Fuel Characteristic Classification

System Design

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Prepared for

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Participants at a series of five regional workshops (for the Boreal, Tropical & Semitropical, Dry, Western Temperate, and Eastern Temperate regions) have provided detailed fuelbed descriptions to populate the system database, and have helped refine some aspects of the system design described here. The two temperate region workshops are described in Beukema 2000[1] and 2001[2].

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[1] **Beukema, S.J. and W.A. Kurz.** 2000. Summary workshop report for the Fuel Characteristic Classification Western Humid-Temperate Region Workshop. Prepared by ESSA Technologies Ltd., Vancouver, BC for Seattle Forest Sciences Laboratory, Seattle, WA. 45 pp.

[2] **Beukema, S.J. and W.A. Kurz.** 2001. Draft summary workshop report for the Fuel Characteristic Classification Eastern Humid-Temperate Region Workshop. Prepared by ESSA Technologies Ltd., Vancouver, BC for Seattle Forest Sciences Laboratory, Seattle, WA.

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1.0 Introduction

This section provides an overview of the value of the national Fuel Characteristic Class (FCC) system to users, how the system will operate, and the terms that are used to describe the system.

1.1 System Overview

The national FCC system is designed to provide the best possible fuel estimates and probable fire parameters based on as much or as little site-specific information as is available. The detailed fuel estimates are needed to support fire hazard assessments and fuel treatment decisions, as well as other research initiatives. The FCC system will provide these detailed estimates based on either *specific fuel data* (types of fuel and their relative abundance) or *general site data* that are available for broader areas (such as Ecoregion Division, vegetation form, cover type, or other data obtained from remote sensing, forest inventories, or models). The system will also accept a mixture of both types of data.

Figure 1.1 illustrates how the system will operate. Essentially, the system will perform four main functions for users throughout the United States:

1. **Select a fuelbed prototype based on general site information or other criteria provided by the user.** The fuelbed prototype will be drawn from an extensive fuelbed database containing fuelbed descriptions from across the United States. The selected fuelbed prototype will provide the best-available predictions of the type and abundance of fuels expected in the user's fuelbed. These detailed fuel abundance predictions will themselves be a significant asset to fire research programs, carbon accounting initiatives, habitat mapping efforts, and other ecological research programs. The FCC system will use these predictions as "default values" to assist the user in preparing a complete input data set, as described in Function 2 below.

   A series of regional workshops have been held across the country to gather the diverse fuelbed descriptions required to populate the database. Once the system is operational, registered users will be able to add additional fuelbed descriptions to the database (subject to data quality control measures discussed later). This will allow the system to grow and evolve over time.

2. **Allow users to customize the fuelbed prototype.** Users will be able to edit and supplement the prototypic fuel abundance data, providing as much specific fuel or forest inventory information as they have available.

3. **Calculate quantitative fuel characteristics (physical, chemical, and structural properties) and probable fire parameters based on the edited fuel abundance data.** Once the user has finished editing the default fuel data, the FCC system will use the resulting input data set to derive numerous fuel properties and fire parameters for the fuelbed in question. These output values will include the total loading, bulk density, surface area and flammability class of each fuel category; fire time constants; maximum spread components; and emission factors. This information can be used with the fuel abundance data to drive sophisticated fire models (such as Behave, Consume, EPM, and FFE-FVS), providing smoke production estimates and other required information.

4. **Assign the fuelbed to one of about two-hundred Fuel Characteristic Classes, or FCCs.** The FCC system will use the fuel properties obtained in Function 3 to calculate the three indices that define each fuel characteristic class (see Section 1.2). These values will be reported to the user as the FCC identity number. Users familiar with the system will be able to use FCC identity numbers to readily communicate fuel conditions to one another. Both empirical fire behavior data and model predictions

will be compiled for each FCC, and stored in the system. Over time, distinct fuel management and fire response recommendations may be developed for particular groups of FCCs.

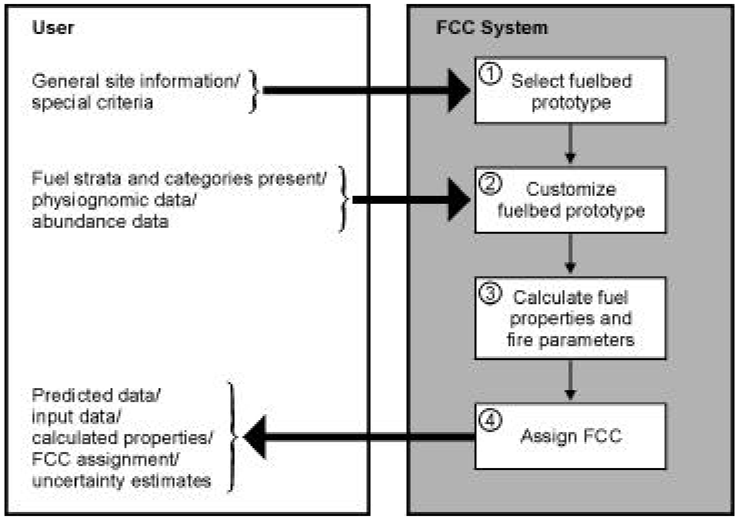


Figure 1.1: *FCC System Operation.* First, the FCC system will use general site information or other criteria provided by the user to select a fuelbed prototype appropriate to the user's fuelbed. Then the system will allow users to edit and supplement the prototypic data, providing any site-specific information that they have available. Next the system will calculate numerous fuel properties and fire parameters based on the customized fuelbed data. Finally, the system will assign the user's fuelbed to a particular Fuel Characteristic Class – "FCC" – and report back to the user.

1.2 Definition of Terms

The remainder of this section first defines some of the terms that are used to describe the FCC system.

Fuelbed strata are vertical layers within a fuelbed. Six different strata are recognized: tree canopy, shrub, low-vegetation, woody-fuel, moss-lichen-and-litter, and ground-fuel.

Fuelbed categories group the various fuels within a stratum according to their biological origin and combustion characteristics. For example, the woody fuel stratum contains four categories to distinguish sound-woody-debris, rotten logs, stumps, and woody-fuel-accumulations (e.g., piles and jackpots). A total of 16 different fuelbed categories are recognized, as listed in Section 2.2 below.

Physiognomic classes describe further morphological, chemical, and physical differences within each fuelbed category. For example, stumps may be assigned to either of three possible physiognomic classes based on their current state: sound, rotten, or lightered (i.e., containing hardened, dry pitch).

Gradient variables are the key quantitative variables needed to characterize the abundance of fuel in each category. The abundance of litter, for example, is characterized by the gradient variables 'percent litter cover' and 'mean litter depth'. Snags are characterized by the variables 'snag density', 'mean snag diameter', and 'mean snag height'. There are over 40 gradient variables in the national system, as shown in Section 2.2 below.

Fuel Characteristic Classes will group fuelbeds according to 3 key attributes. The three key attributes are described in more detail in Section 4.3. They include:

1. a measure of potential spread rate and reaction intensity, of which approximately 8 different levels will be recognized in the system;
2. a measure of the potential for crown fires, of which about 4 levels will be recognized in the system; and
3. a measure of “fire effects” (based on potential residence time and biomass consumption) which will recognize about 6 different levels of severity.

As shown in Figure 1.2, the three key attributes may be seen as the axes of a three-dimensional graph. The FCC number assigned to each fuelbed will tell users where their fuelbed falls within this three-dimensional space. The 8 different spread rate levels, 4 crowning potential levels and 6 fire effects levels would mean that 192 different FCCs are theoretically possible in the system[3]. Rather than being numbered consecutively from 1 to 192, however, all FCCs will be identified by 3-digit numbers giving first the spread-rate level, then the crowning potential level, then the fire effects level. Thus users familiar with the system will be able to read FCC 743 as meaning high spread rate (rated 7th out of the 8 levels), maximum crowning potential (4th of 4 levels), and moderate fire effects (3rd of 6 levels).

