBFM maps. The **normal FBFM** map describes the most common distribution of fuel models on the landscape and will probably be used for many prescribed fire planning and real time wildfire simulations. The **extreme FBFM** map describes the spatial arrangement of fuel models under the most severe conditions (e.g., extreme drought or highest fuel loadings). This map can be used to simulate wildfires for “worst-case” scenarios.

Ancillary Layer Development

Many GIS raster and vector data layers were needed for the successful completion of this vegetation and fuels mapping effort. All ancillary spatial data layers mentioned here were obtained, compiled, or created specifically for this project because they were not available from the Gila National Forest. The support data layers spatially describe topography, soils, climate, and ecosystem dynamics and were needed because they either were direct inputs to FARSITE (e.g., elevation, aspect, slope) or used in the creation of vegetation base layers used to map fuels (Keane and others

1998b). All GIS raster data layers for the GNFC were developed at a 30 m resolution and the GIS vector layers were developed with a minimum mapping polygon size of 1 ha (2.5 acres). Finney (1994) suggests a 30 m pixel size may be so large that it can over predict fire spread for some landforms, but is acceptable because smaller pixel sizes considerably slows FARSITE computer simulations.

The topographic data layers of elevation, aspect, and slope needed to map PVT's, constrain cover types and structural stage assignments, and needed as input into FARSITE, were taken from Digital Elevation Models (DEMs). A DEM is a raster map of a 7.5 minute USGS quadrangle with each 30 meter pixel assigned an elevation (m) measured above mean sea level (USGS 1987). All DEMs within the GNFC study area were acquired from the U.S. Geological Survey in Salt Lake City, Utah. We created one DEM layer for the entire GNFC by "sewing" or "tiling" together 120 USGS DEM quads using methods detailed in Stitt (1990) to define the GNFC study area (Figure 1). We corrected horizontal or vertical banding in some USGS DEM quads using methods presented in Brown and Bara (1994), Keane and others (1998a), and Stitt (1990). Slope and aspect layers were generated from the processed and tiled GNFC DEM layer using the ARC/INFO command (*slope.aspect*) that derives slope and aspect from surrounding elevation pixel values.

Spatial soils information was needed for PVT terrain modeling and also for input to the biogeochemical simulation modeling effort used as a test of the Keane and others (1997b) gradient model. The Soil Conservation Service's STATSGO (1991) data layers were used to develop the soil texture and depth layers needed for the biophysical classification and simulation modeling. We also used spatial simulation modeling to improve the STATSGO assignments following methods outlined in White and others (1996) and created soils inputs to the BGC model from methods in Cosby and others (1984).

Satellite imagery was used to map existing vegetation (cover and structure) and to define polygon boundaries. All imagery data used for this study were obtained from the USDA Forest Service Southwestern Regional Office Engineering Staff. We used remotely sensed imagery taken by the Thematic Mapper (TM) sensor on the LANDSAT 5 satellite taken at two dates (September 1993 and June 1997) for two areas (Row 42 Path 32, Row 42 Path 33, see Figure 1), or four scenes total. A TM scene consists of six layers of at about 30 meter pixel sizes (approximately 250 km by 250 km). Pixel values in each layer quantify the reflectance of electromagnetic radiation in six bands that bound six ranges of wavelengths in the electromagnetic spectrum (Jensen 1986, 1990, Schowengerdt 1997). There is a seventh band in the thermal region of the spectrum with pixel sizes of 120 meters, but we did not use this band for our study. Reflectance is quantified by digital numbers (DN) ranging from 0 to 255 in magnitude. The TM imagery was geo-rectified to less than a half pixel rectification error by EROS Data Center so there was no need to rectify any of the TM imagery. However, we performed many rectification accuracy assessments to ensure the TM layers were accurate across the entire scene, across all bands, and across all dates. These layers were then included in the GNFC GIS once accuracy was verified.

Many other ancillary layers were integrated into the GNFC GIS and used extensively in this study. Cartographic features such as roads, streams, and rivers were compiled from cartographic feature files provided by the Gila National Forest and the Geometronics Service Center in Salt Lake City, Utah. Watershed boundaries at the 4th and 6th Hydrologic Unit Code levels were copied from USGS (1982). Ownership boundaries for USDA Forest Service and private lands were provided by the Forest Service Southwestern Regional office in Albuquerque, New Mexico. All ancillary layers can be found on the CD in the directory *CD\UNIX_GIS***,** however, we created separate ASCII vector boundary files (Gila National Forest boundary and Wilderness Boundary) to be used as overlay in FARSITE simulations (*CD\BOUNDARY*). Lastly, a GNFC bitmap showing the boundaries of each USGS quad and the quad name is contained in the *CD\GNFC_MAP* directory. This map can be used by any PC-based imaging software to reference quad maps for use in FARSITE.

Vegetation Base Layer Development

The three vegetation base layers created in this project were the PVT (biophysical settings), the cover type, and structural stage layers. Again, the FARSITE input fuel maps were created from these base layers by assigning the five FARSITE fuel parameters to each combination of the three base layers. FARSITE fuel assignments were calculated from field data and the opinions of local fire experts. Therefore, these vegetation base layers represent the most critical phase in the FARSITE input development process. These base layers also provide the critical link to mapping other ecosystem characteristics for other land management needs. Many of the ancillary data layers listed above and field data described in the Field Sampling section were used in the development of all base maps.

The first task was to create a common polygon layer for all base vegetation layers in this project. Previously, we tried to create a polygon layer suitable for FARSITE simulations from independently created data layers and found a great deal of error occurred when translating the polygon boundaries from each layer into a common theme (Keane and others 1998a, 1998b). So, we decided to create a universal polygon layer that would be used to spatially describe the distribution of all base vegetation classifications for fuel map creation. This polygon layer could not have polygons that were so large that fuel conditions would be homogenous over large areas. A category from each base vegetation classification would be assigned to each polygon as an attribute, rather than develop three different base vegetation maps and then decide the relevant polygon boundaries after the fact. The universal polygon layer was created by using a textural analysis called “Segment” found in the IPW (Image Processing Workbench) software. This technique uses a moving window to evaluate similar regions based on the values of the surrounding pixels. We imposed a minimum polygon size of 1 ha and a maximum size of 400 ha in this procedure. The final layer was called the **polygon** layer.

Two biophysical settings layers were developed for this study, but only one was used to map fuels. The PVT map was created using terrain modeling where topographical rulebases defined potential vegetation types from attributes derived from the DEM. The PVT map was the primary layer describing biophysical settings layer and only it was used to map FARSITE fuels. The second biophysical settings layer, the Gradient Biophysical Settings (GBS) map, was developed using gradient modeling and simulation modeling (Keane and others 1997b). The GBS layer was only used to test and refine the PVT map and was not used to map FARSITE fuels. In fact, the GBS layer was not essential for the GNFC fuel mapping project but its creation provided an unique application of the gradient model developed by Keane and others (1997a).

Two biophysical settings layers were created for many reasons. First, the integration of the two approaches would remove some of the limitations resulting from using only one approach. For example, PVT terrain models are heavily dependent on field data to create and validate the topographic rulebase, whereas mechanistic gradients can be described with minimal field data using simulation modeling (Barrett and Arno 1992, Waring and Running 1998). Simulated gradients are computed using minimal subjectivity because simulation models objectively compute biogeochemical characteristics the same for every pixel. However, PVT modeling requires subjective interpretations of topographic settings based on highly subjective and variable potential vegetation assignments (Keane and others 1998b). On the other hand, simulated gradients are difficult to verify on the ground because of the temporal element (i.e., most are expressed per unit time, e.g., productivity is tons of carbon per acre per year) and measurement difficulty (e.g., average annual precipitation must be measured over many years), but topographic categories can be easily identified in the field by identifying the PVT from a plant key. Simulated gradients provide a mechanistic context in which to interpret or predict vegetation change while the terrain model is purely an empirical approach with little cause-and-effect implications. Keane and others (1998b) found terrain models could be developed in the absence of extensive field data from expert opinion, yet process-related gradients needed field data to develop statistical predictive functions. Therefore, a completely integrated approach to mapping biophysical settings would utilize all the advantages of each strategy while minimizing the disadvantages. Although this integrated approach is not yet possible for many regional and National Forest mapping projects because of inadequate vegetation inventories and incompatible simulation models, it seems to be the next logical step to accurate and consistently map fuels and fire hazard.

Gradient Biophysical Settings Map — We created the gradient-based biophysical settings layer using a "top-down" approach where we mapped discrete biophysically based environment categories continuously over the entire GNFC from climate and ecosystem gradients computed from simulation models (Keane and others 1997b, Milner and others 1996, Brzeziecki and others 1993, Waring and Running 1998). Since 1995, we have been developing a spatial gradient model that would allow the mapping of important land management entities using biophysical gradients that describe critical ecosystem processes (Keane and others 1997b). This approach has been used in previous studies but with indirect environmental gradients, such as elevation and landform, that act as surrogates to describe the critical biogeochemical processes that govern landscape dynamics (see Kessell 1979). Instead, our approach quantifies those mechanistic ecosystem process gradients that directly dictate vegetation biogeography such as precipitation, productivity, and temperature and uses these gradients to compute vegetation maps useful to landscape management.

Since direct measurement of these mechanistic gradients across an entire landscape would be a complex and expensive task, we use simulation modeling to extrapolate climate variables across the spatial domain and to compute some biogeochemical process variables that relate to vegetation dynamics. This approach to mapping biophysical settings is highly experimental and we did not expect it to be our primary mapping vehicle, but rather, a secondary map refinement tool. Our primary purpose in including the gradient approach was to test its utility in mapping fuels in the southwestern United States, and to improve the PVT terrain model.

The gradient modeling system used here is an integrated system of relational databases, analysis software, and simulation models linked together to compute a list of variables important in ecosystem dynamics (Keane and others 1997b). A set of topographic, climatic, and mechanistic variables (Table 6) are used to develop predictive equations that are implemented across a spatial domain. First, values of all gradient variables in Table 6 were computed for each polygon sampled using the EC or GT plot methodology (see Field Sampling section). Then, a correlation analysis was performed to find the biophysical variables important for mapping

Table 6—Environmental variables evaluated for use in the gradient model.

Variable	Units	Variable	Units
Gross primary productivity	kgC/m2	Average annual degree days	degday
Net primary productivity	kgC/m2	Average annual daylength	seconds
Maintenance respiration	kgC/m2	Average annual snow water depth	cm
Growth respiration	kgC/m2	Moisture content 1 hr wood fuel	Percent
Autotrophic respiration	kgC/m2	Moisture content 10 hr wood fuel	Percent
Litter respiration	kgC/m2	Moisture content 100 hr wood	Percent
Soil respiration	kgC/m2	Moisture content 1000 hr wood	Percent
Heterotrophic respiration	kgC/m2	Ketch-Byram Drought index	none
Ecosystem respiration	kgC/m2	Reaction intensity	btu/ft
Net ecosystem production	kgC/m2	Spread component	ft/min
Evapotranspiration	kgH2O/m2	Energy release component	btu/ft2
Outflow	kgH2O/m2	Burning index	none
Leaf carbon	kgC/m2	Ignition component	Prob
Dead stem carbon	kgC/m2	Spread component threshold sum	days-ft/min
Canopy conductance sensible heat	m/sec	Energy release compon thres sum	days-btu/ft2
Leaf conductance sensible heat	m/sec	Burning index threshold sum	days-none
Soil water potential	Mpa	Ignition component thres sum	days-Prob
Soil volumetric water content	m3/m3	Elevation	m
Average annual maximum temp	degC	Slope	Percent
Average annual minimum temp	degC	Aspect	degrees
Average annual dewpoint temp	degC	Mineral soil cover	Percent
Average annual average temp	degC	Gravel cover	Percent
Average annual soil temp	degC	Rock cover	Percent
Average annual daytime temp	degC	Duff/litter cover	Percent
Average annual nighttime temp	degC	Wood cover	Percent
Average annual precipitation	cm/yr	Moss Lichen cover	Percent
Average annual effective ppt	cm/yr	Basal veg cover	Percent
Average annual relative humidity	Percent	Fuel depth	m
Average annual solar radiation	kw/m2	Duff/litter depth	cm
Average annual days since snow	days	Live tree DBH	cm
Average annual days since rain	days	Live tree basal area	m2/ha
Average annual daily radiation	J/m2/day	Live tree height	m
Average annual corrected rad	J/m2/day	Latitude	dd
Average annual vap press deficit	mbar	Longitude	dd
Average annual absol humidy def	ug/m3	Structural stage	none
Average annual absorbed SW rad	kJ/m2/day	Sand percent by volume	Percent
Average annual transmit SW rad	kJ/m2/day	Silt percent by volume	Percent
Average annual Potential ET	m	Clay percent by volume	Percent

PVTs. Discriminant analysis and other statistical techniques were used to develop predictive equations that predict PVT from the selected biophysical variables. Then, the values of those biophysical variables were computed for all remaining polygons. Predictive equations were then used to assign the PVT value to all unsampled polygons. The polygon validation (PV) plots were used to validate, test, and refine the cluster assignments and the discriminant functions.

Values for all weather variables were computed from the meteorological simulation model DAYMET (Thornton and others 1997) which spatially extrapolates daily weather from a set of base stations to the EC, GT, and PV plot locations in mountainous terrain. We computed daily weather data (see Table 6) for each polygon from daily observations (maximum temperature, minimum temperature, and precipitation) taken at 125 meteorological stations in and around the GNFC for a period of 24 years (1970-1993). DAYMET uses a 1 km^2 DEM to aid in the extrapolation. These weather data were input to the WXGMRS program to compute some simulated weather variables including the National Fire Danger Rating System indices (see Table 6) (Deeming and others 1978). Then, the extrapolated weather data, and a host of other parameters assessed from the sampled field data, were input to the BGC model (Thornton 1998) to compute ecosystem process values (see Table 6). Lastly, field data were augmented with the simulated data to create the gradient database (see Table 6).

PVT Map — The second biophysical settings layer was created using a "bottom-up" strategy where environmental conditions were indirectly coded into a terrain model from hierarchically structured topographic combinations of elevation, aspect, and slope with each combination assigned a PVT category (Keane and others 1998a, Brown and others 1994). Field data were summarized to determine plausible ranges in elevation, aspect, and slope that would consistently and accurately identify these PVTs. This is a time-consuming process of querying the field database and comparing query results with results found in the literature. Important ranges in elevation, aspect, and slope were synthesized from the field data summaries and then coded into an ARC/INFO AML program we created for interactively developing PVT terrain models for our other fuel mapping efforts (Keane and others 1998a, Keane and others 1998b). We adjusted the ranges and PVT assignments to those topographic ranges based on interactive interpretations of intermediate PVT maps and input from Gila National Forest personnel. The final terrain models by ecological zone are shown in Appendix F. This terrain model was used to create a PVT terrain model raster layer where each pixel is assigned a PVT category value.

The final PVT GNFC GIS layer was created by assigning a PVT category to each polygon delineated by the textural analysis of the TM imagery (see Cover Type Map section below). This was accomplished by assigning the modal PVT category value from all pixels in the PVT terrain model layer within the delineated polygon as a polygon attribute using the ARC/INFO command *zonalmajority*. Polygons having no clear dominant PVT assignment (greater than 50 percent pixels having one PVT category) were evaluated on a case-by-case basis to ensure the best PVT was assigned.

Cover Type, Structural Stage, and Canopy Cover Maps — A combined unsupervised- supervised satellite image classification was performed using the two different LANDSAT (TM) scenes for two time periods (1993 and 1997). We used the PCI image processing software to perform this task on a series of IBM UNIX workstations. These two maps can be created using any remotely sensed technology such as aerial photograph interpretation, sketch mapping, and image classification with other satellite or airborne scanners. However, the development of these layers can be highly technical and is best accomplished by experienced professionals.

An initial unsupervised classification created from only one Sept 1993 TM scene was used to divide the GNFC landscape into polygons for field sampling using a clustering algorithm in the PCI software that creates spectral aggregates based on spectral class signatures in the TM image. Only one scene was used because TM scenes for other areas were not yet available. We assumed, and then later validated, that the spectral cluster classes assigned to polygons identified unique cover class and structural stage combinations at a resolution sufficient for plot establishment (Gonzales and Maus 1992). We also assumed, then validated by examination on the ground, that stand conditions within the polygon were sufficiently uniform so we could use the entire polygon as a "training site" in our supervised classification. However, some polygons proved too large, in which case we constrained maximum training site size to 50 ha. Training sites are defined as areas on the ground used to represent a particular cover type or structural stage category (Lachowski and others 1995, Verbyla 1995). Polygons boundaries were verified for accuracy in the field using orthophoto quads (i.e., an aerial photographs for an entire USGS 7.5 minute quadrangle), 1:4000 aerial photos, and walk-through reconnaissance (Lachowski and others 1995, Keane and others 1998a, Howard 1991). We assigned unique cover type and structural stage categories to each spectral class in the unsupervised classified layer to create a draft cover type and structural stage map for GNFC fire management to use during the 1998 fire season (Gonzales and Maus 1997). However, the final product described here included refinements that significantly increased the quality, consistency, and accuracy of the draft layers.

The final cover type map was created using a supervised classification approach that utilized the sampled polygons (created from the unsupervised effort) as training areas to build statistical tables that describe classification category spectral signatures. Sampled field attributes for the base vegetation layers were assigned to each draft polygon (unsupervised clusters) then assigned to the final polygons (textural analysis) using modal values. We performed the maximum likelihood supervised analysis using only those polygons described by field data and the translation from the draft to final did not incur significant error (i.e., there was general agreement between the two). The final cover type classification was stratified by PVT to precisely target specific cover types to the land area where they could occur. The structural stage and canopy cover class maps were performed for the whole scene and not stratified by PVT.

Many other remotely sensed data products could have been used to develop the cover type and structural stage maps. We chose satellite imagery because it was the best product to consistently map fuels and vegetation over large areas like the GNFC (over 2 million ha). Aerial photographs could have been digitized to produce a better product perhaps, but photo interpretation is a time-consuming task that is costly for large areas (Quigley and others 1996). Timber stand atlases or maps could have been described by to vegetation and fuels using sample timber stand data, but rarely do these databases contain the fuels information needed for fire behavior, and rarely are large landscapes entirely and comprehensively mapped or sampled (Grupe 1998, Mark and others 1995). Active remote sensor data products such as Lidar could have been used but the data are especially costly and difficult to obtain for large areas (Dubayah and others 1997, Nelson and others 1988, Naesset, E. 1997).

Previous vegetation mapping efforts revealed that canopy cover might be best mapped from satellite imagery rather than from vegetation type assignments (Redmond and Prather 1996, Keane and others 1998b). Therefore, we used the same supervised approach to compute a cover class category for each polygon from the TM satellite imagery. We also computed a cover type class from the field data for each combination of the vegetation triplet and assigned that cover class to the polygon based on the triplet (see FARSITE Input Layer Development section).

Base Layer Refinement — Because of the need for congruence and consistency across all data layers, we used various ancillary data layers and other base vegetation layers to refine each vegetation base layer and polygon assignments. The PVT map was used to constrain the cover types to those environments where they are expected to occur. For example, if a cover type map polygon was assigned a mixed conifer cover type and this polygon crossed a ravine and occurred on both a north and south-facing slope, then the PVT layer was used to split the polygon into a mixed conifer cover type on the cool, moist, north-facing slope and a pinyon-juniper cover type on the warm, dry, south-facing slope. Conversely, rock, water, and bare soil PVTs were mapped from the cover type classification of satellite imagery because these PVTs are geological phenomenon that are difficult to map from topographic criteria but are easily and more accurately mapped using imagery (Howard 1991, Jensen 1986). Decisions on which PVT-cover type-structural stage combinations were illogical or impossible, and estimates as to what these illogical combinations should be, were based on the summarized field data, information in the literature, and input from fire and resource managers.

FARSITE Input Layer Development

The FARSITE input layers were created by summarizing the field database by all possible combinations of categories for all three vegetation base layers. First, we determined all possible combinations of PVT, cover type, and structural stage attributes for every polygon across the entire GNFC. Then, a database, called the **base layer combination lookup table,** was created as an ASCII file where each line in the file is a PVT-cover type-structural stage combination. Also on that line are all summarized ecological characteristics used to create FARSITE input maps and to develop other maps useful for land management. The format of this lookup table is shown in Appendix G and the file can be found on the CD (*CD/DATABASE/LUT/PCSLUT.DBF*).

