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Field Guide for Identifying Fuel Loading Models

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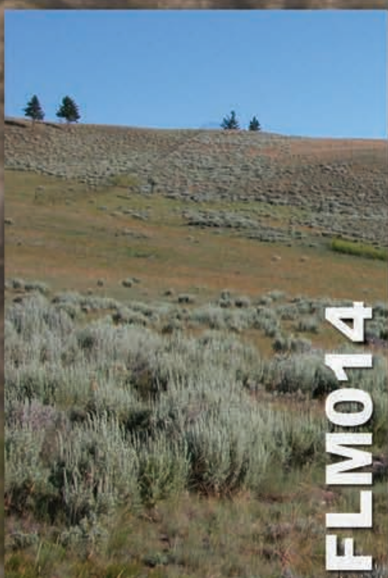

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Abstract

This report details a procedure for identifying fuel loading models (FLMs) in the field. FLMs are a new classification system for predicting fire effects from on-site fuels. Each FLM class represents fuel beds that have similar fuel loadings and produce similar emissions and soil surface heating when burned using computer simulations. We describe how to estimate fuel load in the field, match the load estimates to an appropriate FLM, and use the FLMs to predict the smoke or soil heating that could result from burning those loads. The FLM names can also be used as fuel descriptors in other applications, including inputs into fire models for predicting fire effects, data layers for mapping fuel conditions, and supplements to vegetation data for more complete environmental descriptions to use in restoration or wildlife habitat planning.

Keywords: First-order fire effects, fuel classification, fuel loading, fuel mapping, fuel classification key

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Introduction

Historically, fuel classifications used to estimate fire effects have been based on the vegetative characteristics of a particular site or location (Reinhardt and others 1997; Sandberg and others 2001). Vegetation-based classifications generally use cover type, structural stage, and/or habitat type (Mueller-Dombois 1964; Pfister and Arno 1980) as surrogates for describing the type and quantity of fuels on the ground and in the forest canopy (Hawkes and others 1995; Keane and others 2006; Mark and others 1995; Shasby and others 1981). The rationale for using vegetation characteristics to classify fuels is that fuels are ultimately derived from vegetation, so knowing how much fuel a particular vegetation type produces should provide an acceptable estimate of fuel load on the ground. However, vegetation-based fuel classifications fail to recognize that (1) fuel beds, or the fuels in the surface fuel and litter/lichen/moss strata (Scott 2007), are composed of diverse fuel components (for example, a combination of downed woody debris, shrubs, and herbs as opposed to only shrubs or only litter), (2) each fuel component is highly variable in loading across space and time, (3) the fuels and the vegetation may have different disturbance histories in space and time that affect their correlation (Brown and Bevins 1986), and (4) most sampling methods are limited in their ability to capture both fuel variability and how much fuel is produced by any particular vegetation type (Brown and See 1981; Lutes 1999, 2002).

Alternatives to vegetation-based classifications have been developed to classify fuels that are input into fire behavior computer models such as BEHAVE and FARSITE (Andrews 1986; Andrews and Bevins 1999; Finney 2004). These fuel classifications, which are also known as Fire Behavior Fuel Models (FBFMs), include only fuel bed components that are important for predicting fire behavior. They consist of a limited number of fuel beds that, in turn, have limited load values for fine fuels and live herb and woody material (Anderson 1982; Burgan 1987; Scott and Burgan 2005). They do not include fuel greater than 3 inches (7.6 cm) in diameter because this material does not substantially contribute to fire spread. In a sense, the fuel beds used within these FBFMs are artificial, or stylized, because individual fuel components were manually adjusted within each FBFM class to produce expected fire behaviors that follow the fire spread model of Rothermel (1972). Unfortunately, classifications that use artificial fuel beds, or exclude important fuel components, are inappropriate for computing fire effects like fuel consumption, smoke production, and tree mortality. For accurate simulation of these fire effects, most fire effects computer models, such as CONSUME and FOFEM (Ottmar and others 2008; Reinhardt and others 1997), require actual fuel loadings across all of the major surface fuel components.

Lutes and others (in press) recently created a new classification, called Fuel Loading Models (FLMs) specifically developed to predict fire effects from on-site surface fuels. Their FLM classification is one of the first classifications that categorize fuel beds into readily identifiable classes based on their predicted fire effects. It is unique because the FLM classes are readily identifiable in the field using on-site fuels. Over 4,000 actual fuel beds from across the United States were used to create the new classification and the individual groups within it are distinguished by two important fire effects—the amount of smoke that is produced upon combustion (specifically, the 2.5 μ particulate emissions) and the amount of soil heating. Both of these fire effects are important indicators of the physical and chemical changes that will occur on a site when fuels are burned. Tools, such as FLMs, that aid in predicting these fire effects are critical to fire management.

Unlike the vegetation-based approaches used to classify fire effects, FLMs use computer models to balance the high variability of fuel beds across a stand with the resolution needed to broadly describe unique fuel classes for the continental United States. Therefore, FLMs can be used to capture the variability of individual fuel components within a fuel bed, as well as describe differences in those fuel components across many spatial and temporal scales. FLMs are not designed to replace existing fuel classifications, such as the Fuel Characteristics Classification System (Ottmar and others 2007; Sandberg and others 2001), nor are they designed to eliminate the need for extensive fuel inventories using planar intersect techniques (Brown 1974; Lutes and others 2006). FLMs are solely intended to be an additional tool for managers to describe fuels for fire management. This report presents a quick and easy method for identifying a FLM so that its fuel information can be integrated with other applications, including computer predictions of fire effects.

What is an FLM?

Fuel Loading Models (FLMs) is a new classification system for predicting fire effects from on-site fuels. In this context, the word "model" denotes both the classification itself and the specific sets of fuel loadings and fire effects that define each class within it. Fuel loadings include the quantities of duff, litter, fine-woody debris, and coarse woody debris (logs) in tons per acre (T acre^{-1}) or kilograms per meter^2 (kg m^{-2}). Fire effects include the type and amount of surface fuels consumed, the quantity of PM2.5 emissions (smoke), and the maximum soil heating obtained during combustion at 0.8-inch (2-cm) soil depth.

Like other classification systems, such as the National Vegetation Classification System (http://biology.usgs.gov/npsveg/nvcs.html), there is a hierarchy within the FLMs. The most basic unit, or class, is the fuel loading model. Each FLM class differs significantly from every other FLM class when its fuel load composition is compared statistically ($p<0.05$) (Lutes and others, in press). When an FLM class is assigned to a particular location, it describes both the on-site fuels and the range of consumed fuels, particulate emissions (smoke), and maximum soil heating that may be expected from burning those fuels. For example, FLM 71 represents distinct ranges of smoke and soil heating that result when moderate to heavy logs and light duff are consumed during computer-simulated combustion (table 1). FLM 14, however, has very different predictions for smoke and soil heating because its main fuels consist of sagebrush (*Artemisia* spp.) at loadings of <12 T acre^{-1} (6.2 kg m^{-2}). Because some FLM units produce emissions and soil heating effects that are similar, the classes can be grouped together at a higher hierarchical level. Groups of FLM classes that produce similar ranges of particulate emissions and soil heating are designated "Effects Groups." The number used to name each FLM indicates (1) its Effects Group and (2) its class within an Effect Group. For example, FLM 62 identifies the FLM as a member of Effects Group 6, but has the fuels, smoke, and soil heating characteristics of Class 2 within Effects Group 6. In general, increasing Effect Group numbers indicate higher particulate emissions and increasing maximum soil temperatures. The 10 Effects Groups and their associated fuels and fire effects are described in table 1.

How Were the FLM Classes Developed?

The FLMs were developed using slightly different methods for forested and non-forested areas. In the following sections, we provide an overview of how the classification was created for forested areas, which is taken from Lutes and others (in press). We also summarize how the classification was created for non-forested areas by D. Lutes. The FLM classification for non-forested areas and its development process have not been published elsewhere. A complete description of FLM development for forested areas is provided in Lutes and others (in press).

Forested areas—We define forested areas as having greater than 10% tree cover or having a tree species name for the cover type classification within the sample data. Lutes and others (in press) developed the FLMs classification for the forested areas using the following procedures:

1. An extensive database of plot-level fuel loadings was compiled from sampled fuel beds located across the United States. Initially, data were compiled using over 11,000 fuel beds, but the data used in the final classification of forested areas were ultimately reduced to 4,046 fuel beds that met selection criteria.
2. Each fuel bed was "burned" using computer-aided simulation. The First Order Fire Effects Model (FOFEM) (Reinhardt and others 1997) was used to simulate combustion and obtain predictions of fuel consumption, smoke emissions, and soil heating for each fuel bed.
3. The fire effects' predictions were grouped into statistically unique groups of fuel beds using cluster analysis. The unique groups were called Effects Groups.
4. Unique fuel beds were determined using classification tree analysis (Breiman and others 1984) with the Effects Groups as the independent variable. These unique fuel beds of duff, litter, fine woody debris, and logs became the FLM classes.
5. The classification error was determined and validated using two different methods.
6. A key to the FLMs was created using the classification results.

Table 1—The Effects Groups and their associated Fuel Loading Model (FLM) classes.