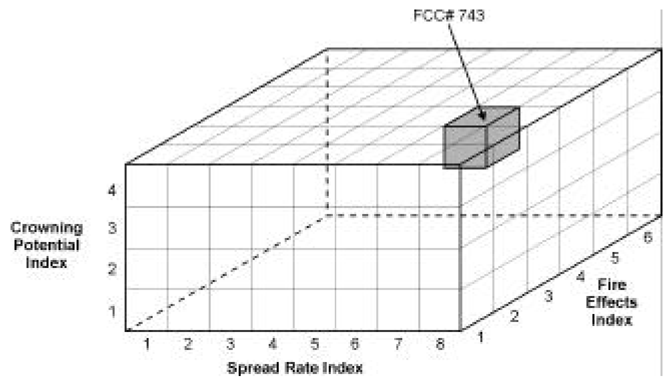


Figure 1.2: *The FCC System Groups Fuelbeds in 3-Dimensional Space*. See text for explanation.

To summarize, the national FCC system will allow fuelbeds to be assigned to a particular fuel characteristic class on the basis of their known or predicted gradient variable values and physiognomic classes. The system will also provide numerous fuel properties and fire behavior parameters calculated specifically for the fuelbed in question.

[3] Note that some of the theoretically possible FCCs may be rare or entirely absent in the real world. It may be, for example, that no fuelbeds with the highest possible spread rate index ever have the lowest possible fire effects index.

2.0 Input Data

The FCC system uses two types of input data: general site information or other criteria with which to select a fuelbed prototype, and fuel abundance data with which to calculate the required fuel properties and fire parameters. As is described in the User Interfaces section, the input fuel abundance data may be either quantitative (if available), or qualitative ("higher" or "lower" than would normally be expected for the fuelbed type).

2.1 General Site Information

Depending on what information the user has available, the system will usually choose an appropriate fuelbed description based on some or all of the following site variables:

1. Ecoregion Division (13 divisions defined by Bailey (1995, 1997));
2. vegetation form (Conifer Forest, Hardwood Forest, Mixed Forest, Shrubland, Savanna, Grassland, Sparsely Vegetated, or Slash);
3. structural class (seven forest structural classes defined by the USDA Forest Service and the USDI Bureau of Land Management (1999), with the addition of several classes appropriate to shrubland and grassland);
4. cover type (as defined the Society of American Foresters (Eyre 1980) and the Society of Range Managers (Shiflet 1994));
5. change agent (e.g., no change agent, recent partial cutting, or ongoing fire suppression)[4];
6. natural fire regime (six natural fire return intervals, as defined by Heinselman (1973)); and / or
7. condition class (three classes designed to measure how far a fuelbed has departed from the historical fire regime, an unpublished classification system currently under development by the USDA Forest Service).

As described in the User Interfaces section below, system users will be allowed to specify these criteria in any order. Alternatively, the user may opt to do a customized search of the fuelbed database and choose a fuelbed description based on any other attribute or combination of attributes contained in the database. For example, a user may want to recall a fuelbed that they previously entered into the data catalogue, find a fuelbed with a particular slash loading, or examine a fuelbed associated with a particular fire behavior outcome.

In any case, the FCC system will select eligible fuelbed prototypes from the existing database by applying the user's criteria in the specified order until either 1) all the criteria have been applied; or 2) the application of the next criterion would eliminate all of the fuelbeds that match the criteria previously applied. If more than one fuelbed remains eligible at that point, the system will select the most common of those fuelbeds to be the prototype (i.e., the fuelbed that has the largest representative area in the United States). The selected fuelbed prototype will be used to predict the type and abundance of fuels on that site. In other words, the selected fuelbed prototype will provide initial 'default values' for all the gradient variables and physiognomic classes (as listed in Section 2.2) present in the fuelbed in question.

[4] Initially, alternative fuelbed descriptions will be developed to capture only gross variation between different disturbance regimes or change events. Later distinctions could capture a greater range of disturbance intensities and time since disturbance.

2.2 Fuel Abundance Data

This section lists all of the gradient variable and physiognomic data (here called "fuel abundance data" for short) that the FCC system requires to describe what fuels are present in the user's fuelbed. As described in Section 2.1 above, selection of a prototypic fuelbed from the system database is used to provide a complete set of default values for these variables. When the user has finished customizing the default values, it is these variables that are used to calculate all of the required system outputs (listed in Section 3).

Table 2.1 lists the fuelbed categories that are distinguished within each of the 6 fuelbed strata recognized in the FCC system. Table 2.2 shows what gradient variable information is required for each physiognomic class in each of the 16 fuelbed categories.

In addition to the fuel abundance data shown in the table, the user will be asked to provide a self-assessment of the quality of data that they have for each fuelbed category (ranging from 'no data available', to 'poor data', 'fair data', and 'good data'). These ratings will be included in the output report on the fuelbed, and will be stored in the fuelbed database for reference when the new fuelbed is re-used as a prototype fuelbed for other sites.

Table 2.1: Fuelbed Categories Recognized within each Stratum.

Canopy Stratum	**Shrub Stratum**	**Low Vegetation Stratum**	**Woody Fuel Stratum**	**Moss, Lichen and Litter Stratum**	**Ground Fuel Stratum**
Trees	Shrubs	Grasses & Sedges	Sound Wood	Moss	Duff
Snags	Needle Drape	Forbs	Rotten Wood	Lichen	Basal Accumulation
Suspended Vegetation			Stumps Wood	Litter	
			Woody Fuel Accumulations		

Table 2.2: Data Required to Describe Each Fuelbed Category.

a) Tree Category

	Total % Cover	Average Height (ft)	Average Crown Height (ft)	Proportion Open Crown Conifer	Proportion Closed Crown Conifer	Proportion Flammable Broadleaf	Proportion Other Broadleaf
Layer 1							
Layer 2 (optional)							
Layer 3 (optional)							

b) Snag Category

	Density (Stems / acre)	Mean Diameter (in)	Mean Height (ft)
Class 1 Conifers with foliage			
All Other Class 1 snags			
Class 2 snags			

Class 3 snags	

c) Suspended Vegetation Category

	Minimum Height (ft)	Maximum Height (ft)	Loading (tons/acre)
Arboreal lichen			
Spanish moss			
Vines			
Ferns			
Fuzzy bark			
Dead branches			

d) Shrub Category

	Species	Foliage Type[1]	Growth Habit[2]	Flammability[3]	% Cover	Mean Height	% Live
Shrub group 1							
Shrub group 2							
Shrub group 3							

1. broadleaf deciduous / broadleaf evergreen / sclerophyllous / microphyllous / succulent / rosette / needle-leaved evergreen
2. single-stemmed / multiple-stemmed / thicket-forming / prostrate
3. fire accelerating / fire neutral / fire retarding

The foliage type, growth habit, and flammability will be inferred from species, if provided.
Note that the three shrub 'groups' may be used to capture different shrub height layers and/or physiognomic distinctions, whichever is more relevant to the fuelbed in question.

e) Needle Drape Category

Loading[1] (tons / acre)

1. Few users may have data on the needle drape loading. As for every other variable, however, the interface (described below) will include a slider-bar with the pointer indicating the modal loading and a highlighted area showing the range between the expected minimum and maximum values. The user need only click one or the other end of the slider bar to indicate that their site has higher or lower than modal needle drape abundance. The system should allow for later development work to make the default loading indicated by the pointer be dependent on any shrub and tree data previously input by the user.

f) Grass & Sedge Category

	Species	Type[1]	Leaf Blade[2]	Growth Habit[3]	% Cover	Mean Height (ft)	% Live
Group 1							
Group 2							

1. grass / sedge
2. fine / coarse
3. for grasses: bunch-forming / sod-forming / annual
   for sedges: bunch-forming / tussock-forming

The type, leaf blade, and growth habit will be inferred from species, if provided.
Again, the two grass and sedge 'groups' may be used to capture height differences and/or physiognomic distinctions, whichever is more relevant to the fuelbed in question.