The base layer combination lookup table was created from an extensive analysis of the field data to compute summaries of each FARSITE fuel input requirements (e.g., stand height, crown height) stratified by the appropriate vegetation combination. This summary analysis mostly used modal values were used to assign FBFMs (i.e. normal and severe fuel models) to each combination.

Stand height, crown height, crown bulk density, and canopy closure were computed as averages across every plot that keyed to the unique triplets. For example, there were four plots in the field database that were assigned a Douglas fir PVT, a ponderosa pine cover type, and a pole structural stage. Stand height for this triplet was computed as an average of the stand height measured on all four plots. Other categorical variables, such as normal and severe FBFMs, were also selected as the most frequently occurring category in the four plots. These summaries were then imported into the GIS database and linked to the polygon layer.

Some combinations of PVT-cover type-structural stage were poorly represented or highly variable in the field database. It was very difficult to find some of the vegetation combinations in the GNFC because they were rare or remote, so they were never sampled. In these situations, we used values taken from the literature and estimates made by fire managers to quantify missing cases. In the winter of 1998, we conducted a two day workshop on the Gila National Forest that was attended by the various Fire Management Officers employed on that and nearby National Forests. We distributed an empty form to everyone (see Appendix H) that listed every vegetation base layer combination and asked workshop attendees to assign a normal and severe FBFM, and also to assign the crown height, to each combination. For efficiency, the workshop attendees were divided into groups and given separate sets of combinations stratified by PVT for the three FARSITE assignments. It took only one day for the attendees to estimate the three values for all combinations. We used the field data to validate and assess the accuracy of these assignments. The final values assigned by managers for all combinations are shown in Appendix H.

The fuel model assignments from this successful workshop provided the GNFC project with a very important data source. First, these assignments were used to fill in values for the combinations with missing or limited field data representation. Second, this form provided an excellent source of “pseudo-ground truth” for all of our FARSITE combination assignments by using them as guides to validate the triplet field data summaries. For example, some base layer combinations were represented by as many as five FBFMs sampled on 10 plots making it difficult to select a modal value with any certainty or reliability. In these cases, we referenced the assignment made by the fire managers and compared that with the highly variable field data, and selected the model which best fit with both data sources. This proved a great help in selecting the final combination assignments and in assessing accuracy and quality of the base layer combination lookup table.

The final base layer combination lookup table was then imported into the GNFC GIS database and then linked to the polygon map for FARSITE input assignments. The PVT-cover type-structural stage assignment for each polygon was referenced to the combination GIS lookup table and the FARSITE input values corresponding to that combination were then assigned to the polygon. GIS raster layers for each FARSITE input requirement were easily created from the polygon map once the combination lookup table was linked to the polygons in the GIS. We developed an ARC/INFO AML to reformat the GIS layers into input FARSITE landscape format required by the program (Finney 1995).

The creation of one huge landscape file for the entire GNFC is not computationally efficient for FARSITE execution (Keane and others 1998b). The program would take too long to load, display, and analyze this extensive spatial layer. So instead, we divided the GNFC area into 7.5 minute blocks (i.e., size of a USGS quad map) and created a landscape file for each corresponding quad and named for that quad. FARSITE landscape files contain other layers besides the eight base FARSITE layers needed for this project. There are also three cartographic layers of roads, trails, and water. FARSITE landscape files were then compressed to optimize CD space and put in the *CD\QUADS* directory.

Accuracy Assessment

We performed an intensive, hierarchical assessment of the accuracy and precision of all field data, vegetation classifications, ancillary data layers, base vegetation layers, and the FARSITE fuel layers using a multitude of ground-truth sources and accuracy assessment methodologies. First, we tested and evaluated the eight key evaluations made in the field for the GT and PV plots from the detailed EC plot information. Ocular estimates of PVT, cover type, structural stage, stand and crown heights, crown closure, crown bulk density, and fire behavior fuel models made on EC plots were compared with an analysis of the detailed ecological data measured on each of these plots (Taylor 1997).

Crown fuel characteristics (stand and crown height, crown bulk density, and crown closure) were objectively computed from EC plot information using a computer program developed for this project called CFCC (Crown Fuel Characteristics Calculator, see *CD/SOFTWARE/CFCC*) that calculates crown bulk densities for successive layers above the ground. Then, a running average is calculated for each layer based on the seven layers below and the seven layers above each layer. Crown height is computed in CFCC as the height to the first layer that exceeds an average bulk density of 0.037 kg m^{-3}. Stand height is computed as the height to the highest layer where the bulk density is greater than 0.037 kg m^{-3}. The bulk density used for the entire crown is taken from the layer with the highest bulk density. Crown closure is computed from empirical estimates of crown widths of each individual tree. Measured fuel characteristics from the EC fuel transects were compared to the loadings in the ocularly estimated FBFM. These comparisons of the computed EC information with the GT and PV plot subjective assessments helped in the interpretation of GIS data layer accuracy assessments. Lastly, we assessed the reliability and consistency of the workshop fuel and crown base height assignments by comparing them to summarized field data in the base layer combination lookup table.

Accuracy and consistency of developed vegetation classifications were estimated from queries of the field database on plant species cover information gathered on the GT and EC plots. All plots were keyed to PVT, cover type, and structural stage category using database queries on the data that were entered into the GF and PC plot forms on the GT and EC plots. The keyed categories were compared to the ocularly assessed categories and the agreement was recorded as percent correct using contingency tables (Congalton 1991, Congalton and Green, 1999). This analysis could then be used to assess the accuracy of the PV plot data.

Testing, validation, and verification of existing and developed spatial data layers involved overlaying the layer in question with the georeferenced field plot data and comparing the plot measurement with the polygon assignment. We used accuracy assessment routines in the PCI image processing software and also designed several GIS routines of our own to display and report the correspondence between the plot data and the layer in question. These reports were summarized into contingency tables and into data files used by other programs written specifically for this project.

Accuracy assessments procedures differed by the type of map. Categorical GIS maps are those maps that portray discrete, nominal classification categories such as cover type and structural stage layers. Continuous maps have polygon values that are measured using continuous data scales such as elevation (m) and slope (percent). We assessed the accuracy of all categorical GNFC maps using the methodologies presented in Congalton (1991), Woodcock and Gopal (1992), and Gopal and Woodcock (1994), where contingency tables of fuzzy sets are constructed comparing the reference (ground-truth) data values to the classified (map) values. In addition, we used the same process to compare ground-truth data to the fuel model assignments from workshop participants, and to the PVT rule assignments designed by local scientists and ecologists. Omission and commission errors were computed for each map category, and a final accuracy was estimated using the KHAT statistic (Congalton 1991, Mowrer and others 1996). The KHAT statistic adjusts overall accuracy to account for the uneven distribution of plot data across classification categories (Congalton 1991).

Accuracy of continuous GNFC maps such as elevation, aspect, and slope were computed using a regression approach similar to that used by Keane and others (1998b). Observed values for each polygon (i.e., plot data) were regressed with the predicted values (i.e., polygon assignments) from the maps using a linear, least-squares regression (Sokal and Rohlf 1969). Three regression statistics were recorded. The coefficient of determination (R^2) provides an index on how tightly correlated the predicted data are to the observed data. Values of R^2 close to 1.0 indicate the data are perfectly correlated (accurate), whereas values near zero mean the data are totally unrelated or inaccurate. The slope of the regression line (alpha) can be used to evaluate trends in the accuracy of predictions. Slopes greater than 1.0 usually indicate map overestimation when observed values (plot data) are high and underestimation when observed values are low. The opposite is true when slopes are less than 1.0 but greater than zero. Ideally, the slope should be 1.0 if the observed values perfectly match the predicted values. Thirdly, the intercept of the regression line (beta) is used to evaluate general overestimation (beta greater than 0.0) or underestimation (beta less than 0.0) of the spatial model (map) predictions to the reference (plot) data. Another statistic called the mean error (ME) was also computed to quantify the error of map predictions (Taylor 1997). It is defined as:

$$ME = \frac{\sum_{i=1}^{N}(O - P)}{N}$$

where O is the observed (plot) value, P is the predicted (map) value for that plot, and N is the number of plots. This statistic is useful for evaluating the magnitude of accuracy error (Taylor 1997).

An assessment of aspect accuracy presented some special problems because of its circular scale. Northern aspects are especially difficult to estimate because they traverse the beginning and end of the azimuth scale. A plot with a measured aspect of 10 degrees and a predicted aspect of 350 degrees are only 20 degrees different ecologically but 340 degrees numerically. We used the following transformation to scale aspects along a more ecologically oriented gradient (Beers and others 1972).

$$\boldsymbol{ASP} = 1 + \boldsymbol{COS}(\boldsymbol{ASPECT})$$

Where ASP is the ecological aspect index (number between 0 and 2), COS is the cosine function, and ASPECT is the aspect in degrees azimuth (0 to 360). This assumes equal weight is given to east and west aspects.

RESULTS

Field Sampling

During 1997, we established exactly one thousand plots across more than two million ha of the Gila National Forest Complex. Exactly 810 of these plots were Ground Truth plots where data from the GF, LL, and PC forms were recorded (Appendix A). Ecosystem Characterization (EC) plots numbered 190 and were also scattered across the entire GNFC to extensively describe various ecosystem characteristics for each PVT, cover type, and structural stage category where we actually measured fuel loadings, tree density, diameter, height, and all other variables mentioned in Appendices A, E, and F. All plot locations were georeferenced to within a 5 meter accuracy using Global Positioning Systems (GPS). Plots were established along environmental gradients to ensure the sampling of all biophysical and vegetational types across the GNFC. However, most plots were located adjacent to roads or trails because of time and cost constraints. All sampled data were entered into several databases (see Appendix G and *CD\DATABASE*) that were linked to the GIS point layer of plot locations created from the GPS coordinates. This GIS point layer and database were essential in the development and accuracy assessment of the GIS base layers and FARSITE input spatial data layers.

We again sampled exactly 1,000 polygons in 1998 using the Polygon Validation (PV) procedures outlined in Appendix A where ocular estimates of all vegetation classification categories and FARSITE input parameters were obtained. These data were also entered into a database (*CD\DATABASE\PV*) where the polygon number in the GIS layer referenced the polygon ID entered on the plot form and into the database (see Appendix G). These data were only used to assess accuracy of the data layers and to refine the PVT terrain model.

Representation of field plots across all base vegetation categories seemed more than adequate for this project (Table 7). The number of plots stratified by PVT class and cover type category seems unbalanced in Table 7, but when adjusted for area (numbers in parenthesis), there appears to be a somewhat even distribution. However, several cells were severely under- or over-sampled. Rock, barren ground, and herblands were not sampled to the level of their occurrence because we were concentrating on documenting the variation in forested communities. The most difficult communities to differentiate with TM imagery are forest types, so we spent the majority of our sampling effort attempting to describe differences in forested communities based on species composition and fuel characteristics. As a result, many non-forest types were not sampled to the level of their occurrence on the landscape. This is

Table 7—Distribution of sample plots stratified PVT and cover type categories. Numbers in parentheses indicate the expected sample size based on the area encompassed by the PVT and CT combinations computed from the final cover type and PVT maps.

Potential vegetation type									
Cover type	**Riparian**	**Spruce-Fir**	**Mixed Conifer**	**Douglas-fir**	**Ponderosa Pine**	**Pinyon-Oak-Juniper**	**Scrub-Grassland**	**Non-Vegetated/Rock**	**Total**
Water								3(3)	3
Rock								25(272)	25
Barren Ground				0(3)	0(43)	14(146)	7(86)	7(0)	28
Mine-Quarry								4(10)	4
Herblands	13(0[+])		2(4)	3(25)	62(113)	160(306)	45(54)		285
Xeric Shrublands				0(5)	5(8)	61(45)	37(71)		103
Mesic Shrublands	2(3)		1(3)	6(13)					9
Broadleaf Riparian Forest	23(25)								23
Broadleaf/Conifer Forest	4(5)	15(1)	21(3)	14(6)					54
Conifer-Gambel Oak Forest			4(1)	34(11)	33(26)				71
Conifer Forest-Woodland Mix			3(0)	29(43)	157(1)				189
Mixed Woodland				1(0)	44(16)	145(40)			190
Mesic Mixed Conifer		9(3)	87(62)						96
Xeric Mixed Conifer		3(2)	60(8)	147(18)	0(36)				210
Aspen		7(1)	7(2)	5(1)					19
Gambel Oak			3(2)	9(4)	3(1)				15
Juniper					12(20)	83(95)			95
Pinyon					6(24)	44(95)			50
Evergreen Oak					5(14)	23(55)			28
Ponderosa Pine			12(5)	52(27)	254(90)				318
Douglas-fir		2(0)	4(0)	18(12)					24
Pinyon-Juniper					23(5)	157(56)			180
Spruce-Fir		29(9)							29
Total	42	65	204	318	604	687	89	39	2048 [++]

[+]Expected sample size may be biased by number of training areas (plots) used to classify any particular cover type
[++]Not all 2048 plots were used in phases of classification due to problems and constraints in sampling methodology and classification requirements.

demonstrated by the over sampling of ponderosa pine (254 plots when only 90 were needed), xeric mixed conifer (147 when only 18 needed), and conifer forest-woodland mix (157 when only one was needed) cover types. Herbaceous and shrublands were also not sampled to expected levels (about 50 percent less than occurrence). It was difficult to compute expected levels prior to field sampling because no map existed that described extents of major cover types for the GNFC area.

Draft Layer Development

We created a set of draft FARSITE input layers for the GNFC fire management because the layers were needed for the 1998 fire season. These draft layers were ONLY for use in 1998 and did not constitute the final product. We created these draft FARSITE layers using the triplet strategy mentioned above but with draft layers of the vegetation base maps. The draft PVT layer was developed from terrain-based rules derived from field data collected in 1997. The rule parameters were then translated to the GIS using a menu-driven routine we programmed in ARC/INFO's macro language (AML) that allows the user to interactively assign PVT category values into a matrix of elevation versus slope and aspect combinations.

This draft PVT map was limited in scope but provided a good baseline for fuels assignment. The draft cover type, structural stage, and canopy closure FARSITE layers were created from the unsupervised classification of the September 26, 1993 LANDSAT Thematic Mapper (TM) satellite scene with classification types derived from 1997 field data. This was the same map that was used to guide polygon selection during the field sampling effort. The draft version of the FARSITE input layers will was given to Gila National Forest personnel in April 1998 to be used for the 1998 fire season.

Final Vegetation Classifications

The eight potential vegetation types (PVTs) that describe biophysical settings in the GNFC are presented in Table 3 and the key to these types is detailed in Appendix E. The terrain model or topographic rulebase used to map the PVTs is presented in Appendix F. We narrowed our list of PVTs from 12 to 8 because when we constructed the 1998 draft vegetation and FARSITE layers, we found some PVTs did not improve our ability to map fuels and vegetation. We aggregated the lowland oak types with the pinyon-juniper PVTs because it was difficult to identify them in the field due to past disturbances. In the end, we found our PVTs were very similar to the life zones described by the General Ecosystem Survey (Carleton and others 1991, Dahms and Geils 1997). Life zones are perhaps the appropriate scale for describing aspects of community development such as succession, disturbance regimes, and most importantly, fuels (Dahms and Geils 1997).

Twenty-four cover types (Table 4) and 12 structural stage categories (Table 5) were used to describe the composition and structure of existing vegetation on the GNFC. Keys to these existing vegetation classifications are presented in Appendix E. Again, categories for both classifications were designed to map many ecological characteristics other than FARSITE fuels. The primary rules used to design the classification were that the categories needed to (1) be easily identified in the field, (2) be keyed from the data collected on the GT and EC plots, (3) have adequate discrimination between fire behavior fuel models, and (4) uniquely describe existing vegetation. Some draft cover types were aggregated because their inclusion did not improve the mapping accuracy or contain information important to map ecological characteristics. For example, a white fir cover type is possible but rare in the GNFC so it was lumped into the mesic mixed conifer type. Moreover, fuel characteristics on a white fir cover type are very similar to those in the Mixed Conifer type. As mentioned, structural stage categories were modified from the processed based approach of O'Hara and others (1996) to a diameter size class approach because the process-based categories were difficult to identify in the field and in the imagery, and the increased detail was not needed for fuel mapping.

Vegetation Base Layer Mapping

Potential vegetation types (PVT) were mapped for over 2 million ha that comprised the GNFC project area using the terrain modeling method (Plate 1). A summary of land area by PVT and cover type, and by cover type and structural stage, is shown in Appendix I.

Mapped PVT categories are unevenly distributed across the GNFC. Thirty-nine percent of the GNFC landscape was mapped as Pinyon-Oak-Juniper, close to 19 percent was mapped as Ponderosa Pine, and about 10 percent as Scrub-Grassland (Table 3). Seventy percent of the area is occupied by just three PVTs because we assumed most herblands (94 percent) were seral to a forest or woodland type (Appendix I). Therefore, the extensive grasslands in the low lying areas surrounding the Gila National Forest were considered to have a woodland or closed forest potential, thereby increasing the land area in the Pinyon-Oak-Juniper PVT. This assumption was based on the eventual conifer encroachment we observed in the foothills of the GNFC, and it was also based on documentation in the literature (Covington and Moore 1994, Dahms and Geils 1997, Dick-Peddie 1993, Savage and Swetnam 1990).

The cover type map is shown in Plate 2. A relatively large portion of the GNFC was mapped as rock or barren ground cover type (527,531 ha or 27 percent of the entire study area) from the satellite imagery (Table 5). Much of this occurs outside the Gila National Forest boundaries to the east and west in desert scrub zones and is partially explained by the TM Scene date (June 1997) which is before monsoonal rains and subsequent green up of the scrub grasslands. Many grasslands and shrublands have similar reflectances to barren ground so the classification often confuses areas that have the potential to support grasslands with true rock or barren grounds. Monsoonal greenup of grassland ecosystems would have helped differentiate these two cover types.

Herblands comprised nearly 25 percent of the GNFC while rock/ barren ground was found on close to 27 percent of the area. This seemed to agree with other classifications of similar landscapes (Gonzales and Maus 1992), but points out that over 50 percent of the GNFC is in nonforest types where confusion between fuel models is minimal. Only 20 percent of the GNFC is closed forest and 15 percent is in woodlands. We were surprised by the low coverage of shrublands (8 percent), but the high cover of shrubs needed to key to shrublands (15 percent) precluded many herblands from keying to shrublands. This was done to distinguish between the grassland (FBFM 1) and shrubland (FBFM 6) fuel models.

The structural stage map had uneven distributions in tree structural stages (Plate 3). Close to 19 percent of the GNFC landscape was mapped as Medium Tree structural stage which is over 94 percent of all mapped forest structural stages (Table 5). This percentage is relatively high and is primarily a result of lacking an adequate structural classification scheme prior to field sampling and lacking prior knowledge of the distribution of structural stages across the landscape. The diameter classes we used to key to structural stages (Table 5) were based on ECODATA criteria and proved too broad to comprehensively describe stand structure for GNFC forests. GNFC closed forests rarely have diameters greater than 20 inches DBH which is the upper limit of the Medium Tree category. However, we found these structural stages were more than adequate for fuel mapping.

FARSITE Input Layer Mapping

Fuel model assignments to base vegetation classification categories are documented in Appendix J and in the database on the CD (*CD\DATABASE\LUT\PCSLUT.DBF* and *CD\DATABASE\LUT\CSCLUT.DBF*).

Final fuels layers are shown in Plates 4 to 8. Woodland fuel models comprised the majority of the GNFC FBFM map (34 percent in Table 8 and see Plate 4). Stand and crown height (Plate 5 and 6, respectively) was very diverse across the GNFC landscape. Forested crown bulk densities were surprisingly uniform (Plate 7). Canopy closure ranged from 0 percent to 99 percent (Plate 8) with the majority of the GNFC having a canopy closure of 3 to 20 percent.

The FARSITE fuels layers in the GNFC GIS were reformatted into the FARSITE landscape format geographically stratified by USGS quadrangle boundaries to create 111 FARSITE landscape files. This was done to optimize FARSITE execution on a laptop PC. Simulation landscapes that are too large take a long time to display and modify in the FARSITE program. On the other hand, simulation areas that are too small run the risk of a simulated fire reaching the edge. We found simulation landscapes about the size of a USGS quadrangle (around 10 km by 10 km) seemed to be the optimal size for both worlds. Each landscape file has the eight FARSITE input raster layers and some vector files of cartographic features (e.g., streams, roads, trails).

Table 8—Spatial summary of crown fuels by surface FBFM Fuel Model (normal conditions).