Effects group number	Effects group characteristics [a]	Fuel load characteristics of FLM classes within the Effects Group (forested sites only)	Abbreviated description of the Effects Group (in bold) [b, c] and its associated FLM classes
1	Low $PM_{2.5}$ particulate emissions (<0.22 T acre^{-1}) <212 °F surface soil temperature	Light to no duff or litter (<2.23 T acre^{-1}) Fine woody debris > 2. 23 T acre^{-1}	**Wispy-Cool-Sparse** FLM 11: Light FWD, light to no duff [d, e] FLM 12: Moderate FWD, light litter FLM 13: Moderate FWD, light to moderate litter, light duff FLM 14: Shrub-Sagebrush with low total load FLM 15: Shrub-Non-sagebrush with low total load
2	Low $PM_{2.5}$ particulate emissions (<0.33 T acre^{-1}) 212 to 392 °F surface soil tem-perature	2.23 to 4.46 T acre^{-1} duff < 8.92 T acre^{-1} logs	**Wispy-Warm-Light** FLM 21: Light logs, light duff
3	Low $PM_{2.5}$ particle emissions (<0.33 T acre^{-1}) 392 to 662 °F surface soil tem-perature	<8.92 T acre^{-1}each of duff and litter <8.92 T acre^{-1}logs	**Wispy-Hot-Moderate** FLM 31: Moderate litter, light duff, light logs
4	Low $PM_{2.5}$ particulate emis-sions(<0.33 T acre^{-1}) 752 to 1112 °F surface soil temperature	Light to no duff, but litter and fine woody debris (>2.23 T acre^{-1}) present	**Wispy-Very Hot-Light** FLM 41: Moderate FWD, light to moderate litter
5	Low $PM_{2.5}$ particulate emissions (0.22 to 0.45 T acre^{-1}) <302 °F surface soil temperature	Heavy concentration of duff (13.4 to 17.80 T acre^{-1}) <4.46 T acre^{-1} logs	**Wispy-Cool-Moderate** FLM 51: Moderate duff, light logs [f] FLM 53: Shrub – Sagebrush with medium total load FLM 54: Shrub – Non-sagebrush with medium total load
6	$PM_{2.5}$ particulate emissions 0.45 to 0.81 T acre^{-1} <392 °F surface soil temperature	Duff highly variable Logs highly variable	**Hazy-Warm-Moderate to Heavy** FLM 61: Moderate to very heavy logs, light duff FLM 62: Moderate duff, light logs, light litter [f] FLM 63: Moderate duff, light to heavy logs, light litter FLM 64: Moderate to heavy duff, light to heavy logs FLM 65: Shrub-Sagebrush with high total load FLM 66: Shrub-Non-sagebrush with high total load
7	Low $PM_{2.5}$ particulate emissions (0.22 to 0.56 T acre^{-1}) 347 to 572 °F surface soil tem-perature	4.46 to 22.30 T acre^{-1} duff; litter present Logs highly variable	**Wispy to Hazy-Hot-Moderate** FLM 71: Moderate to heavy logs, light duff FLM 72: Moderate duff, light to moderate logs, moderate litter

(continued)

Table 1 (Continued).

Effects group number	Effects group characteristics [a]	Fuel load characteristics of FLM classes within the Effects Group (forested sites only)	Abbreviated description of the Effects Group (in bold) [b, c] and its associated FLM classes
8	$PM_{2.5}$ particulate emissions 0.56 to 0.89 T acre^{-1} 212 to 752 °F surface soil temperature	Up to 26.76 T acre^{-1} duff; litter variable Logs 4.46 to 35.69 T acre^{-1}	**Hazy-Warm to Hot-Heavy** FLM 81: Very heavy logs, light duff FLM 82: Moderate duff, light to heavy logs, moderate litter FLM 83: Heavy to very heavy logs, moderate duff
9	$PM_{2.5}$ particulate emissions 0.89 to 2.23 T acre^{-1} <572 °F surface soil temperature	Duff, litter, logs and FWD biomass variable but relatively heavy biomass for each	**Smokey-Cool to Hot-Very Heavy** FLM 91: Heavy duff, light to heavy logs FLM 92: Very heavy logs FLM 93: Heavy duff, heavy to very heavy logs
10	$PM_{2.5}$ particulate emissions >2.23 T acre^{-1} Most < 212 °F soil temp	Very heavy duff OR Light duff but heavy litter and logs <8.2 T acre^{-1}	**Smokey-Cool-Very Heavy** FLM 101: Very heavy duff FLM 102: Heavy litter, light duff, light logs

[a] To convert Effects Groups characteristics to metric:
For metric emissions: Multiply T acre^{-1} by 0.2242 to get Mg km^{-2}
For metric temperature: Multiply (°F – 32) by (5/9) to get °C
For metric fuel load: Multiply T acre^{-1} by 0.22417 to get kg m^{-2}

[b] Effects Group descriptions are arranged as **Emissions-Soil Surface Temperature-Total Fuel Loads** (e.g., Smokey-Cool-Very Heavy). Within each Effects Group, individual FLM classes are distinguished by differences in proportions of duff, litter, fine woody debris, and logs.

[c] Ranges for the abbreviated Effects Group descriptions:

$PM_{2.5}$ Emissions (smoke particles ≤2.5 mμ in diameter): Wispy <0.33 T acre^{-1} (<75 Mg km^{-2}); **Hazy** 0.33 to 0.89 T acre^{-1} (75 to 200 Mg km^{-2}); **Smokey** >0.89T acre^{-1} (>200 Mg km^{-2})

Temperature: Cool <212 °F (100 °C); **Warm** 212 to 392 °F (100 to 200 °C); **Hot** 392 to 752 °F (200 to 400 °C); **Very Hot** >752 °F (>400 °C)

Total Fuel Loads : Sparse Very little duff or litter; usually less than 2.75 T acre^{-1} (0.62 kg m^{-2}) of total fuel load; **Light** Mostly duff; total load is less than 15 T acre^{-1} (3.4 kg m^{-2}) even if coarse woody debris is present; **Moderate** Duff, litter and coarse woody debris present; total load rarely exceeds 30 T acre^{-1} (6.7 kg m^{-2}); **Heavy** Abundant biomass both in duff and logs; total load can vary between 35 T acre^{-1} and 60 T acre^{-1} (7.8 to 13.5 kg m^{-2}); **Very Heavy** Abundant duff and very abundant biomass for logs; total load usually exceeds 45 T acre^{-1} (10 kg m^{-2})

[d] Ranges for fuel load components in abbreviated fuel load descriptions of FLM classes (forested sites only):

Duff: **Light** <12.9 T acre^{-1} (<2.9 kg m^{-2}); **Moderate** 12.9 to 35.6 T acre^{-1} (2.9 to 7.9 kg m^{-2}) **Heavy** 35.7 to 58 T acre^{-1} (8.0 to 13.0 kg m^{-2}); **Very heavy** >58 T acre^{-1} (>13 kg m^{-2})

Litter: **Light** ≤2.7 T acre^{-1} (≤0.6 kg m^{-2}); **Moderate** 2.7 to 8.92 T acre^{-1} (0.7 to 2.0 kg m^{-2}); **Heavy** >8.92 T acre^{-1} (>2.0 kg m^{-2})

Fine woody debris (FWD): **Light** <2.2 T acre^{-1} (<0.5 kg m^{-2}); **Moderate** ≥2.2 T acre^{-1} (≥0.5 kg m^{-2})

Logs: **Light** <8.9 T acre^{-1} (<2 kg m^{-2}); **Moderate** 8.9 to 12.9 T acre^{-1} (2.0 to 2.9 kg m^{-2}); **Heavy** 13.0 to 26.8 T acre^{-1} (3.0 to 6.0 kg m^{-2}); **Very heavy** >26.8 T acre^{-1} (>6 kg m^{-2})

Note: Ranges for the fuel components described above are based on the FLM development rules of Lutes and others (in press). Some adjustments to those rules have been made so that they correspond to breaks in their dichotomous key and the FLM key developed for this paper.

[e] Unless otherwise noted, descriptions for FLMs are for forested sites.

[f] FLM classes 51 and 62 have identical descriptions according to the criteria listed above (that is, *Moderate duff, light logs, light litter*). FLM 51 has approximately 2.23 T acre^{-1} (0.5 kg m^{-2}) more duff load than FLM 62, which produces unique fire effects during computer simulations but does not produce short, unique fuel descriptions using the criteria above. We eliminated the light litter descriptor from FLM 51 to ensure all FLM descriptions were unique.

Data were selected for statistical analysis by Lutes and others (in press) based on the completeness of the data for surface fuel components and their spatial distribution across the United States. Each sample had to include load estimates of fine-woody fuels (i.e., the 1 hr, 10 hr, and 100 hr fuel-moisture classes), coarse-woody fuels (logs >3 inches or 7.62 cm in diameter), and depths of the litter and duff. If any one of these six components was missing, the sample was eliminated from further consideration for the FLM study. Plot-level data quality was maintained by using only datasets that (1) were collected on plots not greater than 0.25 acres (0.1 ha); (2) did not include subjective assessments of loading; and (3) included all six fuel components needed for the FOFEM simulations (Lutes and others, in press). All of the selected datasets contained estimates of downed woody debris loads derived from using the planar intersect method (Brown 1971; van Wagner 1968; Warren and Olsen 1964). Duff and litter load was (a) estimated by averaging multiple depth measurements and multiplying by a predetermined bulk density or (b) calculated from dried samples. To insure that the classification was pertinent to many regions of the United States, the data were also selected based on regional distribution. Most data came from recent research and large inventory or monitoring projects conducted by the Department of Defense, Bureau of Land Management, Bureau of Indian Affairs, U.S. Forest Service, and the Student Conservation Association. Their projects were spread throughout the contiguous United States.