g) Forb Category

% Cover	Mean Height (ft)

h) Sound Wood Category

% Cover	Average Depth (ft)	0 – 0.25 in Loading (tons / ac)	0.26 – 1 in Loading (tons / ac)	1.1 – 3 in Loading (tons / ac)	3.1 – 9 in Loading (tons / ac)	9.1 – 20 in Loading (tons / ac)	> 20 in Loading (tons / ac)

i) Rotten Wood Category

3 - 9 in Loading (tons / ac)	9.1 - 20 in Loading (tons / ac)	> 20 in Loading (tons / ac)

j) Stump Category

	Density (Stumps / acre)	Mean Diameter (in)	Mean Height (ft)
Sound stumps			
Rotten stumps			
Lightered stumps			

k) Woody Fuel Accumulation Category

	Density (# / acre)	Height (ft)	Width (ft)	Length (ft)	Clean / Dirty
Piles				(n/a)	
Jackpots					
Windrows					
Squirrel Middens					

l) Moss Category

	% cover	Depth (in)
Sphagnum moss		
Other mosses		

m) Lichen Category

% cover	Depth (in)

n) Litter Category

Arrange-ment[1]	% Cover	Depth (in)	Proportion short needle pine	Proportion long needle pine	Proportion other conifer	Proportion broadleaf deciduous	Proportion broadleaf evergreen	Proportion palm frond	Pro-portion grass

1. Normal / Fluffy (freshly fallen) / Perched (on grass or forb)

o) Duff Category

	Type[1]	Depth (in)
Upper duff		
Lower duff		

% Rotten Wood in Total Duff

1. Upper duff: dead moss and litter / fibric peat (sphagnum or sedge)
   Lower duff: humus or humic peat

p) Basal Accumulation Category

	Depth (in)	Proportion of trees affected
Bark slough		
Needle litter		

2.3 Seasonal & Moisture Effects

One challenge in measuring and reporting the gradient variables is that some values will vary according to season. For example, grass cover or the percent of shrub material that is live may be much higher in the summer than in winter months. For consistency, the FCC system database will use “growing season” – more precisely defined as the time when leaf area index is largest – values in all cases. If there is sufficient user demand, later system work could develop modules to predict the required growing season values from other input seasonal values, and/or to report other seasonal values inferred from growing season values (i.e., both input and output values could potentially be translated to other seasons). This module would allow users to either 1) tell the system they are inputting data from a dormant season, and have the system translate those data into growing season values and determine the appropriate FCC; or 2) ask the system to tell them what a particular FCC looks like in the dormant season.

Similarly, all loading values (weights in tons/ac) in the system will be assumed to be dry weights. Available fire behavior models will allow users to account for seasonal variation in moisture levels.

3.0 Output Data

The following sections describe the output information that will be produced by the FCC system, and outline some of the output report formats that will be available to system users.

3.1 Inferred, Calculated and Assigned Output Values

Table 3.1 on the following two pages summarizes all of the output information that is produced by the FCC system for each fuelbed stratum, category, and component. For convenience, the table also shows the input information which the system requires in order to derive the output values. As described in Section 2 above, default values for all of the required input information are derived from the fuelbed prototype selected by the user. The user may then edit the default values to incorporate as much site-specific data as they have available.

As shown in Table 3.1, three types of output values are produced by the FCC system. *Inferred associated variables* are physical constants that are inferred based on physiognomic class, size-class, and in some cases cover type. *Calculated associated variables* are physical fuel properties that can be calculated numerically from the input gradient variable information, using the inferred variables where necessary. The calculated associated variables will be reported as total values for each fuelbed component, as listed in the table. *Assigned variables* are fuel model constants that will be assigned to each fuelbed stratum based on classification of the associated variable values.

All of the planned FCC system outputs are shown in Table 3.1 except for the fuelbed-level output variables:

- the three FCC indices;
- the resulting Fuel Characteristic Class in which the fuelbed falls;
- the uncertainty associated with each FCC index assignment; and
- the National Fire Danger Rating and Fire Behavior Rating (NFDRS/FB).

Table 3.1: Summary of Information in the FCC System.

Fuelbed Strata	Fuelbed Categories	Fuelbed Components	**Input Information** (from fuelbed prototype &/or user)	
			Physiognomic Distinctions	**Gradient Variables**
Canopy	Trees - layer 1 - layer 2 - layer 3	for each layer: - conifer overstory - flammable broadleaf overstory - other broadleaf overstory	open crown conifer / closed crown conifer / flammable broadleaf / other broadleaf	for each layer: - % cover - average height - avg. crown height - prop. of cover provided by each physio. class
	Snags	conifer overstory broadleaf overstory sound snagwood rotten snagwood	class 1 with foliage / class 1 w/out foliage / class 2 / class 3	for each physio. class: - snag density - mean diameter - mean height
	Suspended Vegetation	ladder fuels	arboreal lichen / spanish moss / vines / ferns / fuzzy bark / dead branches	for each physio. class: - minimum height - maximum height - loading (tons/acre)
Shrub	Shrubs - Group 1 - Group 2 - Group 3	accelerant shrub: - foliage and twigs - dead stemwood <3" - live stemwood < 1" retardant shrub foliage & twigs neutral shrub foliage & twigs	Foliage Type, Growth Habit, and Accelerant Potential for each shrub group (details in Table 2.2d)	for each shrub group: - % cover - mean height - % live
	Needle Drape	suspended needles	n/a	loading (tons/acre)
Low Vegetation	Grasses & Sedges - Group 1 - Group 2	live grass & sedge dead grass & sedge	Type, Leaf Blade, and Growth Habit for each group (details in Table 2.2f)	for each group: - % cover - mean height - % live
	Forbs	forb	n/a	% cover mean height
Woody Fuel	Sound Wood	very fine fuel (0 – ¼") fine fuel (1/4 – 1") medium fuel (1 – 3") large fuel (3 – 9") very large fuel (9 – 20") huge fuel (> 20")	Size Class (details in Table 2.2h)	% cover avg. depth loading by physio. class
	Rotten Wood	rotten wood	Size Class (details in Table 2.2i)	loading by physio. class
	Stumps	sound stumpwood rotten stumpwood lightered stumpwood	sound / rotten / lightered	for each physio. class: - stump density - mean diameter - mean height
	Woody Fuel Accumulation	piles jackpots windrows squirrel middens	piles / jackpots / windrows / squirrel middens	for each physio. class: - density - height, width, & length - whether clean/dirty
Moss, Lichen & Litter	Moss	live moss	sphagnum / other moss	for each physio. class: - % cover - avg. depth
	Lichen	lichen	n/a	% cover avg. depth
	Litter	litter	normal / fluffy / perched	% cover avg. depth
Ground Fuel	Duff Layer - upper - lower	fermentation layer humic layer	type for each layer (details in Table 2.2o)	depth of each layer % rotten wood in total

	Basal Accumulation	basal accumulation	bark slough / needle litter	for each phsysio class: - depth - trees affected (#/ac)

Output Information		
Inferred Associated Variables (for each physiognomic class)	**Calculated Associated Variables** (summed for each component)	**Assigned Variables** (for each stratum)
Surface area / volume ratio Crown bulk density Particle density	Bulk volume Surface area Fuel loading Fuel particle volume (Spatial distribution based on % cover) (Vertical distrib. based on ht. layer info)	Wind reduction factor Minimum wind adjustment Maximum wind adjustment Maximum spread component And separately for snags: - Time constants for EPM (residual smoldering constant) - Maximum spread component - Emission factors (PM2.5, PM10, PM, CO, NMHC, CH_4)
Surface area / volume ratio Particle density	Surface area Fuel loading Fuel particle volume	
Surface area / volume ratio Particle density	Surface area Fuel particle volume *Fuel loading (from input)*	
Surface area / volume ratio Regression equations (for fuel loading) Particle density	Bulk volume Surface area Fuel loading Fuel particle volume (Spatial distribution based on % cover) (Vertical distribution based on height)	Wind reduction factor Minimum wind adjustment Maximum wind adjustment Maximum spread component
(as for suspended vegetation)	(as for suspended vegetation)	
(as for shrubs)	(as for shrubs)	Dynamic / static code Maximum spread component Emission factors (PM2.5, PM10, PM, CO, NMHC, CH_4)
(as for shrubs)	(as for shrubs)	
Surface area / volume ratio Particle density	Bulk volume Surface area Fuel particle volume *Fuel loading (from input)* (Spatial distribution based on % cover) (Vertical distribution based on depth)	Adjusted fuelbed heat content Adjusted moisture at extinction Adjusted surface / volume ratio Time constants for EPM (maximum flame duration)
Surface area / volume ratio Particle density	Bulk volume, Surface area, Fuel particle volume and *Fuel loading from input*	
Surface area / volume ratio Particle density	Surface area Fuel loading Fuel particle volume	
Surface area / volume ratio Particle density Bulk density Packing ratio	Surface area Fuel loading Fuel particle volume	
Surface area / volume ratio Particle density Bulk density	Bulk volume, Surface area, Fuel loading, and Fuel particle volume	Maximum spread component Emission factors (PM2.5, PM10, PM, CO, NMHC, CH_4)
(as for moss)	(as for moss)	
(as for moss)	(as for moss)	

(as for moss)	(as for moss)	Maximum spread component Emission factors (PM2.5, PM10, PM, CO, NMHC, CH_4)
(as for moss, plus:) Radius affected around each tree	(as for moss)	

3.2 Output Report Formats

The FCC system design allows for the production of three types of output reports on single fuelbeds. Only the first two of these report types, the Full Report and the Summary Report, are expected to be made available during initial system development work. Model-specific output reports will be developed as user interest and resource availability warrant once the system is operational.