			Crown fuel averages			
Fuel model[1]	**Description**	**Mapped percent of GNFC landscape**	**Stand height (m)**	**Crown height (m)**	**Crown closure (%)**	**Crown bulk density (kg m^{-3})**
1	Short grass	8.8	—	—	—	—
2	Timber grass	0.6	5.1	0.8	30	0.066
5	Brush	0.7	—	—	—	—
6	Dormant brush	8.5	4.4	0.6	3	0.017
8	Closed timber litter	5.0	14.2	2.5	60	0.122
9	Ponderosa pine	9.1	14.9	3.8	40	0.081
10	Heavy timber	3.5	17.5	2.0	70	0.198
50	Pinyon-juniper	33.6	1.8	0.2	10	0.006
98	Water	0.1	—	—	—	—
99	Non-vegetated (rock, mines, urban)	29.9	—	—	—	—

[1] From Anderson (1982).

We also reformatted daily weather taken from surrounding National Weather Service weather stations and Remote Automated Weather Stations (RAWS) and included these weather files so managers could have default weather conditions to execute FARSITE. The Weather Service data was obtained from the National Climatic Data Center (NCDC) while the RAWS data was obtained from the Western Regional Climate Center. We stored these data in the directory *CD\WX\NCDC* and *CD\WX\RAWS*, respectively. In addition, we simulated 24 years (1970 to 1994) of weather at sites representative of each PVT with the DAYMET model (Thornton 1998) and included these weather streams in the weather database (*CD\WX\DAYMET*). No wind files were created because of the lack of historical data on wind speeds and duration.

Canopy cover was best described from the satellite imagery rather than as a assignment from base vegetation classification combinations. Therefore, we assigned the canopy cover class to individual polygons based on the spectral imagery classification.

Accuracy Assessment

The summary of the entire hierarchical accuracy assessment for categorical variables is presented in Table 9 where all ocularly estimated categories in the field data, vegetation classifications, and map layers were analyzed to estimate their accuracy. The assessment summary for continuous variables is shown in Table 10. Continuous variable accuracies were estimated using regression techniques while accuracy for categorical variables were estimated from contingency table analysis.

Contingency tables and regression analysis of individual maps are detailed in Appendix K and an example of the PVT classification accuracy assessment is shown in Table 10. Included in the contingency tables is a fuzzy score that provides additional information such as the magnitude and source of error (Gopal and Woodcock 1994, Woodcock and Gopal 1992). The fuzzy scores also provide a more useful way to evaluate a spatial layer that is mapped into discrete categories but is actually continuous on the landscape. Fuzzy scores are rated as 1 (absolutely wrong), 2 (understandable but wrong), 3 (acceptable), 4 (good answer), or 5 (perfect).

Our field sampling crews seemed to maintain a high level of accuracy and consistency (over 85 percent) in ocularly assessing variables at the plots (Table 9 and Table 10). For example, when the PVT field assignments where checked against the ECODATA PC plant species list sampled for the same plot using the GT and EC methodologies, an accuracy of over 89 percent resulted.

Table 9—Accuracy assessment summary for the categorical variables used in the GNFC project. The KHAT statistic adjusts for unequal sampling for each categorical variable.

Evaluated source	Item evaluated	Number of categories	Number of observations (plots only)[1]	Accuracy (%) (plots only)	KHAT statistic (%) (plots only)	Number of observations (plots and polygon validations)[2]	Accuracy (%) (plots and polygon validations)	KHAT statistic (%) (plots and polygon validations)	Fuzzy set accuracy, score 3 or better (%) (plots and polygon validations)
PVTField	Data	8	1000	89	85	—	—	—	—
Structural Stage	Field Data	11	1000	77	71	—	—	—	—
PVT	Classification	8	1000	99	—	—	—	—	—
Cover Type	Classification	23	1000	98	—	—	—	—	—
Structural Stage	Classification	11	1000	98	—	—	—	—	—
FBFM Normal	Assignments	11	—	—	—	2037	55	45	—
FBFM Severe	Assignments	12	—	—	—	2037	49	39	—
FBFM Normal	Layer	11	981	36	26	1825	35	24	62
FBFM Severe	Layer	11	982	38	28	1826	34	24	58
PVT Terrain Model	Layer	8	1000	62	48	—	—	—	—
PVT (Polygon)	Layer	8	982	61	50	1829	57	45	89
Cover Type	Layer	23	982	43	39	1829	36	31	65
Structural Stage	Layer	12	982	52	42	1829	52	39	64
Crown Closure	Layer	11	982	41	26	1829	41	24	—
Lifeform	Layer	7	982	64	55	1829	61	48	—

[1] Plots used in these accuracies were also used as training areas so these results may be biased.
[2] Plots were used in the accuracy assessments and as training areas; polygon validations were used solely for the accuracy assessment.

Table 10—Accuracy assessment summary for the continuous variables used in the GNFC project. The KHAT statistic adjusts for unequal sampling for each categorical variable.

Evaluated source	Item evaluated	Number obs	Coefficient determination r^2	Standard error	Mean error	Units
Stand Height	Field Data	110	0.67	10.51	-8.40	Meters
Crown Height	Field Data	110	0.12	10.85	-7.88	Meters
Stand Height	Layer	1394	0.37	18.08	10.16	Meters
Crown Base Height	Layer	1394	0.21	4.74	1.97	Meters
Crown Bulk Density	Layer	917	0.35	0.06	0.04	Kg/m^3
Elevation	Layer	999	0.99	90.80	19.21	Meters
Aspect	Layer	960	0.68	0.41	0.01	Degrees[+]
Slope	Layer	999	0.76	8.99	0.56	Percent

[+] Degrees were converted for this accuracy assessment using the equation
ASPECT = 1 + COS(ASPECT_DEGREES)

Base vegetation classification accuracies were also quite high. Only 2 percent of the plots sampled with the GT and EC protocols failed to meet the PVT key criteria (Table 9). This compares well to other potential vegetation classifications (Daubenmire 1966, Pfister and others 1977, USDA Forest Service 1997).

GNFC FARSITE CD

All data inputs and products used and created in this study are contained on the CD that accompanies this report. This CD has a unique file structure so that all data can be accessed efficiently and quickly (see Appendix L and the *readme.txt* file in *CD*). The FARSITE input layers in the landscape format have been compressed using the specialized software contained in the *CD\SOFTWARE\PKZIP* directory. These layers, in the *CD\QUAD* directory can be individually loaded onto a laptop or desktop Personal Computer (PC) hard disk for FARSITE simulation. The FARSITE computer program is contained in the directory *CD\FARSITE* and you can install FARSITE onto a computer using this program.

Once FARSITE is installed on a PC, individual quads in landscape format can be copied to the PC's hard disk as needed. It's probably not a good idea to copy all landscape quad files over to the hard disk unless there is abundant disk space (over one gigabyte). However, all weather and custom fuel model files should be copied to special directories on the PC hard disk. Refer to the FARSITE user's manual (Finney 1995) to create a robust hard disk directory structure that will facilitate efficient FARSITE simulations.

DISCUSSION

This mapping project was highly successful for a number of reasons, despite the apparent low accuracies for some vegetation and fuels maps. First, a consistent and comprehensive set of FARSITE input maps was created for a large and diverse area. This extensive data set can be used to simulate many types of fires with FARSITE over large areas and across complex terrain and diverse ecosystems. Although the accuracies of the layers may appear low, erroneous polygon attribute assignments are often quite similar ecologically to those observed on the ground. Usually, fuel model assignments are quite close to observed values even though the mapped FBFM might be wrong when interpreted in the context of fire behavior. Forested types are rarely confused with grassland types, but some woodland types often have the same reflectance characteristics as forests and grasslands.

The comprehensive data set (layers and files) generated from this project provides a framework to create other maps useful for land management. Other non-fuel attributes in the base layer combination lookup table can be used to create maps that might be used for wildlife planning or forest sampling. The procedure of asking fire managers to assign three fuels characteristics to each PVT-cover type-structural stage combination can be used to assign other ecologically relevant attributes to the combination. For example, hiding cover classes for deer and elk can be assigned to the vegetation base layer category combinations to predict those areas on the landscape where big game ungulates would go for cover. Spatial and tabular data sampled, created, simulated, or assigned from this project can be used for a wide variety of land management activities. Fuel loadings can be linked to the base vegetation triplet for input into smoke and planning models (Keane and others 1998b). Diagrammatic succession models can be developed for each PVT, like Keane and Long (1997) did for the Salmon-Challis National Forest, to predict landscape changes over time and quantify historical ranges of variation. Moreover, simulated future landscapes of FARSITE fuels, created from the base vegetation combination lookup table, can be used to simulate fires of the future using FARSITE.

Layer Accuracy

The low accuracies of developed maps may cause some to think perhaps another method of mapping should have been used. While the accuracies seem low (36 percent to 57 percent), they are comparable to accuracies of other similar vegetation maps generated from remotely sensed satellite imagery (Brzeziecki and others

1993, Deitschman 1973, Grupe 1998, Redmond and Prather 1996). The primary reason why fuels and vegetation layers appear inaccurate is simple; fuels and vegetation are continuous, not discrete, ecological characteristics that are highly variable in space and time. So, while vegetated stands can be differentiated across a landscape from classified satellite imagery, it is often difficult to correctly identify those stands as to their composition and structure (see Greer 1996, 1998, Lachowski and others 1995, Redmond and Prather 1996, Shao and others 1996). Therefore, their quantification and classification is highly scale dependent (Daubenmire 1966). Vegetation communities consist of many plant species that vary in abundance, stature, and dominance across environmental and disturbance continua (Whittaker 1965, Whittaker 1967). Fuels consist of many sizes of live and dead biomass that are extremely variable both within stands and across landscapes (Brown and Bevins 1986, Brown and See 1981). Therefore, mapping fuels and vegetation communities into discrete polygons using discrete classifications is tactically difficult and complex (Brown and Bevins 1986, Kessell 1979, Whittaker 1967). When fuzzy set accuracies of the fuels and vegetation layers of score 3 (acceptable) or better are considered, accuracies improve considerably to 89 percent for the PVT, 65 percent for the Cover Type, 64 percent for the Structural Stage, and 62 percent for the FBFM Normal layers (Appendix K). These fuzzy set accuracies provide a more meaningful assessment of continuous landscape attributes mapped as categorical variables than do the overall accuracies.

The effect of the continuous behavior of fuels and vegetation dynamics across the GNFC on map accuracy is somewhat demonstrated in the results of the intensive accuracy assessment (Table 9 and 10). Errors exist in the sampled field data because it is often difficult to estimate continuous variables into the required discrete categorical inherent in the classifications. When the accuracies of the Fire Behavior Fuel Model field calls are compared to the Lookup Table Assignments, accuracies range from 49 to 55 percent. This demonstrates the difficulty inherent in consistently quantifying continuous fuel conditions into discrete categories across a highly variable landscape. When one bases accuracy assessments on reference (field) data that is assumed to be 100 percent accurate and yet the agreement between the reference data and the Lookup Table Assignments is only 49 to 55 percent, these discrepancies are carried through to the fuels spatial layer, resulting in low accuracies. Moreover, continuous variables measured on a site have a high degree of variablility making it difficult to assess GIS layer accuracy. For example, stand and crown base height are hard to ocularly estimate for the computation of crown fire spread when different species and different sized trees have a wide range of observed heights and crown characteristics within the plot.

Because the FARSITE layers are built from the vegetation triplet of PVT, Cover Type, and Structural Stage, errors present in the three layers comprising the triplet are carried through to the FARSITE layers. For instance, if a polygon was classified in the layer as a Ponderosa Pine PVT, Ponderosa Pine cover type, and medium tree structural stage, it would be assigned from the Vegetation Characteristics Lookup Table a FBFM Normal 9, FBFM Severe 9, a Stand Height of 35 ft, and a Crown Base Height of 10 ft. If the reference plot falling within this polygon was sampled as a Ponderosa Pine PVT, Pinyon pine cover type, open woodland structural stage, in the field, it could have been assigned an FBFM Normal 50, FBFM Severe 2, Stand Height 45 ft, and Crown Base Height 1 ft. Thus, only the PVT layer would have been classified correctly and all subsequent layers incorrectly. While the methodology of using the vegetation triplet to describe ecological characteristics is sound and creates multi-user data layers, it can cause errors to be propagated throughout the many layers dependent on the triplet.

With the seemingly low Fire Behavior Fuel Model accuracies, one has to ask the question, why not directly map fuels from remotely sensed data instead of basing them on vegetation characteristics if using this methodology does not confer better results? The answer is this; if fuels are mapped directly, the fuel layers would not be congruent with the other spatial layers necessary to run FARSITE, namely Stand Height, Crown Base Height, Crown Closure, and Crown Bulk Density. In other words, illogical combinations of the input fuel layers would result in inaccurate fire behavior predictions.

The base vegetation classifications contain inherent error because the effects of past disturbance history, integrated site environment, and genetic differences influence the composition and abundance of indicator species that confounds consistent and precise identification of a vegetation category. For example, a small amount of white fir in the understory of a stand can drastically alter crown fire initiation and behavior. Moreover, classification of potential and existing vegetation types has a high degree of error because indicator plant species vary in abundance and dominance because of genotypic variation across complex environments. For example, a ponderosa pine PVT may not be identifiable on the ground because a previous stand-replacement wildfire killed every ponderosa pine tree (Deitschman 1973, Steuver and Hayden 1996).

There are also errors in the fire management workshop estimates because fire managers tend to simplify and synthesize fuel dynamics to broad vegetation types and then assign these simplifications to more detailed vegetation classifications with more categories (Keane and others 1996a). There are errors in the fuels and vegetation GIS maps because of all the compounding errors mentioned above, and because fuels and vegetation are not constantly arrayed in space (i.e., they vary across a continuum). Probably the most frequent source of error in image classification and mapping is that conditions inside the field sample plot do not always represent conditions found throughout the polygon. Therefore, it is doubtful this method of sampling and mapping fuels will ever produce highly accurate GIS layers, and it will require exorbitant amounts of time and money to sample fuels to adequately describe conditions across an entire polygon. Even then, the high variability of the polygon sampling coupled with scale problems may always limit map accuracy.

Another reason for low accuracies in the vegetation layers can be explained by the under-representation of ground truth in common cover types such as rock, herblands and barren (Table 7). We did not extensively sample these areas because we were concerned with describing forest communities. These cover types are easily identified by image processing because of their unique spectral signature (Howard 1991, Verbyla 1995) (Table 11). If we had established ground-truth plots in these cover types at the same level as their occurrence on the landscape, the overall accuracies would have increased to 83 percent for the PVT map, 63 percent for the cover type map, and 77 percent for the structural stage map based on the data in Table 7 and Table 11. Other satellite-based cover type mapping efforts with higher accuracies than this study (Gonzales and Maus 1992) have a proportionately higher percentage of ground-truth plots in the cover types that are most clearly distinguished by satellite imagery such as rock, barren, or water (Verbyla 1995). Because we concentrated our sampling efforts in vegetated areas most affected by fire, we under-sampled in the cover types that would have made our accuracies much higher.

Layer accuracies varied by PVT category ranging from 14 to 92 percent (Table 10). Cover type accuracies were highest in the non-forest types (100 to 67 percent) and lowest for woodland types (6 to 51 percent). This is a direct result of the inability of TM imagery to discriminate between major cover types within one lifeform. Mesic mixed conifer and xeric mixed conifer have different ecological characteristics, but the imagery cannot distinguish between the two. However, the imagery can discriminate between rock and forest quite well (Appendix K).

Table 11—Accuracy of the Potential Vegetation Type (PVT) Classification based on PVT field calls.

		Reference (field) PVTs									
		Riparian	**Spruce-Fir**	**Mixed Conifer**	**Douglas-fir**	**Ponderosa Pine**	**Pinyon-Oak-Juniper**	**Scrub-Grassland**	**Non-vegetated**	**Totals**	**Commission Error (%)**
Classified (layer) PVT	Riparian	21(5)	0(1)	2(1)	9(1)	19(1)	6(1)	1(1)	1(1)	59	64
	Spruce-Fir	0(1)	49(5)	15(4)	7(3)	0(2)	0(1)	0(1)	1(1)	72	32
	Mixed Conifer	1(1)	9(4)	94(5)	67(4)	11(3)	0(1)	0(1)	0(1)	182	48
	Douglas-fir	2(1)	2(3)	33(4)	136(5)	87(4)	3(2)	0(1)	1(1)	264	48
	Ponderosa Pine	2(1)	0(2)	3(3)	37(4)	254(5)	100(4)	1(2)	2(1)	399	36
	Pinyon-Oak-Juniper	6(1)	0(1)	1(1)	18(2)	147(4)	432(5)	46(4)	9(2)	659	34
	Scrub-Grassland	1(1)	0(1)	0(1)	0(1)	0(2)	14(4)	35(5)	1(2)	51	31
	Non-vegetated	5(1)	0(1)	7(1)	8(1)	27(1)	70(2)	6(2)	20(5)	143	86
	Totals	38	60	155	282	545	625	89	35	**1829**	
	Omission Error (%)	45	18	39	52	53	31	61	43		

Format: Number of plots (fuzzy score)
Overall Accuracy = 57%, KHAT Accuracy = 45%.
Fuzzy sets: 89% have a fuzzy score of 3 (acceptable) or better, 87% have a fuzzy score of 4 or better.

There are several ways to increase the accuracies of these maps. First, the mapped categories for the cover type and structural stage layers could be designed to describe what the satellite TM sensor is sensing rather than to comprehensively describe the vegetation. However, the resultant vegetation categories are rarely useful to common land management applications, especially fuels mapping, because many vegetation complexes are missing or aggregated (Verbyla 1995). For example, ponderosa pine cover types would probably have been lumped with xeric mixed conifer in our study, so unique fuel conditions in the ponderosa pine stands would not be identified. Second, fuels could be directly sensed from the satellite imagery thereby eliminating the vegetation triplet approach. This has proved successful for some fuel mapping studies (see Fuel Mapping Studies section) but would probably not be successful for creating FARSITE layers because all five fuel layers must be created congruently. Since some FARSITE layers are continuous (e.g., stand height) and some are categorical (FBFM), direct image classification for all fuel layers would be very difficult. Moreover, the independent image classification of each FARSITE fuel component would probably not be successful because there is a high chance many polygons would have illogical assignments such as having stand heights less than crown heights.

The best way to improve accuracy would be to use new remotely sensed products that comprehensively and consistently distinguish aerial and surface fuel loadings and characteristics. Fuels may not correlate well with the vegetation characteristics best detected by passive sensors such as the Thematic Mapper (Hardwick and others 1996, Kourtz 1977). Aerial photo interpretation may increase accuracies but perhaps not enough to justify the increased cost and effort (Root and others 1985). Schetch mapping where maps are created through field reconnaissance are also costly and require a great deal of human resources (Dendron Resource Surveys 1981). Lidar and SAR are new active remote sensing technologies that show great potential for fuel mapping but have been untested as yet (Bufton 1989, Dubayah and others 1997, Naessent 1997, Nelson and others 1988).

Field Sampling

A major shortcoming of this project was the temporary delineation of polygon boundaries from an unsupervised classification of the satellite imagery. We found major differences in polygon boundaries when we replaced the draft polygon delineations done in 1997 with the permanent delineations derived from the textural analysis of TM imagery in 1998. We did not have the newer TM scene coverages for the field sampling phase so the 1993 TM scene was used to create an unsupervised polygon map of differing spectral clusters as spatial stratification for landscape sampling. This preliminary classification had many problems including inconsistency in polygon sizes and spectral classifications. We then experimented with various image processing methods to create more consistent polygon delineations but this was not finished in time to help in the sampling effort. As a result, it was difficult to assign the data collected for the area defined by the draft polygons to the appropriate final polygon in the final map. For example, a polygon created from the unsupervised image classification might be 50 ha, but the final polygon delineation using textural attributes created two polygons of 20 and 30 ha within the original 50 ha draft polygon. This problem was especially important in the 1998 field sampling because nearly half of the polygons sampled with the PV methodology did not have GPS-estimated UTM coordinates due to time and cost constraints. We had to manually assign the sampled attributes from the PV effort to appropriate polygons in the final map on a case-by-case basis. We should have delineated the polygon boundaries from all TM scenes prior to our sampling effort and these delineations should have been static throughout the entire project. However, this was not possible because we did not obtain GIS and TM imagery in time. We should have also taken GPS geo-referenced positions for every plot regardless of sampling methodology for greater flexibility in using the field data for any polygon delineation. However, the real strength of the PV methodology is its simplicity and rapid assessment. You really shouldn't need to take a GPS location at every PV plot. In fact, the PV method works the most efficient when you are walking a trail or driving a road, to evaluate recognizable polygons to sample the major vegetation and fuel category values.