FOFEM was used to simulate fuel bed burning. FOFEM provided outputs for many fire effects; however, only two outputs were used to create the FLMs. These included 1) the *smoke estimates* measured in lb acre^{-1} or kg m^{-2} for the 2.5 mμ particulate ($PM_{2.5}$) emissions and 2) the *maximum temperature* measured at the soil surface. These two estimates represented important effects resulting from a real burn. They were also poorly correlated, which made them good variables to include in the cluster analysis used to develop the Effects Groups.

Plots were grouped by cluster analysis based on the particulate and soil heating effects using agglomerative hierarchical clustering (Lance and Williams 1967). In this type of clustering, a plot is located in two-dimensional space based on the soil heating (x-axis) and emissions (y-axis). Each plot starts out as its own group; however, during an iterative process, plots are added to groups or groups are recombined until all of the plots are members of one cluster. At each iteration of the clustering process, there will be between 1 and n (for FLMs, n=4,046) clusters, and the plots are grouped in a way that minimizes the increases in the overall sum of the squared within-cluster differences. In the FLM study, the final number of clusters was set at 10 because it was found, through a number of exploratory analyses, that classification rules applied during the FLMs process could not uniquely identify differences between clusters when more than 10 clusters were used. The cluster analysis, and a complementary classification tree procedure used to verify the groupings, produced 21 forest-type FLMs in 10 Effects Groups. The accuracy of the FLM key developed from this process was tested with cross-validation and contingency table analyses, which estimated the misclassification error as 34% and <30% respectively (Lutes and others, in press). Each FLM had a range of loading values for each fuel component that, when consumed, produced a respective smoke and heating effect. The median values for each of these fuel components are summarized for forest FLMs in table 2.

Non-forested areas—Non-forested areas have <10% tree cover and fuels that originate primarily from grass, herbs, or shrubs. The main difference between the process used to create the FLM classification for forested areas and the process used for the non-forested areas concerned how fuel loading was used. In forested areas, loadings of the six individual fuel components were entered directly into FOFEM and emissions and soil heating were calculated automatically. In shrub and grassland areas, fuel data was often collected as TOTAL biomass without distinction as to how much fuel was in each of the six fuel components. Therefore, fire effects had to be estimated using the total biomass for these areas. To use total biomass, a correlation had to be established between total fuel load and the amount of emissions that might result from burning that load so that fire effects were comparable for both forest and non-forest areas. The correlations between load and emissions were established using published emission factors for sagebrush and chaparral (DeBano and others 2005; Fahnestock and Agee 1983; Frandsen 1987; Ottmar and others 1996; Sandberg and others 2002; Taylor and Sherman 1996).

Several assumptions were made to assign maximum soil temperatures as a fire effect in non-forested areas. In general, the heat pulse was considered short in these ecosystems and burn severities were considered minimal (Molina and Llinares 2001; Ryan 2002), thus maximum soil temperatures were also assumed to be low. Soil-temperatures in the non-forested areas were considered to be equivalent to, or less than, the lowest temperatures obtained by burning the forest fuel beds, which were obtained in Effects Groups 1, 5, and 6. None of the temperatures for these Effects Groups exceeded 400 °F (200 °C).

Table 2—Median loadings for each forested FLM by fuel component in tons per acre (T $acre^{-1}$) and kilograms per meter squared (kg m^{-2}).

		Litter		Duff		1-hour		10-hour		100-hour		Logs	
FLM	Effects group	T $acre^{-1}$	kg m^{-2}	T $acre^{-1}$	kg m^{-2}	T $acre^{-1}$	kg m^{-2}	T $acre^{-1}$	kg m^{-2}	T $acre^{-1}$	kg m^{-2}	T $acre^{-1}$	kg m^{-2}
011	01	0.18	0.04	0.00	0.00	0.07	0.01	0.08	0.02	0.04	0.01	0.00	0.00
012	01	0.27	0.06	0.00	0.00	0.27	0.06	1.56	0.35	2.68	0.60	2.59	0.58
013	01	2.50	0.56	1.20	0.27	0.23	0.05	1.52	0.34	2.05	0.46	2.23	0.50
021	02	1.16	0.26	3.30	0.74	0.20	0.04	0.64	0.14	0.67	0.15	0.94	0.21
031	03	1.87	0.42	7.31	1.64	0.27	0.06	0.89	0.20	1.07	0.24	1.52	0.34
041	04	2.41	0.54	0.00	0.00	0.27	0.06	1.67	0.37	2.57	0.58	2.59	0.58
051	05	1.52	0.34	15.83	3.55	0.16	0.04	1.10	0.25	1.42	0.32	1.43	0.32
061	06	0.89	0.20	3.61	0.81	0.29	0.06	1.31	0.29	2.46	0.55	16.73	3.75
062	06	1.34	0.30	20.56	4.61	0.14	0.03	0.93	0.21	1.25	0.28	1.61	0.36
063	06	1.52	0.34	17.04	3.82	0.20	0.04	1.39	0.31	2.38	0.53	7.76	1.74
064	06	2.90	0.65	25.87	5.80	0.31	0.07	1.11	0.25	1.66	0.37	3.35	0.75
071	07	2.19	0.49	9.37	2.10	0.45	0.10	1.42	0.32	2.19	0.49	11.51	2.58
072	07	3.79	0.85	16.77	3.76	0.38	0.09	1.01	0.23	1.33	0.30	2.85	0.64
081	08	0.89	0.20	3.97	0.89	0.33	0.07	1.16	0.26	2.65	0.60	36.35	8.15
082	08	3.79	0.85	17.71	3.97	0.53	0.12	1.58	0.35	3.16	0.71	12.04	2.70
083	08	2.50	0.56	11.91	2.67	0.50	0.11	1.58	0.36	2.87	0.64	22.43	5.03
091	09	1.16	0.26	45.94	10.30	0.31	0.07	1.42	0.32	1.66	0.37	2.90	0.65
092	09	3.03	0.68	14.85	3.33	0.55	0.12	1.60	0.36	3.32	0.74	46.12	10.34
093	09	6.20	1.39	32.83	7.36	0.57	0.13	1.40	0.31	2.40	0.54	21.50	4.82
101	10	9.99	2.24	99.99	22.42	0.39	0.09	0.94	0.21	1.08	0.24	1.61	0.36
102	10	17.97	4.03	10.48	2.35	0.14	0.03	0.49	0.11	1.05	0.24	4.59	1.03

Six FLM classes were created for non-forest areas using the following procedure:

1. We used the $PM_{2.5}$ emissions at the upper and lower boundaries of each Effects Group (from the forest classification) as upper and lower emission limits in the non-forest classification.
2. We calculated the amount of total plot fuel load needed to produce the emission values at the upper and lower boundaries of the selected Effects Group using published emission factors. The formula used for calculating total fuel load from emissions at the Effects Group boundaries was:

   $$L = \frac{E_{pm2.5}}{0.9(EF)}, \text{ where}$$

   L is the total plot fuel load in T $acre^{-1}$ (kg m^{-2}),
   $E_{pm2.5}$ is the $PM_{2.5}$ emissions in lb ac^{-1} (MG km^{-2}), and
   EF is either (a) the $PM_{2.5}$ emissions factor for sagebrush (26.7 lb ton^{-1} or 13.35 kg per metric megagram [MG^{-1}]) **OR** (b) the $PM_{2.5}$ emissions factor for chaparral or herbaceous (17.3 lb ton^{-1} or 8.65 kg MG^{-1}), depending on whether you are calculating sagebrush load or non-sagebrush and using English or metric measures.

   (**Note**: The emissions factors were taken from the Smoke Management Guide [National Wildfire Coordinating Group 2001]. The equation assumes 90 percent consumption of the shrub and herbaceous fuel beds. Fuel consumption in herb and shrub systems is highly variable but 90 percent consumption was used to limit complexity and to represent a typical "worst case" scenario for emissions production. According to Green [1970], even heavily loaded fuel beds such as chaparral can approach consumption levels of 90%. Emissions factors for grassland dominated fuels are similar or slightly lower than in shrub dominated systems [National Wildfire Coordinating Group 1985] so we estimated grassland emissions using the chaparral emissions factors).
3. We selected all non-forested plots from the data set. Most of these plots were from the grasslands and shrublands of the western United States.
4. We compared the total fuel load of each individual plot to the upper and lower fuel load limits that were calculated for each Effects Group in step 2.

We then assigned plots to the Effects Group with the appropriate range of total load and calculated the median emissions value for each Effects Group.

5. We calculated the total on-site fuel load required to obtain those emissions for each of the three Effects Groups using the median emissions value and the equation above (see table 3). We established the range of loadings for each Effects Group by plotting each Effects Group's loading distribution (Appendix I).