Section 5 below (User Interfaces) describes two alternative modes in which users may interact with the FCC system. All of the report formats described in the current section apply to the 'Manual' mode of interaction, in which the user manually inputs information on a single fuelbed. In the alternative 'Batch' mode of interaction, the user directs the system to operate on all the fuelbeds in a tabular data file (e.g., a polygon attribute table, for which the user wants to generate map-ready fuel parameters). These batch jobs will produce simple tabular output files (i.e., delimited text output files, which can be linked to polygon attribute files for map display), as shown in Screen Batch #7 of Section 5.

All of the report formats described below must include the following information:

- user name
- site name
- date and time of printing
- fuelbed number and database file name (if stored in either the system database or the user's database prior to printing).

Under the envisioned system interfaces (Section 5 below), users are invited to provide a site name for their fuelbed at the time they first begin selecting a fuelbed prototype and editing the prototype data. The system will not force the site name to be unique in the database until the fuelbed is complete (i.e., the FCC output values have been calculated) and the user specifies the database in which they wish to save it. In other words, if users generate FCC reports before saving the fuelbed, then the site name on the report may not on its own be unique. Users will nonetheless be able to identify their fuelbed by the presence of their own name on the report.

3.2.1 Full Report

The most complete output file will include the following information:

- the site description provided by the user;
- the identity of the fuelbed prototype used;
- the general site information provided by the user;
- the general site information inferred based on the fuelbed prototype;
- all the fuel data input by the user, with qualitative ('more' and 'less') inputs distinguished from specific numeric inputs;
- the user's self-assessment of the quality of fuel data they have provided for each fuelbed category;
- all the fuel data that that were inferred from the fuelbed prototype;

- for each fuelbed category, the modal and minimum data-quality assessment originally given to the prototype fuel data that the user has not been able to replace with site-specific data[5];
- all the output fuel properties produced by the FCC system, as shown in the last three columns of Table 3.1;
- the FCC number to which the fuelbed has been assigned; and
- the uncertainty estimates calculated for each of the three FCC indices, and a resulting 'reliability' score for each index.

Apart from the fuelbed-level information (e.g., general site information and FCC assignment), all of the other reported information should be organized by fuelbed strata. That is, all of the input and output canopy information should be in one section, all of the input and output shrub information should be in another section, etc. This will allow users to prepare customized reports specific to particular areas of interest by selecting the appropriate stratum or strata from the full report.

To help users easily find the information of interest to themselves, it is expected that the full report will take the form of numerous separate tables. During system implementation, thought should be given to ensuring that the reports for different fuelbeds nonetheless share a consistent, predictable format. In other words, it should be possible to know without reading the report that the total bulk volume of retardant shrubs will be reported on line X in position Y to Z. This consistency will make it possible for users to write scripts that read the output report file and locate the information that they wish to process further. For example, if the report is imported into an Excel file, the bulk volume of retardant shrubs should always come out in the same row and column of the worksheet. That will allow users to prepare their own 'summary' worksheet (to locate and process the values of personal interest on the report worksheet), and have that summary worksheet operate correctly with every successive fuelbed report that they import.

3.2.2 Summary Report

The summary report will include the following information:

- the site description provided by the user;
- the general site information provided by the user or inferred from the fuelbed prototype;
- the approximate total percent tree cover, percent shrub cover, and percent low vegetation cover;
- the total snag loading, and woody fuel loading;
- the total moss, lichen and litter depth, and the total duff depth;
- the user's self-assessment of the quality of fuel data they provided for each fuelbed category;
- for each fuelbed category, the modal data-quality assessment originally given to the prototype fuel data that the user was not been able to replace with site-specific data (see footnote 4 for explanation);
- the FCC number to which the fuelbed was assigned; and
- the 'reliability score' calculated for each of the three FCC indices.

[5] Every time a new fuelbed is created, some of the prototype data in each category may be replaced with site-specific information while other data in the category is not updated. Values such as percent tree cover may often be updated, while values such as the loading of spanish moss seldom get updated. Eventually, therefore, many of the data values in a fuelbed prototype may originate from different fuelbed prototypes. As a result each data value might originally have had a different data quality rating. (Section 4.1.1 describes how the system will use a database table to track the original data quality rating of each value in each new fuelbed. The process is trivial if it is done each time a new fuelbed is created). The modal and minimum original quality rating of the data in each fuelbed category will be reported to the user. Users will themselves have to take into account that what was 'fair' or even 'good' data for its original fuelbed is likely less reliable when transferred to their own site without revision.

3.3.3 Model-specific Reports

As demand warrants, later system development work could create reports pre-formatted for input to specified models. For example, users could be given the option of having the snag and debris information for their fuelbed reported in the form of the 'keywords' needed to initialize the Forest Vegetation Simulator – Fuel and Fire Effects model (FVS-FFE); the option of having fuel properties reported in the form required for input to Behave or Consume, etc.

4.0 Operational Processes

Once all of the required fuel abundance data have been entered by the user or predicted by the system, the system will use this information to calculate the output fuel properties and to assign the fuelbed to an FCC. The following sections outline how this will be done.

4.1 Database Structure

All of the existing fuelbed prototypes will be stored in a relational database, along with other information required for the user interfaces and calculation processes. Some examples of the required fuelbed tables and definition tables are described in the following sections.

4.1.1 Fuelbed Tables

Appendix 1 shows three example fuelbeds from the draft fuelbed database currently being prepared for use with the FCC system. In the completed system database, the *fuelbed data table*[6] will contain all of the input information shown in Appendix 1 (site, physiognomic, and gradient variable information) for each fuelbed, *and* all of the output information produced by the system for each fuelbed. In addition, the fuelbed table will need new columns for the following information:

- the identity number of the fuelbed prototype (if any) used in creating each fuelbed;
- the approximate area of the United States represented by each fuelbed[7];
- whether the represented area has yet been subject to consistency checking (see Section 7.1 regarding quality control issues);
- whether the output results have yet been vetted (see Section 7.1 re. quality control issues); and
- the fuelbed creator's assessment of the quality of data they have provided for each fuelbed category.

A separate table will be required in order to record the origin of every piece of input information for each fuelbed. This *fuelbed data source table* will mirror the table shown in Appendix 1 except that, instead of containing data values, each cell of the table will indicate whether the value in question was numerically input by the fuelbed creator, qualitatively adjusted ('more' or 'less') by the fuelbed creator, or carried over unrevised from the fuelbed prototype. In the latter case, the table cell should record the identity number of the fuelbed from which the data value originates[8].

The fuelbed report formats described above (Section 3) suggest that users should be told the modal and minimum data quality rating originally assigned to the data in each fuelbed category. This information can be assembled by reading the original-source prototype fuelbed for each value from the data source table just described, and then looking up that original prototype in the fuelbed data table to find the quality rating given to data in the applicable fuelbed category. Depending on the strengths and weaknesses of the chosen database

[6] Depending on the strengths and weaknesses of the chosen database management system, the fuelbed table described here may actually be a series of tables linked by the fuelbed identity numbers. Note, however, that the system interfaces (Section 5) are intended to allow the user to select a fuelbed prototype based on any of the input or output characteristics of each fuelbed – regardless of whether the information is stored in one table or many linked tables.