The success of this fuels mapping project was directly related to the quality and quantity of the data obtained from the field sampling effort. Our top-down approach where sampling zones were stratified by geographic area and then by inherent topographic gradients coupled with the hierarchically nested measurement intensities seemed to optimize plot location, data gathering, and available resources for the amount of time and money available for the project. It appears most vegetation and fuels combinations were sampled, even though only 2,000 plots were gathered in this effort (Table 7). However, additional field data could have improved map accuracies and strengthened vegetation classifications by filling in major data gaps and providing deeper coverages in important fuel and vegetation types.

We estimate another 2,000 to 3,000 plots would have helped strengthened our spectral classifications and improved our overall accuracy assessment. The intensive EC method would be used to collect data on only 5 percent of those plots, the GT method would be used for 30 percent, while the remainder be sampling with the quick PV methodology. This means that the majority of plots (greater than 60 percent) could be measured using an uncomplicated methodology. But, even with the doubled field sample, we probably would have only improved map accuracies by only 5 to 10 percent because of the great variability in ecosystem properties over the GNFC landscape.

We ended up spending over 70 percent of our sizeable mapping budget on field sampling and still did not seem to obtain enough plots. This is because collecting data using the GT and EC methodologies required a high level of field expertise that was not available from Gila National Forest personnel. We conducted a week-long EC and GT plot field training session for about 20 people on Gila National Forest staff in the hopes that they could assist in the sampling effort, but their busy schedules during the field season prevented them from providing substantial help. In retrospect, we should have trained these people only in the PV methodology which would have allowed them to quickly sample polygons at their convenience without requiring vast knowledge of ecological sampling and a predetermined sampling schedule. Since our crews consisted of highly trained ecologists and botanists, we could have concentrated on EC and GT sampling in both years and improved our ecological database considerably, thereby strengthening the study, with the PV data provided by the National Forest.

A high level of data quality is essential for the creation of base vegetation and FARSITE input layers. Our sampling crews were well trained and had considerable field experience so the data they collected tended to be of high quality. We double checked the ASCII data files for entry mistakes and ran extensive data checking programs to control error and improve database quality. However, the combination of extensive fire behavior, fuel modeling, and ecological expertise needed to create a high caliber data base for fuel mapping may require additional money to be spent on professional fire ecologists to ensure optimum data and subsequent map quality. Typically, natural resource agencies develop field inventory techniques so that inexperienced field personnel can be trained in a short time to measure ecosystem characteristics with simple techniques. However, fuel mapping seems to require extensive expertise in all phases of fire management so more experienced field crews may be necessary.

Insufficient or low quality field data is usually the major reason cited for low accuracies and poor map quality in a number of vegetation sampling efforts (Hardwick and others 1996, Howard 1991, Jensen 1986, Verbyla 1995). So, how much field data are enough? Perhaps the best plan for field sampling is to replicate our nested sampling intensities and have one experienced field crew sample the detailed ecosystem attributes using the intensive methodologies. Then, several inexperienced crews can be mobilized to gather general data with simplified methodologies such as the PV protocols. It would be optimal if the simplified methods could be taught in less than a day, and only require one person to take the measurements. This approach would allow other natural resource or fire inventory crews to collect data when time allows or collect the fuel data in addition to the data they are already taking. There usually is no upper limit on the amount of data needed for a project because funding, personnel, and access ultimately dictates the size of the field database. Any increase in these factors will result in higher quality and more robust data.

Vegetation and Fuel Layer Development

The application of this vegetation-based methodology to map fuels on the Gila National Forest was highly successful despite the low map accuracies. First, fuels and vegetation were consistently and comprehensively classified and mapped over a large and complex landscape. Second, the vegetation layers provide an ecological context in which to interpret the surface and crown fuels layers. Users can easily understand why a particular fuel complex is assigned to a polygon once the vegetation triplet is known. Moreover, this ecological context allows easy modification of fuels maps if users feel fuel assignments are in error. Next, the vegetation triplet also allows the assignment of other ecological attributes useful to other land management applications. The entire mapping project generated maps and databases that will surely be useful to other phases of land management. Soils and DEM layers could be used to map erosion potential. The DEM, stream layer, and cover type classification could be used to map riparian environments.

Fuels were successfully mapped using the three base vegetation classification maps in concert. We estimate the use of the PVT map to stratify cover type image classifications resulted in an increase of between 5 and 15 percent in map accuracy. Structural stage delineations improved fuel model assignments by about 10 percent.

Linkage of gradient-based biophysical settings with PVTs in this study was highly experimental and generated mixed results. While the gradient biophysical settings layer aided in the refinement of PVT categories and polygons, it certainly was not necessary for the successful completion of this GNFC project. The PVT map refinement using environmental gradients created from current technology could probably increase accuracy by about 5 percent, but the creation of this biophysical settings layer is time consuming and requires specialized expertise. The simulation models and algorithms used to quantify and described biophysical parameters are highly complex and very experimental and do not yet seem to have the inherent resolution needed for fine scale fuel mapping projects. This project could have easily been completed with only the PVT classification and PVT map.

CONCLUSIONS

FARSITE fuel layers were successfully developed for the Gila National Forest Complex using a vegetation-based approach where fuels were mapped from there relationship to biophysical setting, species composition, and stand structure. This approach was also expanded to map other ecological characteristics. This approach is not the only way to create the FARSITE input layers, but rather, it is presented as one of the many tools that can be used to create these complex layers. Current remote sensors do not provide imagery that is directly useful for fuel mapping. Hopefully, future satellite platforms will contain sensors that sense the many characteristics of fuels that influence fire behavior so that accurate, consistent, and useful maps can be used in fire management and planning.

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GLOSSARY

Accuracy assessment — The process of describing the accuracy of the data layers and field data based on ground truth or more intensive measurements.

ASCII file — A digital data file stored on a computer in ASCII (American Standard Coding for Informational Interchange) format.

AVHRR imagery — Advanced Very High Resolution Radiometer satellite sensor. Pixel sizes from this imagery are usually around 1 km on a side.

AVIRIS — Airborne Visible Infra-Red Imaging Spectrometer satellite sensor.

Biophysical setting — The site environment that integrates the influences of climate, soils, topographic setting, and geographical region. Similar terms are biophysical environment, site, and site environment. A biophysical setting or biophysical environment usually creates certain conditions that allow a unique assemblage of plant species in the absence of disturbance. This unique plant community is referred to as the potential vegetation type.

Base vegetation classifications — The three vegetation-based classifications used to map fuels. They include a classification of biophysical settings, cover type, and structural stage. These classifications describe a method to uniquely key plant community types. These classifications should not be confused with image classifications.

CD — Compact Disk or the storage media used to save all information and data used in this project

Composition — The list of species within a plant community or the list of community types or stand types on a landscape

Cover type — A vegetation classification depicting the major tree, shrub or grass species having the plurality of canopy cover.

Data layer — A thematic raster layer describing a section of ground.

DEM — A digital elevation model that is comprised of a grid of georeferenced pixels assigned to the elevation (m) of the piece of ground they represent.

Field data — Ecological data directly measured on the ground using standardized methodologies.

Fire Behavior Fuel Model (FBFM) — This is a set of fuel characteristics by live and dead size classes that define a fuelbed for the propagation of fire. Most FBFM's described in this paper are from Anderson (1982).

Ground truth — Data collected in the field to verify mapped entities.
GIS — Geographical Information System or computerized software to analyze and summarize spatial data

Image classification — The process of classifying spectral reflectance values from one or more ranges of the electromagnetic spectrum into discrete land units for mapping.

Layer — A spatially explicit georeferenced digital file that can either be composed of a grid of pixels (raster layer) or georeferences line vertices (vectors).

Pixel — A square cell in a georeferenced grid of cells. Pixels are assigned values to create a raster layer.

Potential Vegetation Type (PVT) — An expression of the environmental conditions of a stand based on the vegetation that would potentially inhabit the site in the absence of disturbance.

Raster — Data that is organized in a grid of columns and rows.

Terrain model — A model that uses topography (slope, aspect, elevation) to predict some environmental attribute. In this study, terrain modeling was used to predict potential vegetation type.

Thematic Mapper (TM) imagery — Imagery from LANDSAT 5 satellite taken with the Thematic Mapper scanner. Contains 7 spectral bands and has a pixel width of 30 meters.

Vector — Data that represents physical forms such as points, lines, and polygons. In a GIS, vectors usually represent a boundary between spatial objects.

Vegetation triplet — The naming of a mapped polygon using the triple vegetation classifications of PVT, cover type, and structural stage.

APPENDIX A — ECODATA plot forms

GENERAL FIELD DATA FORM (GF) - 2/97
GILA FUELS MAPPING PROJECT

Key Id (Ag R/S NF RD Yr Ex Plt) *F1-7*: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ Name *F8*: _ Mo *F9*: _ _ Day *F10*: _ _

Plot Radius *F32* (ft): _ _ . _

Potential Vegetation

F37-41: Form _ _ Author _ _ _ _ Yr _ _ Ind Spp 1 _ _ _ _ _ _ _ _ _ Ind Spp 2 _ _ _ _ _ _ _ _ _ Ind Spp 3 _ _ _ _ _ _ _ _ _

Existing Vegetation

F43-46: Lifeform: _ _ LSC: _ _ DSC: _ _ CC: _ _ Stand Structure: _ _ _ _

Vegetation Layers *F47-52*: UL Dom Spp1: _ _ _ _ _ _ _ _ _ UL Dom Spp2: _ _ _ _ _ _ _ _ _ (> 6.5 ft tall)

ML Dom Spp1: _ _ _ _ _ _ _ _ _ ML Dom Spp2: _ _ _ _ _ _ _ _ _ (2.5 to 6.5 ft tall)

LL Dom Spp1: _ _ _ _ _ _ _ _ _ LL Dom Spp2: _ _ _ _ _ _ _ _ _ (< 2.5 ft tall)

Live Tree *F86-89*: BAF: _ _ BAN: _ _ BA: _ _ DBH: _ _ Ht: _ _
Dead Tree *F90-92*: BAF: _ _ BAN: _ _ BA: _ _ DBH: _ _ Ht: _ _

Tree Cover (%) *F93-99*: Tot: _ _ Se: _ _ Sa: _ _ PT: _ _ MT: _ _ LT: _ _ VL: _ _

Shrub Cover (%) *F100-103*: Tot: _ _ LS: _ _ MS: _ _ TS: _ _
Herb Cover (%) *F104-107*: Gram: _ _ Forb: _ _ Fern: _ _ Moss: _ _

Site Data

Spec Ftr *F53*: _ _ Landform *F54-56*: _ _ _ _ _ _ Par Mat *F57-59*: _ _ _ _ _ _ Soil Depth (in): _ _ Soil Texture: _ _

Positon *F60-61*: _ _ _ _ Vertical Pos *F62*: _ Horizontal Pos *F63*: _ Topo Map Elevation (ft) *F64*: _ _ _ _ _ _

Aspect (degrees) *F65*: _ _ _ Slope (%) *F66*: _ _ _ Horizons (%) *F67-69*: East: _ _ _ South: _ _ _ West: _ _ _

Ground Cover (%) *F72-79*: BS: _ _ Gr: _ _ Ro: _ _ LD: _ _ Wo: _ _ ML: _ _ BV: _ _ Wa: _ _

Fuels Data

Fire Behavior Model Normal(*F80*): _ _ Fire Behavior Model Severe: _ _ Fuel Depth (ft) *F81*: _ _ . _ DLDepth (in) *F82*: _ _ . _ DWCover (%) *F83*: _ _

Down Log Diam (in) *F84*: _ _ Dom Layer Ht (ft) *F85*: _ _ _ Ht to Crown (ft): _ _ . _ Crown Bulk Density: _ . _ _

LOCATION LINKAGE DATA FORM (LL) - 2/97
GILA FUELS MAPPING PROJECT

Map Data

Plot Name ____________________________________ (landmarks, drainages, trail no., etc)

Quad Name *F26*: ___________________________________

Photo Data

Roll: _ _ _ _ _ Exposure: _ _ Dir/Aspect: _ _ Comments: ________________________________

Roll: _ _ _ _ _ Exposure: _ _ Dir/Aspect: _ _ Comments: ________________________________

GPS Data

File Name: _ _ _ _ _ _ _ _ Mode: _ _ _ _ Entered 2D Elevation (ft): _ _ _ _ _
Source(M/A): _ M=Topo Map
A=Altimeter

Datum: NAD Yr *F44*: 27

Uncorrected Data:

Northing (m): _ _ _ _ _ _ _ UTM Zone: _ _ Elevation (m): _ _ _ _ _
Easting (m): _ _ _ _ _ _

Corrected Data:

Northing *F45* (m): _ _ _ _ _ _ _ _ UTM Zone *F47*: _ _ Elevation (m): _ _ _ _ _
Easting *F46* (m): _ _ _ _ _ _ _

Standard Deviation: _ _ _ _ Total Points: _ _ _ 2D Points: _ _ _

GPS Comments: ____

____

____

____

Plant Composition Data Form (PC) - 2/97
Gila Fuels Mapping Project

Key Id:	Ag	R/S	NF	RD	Yr	Ex	Plt
F1-7:	_ _	_ _	_ _	_ _	_ _	_ _	_ _ _

	F9 LF	F10 Plant Code	F11 CC (%)	F12 Mht (ft)	F13: Size Classes (%) 1	2	3	4	5	6	Notes
1	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
2	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
3	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
4	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
5	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
6	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
7	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
8	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
9	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
10	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
11	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
12	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
13	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
14	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
15	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
16	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
17	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
18	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
19	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
20	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
21	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
22	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
23	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
24	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
25	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
26	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
27	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
28	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
29	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
30	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
31	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
32	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
33	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
34	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
35	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
36	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
37	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
38	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	
39	_	_ _ _ _ _ _ _ _ _	_ _	_ _ _	_ _	_ _	_ _	_ _	_ _	_ _	

Tree Data Form (TD) - 3/97
Gila Fuels Mapping Project

Ag R/S NF RD Yr Ex Plt

Key Id: Subplot radius: *F12*: _ _ . _

F1-7: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Individual Tree Data

Tree Num	Spp Code	Tree Status	DBH (in)	Height (ft)	Crown Ratio	Crown Class	Damage Code 1	Severity Code 1	Damage Code 2	Severity Code 2	Snag Code
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
21											
22											
23											
24											
25											
26											
27											
28											
29											
30											
31											
32											

Tree Num	Spp Code	Tree Status	DBH (in)	Height (ft)	Crown Ratio	Crown Class	Damage Code 1	Severity	Damage Code 2	Severity	Snag Code
33											
34											
35											
36											
37											
38											
39											
40											
41											
42											
43											
44											
45											
46											
47											
48											
49											
50											

Seedling and Sapling Data

	SC 0 (<4.5 ft tall)			SC 1 (0.1-1.0 in DBH)			SC 2 (1.1-2.0 in DBH)		
Spp	Num	Hgt	Hgt to Crown	Num	Hgt	Hgt to Crown	Num	Hgt	Hgt to Crown

	SC 3 (2.1-3 in DBH)			SC 4 (3.1-4.0 in DBH)			SC 5 (4.1-4.9 in DBH)		
Spp	Num	Hgt	Hgt to Crown	Num	Hgt	Hgt to Crown	Num	Hgt	Hgt to Crown

Down Wood Data Form (DW) - 2/97
Gila Fuels Mapping Project

	Ag	R/S	NF	RD	Yr	Ex	Plt
Key Id:							
F1-7:	_ _	_ _	_ _	_ _	_ _	_ _	_ _ _

F8-# of Transects: _ *F9*-Litter & Duff #: 2 *F10*-Integrated#: 2

Transect Lengths(ft): 60

F11-**1 Hour** (<1/4 in): 6 (10-16 ft)

F12-**10 Hour** (1/4 to 1 inch): 6 (10-16 ft)

F13-**100 Hour** (1 to 3 inches): 10 (10-20 ft)

F14-**1000 Hour** (>3 inches): 50 (10-60 ft)

Transect Number

	1	**2**	**3**	**4**	**5**	**6**	**7**
F16-Slope(%):	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _
Size Classes				**Woody Fuel Counts**			
F17-1 Hour:	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _
F18-10 Hour:	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _
F19-100 Hour:	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _

1000 Hour Log Diameters and Decay Classes(dia to closest inch)

Log ID	Dia	LDC	Dia	LDC	Dia	LDC	Dia	LDC	Dia	LDC	Dia	LDC	Dia	LDC
1	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_
2	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_
3	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_
4	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_
5	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_
6	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_
7	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_
8	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_
9	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_
10	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_
11	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_
12	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_	_ _	_

LDC 1 = needles intact(green or brown), recently fallen. 2 = bark and branches present. 3 = bark partially intact, branches gone. 4 = bark and branches gone, partially rotten. 5 = rotten, > half log dia above soil surface.

Duff & Litter Depth Measurements (inches to closest 1/10)

Point #	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1(35 ft)	_ _._	_ _._	_ _._	_ _._	_ _._	_ _._	_ _._
2(60 ft)	_ _._	_ _._	_ _._	_ _._	_ _._	_ _._	_ _._
F20-Sum	_ _._	_ _._	_ _._	_ _._	_ _._	_ _._	_ _._

Integrated Woody Matter Depth Measurements (feet to closest 1/2)

Point #							
1(35 ft)	_ _._	_ _._	_ _._	_ _._	_ _._	_ _._	_ _._
2(60 ft)	_ _._	_ _._	_ _._	_ _._	_ _._	_ _._	_ _._
F21-Sum	_ _._	_ _._	_ _._	_ _._	_ _._	_ _._	_ _._

Comments Data Form (CD) - 2/97
Gila Fuels Mapping Project

Key Id:	Ag	R/S	NF	RD	Yr	Ex	Plt
F1-7:	_ _	_ _	_ _	_ _	_ _	_ _	_ _ _

ID:

1. **General Location:** ____________________

2. **Weather:** ____________________

3. **Sampling Problems:** ____________________

4. **Predominant Features:** ____________________

5. **Disturbance Evidence:** ____________________

6. **Insect/Disease Evidence:** ____________________

7. **Ecological Interpretation:** ____________________

8. **Other:** ____________________

Gila Fuels Mapping Project
Polygon Validation Field Sheet

Examiner Name:

Polygon Number	Quad Name	GPS Plot Position [1]			PVT [2]	Cover Type	Structural Stage	FBFM [3] Normal	FBFM [3] Severe	Canopy Cover Class	Stand Height (ft)	Crown Base Height (ft)	Crown Bulk Density (kg/m_)	Duff & Litter Depth (in)	Soil Textural Class	Bare Soil/ Rock
		Easting	Northing	Elev. (ft)												

[1] GPS Plot Position - NAD 1927, UTM Zones 12, 13
[2] PVT=Potential Vegetation Type
[3] FBFM=Fire Behavior Fuel Model

APPENDIX B — Plot establishment procedures

Ecosystem Characterization (EC) Plot Establishment

1. Procede to a GNFC zone and unsupervised polygon based on accessiblity and the sample levels of PVT, cover type, and structural stage. Establish plot center at least 75 m (approximately 2 pixels distance) from topographic boundaries (e.g. ridgetops, ravines) or polygon edges in a homogeneous area representative of the polygon. A homogenous area is an area that has consistent patterns throughout. For instance, choose areas that do not have major differences in cover types such as Douglas-fir and grassland cover types or major differences in structural stages.

2. Drive a 1 inch x 2 inch x 3 foot wooden stake, labeled with the KEYID from the GF form with a sharpie permanent marker, into the ground until stable. Also pound in an 8 inch nail next to the wooden stake. The nail will aid in plot relocation when using a metal detector. This will be plot center.

3. Mark the plot position and KEYID in pencil on a 7.5 min quadrangle map.

4. Take GPS readings at plot center

5. Flag plot boundaries at 37.2 ft (or Plot Radius, GF Field 32) from plot center. Flag trees on the side facing plot center if they are outside plot boundaries and on the opposite side if trees are within the boundaries.

Ground Truth (GT) Plot Establishment

1. Procede to selected unsupervised polygon (see EC Plot Establishment #1).

2. Mark the plot position and KEYID in pencil on a 7.5 min quadrangle map.

3. Take GPS readings at plot center

Polygon Validation (PV) Plot Establishment

1. Using the GNFC paper maps developed from the previous field season, navigate to selected polygons and record on the paper map the following actual (observed) attributes: 1) Habitat Type, 2) cover type, 3) structural stage, 4) normal FBFM, 5) extreme FBFM. The

GNFC maps will be in the same scale as USGS 7.5 minute quadrangle maps, overlaid with 120 meter contours, polygon boundaries, roads, streams, and trails. Only validate those polygons whose locations are absolutely known because they are adjacent to geographic features that are easily recognizable such as a stream confluence or road junction.