The non-forest FLMs should not be used for tall (>6 ft) shrub communities (for example, California's tall chaparral communities). Tall shrub communities have more biomass than the shrub communities analyzed for this classification, which results in higher fuel loads. They also have a more open structure than short shrub communities, which affects fuel bulk density. With the total fuel load higher, vegetation more volatile, and bulk densities structurally optimal for fuel consumption, the fuels in these systems can burn more completely and at higher intensities. Intense burning can lead to substantially higher emissions and soil heating compared to the minimal-fuel, low-severity fires typical of the non-forested areas classified for this study. Developing FLMs that are appropriate for these shrub communities will require further research.

How Can Managers Use FLMs?

Managers can use FLMs to quickly estimate the fuel loads of six fuel components while in the field. FLMs can be an economical alternative for fuels sampling because sampling can be done quickly or without visiting an area. FLMs can also be easily integrated with other types of plot-level data, such as stand structure or vegetation cover, to create a more comprehensive description of a plot's characteristics with little additional field sampling. Because FLMs can be consistently and accurately identified in the field, they can also be used as map units of fuel loadings. The map units can be used to quantify fire effects and plan, prioritize, and implement fuel treatments. Map accuracy can be easily assessed because the map units can be checked in the field using the FLM identification key presented in this report. The FLM classification also allows users to quickly enter fuel loading data into simulation models to compute fire effects. For example, fuel descriptions can be input into FOFEM using a FLM number instead of inputting detailed information on six separate fuel components.

Many ecosystems were not represented in the FLM fuel bed data so we do not recommend that this classification be applied in some rare ecosystems, such as pocosin bogs, boreal forests, deserts, and some hardwood forest types. More targeted sampling and additional analysis will be required to extend this FLM classification system to these special systems.

Identification of Fuel Loading Models in the Field

FLMs are identified using the tools provided in this field guide, including (1) a field form that outlines which fuel components must be sampled and which FLM key to use (Appendix A); (2) FLM keys to forested and non-forested vegetation types (Appendices E, F, and I); and (3) photographic examples of threshold load values that are specified in the FLM keys (Appendices C, D, G, and H). The field form has space to record all the fuel load information collected in the field and to assign the FLM that summarizes the plot's fuel beds.

During the identification of FLMs, users must make some coarse measurements or visual estimates of fuel load components within their sample area. For users who lack experience visually estimating fuel load, we provide photographs of known fuel loads in this field guide to compare with plot conditions (Appendices C, D, G, and H). Users only need to decide whether the

Table 3—Median of plot loadings for non-forested FLMs.

FLM	Effects group	System	Median plot load T acre^{-1}	Median plot load kg m^{-2}
014	01	Sagebrush	0.75	0.17
053	05	Sagebrush	21.0	4.70
065	06	Sagebrush	40.9	9.20
015	01	Chaparral and herbaceous	1.15	0.26
054	05	Chaparral and herbaceous	32.5	7.30
066	06	Chaparral and herbaceous	63.2	14.2

load for a specific fuel component on their plot appears greater or less than the load shown in the photographs. We also provide three problem sets to practice identifying FLMs from known fuel loads (Appendix J). Each example in the problem set has a photograph of on-site fuels, gives the estimated on-site fuel components, and provides step-by-step instructions to key the data to a specific FLM class.

To key FLMs on your plot, first determine if you are in a forested or non-forested area, then follow the process detailed in the appropriate section below or the steps outlined in the plot form presented in Appendix A. To be considered a forested area, canopy cover of trees must be greater than 10% or the habitat type should key to a forest type. Non-forested areas can consist of sagebrush canopy cover, which have at least 10% canopy cover of *Artemisia* spp., or non-sagebrush canopy cover, whose fuels are derived from other shrubs or grasses that are <6 ft (2 m) tall.

Identifying an FLM in Forests

Step 1: Estimate duff and litter depths. Do this at several points within the sampling unit or plot and take an average of your measurements. Methods for defining and measuring duff and litter can be found in Lutes and others (2006). Record the average depth in the appropriate place on the plot form (Appendix A).

Step 2: Pick an appropriate duff and litter bulk density value. Consult the scientific literature or local experts before you go into the field so that you choose the most appropriate bulk density value for your area. Typical bulk density values are provided in Appendix B, but they may not be realistic for all parts of the United States. You can interpolate between these bulk density values to get values that are more appropriate for your area.

Step 3: Calculate the duff and litter biomass. Biomass is calculated as thickness (depth) multiplied by bulk density (T $acre^{-1}$ in^{-1} or g cm^{-3}). Examples of duff and litter biomasses that have been calculated using common bulk densities are provided in Appendix B. Record the biomasses in the appropriate places in Appendix A.

Step 4: Estimate the fine-woody debris loading. Use Appendix C to determine if the fine-woody debris load is less than 2.4 T $acre^{-1}$ (0.5 kg m^{-2}). Record the load as greater or less than 2.4 T $acre^{-1}$ (0.5 kg m^{-2}) on the field form. If you need to record more precise estimates of the fine-woody component for project objectives, measure the 1 hr, 10 hr, and 100 hr fuels using standard fuel sampling procedures or estimate loads using the methods described in Keane and Dickinson (2007). Record values on the plot form in Appendix A.

Step 5: Estimate log loadings (1000 hr fuels). Precision is important for this fuel component, so we have provided photographs of known log loads (photoloads) to help users estimate this component more accurately in the field. Use the photoloads (Appendix D) to decide whether you have the minimum fuel loads required in the key. Record the value on the plot form in Appendix A.

Step 6: Key to the appropriate FLM. Using the values that you recorded on the plot form, follow the directions through the FLM key for forested areas. Use Appendix E if you have measured the loads in tons per acre and Appendix F if you have measured loads in kilograms per meter squared. Stop at the FLM that best fits your estimates. Watch the greater than or equal to (≥) and less than (<) signs in the key to be sure you are making the correct decisions for the pathways.

Step 7: Record the FLM number on the field form. If you need fuel load values for individual load components to input into a software application, the median loads for each FLM are summarized in table 2.

Identifying an FLM in Grasslands, Shrublands, or Chaparral

Non-forested areas can be keyed to an FLM in the field using several methods, including (a) making visual estimates of the total fuel load using photo series guides, (b) calculating total fuel load from counts or measures of separate fuel components, or (c) clipping and weighing all on-site fuels. The FLM key for the non-forested areas requires an estimate or measurement of total site fuel load that includes FWD, coarse woody debris, duff, litter, and shrub and herbaceous cover. To help users visualize total plot loads, we provide examples of measured site loads using photographs from several photo series guides (Ottmar and Vihnanek 2000; Ottmar and others 2000; Wright and others 2002). The photo series examples contain total load values for each picture plus a list of the individual fuel components that comprise the total load. Any photo series guide can be used to estimate site load. The photographs and data used in this guide are from the Digital Photo Series developed by the U.S.

Forest Service, Pacific Northwest Research Station, Fire and Environmental Research Applications Team (http://depts.washington.edu/nwfire/dps/). However, users may want to use a photo series guide that is specific to their ecosystem or landscape. As long as the photo series has measures of total site load and can be compared with the values required in the non-forest FLM key, it can be used to estimate loads and identify FLMs. Users should visually compare the total loads on their plot with the photo series photographs and decide if their plot looks like it has more or less load than the photos. When total fuel load is determined, the non-forest FLMs are easily identified. The identification process is as follows:

Step 1: Determine the cover type. In non-forested environments, the FLM key is based on whether the fuel bed is created by sagebrush or non-sagebrush vegetation. Sagebrush plots must have at least 10% canopy cover of *Artemisia* spp. Remember, the FLMs were not developed for areas with shrubs greater than 6 ft tall.

Step 2: Estimate the total fuel load on site. Compare your site conditions with the photographs of known fuel loads in Appendix G (sagebrush sites) or Appendix H (non-sagebrush sites). Note that each photo series already includes duff and litter in its total load value so you need only to match the picture with your plot conditions to assign an approximate load. In the appropriate boxes on the field form (Appendix A), record the number and total load of the photo series that most closely matches load on your plot.

Step 3: Key to the appropriate FLM. Use the total load determined in step 2 and match it with the load ranges in the non-forested area key (Appendix I) to pick the FLM that best describes the cover type and load estimate for your plot.

Step 4: Record the FLM number on the field form. If you need fuel-load values for individual load components to input into a software application, the median loads for each FLM are summarized in table 3.