[7] These data will be subject to quality control measures and periodic updating, as described in Section 7.

[8] As explained in footnote 5, this need not be the same as the prototype used to create the current fuelbed. That prototype may itself have had data values carried over from the prototype on which it was based. The database can track this chain of events by simply copying over the ID numbers in the data-source table to each new fuelbed record. Interested users can refer to this table to check just how far the prototype data incorporated in their new fuelbed may have wandered from its original source.

management system, it may be more efficient to simply track this information in a *fuelbed data quality table* each time a new fuelbed is created. This table would also mirror the table shown in Appendix 1, except that each cell of the table would indicate the original data quality rating given to each input value. Every time a new fuelbed was created, the system need only fill in the new data quality ratings given to values that were input by the fuelbed creator, and copy over the quality ratings from the fuelbed prototype for each data value the current fuelbed creator has not edited.

Under the uncertainty reporting system proposed here (see section 4.4 and screen Manual #5 in section 5), three additional tables will be required to store information on how much each of the three FCC indices is influenced by each input data value. These *fuelbed data sensitivity tables* will again mirror the table shown in Appendix 1, except that each cell of the table will indicate the influence of each variable on one of the three FCC indices (in the context of the specified fuelbed; see section 4.4 for further discussion).

4.1.2 Definition Tables

The fuelbed data table will be supported by a series of 'definition' tables. These tables will serve two main purposes. First, they will provide a list of the legitimate 'choices' that are available for each drop-down menu in the user-interfaces (Section 5). Table 4.1 below, for example, shows some sample cover types from which users could choose when asked to provide general site information appropriate to their fuelbed. Only cover types that were already defined in the table would be available to the user[9].

Table 4.1: Example Cover Type Definition Table.

Cover Type ID#	Cover Type Name	Natural Fire Regime[10]
1	Upland Oaks	2
2	Northern Hardwoods	2
3	Pitch Pine	4
4	*etc.*	

The second function filled by the definition tables is to provide required information about each of the classes defined in the table. Table 4.1, for example, also identifies which natural fire regime (Heinselman 1973) is associated with each cover type. Whenever a user selects one of the listed cover types in the interface, the natural fire regime window on the same screen should automatically be updated to show the value associated with the selected cover type. As another example, Table 4.2 both defines the moss types that are distinguished in the FCC system, and specifies the inferred associated variable values for each type.

Table 4.2: Example Moss Type Definition Table.

Moss Type ID#	Moss Type Name	Surface Area / Volume Ratio[8]	Particle Density[8] (lb/ft^3)	Bulk Density[8] (lb/ft^3)
1	Sphagnum	10	0.40	0.2
2	Other Moss	15	0.35	0.1

[9] And only cover types defined in this table could be used in the fuelbed table

[10] These values are provided for illustration only.

4.2 Calculation of Fuel Parameters

The following sections show how the required calculated associated variables will be derived from the input gradient variable data and inferred associated variables for each category (as shown in Table 3.1). The equations shown here were provided by Geoff Cushon in the US Forest Service.

Throughout this section, *inferred associated variables* are shown in italics, input gradient variables are underlined, and calculated values are shown as normal text. The letters '*SV*' here are an abbreviation for the 'surface area to volume ratio'. The units of measure of each variable are as follows:

Bulk Density	lb/ft^3
Particle Density	lb/ft^3
SV	ft^2/ft^3
Height	ft
Diameter	ft
Depth	ft
Bulk Volume	ft^3/ac
Loading	lb/ac
Particle Volume	ft^3/ac
Surface Area	ft^2/ac

4.2.1 Tree Category

1. Perform the following calculations for each physiognomic class in each layer of the tree category:

   i) Bulk Volume = % Cover * 43,560 ft^2/ac * (Height – Crown Height) / 100
   ii) Loading = Bulk Volume * *Crown Bulk Density*
   iii) Particle Volume = Loading / *Particle Density*
   iv) Surface Area = Particle Volume * *SV*

2. Sum the values for open and closed crown conifers to obtain total conifer overstory values in each crown layer.

3. Add crown material from class 1 snags (calculated as follows) to the appropriate overstory crown components, to obtain values for the total crown material in each layer.

4.2.2 Snag Category

1. Perform the following calculations for class 1 snags with foliage, to determine their contribution to total crown materials:

   i) Estimate crown types with foliage based on overstory tree composition at the average snag height.
   ii) Estimate crown height based on data for the overstory tree layer at the average snag height.
   iii) Calculate crown fuel values as in step 1 (i – iv) of tree category calculations. Add to the appropriate overstory crown components.

2. Perform the following calculations for class 1 snags without foliage. The results will be used as the total values for sound snagwood:

   i) Estimate Loading from biomass equations (stemwood only; e.g., Means et al. 1994 BIOPAK equations).
   ii) Particle Volume = Loading / *Particle Density*
   iii) Surface Area = Particle Volume * *SV*

3. Perform the following calculations[11] for class 2 and 3 snags.

   i) Particle Volume = Stems per Acre * (¼) B (Mean Diameter)^2 * Mean Height
   ii) Loading = *Particle Density* * Particle Volume
   iii) Surface Area = Particle Volume * *SV*

4. Add the calculated values for class 2 and 3 snags to obtain total values for rotten snagwood.

4.2.3 Suspended Vegetation Category

1. Perform the following calculations for each physiognomic class:

   i) Particle Volume = Loading / *Particle Density*
   ii) Surface Area = Particle Volume * *SV*

2. Sum the values for each physiognomic class to obtain total values for ladder fuels.

4.2.4 Shrub Category

1. Perform the following calculations for each shrub group:

   i) Bulk Volume = % Cover * 43,560 ft^2/ac * Mean Height / 100
   ii) Loading: calculate from regression equations based on % Cover and Height (e.g., Martin et al. 1981)
   iii) Particle Volume = Loading / *Particle Density*
   iv) Surface Area = Particle Volume * *SV*

2. If any of the shrub groups were identified as accelerant shrubs, partition each variable into stemwood vs. foliage and twigs *(using procedures to be identified later)*. Then use % Live to partition the stemwood component of each variable into live vs. dead material.

4.2.5 Needle Drape Category

1. Perform the following calculations for each physiognomic class:

   i) Particle Volume = Loading / *Particle Density*
   ii) Surface Area = Particle Volume * *SV*

4.2.6 Grass & Sedge Category

1. Perform the following calculations for each grass or sedge group:

[11] Taper functions may be used to improve the accuracy of equation (i) for class 2 snags. Class 3 snags are assumed to have lost much of their original height, with the remaining stem approaching a uniform cylinder in shape.

i) Bulk Volume = % Cover * 43,560 ft^2/ac * Mean Height / 100
ii) Loading: calculate from regression equations based on % Cover and Height (e.g., Payne 1974)
iii) Particle Volume = Loading / *Particle Density*
iv) Surface Area = Particle Volume * *SV*

2. Use % Live to partition each variable in live vs. dead material.

4.2.7 Forb Category

1. Perform the calculations described in step 1 for grasses and sedges.

4.2.8 Sound Wood Category

1. Perform the following calculations for each size class:

   i) Bulk Volume = % Cover * 43,560 ft^2/ac * Depth / 100
   ii) Particle Volume = Loading / *Particle Density*
   iii) Surface Area = Particle Volume * *SV*

4.2.9 Rotten Wood Category

1. Perform the following calculations for each size class:

   i) Particle Volume = Loading / *Particle Density*
   ii) Surface Area = Particle Volume * *SV*

4.2.10 Stump Category

1. Perform the following calculations for each physiognomic class:

   i) Loading = Stumps per Acre * (¼) B (Mean Diameter)^2 * Mean Height * *Particle Density*
   ii) Particle Volume = Loading / *Particle Density*
   iii) Surface Area = Particle Volume * *SV*