GPS Procedures

Plot locations — Because accurate plot locations are critical to the satellite imagery classification effort, care must be taken to ensure that all locations be accurately georeferenced. The most accurate GPS readings are recorded when the GPS unit is in 3-D mode and all attempts should be made to receive satellite signals in 3-D mode. For example, if under a dense canopy and no satellites are being received, move within the plot boundaries to more open areas in the canopy or try obtaining position at a later time. The following procedures detail how to use the GEOEXPLORER GPS unit to obtain positions.

1. Using the GEOEXPLORER GPS

I. Buttons

A. The bottom button turns the unit on and off.

B. ESC button is used to escape out of all selections and to go back to previous menus.

C. The up and down arrow buttons are used to scroll thru menus and to change setting numbers.

D. The left and right arrow keys are used to change numbers in certain fields.

E. The center button is used to select features when they are highlighted in the middle of the screen.

F. The bent arrow button is not used during any applications.

II. Power

A. The unit uses four AA batteries. To replace batteries turn unit off (active files may remain open), press tab at bottom of the unit towards the front and slide battery pack down. Replace batteries and slide battery pack into place. Be sure cords don't interfere with proper connection of battery pack.

B. Replace batteries as soon as possible. If unit is left without power for more than a few minutes, the memory will be lost.

C. To turn unit on press the bottom button. To turn unit off press and hold bottom button for 5 seconds.

III. Checking Configuration Settings

A. Under the Main Menu (if not on Main Menu, press the escape button until Main Menu appears at the top of the screen) select Option 6. Configuration

B. Select 1.Rover Options

C. Check the following settings.

Only the Pos Mode, PDOP Mask and 2D Alt need to be checked before collecting points as these are the only options that should ever be changed.

Settings should be as follows:

Elev Mask -15
SNR Mask - 5
PDOP Mask -6
PDOP Switch -9
Antenna Ht. -1.00 meter or 3.28 feet
Log DOP's - On
Velocity -Off
File Prefix -Depends on unit
Feature Logging
  Points -1 second
  Line/Area -N.A.
Min Posn -Off
Not in Feature
  Rate -All
High Accuracy
  Recording -Off
  Log Rate -N.A.
  Min Time -N.A.
  Pt Feature -Off
  Dynamics -Land
  Pos Mode -May be 3ODS, Manual 3D, or Manual 2D. Manual 3D is the desired setting.
  2D Alt -Need to enter if using Auto 2D/3D or Manual 2D. Elevation should be entered as height above mean sea level in feet.

D. Escape back to Configuration Menu

E. Check Settings

1. Option 3. Coordinates -UTM
2. Option 4. Datum -N-AM. 1927 Conus
3. Option 5. Units -English
   a. Custom Setup
      i. Option 4. Altitude Units -feet
      ii. Option 5. Alt Reference -Geoid (MSL)

IV. Collecting Points

A. From Main Menu, select option 1. Data Capture

B. Under Data Capture, select Option 1. Open Rover File (Never choose Open Base File)

File name will appear at top of screen

Ex. A061015A

A=unit prefix, different for each unit

06=month

10=day

15=hour, according to Greenwich Mean Time

A=letter differentiates between files opened in the same hour. A=first file opened in that hour, B=second file opened in that hour, etc.

1. Number in upper right hand corner = the # of positions collected.

2. **Collect at least 120 positions (preferably 180) at each location.**

C. Under Main Menu, select Option 2. Position

1. This screen shows the coordinates according to the selected datum, coordinate system and units.

D. Under Main Menu, select Option 3. GPS Status

E. Under GPS Status, select Option 1. Sat. Tracking

1. This screen shows the satellites currently being tracked by the unit.

2. An arrow beside a satellite number indicates that a signal is being received from that satellite and is being used to determine a position. Four satellites are needed to determine a 3D position, three sat. for a 2D position.

3. The PDOP number in the lower right-hand corner needs to be below 6.00 when four satellites (3D position) are being tracked for the unit to start determining positions (this number is related to the geometry of the satellites in relation to each other).

F. When the required number of position has been reached record file name and coordinates from the position screen on the Location Linkage3 (LL) form..

G. Close File, Option 3 under Data Capture

H. Under Close File, choose Yes.

2. What to do if GPS is not receiving in 3-D mode

If 3-D mode cannot be obtained, follow these procedures:

1. If four satellites are being tracked with the PDOP mask set at 6 in 3-D mode, but no satellites are received, raise the PDOP

to 12 to obtain readings. Set PDOP back to 6 after closing the file.

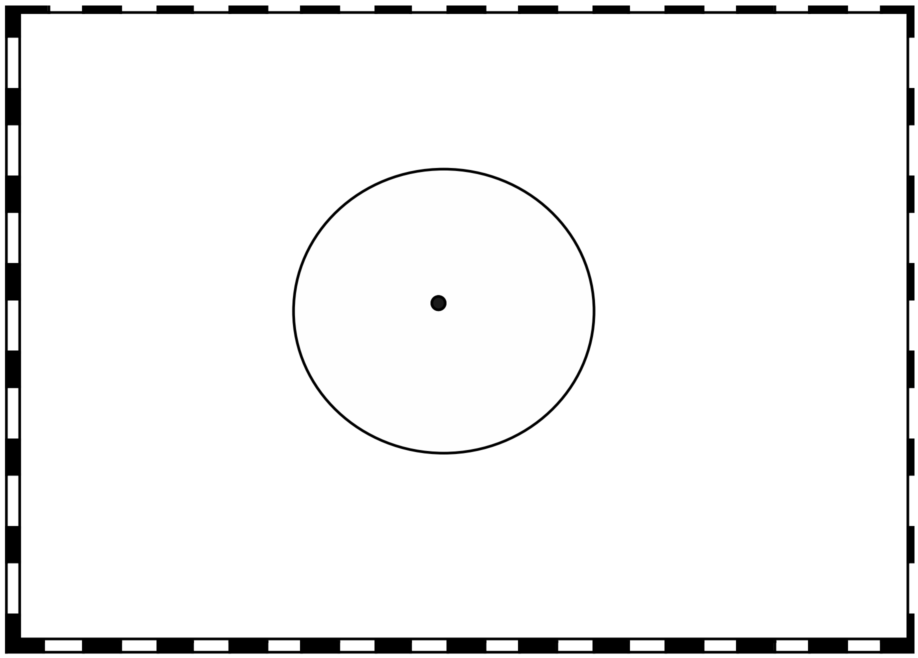
2. Enter elevation manually into the GPS and record points in 2-D only mode. Elevation is determined by an altimeter whose elevation has been initialized at a known benchmark. In variable weather, the altimeter must be set throughout the day. Elevation can also be determined from a 7.5 min quad map. These two methods can be used in conjunction to estimate elevation for input into the GPS.

3. If elevation cannot be determined by the above procedures, consider returning to the plot at a later time. Because plot locations will be clustered in the sample areas, crews will be returning to the same location until 90 percent of the area is sampled, thereby providing the opportunity to return to plots not sampled.

4. As a last resort, crews can measure distances and azimuths to known points such as road switchbacks, stream junctions, or other readily-identified spots on the quad map.

APPENDIX C — ECODATA Down Woody (DW) Methods

Measurement of downed woody fuels using the ECODATA DW methods



Downed woody fuel will be estimated using the intersect method describe by Brown (1978) where woody fuel intersecting a vertical plane originating from ground line will be counted in four size classes of 0-0.25 inch diameter (1 hour), 0.25-1.0 dia (10 hour), 1-3 in dia (100 hour) and 3+ in dia (1000 hour). The vertical plane is referenced to a transect that is established by stretching a cloth tape between two points. Downed woody transects will be 60 feet long but fuel intersections will be counted only on the last 50 feet. A cloth tape will be stretched due EAST from plot center. Crews will then walk to the 10 foot mark and start counting fuel intersections. Down woody 1 hour and 10 hour fuels (0-0.25 and 0.25-1 inch diameter particles) will be sampled along the first 6 feet of the transect (10 foot mark to 16 foot mark). Hundred hour fuels (1-3 inch dia) will be sampled on the first 10 feet (10 foot mark to 20 foot mark) and 1000 hour fuels (>3 inch dia) will be sampled on the entire 50 feet (10 foot mark to 60 foot mark). Only downed, dead woody material that is part of the fuelbed is sampled along this transect. Dead limbs extending from standing live or dead trees are not measured with this technique. Stumps are not measured as 3+ woody in this study. Logs intersecting sampling plane are individually measured to the nearest inch and their log decay class is estimated using one of five classes on the DW form.

Duff and litter depth and Integrated fuel depth will be measured at the 35 foot mark and 60 foot mark of the tape. Duff and litter depth are measured within 1 foot from tape at a point representative of the duff/litter layer of the surrounding area (3 foot radius circle). If duff/litter depth cannot be measured at the first point, crews will go 1 foot from the other side of the tape. The RIGHT side of the tape (looking toward the end or 60 foot mark) is always the starting side.

The next transect is established at a 60^o angle from the first transect at a azimuth of 330^o. An azimuth of 240^o is used for the third transect. If there are less than 100 intersections for all 1, 10, 100 and 1000 hour size classes, then additional transects are established in the order and direction shown in Figure 5. If 100 transects can be accomplished with just 3 transects, then the 3rd transect can be directed back to macroplot center for efficiency. However, if after 2 transects have been measured and it is evident that many more are needed to get 100 intersections, then the outside route that surrounds macroplot must be used (i.e., hexagonal sampling route) (Figure). Fuel measurement may stop once 100 intersects are counted, however, the entire transect must be finished. Crews must measure at least three transects to get 100 intersections.

APPENDIX D — Tree Data (TD) Methods

Measurement of tree data (TD) using ECODATA methods.

Conifer and Broadleaf Forests

Live trees will be recorded on the TD form. All live and dead trees greater than 4.9 inches DBH (Poles and Matures) will be recorded individually in Table 1 of the TD form if they occur in the tenth acre circular plot. Live trees less than 4.9 inches DBH (Saplings and Seedlings) are recorded in Table 2 if they occur within a one-hundredth acre plot (11.8 feet radius).

Tree status, DBH, height, crown position and ratio, insect and disease evidence are recorded for all Poles and Matures as per ECODATA instructions. No ages will be determined for any trees in this study. Sapling and seedling trees will be measured for DBH (to nearest inch) and tallied in Table 2. Then average tree height and crown height across all trees in that DBH category. Insect and disease evaluations are a critical part of this inventory. All species of insects and all pathogens (or symptoms) will be recorded for trees on the macroplot. These agents can be either recorded in Table 1 of the TD form or described in the comments (CD form).

The first tree to be measured is the tree due North of plot center. Trees are measured in a clockwise sequence from the first tree. Tree heights are only measured on 3-5 trees representative of each tree layer present on the plot. Heights for remaining trees are estimated to nearest 3 feet.

Special attention should be given to trees that fork or exist in clusters. They are treated like any other single stem tree — recorded on Table 1 if stem is > 4.9 inches in tenth acre plot, or tallied on Table 2 if < 4.9 inches within hundredth acre plot. Forks above DBH are treated as single stems, forks below DBH are multiple stems.

Woodlands

Tree species on woodland sites will NOT be measured using TD techniques. Instead, a separate size class canopy cover stratification was developed to describe woodland species dynamics. This stratification is implemented on the PC (Plant Composition) form rather than the TD form. Cover for each woodland tree species will be estimated for the entire species and for the following height classes:0 to 6.5 feet, 6.6 to 25.0 feet, greater than 25 feet, entered in the consecutive columns in the Size Class fields on the PC forms. This was done to simplify and standardize methods across all ecosystems and resource desires.

APPENDIX E —Classification Keys Potential Vegetation Type, Cover Type, and Structural Stage.

Potential Vegetation Type Classification

PVT Key

1. Sites with < 10% vegetation cover...**Non-Vegetated(08)**
1. Sites with Æ 10% vegetation cover...2

    2. Sites with tree or woodland species* present...3
    2. Sites with tree and woodland species absent or accidental...11

3. Broadleaf species (*Populus spp*., *Acer negundo*, *Alnus oblongifolia*, *Platanus wrightii*, *Fraxinus spp*., *Celtis reticulata*, or *Salix goodingii*) other than aspen (*Populus tremuloides*) or oaks (*Quercus spp*.) well-represented... **Riparian PVT(01)**
3. Broadleaf species not well-represented...4

    4. Subalpine fir (*Abies lasiocarpa*) and/or Engelmann spruce (*Picea engelmannii*) common and/or reproducing successfully...**Spruce-Fir PVT(02)**
    4. Subalpine fir (*A. lasiocarpa*) and Engelmann spruce (*P. engelmannii*) absent or accidental...5

5. White fir (*Abies concolor*) and/or blue spruce (*Picea pungens*) common and/or reproducing successfully...**Mixed Conifer PVT(03)**
5. White fir (*A. concolor*) and blue spruce (*P. pungens*) absent or accidental...6

    6. Douglas-fir (*Pseudotsuga menziesii*) common and/or reproducing successfully... **Douglas-fir PVT(04)**
    6. Douglas-fir (*P. menziesii*) absent or accidental...7

7. Aspen (*Populus tremuloides*) well-represented...**Mixed Conifer PVT(03)**
7. Aspen (*P. tremuloides*) not well-repesented...8

    8. Ponderosa pine (*Pinus ponderosa*) or Chihuahuan pine (*P. leiophylla*) common and/or reproducing successfully...**Ponderosa Pine PVT(05)**
    8. Ponderosa pine (*P. ponderosa*) or Chihuahuan pine (*P. leiophylla*) absent or accidental...9

9. Gambel oak (*Quercus gambelii*) well-represented...**Douglas-fir PVT(04)**
9. Gambel oak (*Q. gambelii*) not well-represented...10

    10. Pinyon (*Pinus edulis* or *P. cembroides*), Juniper (*Juniperus deppeana*, *J. monosperma*, *J. osteosperma*, *J. scopulorum*), Gray oak (*Quercus grisea*) and/or Emory oak (*Q. emoryi*) common...**P-O-J PVT(06)**
    10. Pinyon (*P. edulis* or *P. cembroides*), Juniper (*Juniperus deppeana*, *J. monosperma*, *J. osteosperma*, *J. scopulorum*), Gray oak (*Q. grisea*) and/or Emory oak (*Q. emoryi*) not common...11

11. Mountain mahogany (*Cercocarpus montanus*) well-represented...**P-O-J PVT(06)**
11. Mountain mahogany (*C. montanus*) not well-represented...12

    12. Willows (*Salix spp*.) well-represented...**Riparian PVT(01)**
    12. Willows (*Salix spp*.) not well-represented...13

13. Chihuahuan desert species* * well-represented, apparently below zone dominated by P-O-J...**Desert Scrub/Grassland PVT(07)**
13. Not as above...14

    14. Riparian graminoids and/or forbs well-represented...**Riparian PVT(01)**
    14. Non-Riparian shrubs and/or herbaceous species dominate the site, but surrounding sites indicated climax is coniferous or woodland PVT, then determine PVT by extrapolating from surrounding sites using key numbers 4-10

Definitions:
Present - Not restricted to microsites.
Reproducing successfully - 01 canopy cover class in either the seedling or sapling size class.
Common - Æ1% (03 canopy cover class).
Well-represented - Æ5% (10 canopy cover class).
Abundant - Æ25% (30 canopy cover class).
* Reference Gila Fuels Mapping Project Vascular Plant List to determine appropriate lifeforms (ex. Tree, woodland, shrub, gramminoid, forb)
**Common Representative Chihuahuan Desert Species
Shrubs
Acacia spp.
Ephedra spp.
Larrea tridentata (creosotebush)
Mimosa spp.
Opuntia spp.
Prosopis glandulosa (mesquite)
Quercus turbinella (shrub live oak)
Grasses
Bouteloua eriopida (black grama)
Bouteloua hirsuta (hairy grama)
Erioneuron pulchellum (fluff grass)
Muhlenbergia porteri (bush muhly)
Muhlenbergia torreyi (ring muhly)

Cover Type Classification

Cover Type Key

1\. Vegetation cover Æ15%...5
1\. Vegetation cover <15%...2

2\. Site covered by persistant water...**100 Water**
2\. Not as above...3

3\. Site covered by rock exposed by mining or quarry activity...**203 Mine/Quarry**
3\. Not as above...4

4\. Rock, scree and/or talus with Æ45% cover...**201 Rock**
4\. Not as above...**202 Barren Land**

5\. Trees with Æ15% cover...6
5\. Trees with <15% cover...16

6\. Broadleaf trees with Æ15% cover and coniferous trees with <15% cover...7
6\. Not as above...9

7\. Aspen with Æ15% cover...**410 Aspen**
7\. Not as above...8

8\. Gambel oak with Æ15% cover...**411 Gambel Oak**
8\. Other broadleaf trees with Æ15% cover...**401 Broadleaf Riparian Forest**

9\. Broadleaf (excluding gambel oak) and coniferous trees each with >25% of the **relative** tree cover... **402 Broadleaf/Conifer Forest**
9\. Not as above...10

10\. Coniferous trees with Æ15% cover, but <55% cover and Gambel Oak with Æ15% cover... **403 Conifer/Gambel Oak Forest**
10\. Not as above...11

11\. Coniferous trees with Æ15% cover, but <55% cover and woodland species with Æ15% cover... **404 Conifer Forest/Woodland Mix**
11\. Not as above...12

12\. Ponderosa pine and/or Chihuahuan pine with >66% of the **relative** tree cover...**415 Ponderosa Pine**
12\. Not as above...13

13\. Douglas-fir with >66% of the **relative** tree cover...**416 Douglas-fir**
13\. Not as above...14

14\. Subalpine fir and/or Engelmann spruce with Æ20% of the **relative** tree cover ...**424 Spruce/Fir**
14\. Not as above...15

15\. White fir and/or blue spruce with Æ20% of the **relative** tree cover...**406 Mesic Mixed Conifer**
15\. Not as above...**407 Xeric Mixed Conifer**

16\. Shrub species with Æ15% cover and woodland species with <15% cover...17
16\. Not as above...18

17\. Shrub species include *Acer glabrum*, *Amelanchier utahensis*, *Holodiscus dumosus*, *Jamesia americana*, *Physocarpus monogynous*, *Prunus spp*., *Quercus gambellii*, *Rhamnus spp*., *Ribes spp*., *Robinia neomexicana*, *Rubus spp*., *Salix spp*., and/or *Symphoriocarpus spp*...**322 Mesic Shrubland**
17\. Not as above...**321 Xeric Shrubland**

18\. Woodland cover Æ15%...19
18\. Woodland cover <15%...23

19\. One species (any combination of junipers = 1 species or any combination of evergreen oaks =1 species) with >66% of the **relative** woodland cover...20
19\. Not as above...22

20. Any combination of juniper species...**412 Juniper**
20. Not as above...21

21. Pinyon the indicated species...**413 Pinyon**
21. Any combination of evergreen oaks...**414 Evergreen Oak**

22. Pinyon and juniper with >80% of the **relative** woodland cover...**421 Pinyon/Juniper**
22. Not as above...**405 Mixed Woodland**

23. Herbaceous cover Æ15%...**310 Herbalands**
23. Combined woodland and shrub cover Æ15%...**405 Mixed Woodland**

Representative Species by Cover Type

406 Mesic Mixed Conifer
White fir
Blue spruce
-Douglas-fir
-Southwestern white pine
-Pondeosa pine
-Subalpine fir
-Engelmann spruce

424 Spruce/Fir
Engelmann spruce
Subalpine fir
-Douglas-fir
-Southwestern white pine
-White fir
-Blue spruce

407 Xeric Mixed Conifer
Douglas-fir
Southwestern white pine
Ponderosa pine
-minor amounts of any other conifer

414 Evergreen Oaks
Quercus grisea
Q . emoryi
Q. arizonica
Q. hypoleucoides
Q. rugosa

Structural Stage Classification Key

1. Cover Type is Water... **98 WATER**
1. Not as above...2

    2. Cover Type is Rock, Barren, or Mines/Quarries...**99 ROCK**
    2. Not as above...3

3. Cover Type is Herbland...4
3. Cover Type is not Herbland...5

    4. Herbaceous cover Æ55%...**01 CLOSED HERBLAND**
    4. Herbaceous cover <55%...**02 OPEN HERBLAND**

5. Cover Type is Xeric or Mesic Shrubland...6
5. Not as above...7

    6. Shrub cover Æ55%...**03 CLOSED SHRUBLAND**
    6. Shrub cover <55%...**04 OPEN SHRUBLAND**

7. Cover Type is Juniper, Pinyon, Evergreen Oak, Pinyon/Juniper or Mixed Woodland...8
7. Cover Type is Broadleaf Riparian Forest, Broadleaf/Conifer Forest, Conifer/Gambel Oak Forest, Conifer Forest/Woodland Mix, Mesic Mixed Conifer, Xeric Mixed Conifer, Aspen, Gambel Oak, Ponderosa Pine, Douglas-fir or Spruce/Fir...9

    8. Woodland vegetation plus shrubs in approximately the same height rangeÆ55% cover... **05 CLOSED WOODLAND**
    8. Woodland vegetation plus shrubs in approximately the same height range <55% cover... **06 OPEN WOODLAND**

9. Trees Æ21.0 inches DBH with Æ15% cover...**09 LARGE TREE**
9. Not as above...10

    10. Trees Æ5.0 inches DBH withÆ15% cover...**08 MEDIUM TREE**
    10. Trees Æ5.0 inches DBH with <15% cover...**07 SMALL TREE**

APPENDIX F — Terrain models used to construct the PVT layer by ecological zone.