Management Advice

As users begin to apply this classification, we would like to stress several points about its use and applicability. First, make this classification as convenient for your work situation as possible. You can use this classification without using the field form provided in this paper. Simply add fields on your normal field form if it makes recording the FLM data more convenient. By using the key regularly, we are confident that you will soon be able to recognize fuel load thresholds and identify FLMs in your area very quickly so you should make recording the data as convenient as possible. Second, there may be times when the fuels on your site may not seem to fit into this classification. In these situations, first ensure that you are in an appropriate vegetation type for the FLM key. As stated previously in this paper, do not use this key in rare ecosystems such as pocosin swamps or on sites with tall shrub vegetation (>6 ft tall). If you are in an applicable vegetation type and are unable to make the key fit, make sure that you are reading the greater than or equal to (≥) and less than (<) symbols correctly, as they can be confusing when you start out. If one column does not seem to fit your fuel load data, then step back a row and try again, paying close attention to these symbols. This key is designed to help you make estimates accurately and quickly. Estimating fuels takes practice, so recheck your field estimates to make sure that you have accurately portrayed the on-site fuels. Some of the FLMs in this classification have very small differences in fuel components, such as duff thickness, which may require measurement instead of estimation of their values. When you begin your identification of FLMs, pull out the ruler and measure these critical thicknesses, if necessary. If you still have trouble fitting a site's characteristics to the FLM key after checking all of these items, remember that this key misclassified plots 34% of the time during its development and this could be what is affecting your ability to correctly identify an FLM (Lutes and others, in press). New classification systems invariably need adjustments as they are applied to new locations and used by more people and programs. As more plots and data are collected and analyzed across ecosystems, the extent of the FLM misclassification problem can be investigated and rectified to improve the FLM classification. Finally, and perhaps most importantly, we want to stress that this classification does have limitations. Do not attempt to extrapolate fire effects for FLMs to effects caused by canopy fuel consumption. The FLM key is designed to predict fire effects only from the surface fuels.

FLMs constitute an important advance in fuel classification because they relate actual on-site fuels to the smoke and soil heating that may result from burning those fuels. As such, the FLMs can be an important tool in many fire studies and management decisions. There may be fire effects in addition to smoke and soil heating that could be incorporated into the FLM classes in the future that would make them more pertinent to some wildlife, vegetation, and microbe studies. However, the current FLM classes are a positive step in the process to create a fuels classification that directly relates cause to effect in fuels consumption, and they should be an improvement over earlier fuel classification methods for many applications.

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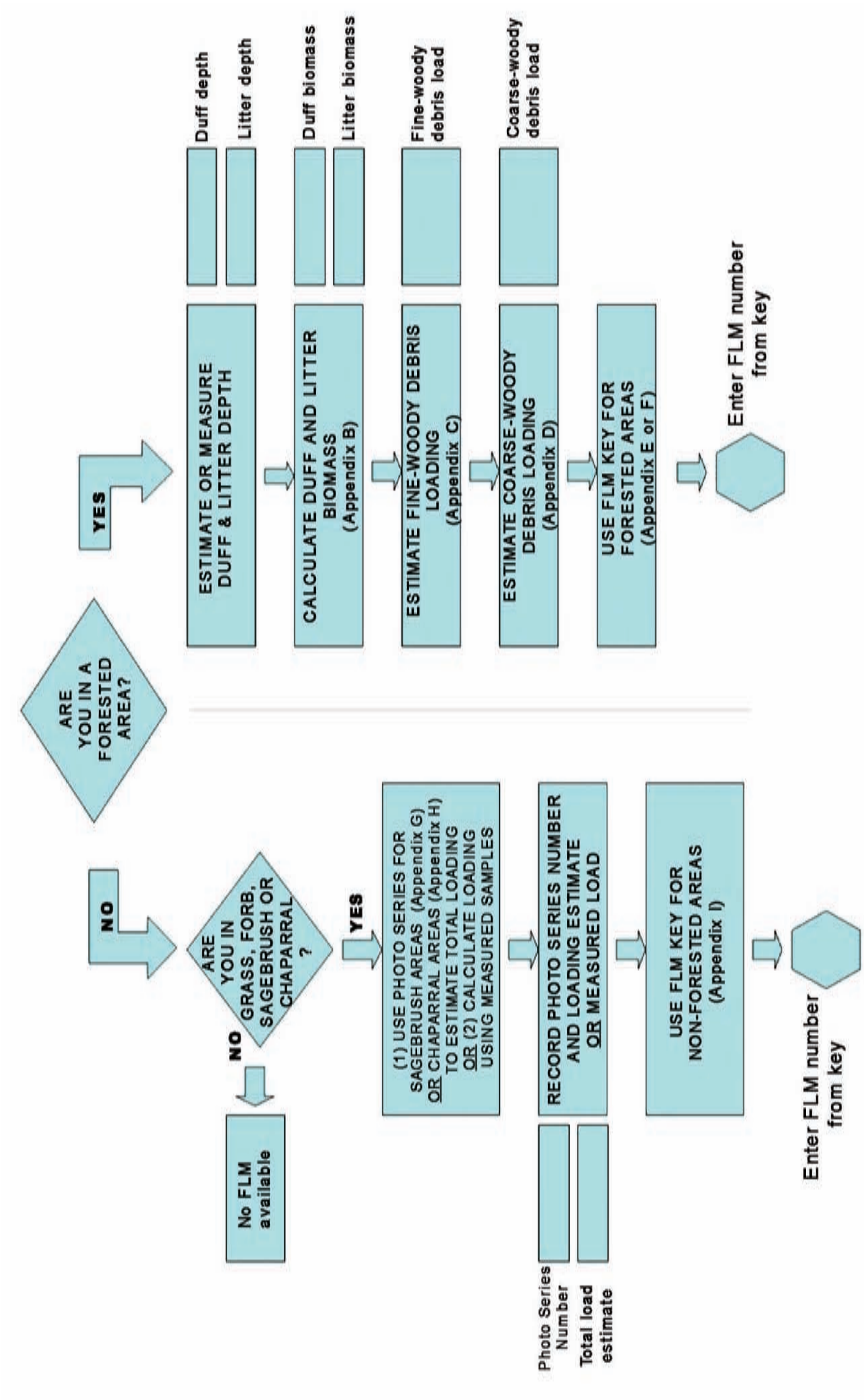
Appendix A—Field Form for Recording FLM Data



Appendix B—Tables for Calculating Biomass of Duff and Litter in Forested Areas

Table B1. Biomass calculation in English units (T acre^{-1})

Find your duff or litter depth in the left column of each table and pick one density value along the top row. Biomass is the value at the intersection of these columns. Use these tables for English units. Use the tables on the next page for metric units.

If you chose a different bulk density than is listed in these tables, multiply your duff depth or litter depth by bulk density to get biomass in T acre^{-1}.

	Duff bulk density (T acre^{-1} in^{-1}) [a]			
Duff	**4.0**	**7.0**	**12.0**	**15.0**
depth (in.)	**Biomass (T acre^{-1})**			
0.10	0.40	0.70	1.20	1.50
0.50	2.00	3.50	6.00	7.50
1.00	4.00	7.00	12.00	15.00
1.50	6.00	10.50	18.00	22.50
2.00	8.00	14.00	24.00	30.00
2.50	10.00	17.50	30.00	37.50
3.00	12.00	21.00	36.00	45.00
4.00	16.00	28.00	48.00	60.00
6.00	24.00	42.00	72.00	90.00
8.00	32.00	56.00	96.00	120.00
10.00	40.00	70.00	120.00	150.00
12.00	48.00	84.00	144.00	180.00
14.00	56.00	98.00	168.00	210.00

	Litter bulk density (T acre^{-1} in^{-1}) [b]			
Litter	**1.5**	**2.2**	**4.0**	**6.0**
depth (in.)	**Biomass (T acre^{-1})**			
0.10	0.15	0.22	0.40	0.60
0.20	0.30	0.44	0.80	1.20
0.50	0.75	1.10	2.00	3.00
1.00	1.50	2.20	4.00	6.00
1.50	2.25	3.30	6.00	9.00
2.00	3.00	4.40	8.00	12.00

[a] **Examples of duff bulk densities from common stand types are:** Sierra Nevada ponderosa pine, 2 to 8 T acre^{-1} in^{-1}; white fir, 5 to 16 T acre^{-1}in^{-1} (Stephens and others 2004); northern Rocky Mountain subalpine fir, 8 to12 T acre^{-1} in^{-1}; Douglas-fir, 7 to 17 T acre^{-1} in^{-1}; western red cedar, 10 to 15 T acre^{-1} in^{-1}; western hemlock, 10 to 15 T acre^{-1} in^{-1} (Brown 1981).

[b] **Examples of litter bulk densities from common stand types are:** northern Rocky Mountain ponderosa pine, 1.2 to 5 T acre^{-1} in^{-1}; low elevation subalpine fir, 0.2 to 19 T acre^{-1} in^{-1}; high elevation subalpine fir, 5 to 13 T acre^{-1} in^{-1} (Snell 1979); Douglas-fir, 3 to 7 T acre^{-1} in^{-1}; western red cedar, 5 to 9 T acre^{-1} in^{-1} (Brown 1981).

Table B2. Biomass calculation in metric units (g cm^{-2})

Find your duff or litter depth in the left column of each table and pick one density value along the top row. Biomass is the value at the intersection of these columns.

If you chose a different bulk density than is listed in these tables, multiply your duff depth or litter depth by bulk density to get biomass in g cm^{-2}.