4.2.11 Woody Fuel Accumulation Category

1. Perform the following calculations for each physiognomic class:

   i) Bulk Volume: calculate from regression equations based on Length, Width, and Height (e.g., Hardy 1996), multiplied by Number per Acre.
   ii) Particle Volume = Bulk Volume * *Packing Ratio*
   iii) Loading = Particle Volume * *Particle Density*
   iv) Surface Area = Particle Volume * *SV*

4.2.12 Moss Category

1. Perform the following calculations for each physiognomic class:

    i) Bulk Volume = % Cover * 43,560 ft^2/ac * Depth / 100
    ii) Loading = Bulk Volume * *Bulk Density*
    iii) Particle Volume = Loading / *Particle Density*
    v) Surface Area = Particle Volume * *SV*

2. Sum the values for each physiognomic class to obtain total values for live moss.

4.2.13 Lichen Category

1. Perform the calculations described in step 1 for moss.

4.2.14 Litter Category

1. Perform the calculations described in step 1 for moss.

4.2.15 Duff Category

1. Use % Rotten Wood to allocate total depth of each layer into rotten wood depth vs. other duff depth.

2. Perform the following calculations for rotten wood and other duff in each layer:

    i) Bulk Volume = 43,560 ft^2/ac * Depth
    ii) Loading = Bulk Volume * *Bulk Density*
    iii) Particle Volume = Loading / *Particle Density*
    iv) Surface Area = Particle Volume * *SV*

3. Sum the values for rotten wood and other duff to obtain total duff values for each layer.

4.2.16 Basal Accumulation Category

1. Perform the following calculations for each physiognomic class:

    i) Bulk Volume = Affected Trees per Acre * B (*Affected Radius*)^2 * Depth
    ii) Loading = Bulk Volume * *Bulk Density*
    iii) Particle Volume = Loading / *Particle Density*
    iv) Surface Area = Particle Volume * *SV*

2. Sum the values for each physiognomic class to obtain total basal accumulation values.

4.3 Calculation of FCC Indices

The three FCC indices will be based on key output associated and assigned variables, summed across the relevant fuelbed components. The mathematical details of each index are still under development by the US Forest Service, but the concept behind each index is as follows:

1. The *Spread Rate Index* will be a measure of the relative rate of spread or reaction intensity of a surface fire. This measure will be based on the available surface area of fine fuels (including flammable shrubs, grasses, sedges, forbs, fine sound woody fuel, and litter), and their horizontal continuity (as inferred from the percent cover value for each fine fuel type).

2. The *Crowning Potential Index* will measure the probability of fire reaching the tree canopy and being carried through the canopy. This measure will be based on 1) the abundance and vertical continuity of shrubs and ladder fuels (suspended vegetation) to carry fire up to the tree crowns; 2) the horizontal continuity of tree crowns within each canopy layer (as implied by % cover in the layer), and the vertical continuity between layers; and iii) the flammability class of the crown material present.

3. The *Fire Effects Index* will measure the potential residence time of fire and consequent biomass consumption. This measure will be based on the abundance of smoldering fuels such as class 2 and 3 snags, rotten wood, stumps, and duff.

4.4 Estimating Uncertainty

The core system processes described above and the interfaces described below will provide for a continuum of users, from users who have all the empirical data required to fully describe the type and abundance of fuels present (as outlined in Table 2.2) to users who want to infer an FCC based only on Ecoregion Division and vegetation form. The majority of users will probably fall somewhere in between these two extremes. All these different users will be able to say “The system assigned my fuelbed to FCC #244.” Clearly, however, the level of certainty behind this FCC assignment is going to vary widely depending on the quality of data supplied to the system. *This makes it highly desirable that the even the first phase of system implementation provide some estimate of the certainty of each FCC assignment.*

A measure of uncertainty could be achieved as follows:

1. During system development[12], evaluate the contribution of each gradient variable and physiognomic distinction to each of the three FCC indices.

   As is clear from the index definitions in the previous section, each index will be more sensitive to some variables than to others. Unfortunately, the sensitivity of each index to a given variable will also vary depending on other conditions in the fuelbed. In cover types where lichen levels are generally high but dead branch biomass is relatively low and constant, for example, the crowning potential index will strongly depend on input lichen values and be insensitive the normal range of variation in branch values. In other words, it is possible only to say how influential each variable is in a given fuelbed type, and not to assign one all-purpose influence rating to each variable.

   At a minimum, the necessary sensitivity analysis should be done for every unique combination of ecoregion division and dominant vegetation type (e.g., Marine forest, marine shrubland, etc.). Ideally, it would be done separately for every fuelbed prototype.

[12] And ideally also at the time that each new fuelbed is added to the official database during use.

The sensitivity analyses would go as follows. For each example fuelbed, test the influence of every input variable. For example, does varying percent forb cover from the minimum to the maximum value for the fuelbed prototype in question change the crowning potential index at all? And if so, by how much? How much more impact does varying percent shrub cover have? Determine which variables have the most influence, and roughly proportion their influence – for example, "The crowning potential index in this fuelbed type is 50% determined by the amount of overlap between shrub height and minimum crown height, 30% determined by total percent shrub cover, and 20% determined by total woody debris loading."

2. During use of the FCC system, sum the influence of each of the variables that had to be inferred by the system for a particular FCC assignment. To use the example given, if the user provided woody debris data but all shrub and tree data had to be inferred from the fuelbed prototype data, the system should report that crowning potential index was 80% (50% + 30%) based on inferred data ("80% inferred", for short). This will give the user, and others with whom they communicate their results, some idea of how much faith to put in the results.

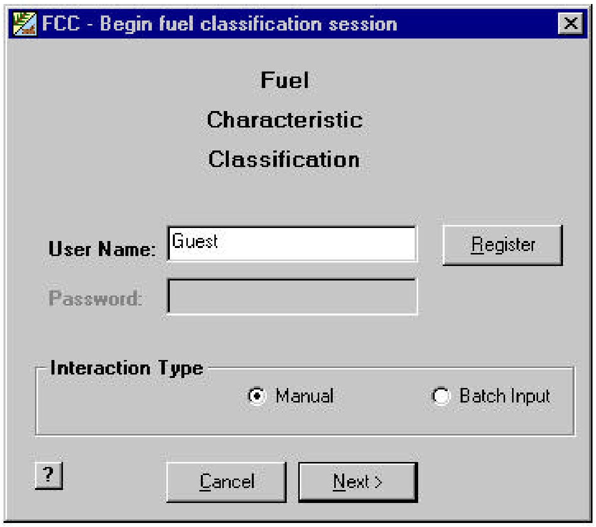
The results of the sensitivity analyses should be stored in the database as described in Section 4.1 above. Then the sensitivity analyses can be used to give guidance to the user about the variables for which it is most worthwhile to provide detailed data, as shown in screen Manual #5 in Section 5 below.

Note that the discussion above makes no distinction between actual numeric data entries by the user and 'up' / 'down' clicks on the slider bar. They could be reported separately if desired – for example, "the crowning potential index was 20% based on the user's input data, 10% based on the user's specification of higher or lower than modal values, and 70% inferred."

Also note that, for the suggested measure of uncertainty to be accurate, system users must distinguish whether they are leaving prototype data values unchanged because they have no site-specific data or because the prototype values already match their own data. In the latter case, the user should indicate this by 'entering' the data values already displayed on the screen (i.e., click on or tab to the data window in question, and then hit the 'enter' key on their keyboard). This will also tell the system that, although they are unchanged in value, the data values in question should now have the data quality rating assigned to this fuelbed category by the current user (instead of the data quality rating applicable to the fuelbed prototype).