San Mateo Zone

PVT Number	PVT Name	Aspect(deg)	Elevation(m)	Slope(%)	Comments
1	Riparian	—	—	—	Not in SM
2	Spruce-Fir	—	—	—	Not in SM
3	Mixed Conifer	315-90	>2600	All	
		91-314	—	—	
4	Douglas-fir	315-90	2300-2600	All	
		91-314	>2400	All	
5	Ponderosa Pine	315-90	2100-2299	All	
		91-314	2150-2400	All	
6	P-O-J	315-90	1700-2099	All	
		91-314	1700-2149	All	
7	Desert Scrub/Grassland	All	<1700	All	
8	Non-vegetated	—	—	—	From imagery

Burro Mountains Zone

PVT Number	PVT Name	Aspect(deg)	Elevation(m)	Slope(%)	Comments
1	Riparian	—	—	—	Streamside Buffer
2	Spruce-Fir	—	—	—	Not in BM
3	Mixed Conifer	—	—	—	Not in BM
4	Douglas-fir	—	—	—	Not in BM
5	Ponderosa Pine	315-90	>2050	All	
		91-314	>2300	All	
			2050-2300	≤20	
6	P-O-J	315-90	1600-2049	All	
			1450-1599	>30	
		91-314	2050-2300	>20	
			1800-2049	All	
			1450-1799	>10	
7	Desert Scrub/Grassland	315-90	1450-1599	≤30	
			<1450	All	
		91-314	1450-1799	≤10	
			<1450	All	
8	Non-vegetated	—	—	—	From imagery

Black Range Zone

PVT Number	PVT Name	Aspect(deg)	Elevation(m)	Slope(%)	Comments
1	Riparian	—	—	—	Streamside Buffer
2	Spruce-Fir	315-90	>3050	All	
3	Mixed Conifer	315-90	2550-3049	All	
			2400-2549	≥35	
		91-314	>2900	All	
4	Douglas-fir	315-90	2500-2549	<35	
			2400-2499	10-35	
			2300-2399	≥10	
		91-314	2400-2899	All	
5	Ponderosa Pine	315-90	2300-2499	<10	
			2100-2299	≥10	
		91-314	2300-2399	All	
			2200-2299	<10	
6	P-O-J	315-90	1600-2099	All	
			2100-2299	<10	
		91-314	1700-2199	All	
			2200-2299	≥10	
7	Desert Scrub/Grassland	315-90	<1600	All	
		91-314	<1700	All	
8	Non-vegetated	—	—	—	From imagery

Pinos Altos Zone

PVT Number	PVT Name	Aspect(deg)	Elevation(m)	Slope(%)	Comments
1	Riparian	—	—	—	Streamside Buffer
2	Spruce-Fir	—	—	—	Not in PA
3	Mixed Conifer	—	—	—	Not in PA
4	Douglas-fir	315-90	>2300	All	
			2100-2300	>35	
		91-314	>2350	All	
5	Ponderosa Pine	315-90	2100-2300	≤35	
			2000-2099	All	
		91-314	2200-2350	All	
6	P-O-J	315-90	1600-1999	All	
			1450-1599	>35	
		91-314	1600-2199	All	
7	Desert Scrub/Grassland	315-90	1450-1599	≤35	
			<1450	All	
		91-314	<1600	All	
8	Non-vegetated	—	—	—	From imagery

Western Gila Zone

PVT Number	PVT Name	Aspect(deg)	Elevation(m)	Slope(%)	Comments
1	Riparian	—	—	—	Streamside Buffer
2	Spruce-Fir	301-90	>2750	All	
		91-300	>3000	All	
3	Mixed Conifer	301-90	2550-2750	>10	
		91-300	2800-3000	All	
			2600-2799	<10	
4	Douglas-fir	301-90	2600-2749	<10	
			2250-2549	>10	
			2100-2249	>35	
		91-300	2600-2799	>10	
			2500-2599	All	
5	Ponderosa Pine	301-90	2200-2549	<10	
			2100-2249	11-35	
			2050-2099	>10	
		91-300	2300-2499	All	
6	P-O-J	301-90	2050-2199	<10	
			1600-2049	All	
		91-300	1700-2299	All	
7	Desert Scrub/Grassland	301-90	<1600	All	
		91-300	<1700	All	
8	Non-vegetated	—	—	—	From imagery

APPENDIX G —GNFC field database formats

General Field Form Format

FIELD	UNITS	DESCRIPTION
PLOT NO	None	Plot number
FORM	Alpha code	Potential vegetation formation
PVT_SPP1[1]	6 letter species code	Overstory indicator species (Series level classification)
PVT_SPP2	6 letter species code	Understory indicator species (climate community type, association, or habitat type level classification)
PVT_SPP3	6 letter species code	Additional understory indicator species (habitat type phase)
LF	Alpha code	Dominant live life form
LSC	Alpha code	Live life form size class
DSC	Alpha code	Dead life form size class
CC	Alpha code	Live canopy cover class
SS	Alpha code	Stand Structure
UL DOM SPP1	6 letter species code	Dominant species in the upper layer (>6.5 ft)
UL DOM SPP2	6 letter species code	Co-dominant species in the upper layer (> 6.5 ft)
ML DOM SPP1	6 letter species code	Dominant species in the middle layer (2.5 to 6.5 ft)
ML DOM SPP2	6 letter species code	Co-dominant species in the middle layer (2.5 to 6.5 ft)
LL DOM SPP1	6 letter species code	Dominant species in the lower layer (<2.5 ft)
LL DOM SPP2	6 letter species code	Co-dominant species in the lower layer (<2.5 ft)
LIVE_TREE_BAF	None	Live tree Basal Area Factor (10, 20, 40, etc)
BAN	None	Number of live trees counted with the above BAF
BA	ft^2/ac.	Basal Area estimate (BAF x BAN) of live trees
DBH	Inches	Mean DBH of live trees counted with BAF
HT	Feet	Average height of live trees counted with BAF
DEAD_TREE_BAF	None	Dead tree (no live crown) Basal Area Factor (10, 20, 40, etc)
BAN_D	None	Number of dead trees counted with the above BAF
BA_D	ft^2/ac.	Basal Area estimate (BAF x BAN) of dead trees
DBH_D	Inches	Mean DBH of dead trees counted with BAF
HT_D	Feet	Average height of dead trees counted with BAF
TREE_COV_T	Percent code	Total tree canopy cover (100% maximum)
SE	Percent code	Total seedling (<4.5 ft tall) canopy cover
SA	Percent code	Total sapling (0.1 to 4.9 in dbh) canopy cover
PT	Percent code	Total pole tree (5.0 to 8.9 in dbh) canopy cover
MT	Percent code	Total medium tree (9.0 to 20.9 in dbh) canopy cover
LT	Percent code	Total large tree (21 to 32.9 in dbh) canopy cover
VL	Percent code	Total very large tree (>=33 in dbh) canopy cover
WOODLAND_COV_TOT	Percent code	Total woodland canopy cover (100% maximum)
LW	Percent code	Total low woodland (<10 ft in height) canopy cover
MW	Percent code	Total medium woodland (10 to 25 ft in height) canopy cover
TW	Percent code	Total tall woodland (>25 ft in height) canopy cover
SHRUB_COV_	Percent code	Total shrub cover
LS	Percent code	Total low shrub (<2.5 ft) cover
MS	Percent code	Total medium shrub (2.5 - 6.5 ft) cover
TS	Percent code	Total tall shrub (>6.5 ft) cover
GRAM_COV_T	Percent code	Total cover of gramminoids on plot
FORB_COV_T	Percent code	Total cover of forbs on plot
FERN_COV_T	Percent code	Total cover of ferns and fern allies on plot
MOSS_COV_T	Percent code	Total cover of moss and lichen
LANDFORM	Alpha code	Landform setting of plot
POSITION	Alpha code	Topographic position of plot
VERT_POS	Alpha code	Shape of slope perpendicular to the contour
HOR_POS	Alpha code	Shape of slope parallel to the contour
MAP_ELEV	Feet	Elevation of plot from topo. map
ASPECT	Degrees	Average aspect of plot
SLOPE	Percent	Average slope of plot
BS	Percent code	Total ground cover of exposed soil on plot
GR	Percent code	Total ground cover of gravel (0.625 - 3 in) on plot
RO	Percent code	Total ground cover of rock (> 3 in) on plot

LD	Percent code	Total groung cover of litter and duff on plot
WO	Percent code	Total ground cover of wood (> 0.25 in diameter) on plot
ML	Percent code	Total ground cover of moss and lichens on plot
BV	Percent code	Total ground cover of basal (stems) vegetation on plot
WA	Percent code	Total ground cover of water on plot
FBFM_NORMAL	None	Anderson fuel model or custom fuel model number
FBFM_SEVERE	None	Anderson fuel model or custom fuel model number
FUEL_DEPTH	Feet	Mean height of surface fuels up to 6.5 ft high
DLDEPTH	Inches	Total depth of duff and litter
DWCOVER	Percent code	Total cover of 1000 hr fuels
DOWN_LOG_DIAM	Inches	Mean diameter of 1000 hr fuels
DOM_LAYER_HT	Feet	Stand Height(Farsite attribute)
HT_TO_CROWN	Feet	Crown Base Height(Farsite attribute)
EASTING	Meters	Plot location from GPS (NAD 27, UTM Zone 12 or 13)
NORTHING	Meters	Plot location from GPS (NAD 27, UTM Zone 12 or 13)
ELEV	Feet	Height above mean sea level from GPS

[1]Reference Steuver and Hayden 1996 and Szaro 1989

Plant Composition Form Format

Field	Units	Desciption
PLOT	None	Plot number
LIFEFORM	Alpha Code	Lifeform of species (Tree, shrub, grass, forb, etc.)
SPECIES	6 letter species code	Individual plant species
CAN_COV	Percent code	Total canopy cover of species on plot
HEIGHT	Feet	Mean height of species on plot
SC1	Percent code	Total cover of species in size class 1
SC2	Percent code	Total cover of species in size class 2
SC3	Percent code	Total cover of species in size class 3
SC4	Percent code	Total cover of species in size class 4
SC5	Percent code	Total cover of species in size class 5
SC6	Percent code	Total cover of species in size class 6

Tree Data Form Format

FIELD	UNITS	DESCRIPTION
PLOT NO	None	Plot number
TNUM	None	Tree number
SPP	Alpha Code	Tree species
STAT	Numeric Code	Health of tree
DBH	Inches x 10	Diameter at Breast Height of tree
HT	Feet	Height of tree
CROWN RATIO	Numeric code	Percent of tree with live crown
CROWN CLASS	Alpha code	Position of tree crown in stand
DAM1	Numeric code	Damage code agent 1
SEV1	Numeric code	Measure of severity of damage code 1
DAM2	Numeric code	Damage code agent 2
SEV2	Numeric code	Measure of severity of damage code 2
DAM3	Numeric code	Damage code agent 3
SEV3	Numeric code	Measure of severity of damage code 3
SNAG CODE	Numeric code	Estimate of the condition of the snag

Seedling/Sapling (TD2) Form Format

FIELD	UNITS	DESCRIPTION
PLOT NO	None	Plot number
SPP	Alpha code	Species of seedling or sapling
SC	Numeric code	Size class of tallied species
NUMT	None	Number of seedlings or saplings counted
HEIGHT	Feet	Mean height of size class
HT TO CRN	Feet	Mean height to crown for size class

Down Wood Data Form Format

FIELD	UNITS	DESCRIPTION
PLOT NO	None	Plot number
TRAN NO	None	Transect line number on plot
SLOPE	Percent	Slope of transect line
DUFF1	Inches	Measured duff and litter thickness at 35 foot mark along transect
DUFF2	Inches	Measured duff and litter thickness at 60 foot mark along transect
DUFF SUM	Inches	Sum of Duff1 and Duff2 measurements
INT WOODY1	Feet	Mean height of surface fuels at 35 foot mark along transect
INT WOODY2	Feet	Mean height of surface fuels at 60 foot mark along transect
INTWOODY SUM	Feet	Sum of INTWOODY1 and INTWOODY2 measurements
1 HR	None	Count of 1hr fuels
10 HR	None	Count of 10 hr fuels
100 HR	None	Count of 100 hr fuels
1000 HR NUM	None	Number of 1000 hr fuels along transect
LOG1-16 DIAM	Inches	Diameter of each log along transect, Field repeats for each log encountered
LOG1-16 LDC	Numeric code	Log decay class of each log, Field repeats for each log encountered

Polygon Validation (DATA_98) Format

FIELD	UNITS	DESCRIPTIONS
POLY98_UNQ	None	Unique ID
POLYNO_ORG	None	Polygon number (GIS)
POLYNO_COR	None	Corrected polygon number (GIS)
QUAD_NAME	None	USGS quad name
EASTING	Meters	GPS Coodinate (NAD 27, UTM Zone 12 or 13)
NORTHING	Meters	GPS Coodinate (NAD 27, UTM Zone 12 or 13)
ELEV	Feet	Height above Mean Sea Level from GPS
PVT_V2	Numeric code	Potential Vegetation Type for polygon
CT	Numeric code	Cover Type for polygon
SS	Numeric code	Structural stage for polygon
FBFM_NORMAL	None	Anderson fuel model or custum fuel model under normal fuel conditions
FBFM_SEVER	None	Anderson fuel model or custum fuel model under extreme fuel conditions
CNPY_CVR	Numeric code	Total canopy cover of forest and/or woodland cover (FARSITE attribute)
STND_HGHT	Feet	Mean height of forest or woodland stand (FARSITE attribute)
CBH	Feet	Crown base height of forest or woodland stand (FARSITE attribute)
CBD	kg/m3	Crown Bulk Density of stand (FARSITE attribute)
DUFF_LIT	Inches	Mean depth of litter and duff
SOIL_TEXTU	Code	Estimate of soil texture
BARE_SOIL	Percent	Estimate of exposed soil surface

Gila_stand Database Format

FIELD	UNITS	DESCRIPTIONS
PLOT	None	Plot number
NO ITEMS	None	
LIVE BA	ft^2/ac	Live stem basal area
SNAG BA	ft^2/ac	Dead stem basal area
TPA	trees/ac	Number of trees/acre
SPA	saplings/ac	Number of saplings/acre
SNAG/AC	snags/ac	Number of snags/acre
DOMDBH	Inches	Dominant DBH for Plot
AVEDBH	Inches	Average DBH for all trees
SNAGDBH	Inches	Average DBH for snags
DOMHT	Feet	Height of dominant tree layer

AVEHT	Feet	Average height for all trees
HT(CBD)	Feet	Height estimated from crown bulk density
CBH(AVE)	Feet	Average crown base height
CBH(CBD)	Feet	crown base height estimated from crown bulk density
CBD	kg/m^3	Crown Buld Density
LAI	m^2/m^2	Leaf area index (all sided)
LAI(PRJCTD)	m^2/m^2	Leaf area index (projected)
LEAF WT	kg/m^2	leaf weight

Fuel Loadings (Dw_sum) Database Format

FIELD	UNITS	DESCRIPTIONS
PLOT_NO	None	Plot number
1HR	Tons/acre	1 hr fuel loadings
10HR	Tons/acre	10 hr fuel loadings
100HR	Tons/acre	100 hr fuel loadings
DUFF_DEPTH	Inches	Duff and litter depth
WOODY_DEPT	Feet	Surface fuel depth
1000HR_SOU	Tons/acre	1000 hr fuel loadings (sound logs)
1000HR_ROT	Tons/acre	1000 hr fuel loadings (rotten logs)
1000HR_TOT	Tons/acre	Total 1000 hr fuel loadings

PVT-CT-SS Assignments Database Format

FIELD	UNITS	DESCRIPTIONS
PLOT_NO	None	Plot number from 1997 plots
PVT	Numeric code	Potential vegetation type from key
CT	Numeric code	Cover type from key
SS	Numeric code	Structural stage from key

Plantlist Database Format

FIELD	UNITS	DESCRIPTION
LIFEFORM	Alpha code	Species lifeform
ACRONYM	6 letter species code	6 letter plant code
PLANT_NAME	None	Species scientific name
SYNONYM	None	Accepted synonyms
COMMON_NAME	None	Common name

Custom Fuel File (*.FMD) Format

FIELD	DATA TYPE	UNITS	DESCRIPTIONS
FMod	Interger	14-50	Fuel Model
1H	Decimal	Tons/acre	1 hr fuel loadings
10H	Decimal	Tons/acre	10 hr fuel loadings
100H	Decimal	Tons/acre	100 hr fuel loadings
LiveH	Decimal	Tons/acre	Live herbaceous loadings
LiveW	Decimal	Tons/acre	Live woody loadings
1HSAV	Integer	1/ft	1 Hr fuel surface-area-to-volume ratio
LiveHSAV	Integer	1/ft	Live Herbaceous fuel surface-area-to-volume ratio
LiveWSAV	Integer	1/ft	Live Woody fuel surface-area-to-volume ration
Depth	Decimal	Feet	Fuel Bed Depth
XtMoist	Integer	Percent	Extinction Moisture
DHt	Interger	BTU/lb	Heat content of dead fuels
LHt	Interger	BTU/lb	Heat content of live fuels

PCSLUT.DBF Format

FIELD	UNITS	DESCRIPTIONS
PVTFINAL	Integer	Potential Vegetation Type Code
CTFINAL	Integer	Cover Type Code
SSFINAL	Integer	Structural Stage Code
STND_HGTFT	Feet, Integer	Stand Height
CBHFT	Feet, Integer	Crown Base Height
PVTCTSSFIN	Integer	(PVTFINAL * 100,000) + (CTFINAL * 100) + SSFINAL

		Use as joinitem for Lookup table
STDHTM	Meters, Integer	Stand Height
CBHM	Meters, Decimal	Crown Base Height
CBHM10	Meters, Integer	Crown Base Height * 10
FBFMNORM	Integer	Fire Behavior Fuel Model under Normal Conditions
FBFMSEV	Integer	Fire Behavior Fuel Model under Severe Conditions

CSCLUT.DBF Format

FIELD	**UNITS**	**DESCRIPTIONS**
VALUE	Integer	(CTFINAL * 10,000) + (SSFINAL * 100) + CCFINAL Use as joinitem for Lookup table
CTFINAL	Integer	Cover Type Code
SSFINAL	Integer	Structural Stage Code
CCFINAL	Integer	Canopy Closure Code
CBD	Kg/m^3, Decimal	Crown Bulk Density
CBD_100	Kg/m^3, Integer	Crown Bulk Density * 100
CTSSCCFINA	Integer	(CTFINAL * 10,000) + (SSFINAL * 100) + CCFINAL Use as joinitem for Lookup table, same as VALUE