Duff depth (cm)	Duff bulk density (g cm^{-3}) [c] 0.04	0.06	0.11	0.13
	Biomass (g cm^{-2})			
0.50	0.02	0.03	0.06	0.07
1.00	0.04	0.06	0.11	0.13
2.50	0.10	0.15	0.28	0.33
4.00	0.16	0.24	0.44	0.52
5.00	0.20	0.30	0.55	0.65
6.50	0.26	0.39	0.72	0.85
7.50	0.30	0.45	0.83	0.98
10.00	0.40	0.60	1.10	1.30
15.00	0.60	0.90	1.65	1.95
20.00	0.80	1.20	2.20	2.60
25.50	1.02	1.53	2.81	3.32
30.50	1.22	1.83	3.36	3.97
35.50	1.42	2.13	3.91	4.62

Litter depth (cm)	Litter bulk density (g cm^{-3}) [d] 0.01	0.02	0.04	0.05
	Biomass (g cm^{-2})			
0.20	0.00	0.00	0.01	0.01
0.50	0.01	0.01	0.02	0.03
1.00	0.01	0.02	0.04	0.05
4.00	0.04	0.08	0.16	0.20
5.00	0.05	0.10	0.20	0.25
6.00	0.06	0.12	0.24	0.30

[c] **Examples of duff bulk densities from common stand types are**: Sierra Nevada ponderosa pine, 0.01 to 0.07 g cm^{-3}; white fir, 0.04 to 0.14 g cm^{-3} (Stephens and others 2004); northern Rocky Mountain subalpine fir, 0.07 to 0.11 g cm^{-3}; Douglas-fir, 0.06 to 0.15 g cm^{-3}; western red cedar, 0.09 to 0.13 g cm^{-3}; western hemlock, 0.09 to 0.13 g cm^{-3} (Brown 1981).

[d] **Examples of litter bulk densities from common stand types are**: northern Rocky Mountain pine, 0.01 to 0.04 g cm^{-3}; low elevation subalpine fir, 0.00 to 0.17 g cm^{-3}; high elevation subalpine fir, 0.04 to 0.11 g cm^{-3} (Snell 1979); Douglas-fir, 0.03 to 0.06 g cm^{-3}; western red cedar, 0.04 to 0.08 g cm^{-3} (Brown 1981).

Appendix C—Fine-Woody Debris Loadings for Forested Areas

Figure C-1—Fine-woody debris, **2.4 T acre^{-1}** (0.53 kg m^{-2}). Photograph is a composite of 1 hour, 10 hour, and 100 hour photoloads of fuels in approximately a 1:2:1 ratio. Photograph covers 11 ft^2 (1 m^2). Modified from Keane and Dickinson (2007).

Figure C-2—Fine-woody debris, **2.4 T acre^{-1}** (0.53 kg m^{-2}). Photograph uses same fuels as photograph C-1 but in approximately a 1:4:6 ratio. Photograph covers 11 ft^2 (1 m^2). Modified from Keane and Dickinson (2007).

Appendix D—Photoloads of Coarse Woody Debris Loadings for Forested Areas

Figure D-1—Coarse-woody debris loading of **4.5 T acre^{-1}** (1.0 kg m^{-2}) made from 6-inch diameter (15.24-cm) "logs" constructed from cardboard tubes. Total log length = 43 ft (13 m). Each yellow square is 1,075 ft^2 (100 m^2). White staff is 5.5 ft (1.6 m) tall. Contrast with the same loading made from 10-inch (25.4-cm) logs in D-2. Modified from Keane and Dickinson (2007).

Figure D-2—Coarse-woody debris loads of **4.5 T acre^{-1}** (1.0 kg m^{-2}) made from 10-inch diameter (25.4-cm) "logs" constructed from cardboard tubes. Total log length = 16 ft (4.8 m). Each yellow square is 1,075 ft^2 (100 m^2). White staff is 5.5 ft (1.6 m) tall. Modified from Keane and Dickinson (2007).

Figure D-3—Coarse-woody debris loads of **8.2 T acre^{-1}** (1.8 kg m^{-2}) made from 6-inch (15.4-cm) diameter logs. Total log length = 78 ft (23.5 m). Contrast with same loading from 10-inch (25.4-cm) diameter debris in D-4. Modified from Keane and Dickinson (2007).

Figure D-4—Coarse-woody debris loads of **8.2 T acre^{-1}** (1.8 kg m^{-2}) made from 10-inch (25.4-cm) diameter logs. Total log length = 28 ft (8.5 m). Modified from Keane and Dickinson (2007).

Figure D-5—Coarse-woody debris loads of **10.1 T acre^{-1}** (2.3 kg m^{-2}) using 6-inch (15.4-cm) diameter logs. Total log length = 102 ft (31 m). Modified from Keane and Dickinson (2007).

Figure D-6—Coarse-woody debris loads of **10.1 T acre^{-1}** (2.3 kg m^{-2}) using 10-inch (25.4-cm) diameter logs. Total log length = 36.5 ft (11 m). Modified from Keane and Dickinson (2007).

Figure D-7—Coarse-woody debris loads of **15.9 T acre^{-1}** (3.6 kg m^{-2}) using 6-inch (15.24-cm) diameter logs. Total log length = 158 ft (48 m). Modified from Keane and Dickinson (2007).

Figure D-8—Coarse-woody debris loads of **15.9 T acre^{-1}** (3.6 kg m^{-2}) using 10-inch (25.4-cm) diameter logs. Total log length = 57 ft (17 m). Modified from Keane and Dickinson (2007).

Figure D-9—Coarse-woody debris loads of **28.3 T acre^{-1}** (6.4 kg m^{-2}) using 10-inch (25.4-cm) diameter logs. Total log length = 101 ft (30.5 m). A comparison of loading with 6-inch (15.24-cm) diameter logs is not provided, but the total log length using 6-inch (15.24-cm) diameter logs would equal 280 feet (85 m). Modified from Keane and Dickinson (2007).

Figure D-10—Coarse-woody debris loads of **35.1 T acre^{-1}** (7.9 kg m^{-2}) using 10-inch (25.4-cm) diameter logs. Total log length = 125 ft (38 m). A comparison of loading with 6-inch (15.24-cm) diameter logs is not provided, but the total log length using 6-inch (15.24-cm) diameter logs would equal 346 feet (105.5 m). Modified from Keane and Dickinson (2007).

Appendix E—FLM Key for Forested Areas (T acre^{-1})

Step 1: Select the duff biomass range (in orange) that best fits the calculated biomass value that you entered on the field form (Appendix A).

Step 2: Follow down the appropriate duff biomass column and match all remaining column criteria to your field values for FWD load, litter biomass, or log load as required. Pay particular attention to greater than or equal to (≥) and less than (<) signs. All loadings are in tons per acre (T acre^{-1}). Non-critical elements for each section are marked with "≥0". Examples of how to use the key are found in the main text.

Step 3: Use the photographs of known loadings in Appendix C and D to make critical loading decisions if needed. References are placed in this key where these photographs may be required. The pictures are referenced by a letter (for the Appendix) and a number (for the picture number within the appendix). For example, C-1 refers to Appendix C, photo 1.

Step 4: From the bottom of the column, read the resulting fuel-load model number that matches all of your load criteria. If a lower row does not match your observed conditions, step back up one row and select another column to the right.

What is your Duff Biomass?	Duff not present			0.04 to 1.89 T acre^{-1}			1.9 to 4.99 T acre^{-1}		
What is your FWD load?	<2.4 C-1, C-2	≥2.4 C-1, C-2	≥2.4 C-1, C-2	<2.4 C-1, C-2	≥2.4 C-1, C-2	≥2.4 C-1, C-2	≥0		
What is your Litter Biomass?	≥0	<0.93	≥0.93	≥0	<0.93	≥0.93	≥0		
What is your CWD load?	≥0	≥0	≥0	≥0	≥0	≥0	<10.1 D-6	10.1 to 28.29 D-6, D-9	≥28.3 D-9
The FLM is:	11	12	41	11	12	13	21	61	81

What is your Duff Biomass?	5 to 10.24 T acre^{-1}				
What is your Litter Biomass?	<10.8	≥10.8	≥0	≥0	≥0
What is your CWD load?	<8.2 D-3, D-4	<8.2 D-3,D-4	8.2 to 15.89 D-4, D-8	15.9 to 35.0 D-8, D-10	≥35.1 D-10
The FLM is:	31	102	71	83	92

What is your Duff Biomass?	10.25 to 13.29 T acre^{-1}				
What is your Litter Biomass?	<10.8	≥10.8	≥0	≥0	≥0
What is your CWD load?	<8.2 D-3,D-4	<8.2 D-3, D-4	8.2 to 15.89 D-4, D-8	15.9 to 35.0 D-8, D-10	≥35.1 D-10
The FLM is:	31	102	71	83	92

What is your Duff Biomass?	13.3 to 18.89 T acre $^{-1}$							
What is your Litter Biomass?	<2.6				≥2.6			
What is your CWD load?	<4.5 D-1, D-2	4.5 to 15.89 D-2, D-8	15.9 to 35.0 D-8, D-10	≥35.1 D-10	<4.5 D-1, D-2	4.5 to 15.89 D-2, D-8	15.9 to 35.0 D-8, D-10	≥35.1 D-10
The FLM is:	51	63	83	92	72	82	83	92

What is your Duff Biomass?	18.9 to 21.69 T acre $^{-1}$							
What is your Litter Biomass?	<2.6				≥2.6			
What is your CWD load?	<4.5 D-1, D-2	4.5 to 15.89 D-2, D-8	15.9 to 35.0 D-8, D-10	≥35.1 D-10	<10.2 D-6	10.2 to 15.89 D-6, D-8	15.9 to 35.0 D-8, D-10	≥35.1 D-10
The FLM is:	62	63	83	92	72	82	83	92

What is your Duff Biomass?	21.7 to 26.29 T acre $^{-1}$			26.3 to 37.69 T acre $^{-1}$			37.7 to 59.79 T acre $^{-1}$			≥59.8 T acre $^{-1}$
What is your Litter Biomass?	≥0	≥0	≥0	≥0	≥0	≥0	≥0	≥0	≥0	≥0
What is your CWD load?	<15.9 D-8	15.9 to 35.0 D-8, D-10	≥35.1 D-10	<15.9 D-8	15.9 to 35.0 D-8, D-10	≥35.1 D-10	<15.9 D-8	15.9 to 35.0 D-8, D-10	≥35.1 D-10	≥0
The FLM is:	64	83	92	64	93	92	91	93	92	101

Appendix F—FLM Key for Forested Areas (kg m^{-2})

Step 1: Select the duff biomass range (in orange) that best fits the calculated biomass value that you entered on the field form (Appendix A).