5.0 User Interfaces

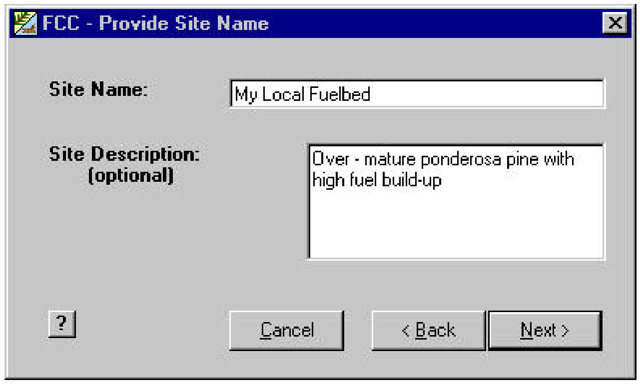
As described in Section 7, users will access the FCC system over the internet. This section illustrates the envisioned system interface. The final interface screens may differ in esthetic details from the sample screens shown here, but they should provide the same basic functions. The sample screens are also available in electronic form, so that they may be installed on the viewer's computer for more active exploration. Contact the report author or Geoff Cushon in the USFS Seattle Forestry Sciences Laboratory to obtain a copy.



Entry Screen: Begin fuel classification session. The entry screen requires users to provide a user name. No password is required under the user name 'Guest'.

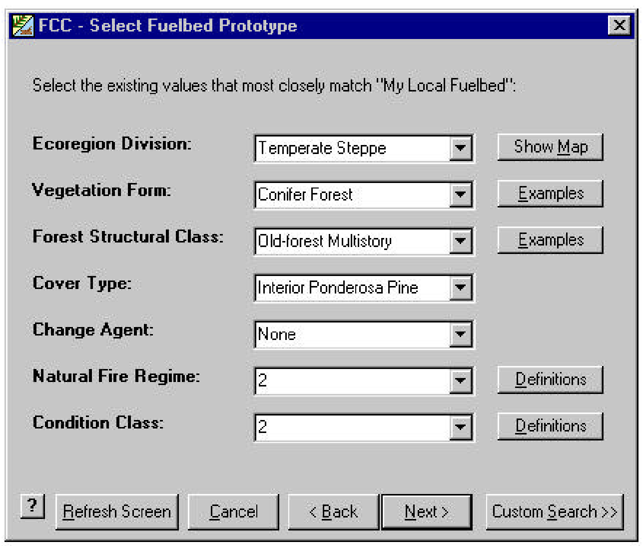
The *Register* button will allow new users to register on the system. Once cleared, registered users may enter a password to obtain secure access to the system. These users will be given the option to save their fuelbed information in the system database. The registration process will require these users to provide qualifications and contact information for possible follow-up questions during database quality control work (discussed in Section 6). Other users will be able to save their fuelbeds on their own computers.

The entry screen allows users to specify whether they wish to interact with the system manually (working on one fuelbed at a time) or in 'batch input' mode (directing the system to a tabular file containing input data on all the fuelbeds in their study area). Batch input capability will be desired for processing map polygon attribute data, for example. It may also facilitate the initial population and future expansion of the system database. The interface for batch input is described following the Manual interface below.



Screen Manual #1: Provide Site Name. The fuelbed site name is used to label output reports for the user. If the user later opts to save their fuelbed information in the system database or their own FCC database, the system will check that the name is unique in the identified database and query the user for a modified name if necessary. The site description is optional, but if provided it will be included in the output reports and saved in the database.

The *Back* button on this screen and each following screen offers users the chance to return to a previous screen and change the selections they have made.



Screen Manual #2: Select Fuelbed Prototype. This screen allows users to specify the criteria by which the system will choose a fuelbed prototype. The screen lists all of the general site variables described in Section 2.1. All of the input boxes will be blank when the screen first appears, and the *Next* button will not be available until the user has specified the values of at least one variable.

The drop-down menus for each variable will initially show all of the values that are available for any fuelbed defined in the database. As soon as the user specifies the value of any one variable, however, the system will reduce the drop-down menus for every other variable to only display values that are available in combination with the variable specified (e.g., if the 'Marine' division is specified, only the cover types that are represented in that division in the database will be shown in the drop-down cover type menu). At the same time, the system will determine which of the fuelbeds that meet the specified value represents the largest total area. That is, every fuelbed stored in the database must specify what total area of the United States is represented by that fuelbed.

(General fuelbed types such as Marine Conifer Forest will cover large areas, while specific fuelbed types within them – such as Marine Old-Forest Multistory Douglas-fir with Root Disease in Condition Class 3 – will cover smaller areas within the general types). The database will determine the most common fuelbed that meets the specified value. The system will then display the other variables appropriate to that fuelbed as default values in each interface window.

The user can go on to select more appropriate values from each drop-down menu. Each time a selection is made, the system will repeat the process of limiting the remaining drop-down menus to choices that are available in combination with the variables already specified, and selecting the most common fuelbed that meets all of the specified criteria.

When the user is satisfied with the criteria they have specified, that most common fuelbed will be chosen as the *fuelbed prototype*. This fuelbed prototype will provide a complete set of default fuel values to assist the user in completing the coming tasks.

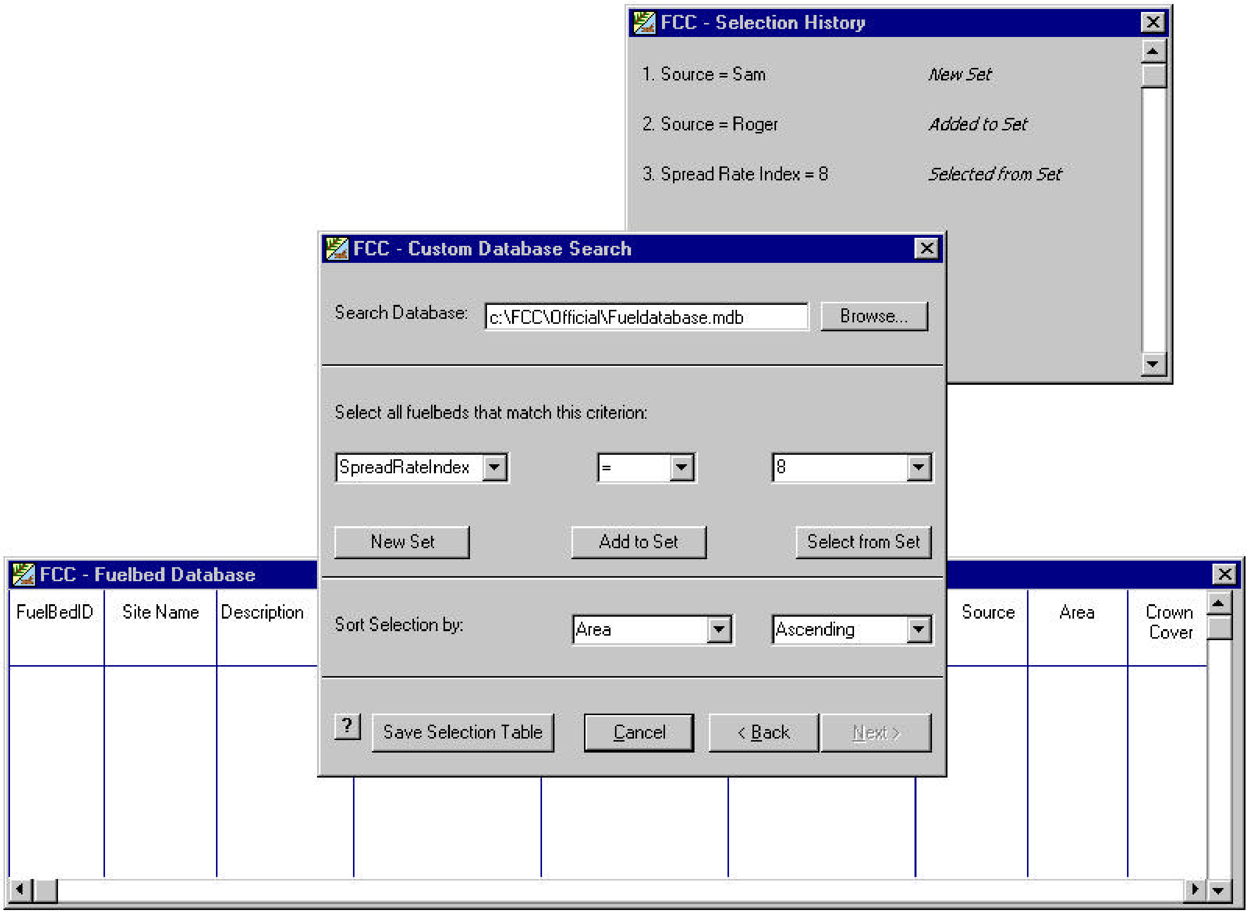
The *Refresh Screen* button instantly allows users to clear all of their previously selected values on this screen, restoring a full range of options on every drop-down menu. This option is provided in case users their preceding specifications leave them unable to match a variable of more primary concern. For example, after specifying 'old-forest' 'ponderosa pine' with 'recent partial-cutting', a user may find that there are no fuelbeds available in the fire-suppressed condition class appropriate to their site. They may then 1) accept the closest available condition-class; 2) re-set one or two other values in the hope of broadening the available condition-classes (re-setting the 'change agent' might be a good choice); or 3) refresh the whole screen, this time specifying the desired condition class as their first choice.