APPENDIX H — Gila Fuels workshop assignment form and results

FIRE BEHAVIOR FUEL MODEL ASSIGNMENTS

Potential Vegetation Type	CT Code	Cover Type	SS CODE	Structural Stage	FBFM Normal	FBFM Severe	HLCB (ft)
01	401	Broadleaf Riparian Forest	07	Small Tree	50	2	1
Broadleaf			08	Medium Tree	8	8	1
Riparian			09	Large Tree	2	2	10
Forest	402	Broadleaf-Conifer Forest	07	Small Tree	10	10	5
			09	Large Tree	10	10	20
02	402	Broadleaf-Conifer Forest	08	Medium Tree	8	8	3
Spruce - Fir	410	Aspen	08	Medium Tree	8	8	30
	416	Douglas-fir	08	Medium Tree	10	10	10
			09	Large Tree	10	10	20
	424	Subalpine Fir-Engelmann Spruce	08	Medium Tree	10	10	1
			09	Large Tree	10	10	3
03	322	Mesic Shrubland	04	Open Shrubland	5	5	-
Mixed Conifer	402	Broadleaf-Conifer Forest	08	Medium Tree	8	8	3
	403	Conifer-Gambel Oak Forest	07	Small Tree	9	9	1
			08	Medium Tree	9	9	2
			09	Large Tree	9	9	5
	406	Mesic Mixed Conifer	07	Small Tree	8	8	1
			08	Medium Tree	8	8	1
			09	Large Tree	8	8	1
	410	Aspen	08	Medium Tree	8	8	30
	411	Gambel Oak	07	Small Tree	9	9	1
			08	Medium Tree	9	9	3
	415	Ponderosa Pine	08	Medium Tree	9	9	30
	416	Douglas-fir	08	Medium Tree	10	10	10
04	202	Barren	99	Rock	99	99	-
Douglas-fir	310	Herbland	01	Closed Herbland	2	2	-
	322	Mesic Shrubland	03	Closed Shrubland	5	4	-
			04	Open Shrubland	2	2	-
	402	Broadleaf-Conifer Forest	07	Small Tree	8	8	1
			08	Medium Tree	10	10	5
			09	Large Tree	10	10	5
	403	Conifer-Gambel Oak Forest	07	Small Tree	2	2	5
			08	Medium Tree	8	9	5
			09	Large Tree	8	9	10
	404	Conifer Forest-Woodland Mix	07	Small Tree	8	6	5
			08	Medium Tree	8	9	5
	407	Xeric Mixed Conifer	07	Small Tree	2	2	10
			08	Medium Tree	9	9	15
			09	Large Tree	10	10	20
	410	Aspen	08	Medium Tree	8	8	35
	411	Gambel Oak	07	Small Tree	6	4	1
			08	Medium Tree	42	6	5
	415	Ponderosa Pine	07	Small Tree	9	2	10
			08	Medium Tree	9	9	20
	416	Douglas-fir	07	Small Tree	2	2	5
			08	Medium Tree	8	2	10
05	202	Barren	99	Rock	99	99	-
Ponderosa Pine	310	Herbland	01	Closed Herbland	2	2	-
	322	Mesic Shrubland	04	Open Shrubland	5	2	-
	402	Broadleaf-Conifer Mix	07	Small Tree	8	8	1

Potential Vegetation Type	CT Code	Cover Type	SS CODE	Structural Stage	FBFM Normal	FBFM Severe	HLCB (ft)
05 Ponderosa Pine	403	Conifer-Gambel Oak Forest	07	Small Tree	2	2	5
			08	Medium Tree	8	9	5
			09	Large Tree	8	9	5
	404	Conifer Forest -Woodland Mix	07	Small Tree	8	6	5
			08	Medium Tree	8	9	5
			09	Large Tree	9	9	10
	405	Mixed Woodland	05	Closed Woodland	6	6	2
	411	Gambel Oak	07	Small Tree	6	6	5
			08	Medium Tree	2	6	5
	412	Juniper	05	Closed Woodland	6	2	2
			06	Open Woodland	2	2	2
	413	Pinyon	05	Closed Woodland	50	6	2
			06	Open Woodland	2	2	2
	414	Evergreen Oak	05	Closed Woodland	5	6	2
			06	Open Woodland	50	6	2
	415	Ponderosa Pine	07	Small Tree	9	9	10
			08	Medium Tree	9	9	15
			09	Large Tree	9	9	20
	421	Pinyon-Juniper	05	Closed Woodland	6	6	1
			06	Open Woodland	2	2	2
06 Pinyon - Oak - Juniper	202	Barren	99	Rock	99	99	-
	310	Herbland	01	Closed Herbland	1	1	-
			02	Open Herbland	50	2	-
	321	Xeric Shrubland	03	Closed Shrubland	6	6	-
			04	Open Shrubland	50	50	-
	322	Mesic Shrubland	03	Closed Shrubland	6	6	-
			04	Open Shrubland	50	50	-
	405	Mixed Woodland	05	Closed Woodland	50	6	5
			06	Open Woodland	50	6	5
	412	Juniper	05	Closed Woodland	50	2	5
			06	Open Woodland	50	50	5
	413	Pinyon	05	Closed Woodland	2	2	10
			06	Open Woodland	50	6	2
	414	Evergreen Oak	05	Closed Woodland	50	6	-
			06	Open Woodland	1	1	-
	421	Pinyon-Juniper	05	Closed Woodland	50	6	2
			06	Open Woodland	50	6	2
07 Desert Scrub/ Grassland	202	Barren	99	Rock	50	50	-
	310	Herbland	01	Closed Herbland	2	2	-
			02	Open Herbland	1	1	-
	321	Xeric Shrubland	03	Closed Shrubland	6	6	-
			04	Open Shrubland	50	50	-
	322	Mesic Shrubland	03	Closed Shrubland	6	6	-
			04	Open Shrubland	50	50	-
08 Non-vegetated/Barren	100	Water	98	Water	98	98	-
	201	Rock	99	Rock	99	99	-
	202	Barren	99	Rock	99	99	-
	203	Mine/Quarry	99	Rock	99	99	-

APPENDIX I — Land summaries of base vegetation classifications

Distribution of area (hectares) by PVT and Cover Type

	Potential Vegetation Type								
Cover Type	**Spruce-Riparian**	**Mixed Fir**	**Douglas-Conifer**	**Ponderosa fir**	**Pinyon-Oak-Pine**	**Scrub-Juniper**	**Non-vegetated/Grassland**	**Rock**	**Totals**
Water								2723	2723
Rock								401682	401682
Barren Ground	520		50	3165	40989	148824	97562		291110
Mine-Quarry								9918	9918
Urban								5042	5042
Herblands	158	352	3807	25102	112241	327800	76076		545536
Xeric Shrublands				5217	8400	51564	77274		142455
Mesic Shrublands	3109	298	2941	13692	1339				21379
Broadleaf Riparian Forest	23961								23961
Broadleaf/Conifer Forest	5408	616	3439	6680					16143
Conifer-Gambel Oak Forest			1001	10350	25323				36674
Conifer Forest-Woodland Mix				42717	8900				51617
Mixed Woodland					29167	62652			91819
Mesic Mixed Conifer		3267	76553						79820
Xeric Mixed Conifer		473	4677	22078	34650				61878
Aspen		979	2027	1197					4203
Gambel Oak			2073	4688	1409				8170
Juniper					20004	98967			118971
Pinyon					29171	116953			146124
Evergreen Oak					22613	58505			81118
Ponderosa Pine			4456	28426	103135				136017
Douglas-fir		66	565	11750					12381
Pinyon-Juniper					7398	63894			71292
Spruce-Fir		8380							8380
Totals	33156	14431	101589	175062	444739	929159	250912	419365	2368415

Distribution of area (hectares) by Cover Type and Structural Stage.

	Structural Stage												
Cover Type	**Closed Herbland**	**Open Herbland**	**Closed Shrubland**	**Open Shrubland**	**Closed Woodland**	**Open Woodland**	**Small Tree**	**Medium Tree**	**Large Tree**	**Urban**	**Water**	**Rock**	**Totals**
Water											2723		2723
Rock												401682	401682
Barren Ground												291110	291110
Mine-Quarry												9918	9918
Urban										5042			5042
Herblands	209306	336231											545537
Xeric Shrublands			21245	121210									142455
Mesic Shrublands			17630	3751									21381
Broadleaf Riparian Forest							4544	19375	41				23960
Broadleaf/Conifer Forest							628	15391	123				16142
Conifer-Gambel Oak Forest							3631	32996	47				36674
Conifer Forest-Woodland Mix							189	51402	26				51617
Mixed Woodland					58422	33397							91819
Mesic Mixed Conifer							704	76907	2209				79820
Xeric Mixed Conifer							647	61087	145				61879
Aspen							1229	2974					4203
Gambel Oak			93				7686	391					8170
Juniper					13764	105207							118971
Pinyon					108254	37870							146124
Evergreen Oak					13866	67252							81118
Ponderosa Pine							417	135540	61				136018
Douglas-fir							311	11929	141				12381
Pinyon-Juniper					3639	67653							71292
Spruce-Fir							12	8138	230				8380
Totals	209306	336231	38968	124961	197945	311379	19998	416130	3023	5042	2723	702710	2368415

APPENDIX J — Fuel model assignments to base vegetation classification combinations

Codes used in table

Potential Vegetation Type
1 Riparian
2 Spruce-Fir
3 Mixed Conifer
4 Douglas-fir
5 Ponderosa Pine
6 Pinyon-Oak-Juniper
7 Scrub-Grassland
8 Non-vegetated

Cover Type
100 Water
201 Rock
202 Barren Ground
203 Mine-Quarry
205 Urban
310 Herblands
321 Xeric Shrublands
322 Mesic Shrublands
401 Broadleaf Riparian Forest
402 Broadleaf/Conifer Forest
403 Conifer-Gambel Oak Forest
404 Conifer Forest-Woodland Mix
405 Mixed Woodland
406 Mesic Mixed Conifer
407 Xeric Mixed Conifer
410 Aspen
411 Gambel Oak
412 Juniper
413 Pinyon
414 Evergreen Oak
415 Ponderosa Pine
416 Douglas-fir
421 Pinyon-Juniper
424 Spruce-Fir

Structural Stage
1 Closed Herbland
2 Open Herbland
3 Closed Shrubland
4 Open Shrubland
5 Closed Woodland
6 Open Woodland
7 Small Tree
8 Medium Tree
9 Large Tree
96 Urban
98 Water
99 Rock

Potential Vegetation Type	Cover Type	Structural Stage	Stand Height (m)	Crown Base Height (m)	FBFM Normal	FBFM Severe
1	202	99	0	0	99	99
1	310	1	0	0	1	1
1	310	2	0	0	50	1
1	322	3	0	0	5	5
1	401	7	7	0.9	50	2
1	401	8	15	4	9	2
1	401	9	21	8.5	9	2
1	402	7	9	1.2	2	2
1	402	8	12	1.8	2	2
1	402	9	22	7.6	9	9
2	310	1	0	0	1	1
2	322	3	0	0	5	5
2	402	7	12	1.5	8	8
2	402	8	21	2.4	10	10
2	402	9	22	4.6	10	10
2	406	8	21	2.4	10	10
2	406	9	24	4.6	10	10
2	407	7	10	1.5	8	8
2	407	8	20	1.5	8	10
2	407	9	22	3	8	10
2	410	7	9	4.6	8	8
2	410	8	17	9.1	8	8
2	416	7	10	1.5	8	8
2	416	8	18	2.4	8	10
2	416	9	22	3	8	10
2	424	7	10	1.5	8	8
2	424	8	20	3	10	10
2	424	9	24	4.6	10	10
3	202	99	0	0	99	99
3	310	1	0	0	1	1
3	310	2	0	0	50	1
3	322	3	0	0	5	5
3	322	4	0	0	2	2
3	402	7	12	2.4	8	8
3	402	8	18	3	8	10
3	402	9	27	3	8	10
3	403	7	12	0.6	8	2
3	403	8	18	3.7	8	2
3	403	9	19	4.6	8	2
3	406	7	12	2.4	8	8
3	406	8	17	1.8	10	10
3	406	9	21	4.6	8	10
3	407	7	12	2.4	8	8
3	407	8	17	2.7	8	8

Potential Vegetation Type	Cover Type	Structural Stage	Stand Height (m)	Crown Base Height (m)	FBFM Normal	FBFM Severe
3	407	9	21	5.5	8	8
3	410	7	9	4.6	8	8
3	410	8	15	7	8	8
3	411	3	0	0	6	6
3	411	7	2	0.6	6	6
3	411	8	6	1.5	2	2
3	415	7	10	3	9	9
3	415	8	20	4.6	9	2
3	415	9	25	6.1	2	2
3	416	7	10	1.8	8	8
3	416	8	14	3	8	10
3	416	9	20	3.7	8	10
4	202	99	0	0	99	99
4	310	1	0	0	1	1
4	310	2	0	0	50	1
4	321	3	0	0	6	6
4	321	4	0	0	2	2
4	322	3	0	0	5	5
4	322	4	0	0	2	2
4	402	7	7	0.9	8	8
4	402	8	15	2.4	8	8
4	402	9	16	3	8	8
4	403	7	10	1.8	8	2
4	403	8	14	2.4	8	2
4	403	9	18	6.1	8	2
4	404	7	9	0.9	8	8
4	404	8	12	1.8	8	8
4	404	9	16	3	8	8
4	407	7	12	2.4	8	8
4	407	8	16	2.4	8	2
4	407	9	19	5.5	8	10
4	410	7	9	4.6	8	8
4	410	8	17	7.9	8	8
4	411	3	0	0	6	6
4	411	7	2	0.3	6	6
4	411	8	6	1.2	2	2
4	415	7	10	3	9	9
4	415	8	16	4.3	9	9
4	415	9	21	7	9	2
4	416	7	12	1.8	8	8
4	416	8	17	2.7	8	8
4	416	9	20	3.7	8	8
5	202	99	0	0	99	99
5	310	1	0	0	1	1

Potential Vegetation Type	Cover Type	Structural Stage	Stand Height (m)	Crown Base Height (m)	FBFM Normal	FBFM Severe
5	310	2	0	0	50	1
5	321	3	0	0	6	6
5	321	4	0	0	2	2
5	403	7	10	1.5	2	2
5	403	8	13	2.4	9	9
5	403	9	15	3	2	2
5	404	7	8	1.5	8	2
5	404	8	10	1.5	8	8
5	404	9	21	6.1	8	9
5	405	5	4	0.6	50	6
5	405	6	4	0.6	50	2
5	407	7	10	3	9	9
5	407	8	15	4	9	9
5	407	9	21	7	9	9
5	411	7	3	0.8	2	6
5	411	8	8	0.6	2	2
5	412	5	4	0.6	6	6
5	412	6	3	0.3	50	2
5	413	5	5	0.6	6	6
5	413	6	10	0.3	50	2
5	414	5	4	0.3	6	6
5	414	6	3	0.6	50	2
5	415	7	10	3	9	9
5	415	8	15	4	9	9
5	415	9	21	7	9	2
5	421	5	5	0.6	6	6
5	421	6	4	0.6	50	2
6	202	99	0	0	99	99
6	310	1	0	0	1	1
6	310	2	0	0	50	1
6	321	3	0	0	6	6
6	321	4	0	0	50	2
6	405	5	4	0.6	6	6
6	405	6	4	0.6	50	2
6	412	5	5	0.9	6	6
6	412	6	4	0.3	50	2
6	413	5	6	0.9	6	6
6	413	6	6	0.9	50	2
6	414	5	5	0.6	6	6
6	414	6	3	0.3	50	2
6	421	5	4	0.6	6	6
6	421	6	4	0.6	50	2
7	202	99	0	0	99	99
7	310	1	0	0	1	1
7	310	2	0	0	50	1
7	321	3	0	0	6	6
7	321	4	0	0	50	50
8	100	98	0	0	98	98
8	201	99	0	0	99	99
8	203	99	0	0	99	99
8	205	96	0	0	99	99
5	322	3	0	0	5	5
5	402	8	18	3.7	8	8

APPENDIX K — Accuracy assessment summaries

Accuracy of the Potential Vegetation Type (PVT) Classified Layer based on PVT Field Calls

		Reference (Field) PVT's									
		Riparian	Spruce-Fir	Mixed Conifer	Douglas-fir	Ponderosa Pine	Pinyon Oak-Juniper	Scrub-Grassland	Non-Vegetated	Totals	Commission Error(%)
Classified (Layer) PVT	Riparian	21(5)	0(1)	2(1)	9(1)	19(1)	6(1)	1(1)	1(1)	59	64
	Spruce-Fir	0(1)	49(5)	15(4)	7(3)	0(2)	0(1)	0(1)	1(1)	72	32
	Mixed Conifer	1(1)	9(4)	94(5)	67(4)	11(3)	0(1)	0(1)	0(1)	182	48
	Douglas-fir	2(1)	2(3)	33(4)	136(5)	87(4)	3(2)	0(1)	1(1)	264	48
	Ponderosa Pine	2(1)	0(2)	3(3)	37(4)	254(5)	100(4)	1(2)	2(1)	399	36
	Pinyon-Oak-Juniper	6(1)	0(1)	1(1)	18(2)	147(4)	432(5)	46(4)	9(2)	659	34
	Scrub-Grassland	1(1)	0(1)	0(1)	0(1)	0(2)	14(4)	35(5)	1(2)	51	31
	Non-vegetated	5(1)	0(1)	7(1)	8(1)	27(1)	70(2)	6(2)	20(5)	143	86
	Totals	38	60	155	282	545	625	89	35	**1829**	
	Omission Error (%)	45	18	39	52	53	31	61	43		

Format: Number of plots (fuzzy score)
Overall Accuracy = 57%, KHAT Accuracy = 45%.
Fuzzy scores are rated as 1 (absolutely wrong), 2 (understandable but wrong), 3 (acceptable), 4 (good answer), or 5 (perfect).
Fuzzy sets: 89% have a fuzzy score of 3 or better, 87% have a fuzzy score of 4 or better.