Step 2: Follow down the appropriate duff biomass column and match all remaining column criteria to your field values for litter biomass, FWD load, or log load as required. Pay particular attention to greater than or equal to (≥) and less than (<) signs. All loadings are in kilograms per meter squared (kg m^{-2}). Non-critical elements for each section are marked with "≥0". Examples of how to use the key are found in the main text.

Step 3: Use the photographs of known loadings in Appendix C and D to make critical loading decisions if needed. References are placed in this key where these photographs may be required. The pictures are referenced by a letter (for the Appendix) and a number (for the picture number within the appendix). For example, C-1 refers to Appendix C, photo 1.

Step 4: From the bottom of the column, read the resulting fuel-load model number that matches all of your load criteria. If a lower row does not match your observed conditions, step back up one row and select another column to the right.

What is your Duff Biomass?	Duff not present			0.01 to 0.42 kg m^{-2}			0.43 to 1.10 kg m^{-2}		
What is your FWD load?	<0.53 C-1, C-2	≥0.53 C-1, C-2	≥0.53 C-1, C-2	<0.53 C-1, C-2	≥0.53 C-1, C-2	≥0.53 C-1, C-2	≥0		
What is your Litter Biomass?	≥0	<0.21	≥0.21	≥0	<0.21	≥0.21	≥0		
What is your CWD load?	≥0	≥0	≥0	≥0	≥0	≥0	<2.27 D-6	2.27 - 6.34 D-6, D-9	≥6.35 D-9
The FLM is:	11	12	41	11	12	13	21	61	81

What is your Duff Biomass?	1.11 to 2.29 kg m^{-2}					2.3 to 2.98 kg m^{-2}				
What is your Litter Biomass?	<2.43	≥2.43	≥0	≥0	≥0	<2.43	≥2.43	≥0	≥0	≥0
What is your CWD load?	<1.83 D-3, D-4	<1.83 D-3,D-4	1.83 to 3.56 D-4, D-8	3.57 to 7.87 D-8, D-10	≥7.88 D-10	<1.83 D-3,D-4	<1.83 D-3, D-4	1.83 to 3.56 D-4, D-8	3.57 to 7.87 D-8, D-10	≥7.88 D-10
The FLM is:	31	102	71	83	92	31	102	71	83	92

What is your Duff Biomass?	2.99 to 4.22 kg m $^{-2}$							
What is your Litter Biomass?	<0.62				≥0.62			
What is your CWD load?	<1.01 D-1, D-2	1.01 to 3.56 D-2, D-8	3.57 to 7.87 D-8, D-10	≥7.88 D-10	<1.01 D-1, D-2	1.01 to 3.56 D-2, D-8	3.57 to 7.87 D-8, D-10	≥7.88 D-10
The FLM is:	51	63	83	92	72	82	83	92

What is your Duff Biomass?	4.23 to 4.86 kg m $^{-2}$							
What is your Litter Biomass?	<0.62				≥0.62			
What is your CWD load?	<1.01 D-1, D-2	1.01 to 3.56 D-2, D-8	3.57 to 7.87 D-8, D-10	≥7.88 D-10	<2.29 D-6	2.29 to 3.56 D-6, D-8	3.57 to 7.87 D-8, D-10	≥7.88 D-10
The FLM is:	62	63	83	92	72	82	83	92

What is your Duff Biomass?	4.87 to 5.89 kg m $^{-2}$			5.9 to 8.44 kg m $^{-2}$			8.45 to 13.40 kg m $^{-2}$			≥13.41 kg m $^{-2}$
What is your Litter Biomass?	≥0	≥0	≥0	≥0	≥0	≥0	≥0	≥0	≥0	≥0
What is your CWD load?	<3.57 D-8	3.57 to 7.87 D-8, D-10	≥7.88 D-10	<3.57 D-8	3.57 to 7.87 D-8, D-10	≥7.88 D-10	<3.57 D-8	3.57 to 7.87 D-8, D-10	≥7.88 D-10	≥0
The FLM is:	64	83	92	64	93	92	91	93	92	101

Appendix G—Representative Fuel Loads in Sagebrush Areas

Surface material	1.53 T acre^{-1}	0.34 kg m^{-2}
Downed woody	4.19	0.94
Vegetation biomass	4.94	1.12
Total biomass	10.66	2.34

Figure G-1—Total biomass = **11.0 T acre^{-1}** (2.5 kg m^{-2}). From photo series HI-S 03, Wright and others (2002). **Note:** This site is not a sagebrush site, but it is typical of 11 T acre^{-1} load.

Surface material	4.9 T acre^{-1}	1.10 kg m^{-2}
Downed woody	3.23	0.72
Vegetation biomass	7.17	1.61
Total biomass	15.30	3.43

Figure G-2—Total biomass = **15 T acre^{-1}** (3.4 kg m^{-2}). Photo series SWSB 11, Ottmar and others (2000).

Sagebrush Sites

Appendix H—Representative Fuel Loads in Non-Sagebrush Areas

Surface material	0.66 T $acre^{-1}$	0.15 kg m^{-2}
Downed woody	--	--
Vegetation biomass	1.66	0.37
Total biomass	2.32	0.52

Figure H-1—Total biomass = **2 T $acre^{-1}$** (0.45 kg m^{-2}). Photo series TP 08, Ottmar and others (2000).

Surface material	2.39 T $acre^{-1}$	0.54 kg m^{-2}
Downed woody	--	--
Vegetation biomass	10.00	2.24
Total biomass	12.39	2.78

Figure H-2—Total biomass approximately **11.0 T $acre^{-1}$** (2.5 kg m^{-2}). Photo series P-S 04, Ottmar and Vihnanek(2000).

Grass - Shrub - Chaparral Sites

Surface material	2.79 T acre^{-1}	0.63 kg m^{-2}
Downed woody	--	--
Vegetation biomass	9.97	2.23
Total biomass	12.76	2.86

Figure H-3—Total biomass approximately **11.0 T acre^{-1}** (2.5 kg m^{-2}). Photo series P-S 05, Ottmar and Vihnanek (2000).

Surface material	0.0 T acre^{-1}	0.0 kg m^{-2}
Downed woody	--	--
Vegetation biomass	17.6	4.0
Total biomass	17.6	4.0

Figure H-4—Total biomass = **18 T acre^{-1}** (4.03 kg m^{-2}). Photo series CH 09, Ottmar and others (2000).

Grass - Shrub - Chaparral Sites

Surface material	0.0 T acre^{-1}	0.0 kg m^{-2}
Downed woody	--	--
Vegetation biomass	17.6	3.95
Total biomass	17.6	3.95

Figure H-5—Total biomass approximately **19.0 T acre^{-1}** (4.26 kg m^{-2}). Photo series HI-S 06, Wright and others (2002).

Surface material	3.85 T acre^{-1}	0.86 kg m^{-2}
Downed woody	--	--
Vegetation biomass	19.30	4.33
Total biomass	23.15	5.19

Figure H-6—Total biomass approximately **19.0 T acre^{-1}** (4.26 kg m^{-2}). Photo series P-S 06, Ottmar and Vihnanek (2000).