Accuracy of the Cover Type Classified Layer based on Cover Type Field Calls

Classified (Layer) Cover Type vs. **Reference (Field) Cover Type**

	Wa	Ro	Ba	MQ	He	XS	MS	BR	BC	CG	CW	MW	MC	XC	As	GO	Ju	Pi	EO	PP	DF	PJ	SF	Totals	Commission Error (%)
Water	2(5)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	2	0
Rock	0(1)	14(5)	4(4)	0(4)	23(2)	9(1)	1(1)	2(1)	0(1)	1(1)	14(1)	16(1)	0(1)	5(1)	2(1)	0(1)	16(1)	3(1)	1(1)	12(1)	0(1)	15(1)	0(1)	138	90
Barren Ground	0(1)	4(4)	18(5)	0(4)	61(2)	14(2)	0(1)	1(1)	0(1)	0(1)	2(1)	7(1)	0(1)	0(1)	0(1)	0(1)	10(1)	0(1)	2(1)	0(1)	0(1)	9(1)	0(1)	128	86
Mine-**Q**uarry	0(1)	0(4)	0(4)	3(5)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	3	0
Herblands	1(1)	0(2)	1(2)	0(1)	148(5)	9(1)	0(1)	0(1)	0(1)	6(1)	17(1)	16(1)	1(1)	6(1)	0(1)	0(1)	13(1)	2(1)	2(1)	31(1)	4(1)	24(1)	2(1)	283	48
Xeric **S**hrublands	0(1)	0(1)	2(1)	0(1)	14(1)	40(5)	0(4)	0(1)	0(1)	1(1)	5(1)	14(1)	0(1)	2(1)	0(1)	0(1)	0(1)	2(1)	2(1)	0(1)	0(1)	2(1)	0(1)	84	52
Mesic **S**hrublands	0(1)	2(1)	0(1)	0(1)	4(1)	2(4)	4(5)	3(3)	1(1)	4(1)	3(1)	0(1)	2(1)	4(1)	0(1)	0(1)	0(1)	0(1)	0(1)	1(1)	0(1)	1(1)	0(1)	31	87
Broadleaf **R**iparian Forest	0(1)	0(1)	1(1)	0(1)	2(1)	2(1)	0(3)	14(5)	0(4)	1(1)	7(1)	4(1)	0(1)	1(1)	0(1)	0(1)	0(1)	0(1)	2(1)	2(1)	0(1)	1(1)	0(1)	37	62
Broadleaf/**C**onifer Forest	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(4)	12(5)	2(2)	3(2)	1(1)	1(3)	6(3)	1(4)	1(1)	0(1)	0(1)	0(1)	0(4)	0(4)	0(1)	1(4)	28	57
Conifer-**G**ambel Oak Forest	0(1)	0(1)	0(1)	0(1)	0(1)	1(1)	0(1)	0(1)	0(2)	12(5)	5(3)	3(1)	2(3)	8(3)	0(1)	0(3)	0(1)	1(1)	0(1)	8(4)	0(4)	2(1)	0(2)	42	71
Conifer Forest-**W**oodland Mix	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(2)	7(3)	7(5)	3(2)	0(2)	7(3)	0(1)	0(1)	0(4)	1(4)	0(4)	23(4)	0(4)	1(4)	0(2)	49	86
Mixed **W**oodland	0(1)	0(1)	0(1)	0(1)	1(1)	3(1)	0(1)	0(1)	0(1)	2(1)	6(2)	9(5)	0(1)	6(1)	0(1)	0(1)	2(4)	1(4)	2(4)	6(1)	0(1)	4(4)	0(1)	42	79
Mesic Mixed **C**onifer	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	13(3)	4(3)	1(2)	0(1)	64(5)	49(4)	0(1)	0(1)	0(1)	0(1)	0(1)	6(2)	8(3)	0(1)	6(3)	151	58
Xeric Mixed **C**onifer	0(1)	1(1)	0(1)	0(1)	0(1)	1(1)	1(1)	0(1)	1(3)	8(3)	11(3)	2(1)	6(4)	38(5)	0(1)	0(1)	0(1)	0(1)	0(1)	17(4)	1(4)	1(1)	0(2)	88	57
Aspen	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	5(4)	0(1)	0(1)	0(1)	0(1)	1(1)	15(5)	0(2)	0(1)	0(1)	0(1)	0(1)	1(1)	0(1)	1(1)	23	35
Gambel **O**ak	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	1(1)	0(1)	2(1)	4(4)	1(1)	0(1)	1(1)	3(1)	0(2)	13(5)	0(1)	0(1)	0(1)	2(1)	1(1)	0(1)	0(1)	28	54
Juniper	0(1)	0(1)	2(1)	0(1)	3(1)	5(1)	0(1)	0(1)	0(1)	1(1)	10(4)	26(4)	0(1)	2(1)	0(1)	0(1)	39(5)	5(3)	0(3)	15(1)	0(1)	51(4)	0(1)	159	75
Pinyon	0(1)	0(1)	0(1)	0(1)	1(1)	6(1)	0(1)	1(1)	0(1)	4(1)	22(4)	26(4)	0(1)	3(1)	0(1)	0(1)	3(3)	23(5)	4(3)	14(1)	0(1)	19(4)	0(1)	126	82
Evergreen **O**ak	0(1)	1(1)	0(1)	0(1)	11(1)	7(1)	0(1)	1(1)	1(1)	0(1)	7(4)	18(4)	0(1)	2(1)	0(1)	0(1)	2(3)	0(3)	11(5)	5(1)	0(1)	4(2)	0(1)	70	84
Ponderosa **P**ine	0(1)	0(1)	0(1)	0(1)	2(1)	0(1)	0(1)	0(1)	1(4)	3(4)	23(4)	3(1)	2(2)	19(4)	0(1)	1(1)	2(1)	1(1)	1(1)	122(5)	1(4)	2(1)	0(2)	183	33
Douglas-**f**ir	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	4(4)	2(4)	2(4)	0(1)	2(3)	9(4)	0(1)	0(1)	0(1)	0(1)	0(1)	6(4)	6(5)	0(1)	0(3)	31	81
Pinyon-**J**uniper	0(1)	0(1)	0(1)	0(1)	1(1)	0(1)	0(1)	0(1)	0(1)	1(1)	20(4)	10(4)	0(1)	0(1)	0(1)	0(1)	3(4)	6(4)	0(2)	10(1)	0(1)	27(5)	0(1)	78	65
Spruce-**F**ir	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	4(4)	0(2)	0(2)	0(1)	1(3)	0(2)	0(1)	0(1)	0(1)	0(1)	0(1)	0(2)	1(3)	0(1)	19(5)	25	24
Totals	3	22	28	3	271	99	7	22	44	63	166	158	82	171	18	15	90	45	27	280	23	163	29	**1829**	
Omission Error (%)	33	36	36	0	45	60	43	36	73	81	96	94	22	78	17	13	57	49	59	56	74	83	34		

Format: Number of plots (fuzzy score)
Overall Accuracy = 36%, KHAT Accuracy = 31%.
Fuzzy scores are rated as 1 (absolutely wrong), 2 (understandable but wrong), 3 (acceptable), 4 (good answer), or 5 (perfect).
Fuzzy sets: 65% have a fuzzy score of 3 or better, 59% have a fuzzy score of 4 or better.

Accuracy of the Structural Stage Classified Layer based on Structural Stage Field Calls

Classified (Layer) Structural Stage		Reference (Field) Structural Stage												
		Closed Herbland	Open Herbland	Closed Shrubland	Open Shrubland	Closed Woodland	Open Woodland	Small Tree	Medium Tree	Large Tree	Water	Rock	Totals	Commission Error (%)
	Closed Herbland	89(5)	8(4)	1(1)	3(1)	1(1)	28(1)	3(1)	48(1)	4(1)	0(1)	0(1)	185	52
	Open Herbland	35(4)	16(5)	0(1)	5(1)	1(1)	27(1)	0(1)	12(1)	0(1)	1(1)	1(1)	98	84
	Closed Shrubland	4(1)	0(1)	8(5)	3(4)	1(1)	3(1)	5(1)	19(1)	2(1)	0(1)	2(1)	47	83
	Open Shrubland	3(1)	11(1)	3(4)	32(5)	9(1)	8(1)	0(1)	0(1)	0(1)	0(1)	2(1)	68	53
	Closed Woodland	5(1)	0(1)	4(1)	3(1)	42(5)	39(4)	3(1)	57(1)	0(1)	0(1)	1(1)	154	73
	Open Woodland	10(1)	2(1)	3(1)	11(1)	44(4)	170(5)	1(1)	75(1)	3(1)	0(1)	2(1)	321	47
	Small Tree	2(1)	0(1)	1(1)	0(1)	2(1)	0(1)	12(5)	44(4)	2(3)	0(1)	0(1)	63	81
	Medium Tree	2(1)	0(1)	4(1)	1(1)	15(1)	14(1)	15(4)	537(5)	19(4)	0(1)	2(1)	609	12
	Large Tree	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(3)	10(4)	3(5)	0(1)	0(1)	13	77
	Water	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	2(5)	0(1)	2	0
	Rock	18(1)	66(1)	8(1)	16(1)	5(1)	74(1)	5(1)	31(1)	3(1)	0(1)	43(5)	269	84
	Totals	168	103	32	74	120	363	44	833	36	3	53	**1829**	
	Omission Error (%)	47	84	75	57	65	53	73	36	92	33	19		

Format: Number of plots (fuzzy score)
Overall Accuracy = 52%, KHAT Accuracy = 39%.
Fuzzy scores are rated as 1 (absolutely wrong), 2 (understandable but wrong), 3 (acceptable), 4 (good answer), or 5 (perfect).
Fuzzy sets: 64% have a fuzzy score of 3 or better.

Accuracy of the Fire Behavior Fuel Model (FBFM) ***Normal*** *Classified Layer based on FBFM Normal Field Calls*

		Reference (Field) Normal FBFM											
		1	2	5	6	8	9	10	50	98	99	Totals	Commission Error (%)
Classified (Layer) Normal FBFM	1	98(5)	39(3)	0(1)	0(1)	21(1)	4(1)	2(1)	21(3)	0(1)	0(1)	185	47
	2	1(3)	3(5)	0(1)	2(1)	8(1)	1(1)	0(1)	2(3)	0(1)	0(1)	17	82
	5	4(1)	4(1)	0(5)	6(3)	7(1)	3(1)	2(1)	1(1)	0(1)	2(1)	29	100
	6	12(1)	35(1)	4(3)	24(5)	31(1)	20(1)	1(1)	54(1)	0(1)	1(1)	182	87
	8	4(1)	26(1)	1(1)	7(1)	96(5)	46(3)	18(3)	5(1)	0(1)	0(1)	203	53
	9	10(1)	40(1)	5(1)	8(1)	82(3)	89(5)	3(3)	23(1)	0(1)	1(1)	261	66
	10	0(1)	7(1)	0(1)	0(1)	94(3)	9(3)	61(5)	1(1)	0(1)	0(1)	172	65
	50	100(3)	72(3)	2(1)	13(1)	60(1)	24(1)	0(1)	234(5)	1(1)	1(1)	507	54
	98	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	2(5)	0(1)	2	0
	99	56(1)	26(1)	2(1)	3(1)	26(1)	5(1)	0(1)	125(1)	0(1)	24(5)	269	91
	Totals	285	252	14	63	425	201	87	466	3	29	**1825**	
	Omission Error (%)	66	99	100	62	77	56	30	50	33	17		

Format: Number of plots (fuzzy score). Overall Accuracy = 35%, KHAT Accuracy = 24%.
Fuzzy scores are rated as 1 (absolutely wrong), 2 (understandable but wrong), 3 (acceptable), 4 (good answer), or 5 (perfect).
Fuzzy sets: 62% have a fuzzy score of 3 or better.

Accuracy of the Fire Behavior Fuel Model (FBFM) ***Severe*** *Classified Layer based on FBFM Severe Field Calls*

		Reference (Field) Severe FBFM												
		1	2	4	5	6	8	9	10	50	98	99	Totals	Commission Error (%)
Classified (Layer) Severe FBFM	1	139(5)	81(3)	1(1)	0(1)	5(1)	25(1)	3(1)	3(1)	23(3)	1(1)	0(1)	283	51
	2	30(3)	144(5)	3(1)	1(1)	78(1)	72(1)	45(1)	14(1)	93(3)	0(1)	2(1)	482	70
	4	0(1)	0(1)	0(5)	0(3)	0(3)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0	100
	5	3(1)	4(1)	1(3)	0(5)	8(3)	6(1)	2(1)	3(1)	0(1)	0(1)	2(1)	29	100
	6	6(1)	43(1)	10(3)	3(3)	63(5)	29(1)	24(1)	2(1)	17(1)	0(1)	1(1)	198	68
	8	0(1)	25(1)	0(1)	0(1)	9(1)	31(5)	34(3)	26(3)	2(1)	0(1)	0(1)	127	76
	9	4(1)	54(1)	1(1)	0(1)	16(1)	57(3)	85(5)	6(3)	4(1)	0(1)	0(1)	227	63
	10	0(1)	6(1)	0(1)	0(1)	2(1)	43(3)	12(3)	122(5)	0(1)	0(1)	0(1)	185	34
	50	12(3)	5(3)	0(1)	0(1)	2(1)	0(1)	0(1)	0(1)	7(5)	0(1)	0(1)	26	73
	98	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	2(5)	0(1)	2	0
	99	83(1)	53(1)	4(1)	1(1)	16(1)	21(1)	8(1)	0(1)	59(1)	0(1)	24(5)	269	91
	Totals	277	415	20	5	199	284	213	176	205	3	29	**1826**	
	Omission Error (%)	50	65	100	100	68	89	60	31	97	33	17		

Format: Number of plots (fuzzy score)
Overall Accuracy = 34%, KHAT Accuracy = 24%.
Fuzzy scores are rated as 1 (absolutely wrong), 2 (understandable but wrong), 3 (acceptable), 4 (good answer), or 5 (perfect).
Fuzzy sets: 58% have a fuzzy score of 3 or better.

Accuracy of the Canopy Closure Classified Layer based on Canopy Closure Class Field Calls

	Reference (Field) Canopy Closure							
		0	1-15	16-45	46-75	76-99	Totals	Commission Error (%)
Classified (Layer) Canopy Closure	0	252	134	227	48	8	669	62
	1-15	13	14	93	92	2	214	93
	16-45	11	13	298	125	3	450	34
	46-75	2	2	109	134	11	258	48
	76-99	1	0	35	158	44	238	82
	Totals	279	163	762	557	68	1829	
	Omission Error (%)	10	91	61	76	35		

Format: Number of plots
Overall Accuracy = 41%, KHAT Accuracy = 24%.

Accuracy of the Lifeform Classified Layer based on Lifeform Field Calls

	Reference (Field) Lifeform									
		Herblands	Shrublands	Woodlands	Broadleaf Forest	Conifer Forest	Water	Rock	Totals	Commission Error (%)
Classified (Layer) Lifeform	Herblands	148	9	57	67	67	1	1	283	48
	Shrublands	18	46	21	22	22	0	4	115	60
	Woodlands	17	21	295	136	136	0	3	475	38
	Broadleaf Forest	2	3	8	39	39	0	1	116	46
	Conifer Forest	2	3	23	516	516	0	1	569	9
	Water	0	0	0	0	0	2	0	2	0
	Rock	84	24	79	34	34	0	43	269	84
	Totals	271	106	483	814	814	3	53	1829	
	Omission Error (%)	45	57	39	37	37	33	19		

Format: Number of plots
Overall Accuracy = 61%, KHAT Accuracy = 48%.

APPENDIX L — The directory structure and description of the CD

FARSITE Input Data Layers for the Gila National Forest Complex, Version 1.0, May 1999

INTRODUCTION:

This disk contains Version 1.0 of the fuel and vegetation data layers needed for input to the FARSITE 3.0 (Fire Area Simulator) model for lands in the Gila National Forest Complex (GNFC), New Mexico, USA.

FARSITE is a spatially-explicit fire model used to predict the spread, intensity, direction, size, and pattern of wildland fires. The FARSITE input maps were created by assigning fire behavior fuel models and vegetation attributes to unique combinations of potential vegetation type, cover type, and structural stage data layers.

These input data layers have been converted to the landscape file format required by FARSITE and stored as USGS quads in a special directory structure. Also included on this disk are the data layers developed for FARSITE in Arc/Info raster format, several accessory vector layers, and a report documenting details of this fuels mapping effort. Version 1.0 was completed by the Fire Modeling Institute at the Rocky Mountain Fire Sciences Laboratory, Missoula, Montana, USA.

DIRECTORY STRUCTURE:

A brief description of the directory structure and data included on this disk.

FARSITE INPUT LAYERS:

The following directories contain map themes to be used with Farsite. ARCINFO layers of the map themes required for Farsite were “cut” into 7.5' USGS quadrangle files, then exported out of ARCINFO using the GRIDASCII command and converted to DOS format. Several ARCINFO vector layers that can viewed in FARSITE as an overlay to the raster layers were also “cut” into quad files, then exported out of ARCINFO using the UNGENERATE command and converted to DOS format. Prior to creating this disk, a landscape file was created for each quad from the 8 ascii raster map themes required for Farsite. The landscape file and all accessory ascii files for each quad were zipped together into one zip file labeled with an abbreviation of the quadrangle’s name. The preferred (and fastest) method of running FARSITE is to first copy the needed quadrangle map themes to your PC hard disk and then run FARSITE.

7.5 minute QUADS: Zipped files created on an IBM Unix system with the pkzip for unix command. They can be unzipped with either the MSDOS or the Windows 95 version of PKZIP, both of which are provided on this disk. Each Zip file contains all of the map themes needed to run FARSITE for a 7.5' quad and is named with an abbreviation of the quad name. Included in each zip file are the following files (each prefixed with the abbreviated quad name and given the extension listed in parentheses):

FARSITE landscape (.LCP) files: Each LCP contains 8 raster themes (elevation, slope, aspect, surface fuel model — normal, canopy cover, stand height, crown height, crown bulk density). The surface fuel theme is for normal burning conditions. The LCP can ONLY be read by FARSITE.
SEVERE FUEL MODELS (.SEV): Ascii raster surface fuels theme for severe wildfire conditions. These files can be spliced into normal LCP files above using utilities in the FARSITE program.
CONTOURS (.CTR): Ascii vector theme showing 100 meter topographic contours. Contours were derived from the 30 meter USGS Digital Elevation Model (DEM).
ROADS (.RDS): Ascii vector theme showing roads. Roads are a combination of a roads layer obtained from the Gila National Forest, Silver City, NM, and a roads layer generated from 1:24,000 USGS Cartographic Feature Files (CFFs). Roads within the Gila National Forest boundary were taken from the GNF layer; roads outside the forest boundary came from a CFF layer generated at the Fire Sciences Lab. ** NOTE: CFFS for several quads within the GNF are not currently available.
STREAMS (.HYD): Ascii vector theme showing streams. This streams layer was obtained from the Gila National Forest, Silver City, NM in September 1998. It originated from Cartographic Feature Files (CFFs) and was extensively edited by GNF staff. CFFs for a few quads on the Cibola NF were added to this layer at the Fire Sciences Lab. ** NOTE: CFFs for several quads within the GNF are not currently available.
TRAILS (.TRL): Ascii vector theme showing trails. Trails are a combination of a trails layer obtained from the Gila National Forest, Silver City, NM, and a trails layer generated from 1:24,000 USGS Cartographic Feature Files. Trails within the Gila National Forest boundary were taken from the GNF layer; trails outside of the GNF came from CFFs. ** NOTE: CFFs for several quads within the GNF are not currently available.

All Zip files should have a Landscape, Severe Fuel Models, and Contours file, however Roads, Streams, and Trails files may or may not exist for a particular quad.

\BOUNDARY BOUNDARIES: Two ASCII vector files provided. These files were NOT clipped to 7.5' quads. They can be viewed as an additional overlay in FARSITE.
FOREST_BDY.ASC: Vector theme showing the Gila National Forest boundary and the portion of the Cibola National Forest boundary that is included in the GNFC.
WILDERNESS.ASC: Vector theme showing the Gila Wilderness & Aldo Leopold Wilderness boundaries, obtained from Gila National Forest, Silver City, NM.

OTHER DIRECTORIES:

\CUSTOM CUSTOM Fuel Model: This directory contains a custom fuel model file that quantifies the necessary parameters for Fuel Model 50. This file will be REQUIRED for FARSITE to run. It must be copied over to your PC along with the FARSITE input files.

\WEATHER \WEATHER\DAYMET: This directory contains simulated weather data (*.wtr) that are ready to be input directly into FARSITE. See readme.txt file in directory for more specific information on format.

\WEATHER/NCDC: This directory contains weather data from the National Climatic Data Center's EarthInfo Cd. Files are not in *.wtr fromat required by FARSITE. See readme.txt file in directory for more specific information on format.

\WEATHER\RAWS: This directory contains weather (*.wtr) and wind (*.wnd) files summarized from RAWS data that are ready to be input directly into FARSITE. See readme.txt file in directory for more specific information on format.

\DATABASE \DATABASE\DATA: This directory contains copies of the *.dbf ground-truth databases.

\DATABASE\FORMATS: This directory contains a copies of the formats used in the *.dbf databases.

\DATABASE\PV: This directory contains the *.dbf's of the Polygon Validation data.

\DATABASE\LUTS: This directory contains lookup tables in *.dbf format of fire behavior model assignments and vegetation attributes. PCSLUT.DBF is the lookup table assigning fuel models, crown base height, and stand height to PVT-Cover Type-Structural Stage Combinations. CSCLUT.DBF is the lookup table assigning crown bulk density to Cover Type-Structural Stage-Canopy Cover combinations.

\DOC DOCumenation: This directory contains the project report detailing the methods used to develop all the Version 1.0 FARSITE spatial data layers and the 1998 progress report. The directory also contains lookup tables in *.dbf format of fire behavior model assignments and vegetation attributes.

\GNFC_MAP Gila National Forest Complex MAP: A map showing forest boundaries of the Gila NF and the portion of the Cibola NF included in this project, wilderness boundaries, and 7.5' USGS quadrangles (including names). The map is provided in three formats- a Bitmap, JPEG, and postscript. The postscript will produce the best paper copy if so desired. The Bitmap or JPEG file may be loaded into a Windows graphics program as an on-screen reference to quadrangle locations and names.

\UNIX_GIS UNIX GIS: This directory contains all the Version 1.0 GIS raster data layers developed for FARSITE and several ancillary vector layers. The directory is in UNIX ARCINFO format and can only be read by ARCVIEW 3.0 on a PC/DOS system or ARCVIEW and ARCINFO on a UNIX system.

\FARSITE FARSITE: This directory contains a self-extracting, self-installing copy of FARSITE Version 3.0 that can be loaded onto a PC. FARSITE 3.0 requires Windows 95 or Windows NT 4.0; it will not work on Windows 3.1. FARSITE will NOT run from this directory.

\SOFTWARE \SOFTWARE\PKZIP\MSDOS: This directory contains a copy of the MSDOS version of PKZIP.

\SOFTWARE\PKZIP\WIN95: This directory contains a copy of the Windows 95 version of PKZIP. Quad files can be unzipped using either version.

\SOFTWARE\CFCC: This directory contains the Crown Fuel Characteristics Calculator software used to compute crown characteristics from stand data. The executable file is CFCC.

DISCLAIMER:

The data and computer programs provided on this CDROM are available with the understanding that the Fire Science Laboratory — Rocky Mountain Research Station — USDA Forest Service cannot assure their accuracy, completeness, reliability, or suitability for any particular purpose. Spatial information may not meet National Map Accuracy Standards. The use of trade or firm names in any documentation is for reader information only; it does not imply endorsement of any product or service. This data will not be maintained by the Rocky Mountain Fire Science Laboratory, but may be updated without further notification.

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RMRS
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