Grass - Shrub - Chaparral Sites

Surface material	0.0 T acre^{-1}	0.0 kg m^{-2}
Downed woody	--	--
Vegetation biomass	39.7	8.9
Total biomass	39.7	8.9

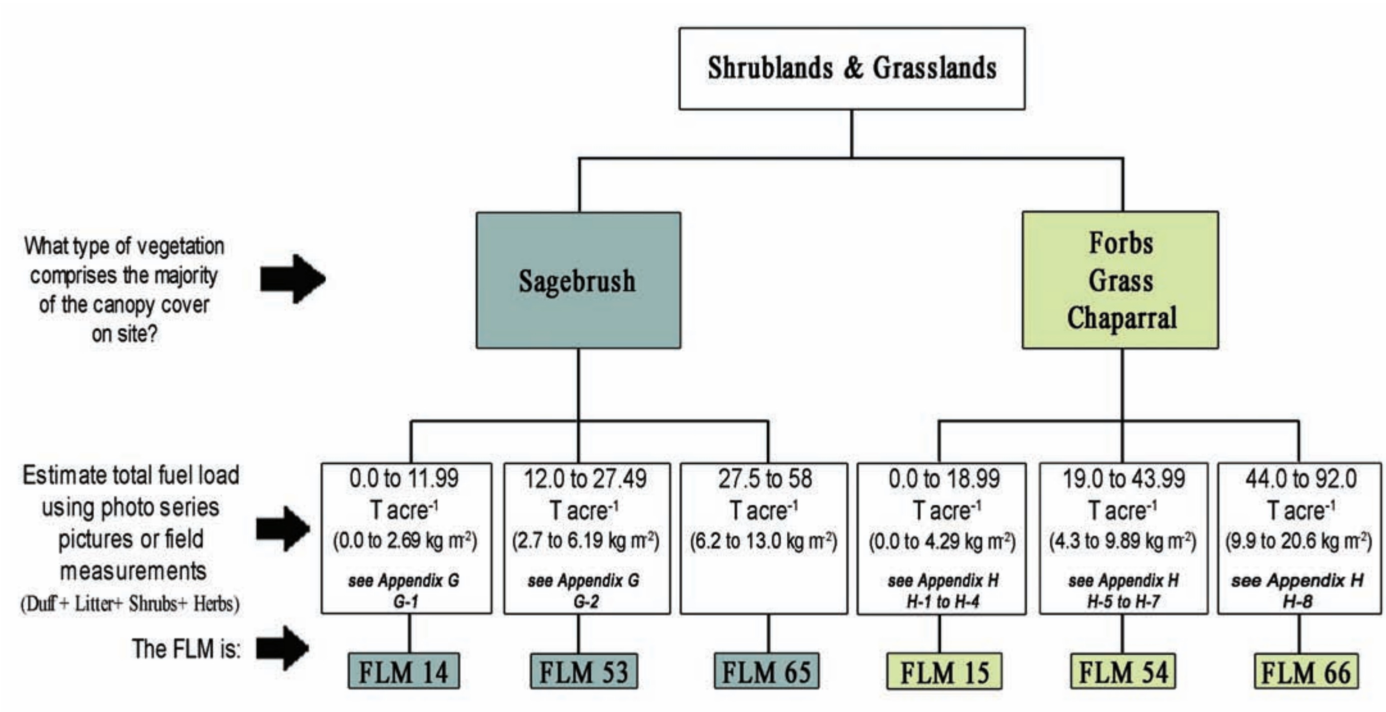
Figure H-7—Total biomass = **40 T acre^{-1}** (kg m^{-2}). Photo series CH 15, Ottmar and others(2000). Note: This photo shows how much fuel is needed to approach the 19 to 44 T acre^{-1} requirements for FLM 54, but its fuel bed exceeds the 6-ft (1.8-m) upper limit for FLMs.

Surface material	0.0 T acre^{-1}	0.0 kg m^{-2}
Downed woody	--	--
Vegetation biomass	52.2	11.7
Total biomass	52.2	11.7

Figure H-8—Total biomass = **52 T acre^{-1}** (11.7 kg m^{-2}). Photo series CH 16, Ottmar and others (2000). Note: This photo shows how much fuel is needed to approach the 44 to 92 T acre^{-1} requirements for FLM 66, but its fuel bed exceeds the 6-ft (1.8-m) upper limit for FLMs.

Grass - Shrub - Chaparral Sites

Appendix I—FLM Key for Non-Forested Areas



Appendix J—Practice Set: Using the FLM Key

Problem 1: Identify the FLM that best describes the fuel components in this mixed hardwood and conifer site in Alaska (Ottmar and Vihnanek 2002). Its fuels are distributed as follows:

Duff: 20.78 T acre^{-1}
Litter: 0.81 T acre^{-1}
Fine woody debris (FWD): 3.7 T acre^{-1}
Coarse woody debris (CWD): 3.0 T acre^{-1}

Solution: Notice that the measures of fuel load in this example are in tons per acre (T acre^{-1}) so you will be using Appendix E to solve this problem. Appendix E is arranged so that you can make selections by working downward, row by row. Within each row, boxes or columns display different ranges of loadings (biomass). Select the columns that best fit the field data for this site as follows:

1. Select the orange box whose duff values best match the 20.78 T acre^{-1} of duff on this site. You should select the box with duff ranging from 18.9 to 21.69 T acre^{-1}.
2. In the yellow litter row, choose the "less than 2.6" column because the litter loading for this site is 0.81.
3. In the CWD load row, choose the "less than 4.5" load. This best fits the 3.0 T acre^{-1} conditions on the site.
4. Read the FLM value from the lowest row. The FLM that best describes this site is FLM 62.

What is your Duff Biomass?	(1) 18.9 to 21.69 T acre^{-1}							
What is your Litter Biomass?	(2) <2.6				>2.6			
What is your CWD load?	(3) <4.5 D-1, D-2	4.5 to 15.9 D-2, D-8	15.9 to 35.1 D-8, D-10	>35.1 D-10	<10.2 D-6	10.2 to 15.9 D-6, D-8	15.9 to 35.1 D-8, D-10	>35.1 D-10
The FLM is:	(4) 62	63	83	92	72	82	83	92

Notice that within this range of duff biomass, the fine woody debris values are not needed to identify the FLM.

Problem 2: Identify the FLM that best describes the fuel components on this jack pine forest site in northern Minnesota (Ottmar and others 2002). The fuel loadings are distributed as follows:

Duff: 9.32 T acre^{-1}
Litter: 1.83 T acre^{-1}
Fine woody debris (FWD): 2.3 T acre^{-1}
Coarse woody debris (CWD): 7.7 T acre^{-1}

Solution: Like the previous problem, the units for this problem are in tons per acre (T acre^{-1}) so you will use Appendix E to identify the FLM that best describes the fuel loads on this site. Use the field data from the site to make decisions in the key as follows:

1. The duff value estimated for this site is 9.32 T acre^{-1}. The best fit for this value is the orange box with duff between 5.0 and 10.24 T acre^{-1}.
2. Match the litter value from this site (1.83 T acre^{-1}) to values in the litter row (yellow) in the key. At this point, you have several possibilities that could fit the site values, including the box containing "<10.8" or any of the boxes containing "≥0". The "≥0" in the boxes means that they could contain any litter value. Since you can not rule out any of the boxes with "≥0", you will have to consider all of these boxes simultaneously as you go to the next row in the key.
3. Pick the CWD column that best fits the site load (7.7 T acre^{-1}), which is the box containing <8.2. With this decision made, the only combination of litter and CWD values that fits this site is "<10.8" for the litter and "<8.2" for the CWD.
4. Using these choices, read the FLM number from the lowest row of the key. The FLM that best fits this site is FLM 31. Again note that the FWD is not used to determine FLMs for this range of duff values.

What is your Duff Biomass?	(1) 5 to 10.24 T acre^{-1}				
What is your Litter Biomass?	(2) <10.8	>10.8	(2) ≥ 0	(2) ≥ 0	(2) ≥ 0
What is your CWD load?	(3) <8.2 D-3, D-4	<8.2 D-3,D-4	8.2 to 15.9 D-4, D-8	15.9 to 35.1 D-8, D-10	> 35.1 D-10
The FLM is:	(4) 31	102	71	83	92

Problem 3: This ponderosa pine coniferous forest site in western Montana (Keane and Dickinson 2007) has the following distribution of fuel loadings:

Duff: 0.32 kg m^{-2}
Litter: 0.00 kg m^{-2}
Fine woody debris (FWD): 1.12 kg m^{-2}
Coarse woody debris (CWD): 0.34 kg m^{-2}

Identify the FLM that best describes its fuel components.

Solution: Notice that the measures of fuel load in this example are in kilograms per meter squared (kg m^{-2}) so you must use Appendix F to solve this problem.

1. Select the orange box that has a duff loading (biomass) range between 0.01 and 0.42 kg m^{-2} in Appendix F. This box best fits the field value of 0.32 kg m^{-2}.
2. In the FWD row (gray), choose the "greater than 0.53" columns because the litter loading for this site is 1.12 kg m^{-2}. You will have to consider both of these columns as you move to the next row.
3. Choose "less than 0.21" column for the litter biomass. This is the only column that fits the 0.00 kg m^{-2} conditions on the site. Unlike the previous problems, litter biomass is critical for identifying the FLM at sites that have very low duff biomass.
4. Read the FLM value from the lowest row. The FLM that best describes this site is FLM 12.

What is your Duff Biomass?	0.0 to 0.01 kg m^{-2}			(1) 0.01 to 0.42 kg m^{-2}		
What is your FWD load?	<0.53 C-1, C-2	>0.53 C-1, C-2	>0.53 C-1, C-2	<0.53 C-1, C-2	(2) >0.53 C-1, C-2	(2) >0.53 C-1, C-2
What is your Litter Biomass?	≥0	<0.21	>0.21	≥0	(3) <0.21	>0.21
What is your CWD load?	≥0	≥0	≥0	≥0	≥0	≥0
The FLM is:	11	12	41	11	(4) 12	13

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