Note that "Natural Fire Regime" will usually be determined by the choice made for "Cover Type". The fire regime selection window, however, is provided to give users who do not know the cover type of their site another means by which to select an appropriate fuelbed prototype. Also note that the value shown here as "Forest Structural Class" will be changed to a more general "Structural Class" with the addition of several classes appropriate to shrubland and grassland.

The *Show Map*, *Examples*, and *Definitions* buttons allow users to obtain more information about each of the variables on the screen. The *Custom Search* button allows user to select a fuelbed prototype from the database based their own unique criteria, as is shown on the following screen.

Users might also like to have an additional button that is not illustrated on the sample screen. A *View Eligible Fuelbeds* button could allow users to see all the fuelbeds that currently meet the selection criteria they have specified, and to select a final prototype themselves from that list rather than letting the system simply select the most common one. Note, however, that these capabilities are already available in the custom search interface described in the next screen. There may be an advantage to keeping the standard search screen as simple as possible.

Note for readers viewing the electronic screens: Readers who view this screen in electronic form will find that only the first drop down menu provides any alternate selection. This restriction is because the operational version of the screen would not permit arbitrary recombination of the choices on each menu. That is, the choices available on successive menus would be modified to reflect the options that are available in the database, given the choices already made by the user. All of the following sample screens offer a broader range of drop-down menu choices, reflecting a portion of the diversity that the FCC system will encompass.



Screen Manual #2-Custom: Custom Database Search. If they prefer, the user may select a fuelbed prototype based on any other fuelbed information stored in the database. This interface allows them to specify which database they wish to search. The default database (and the one always used in the standard search shown on Screen Manual #2) will be the 'official' FCC database accessed over the internet, but the user may also refer back to a private database of fuelbeds they have previously compiled (by having the system save their fuelbeds to their own computer in the FCC format).

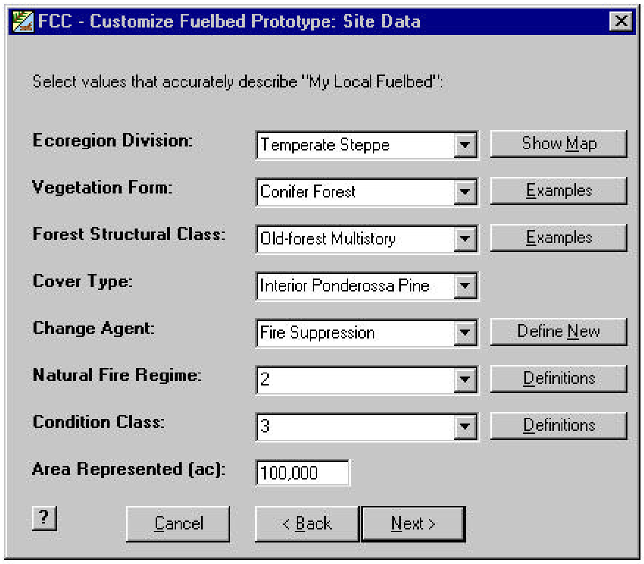
The interface then allows the user to select fuelbeds from the database according to the value of any available database field[13.] They may make repeated selections, with each selection being either a sub-set of the first ("*Select from Set*"), an addition to the first ("*Add to Set*"), or a replacement of the first ("*New Set*"). In the background, the interface will show which database fuelbeds are currently selected and the selection history specified by the user. In the example shown, the user has selected all the fuelbeds created by "Sam" (first selection) or "Roger" (second selection added to first) that have a spread rate index of 8 (third selection drawn from within the previously selected fuelbeds).

The *"Sort Selection by:"* part of the search screen also allows the user to specify the order in which they would like these fuelbeds to be sorted in the background, according to ascending or descending values of any variable. When they find the fuelbed they want, the user may either click on it in the background table or enter its identity

[13] If desired, the drop-down menu on the right could also allow users to specify that the variable on the left was to have a particular relationship with any other variable For example, the interface could allow users to select fuelbeds such that "spread rate index is greater than crowning potential index", instead of "spread rate index equals 8". This would allow the use of selection criteria such as "mass of suspended vegetation is greater than shrub mass", instead of having to specify a numeric threshold.

number in the search screen (i.e., specify “FuelbedID = 2247” as a search criterion). The *Next* button will not become available until the user has narrowed the selection to a single fuelbed through one means or another.

The *Save Selection Table* button allows users to save whichever fuelbeds are currently selected (as shown in the background table) in a tabular file format on their own computer. This is simply an optional convenience provided for users who wish to compile data on selected fuelbed types for another purpose.

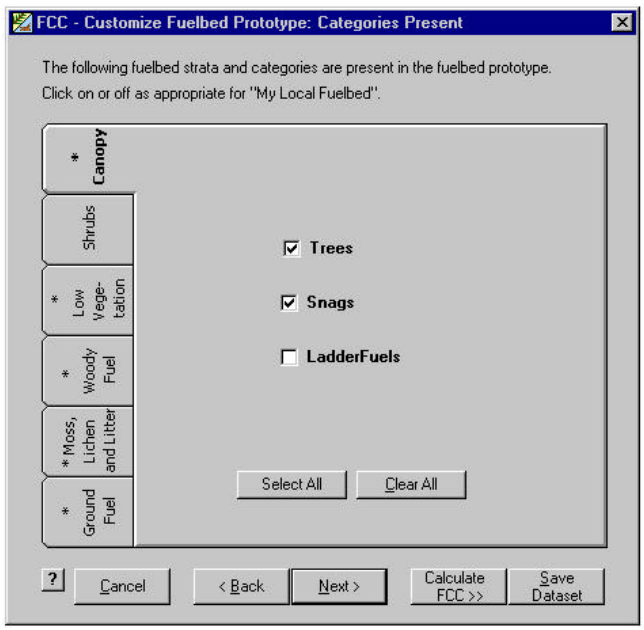


Screen Manual #3: Customize Fuelbed Prototype: Site Data. This screen allows users to specify the general site information that most accurately describes their fuelbed (without the restriction of matching an existing fuelbed in the database, as was done on Screen Manual #2). This screen is required because, initially, the fuelbed database may not contain protypic fuelbeds for all possible combinations of the site variables. For example, there may be no fuelbed for stem-exclusion-closed-canopy (SECC) Douglas-fir after partial-cutting. In this case, the user may opt to select the fuelbed prototype for SECC Douglas-fir with no change agent on Screen Manual #2, and then customize the fuelbed. Screen Manual #3 then allows the user to specify the general site variables that accurately reflect their fuelbed – i.e., SECC Douglas-fir with partial-cutting. In other words, the system will first ask users what general site variables they wish to use as criteria for the selection of a prototypic fuelbed (Screens Manual #2 and #2-custom), and then what site variables actually describe their own fuelbed. Although few of the site variables are used to calculate output fuel properties or FCC indices (in the first anticipated version of the FCC system), the appropriate values must be put in place for when the customized fuelbed is subsequently added to the database.

The default values shown on this screen will be the values that match the selected fuelbed prototype. The dropdown menus, however, will show all the values for each variable that have been previously defined in the database. Each drop-down menu will also provide the option of “[Unknown]”. This is both to accommodate users who have little site-specific information on their fuelbed, and to permit the creation of general average-condition fuelbed types (such as an ‘average’ fuelbed for young conifer forest in the temperate steppe ecoregion).

The *Define New* button on this screen allows users to also specify new “Change Agents” that have never before been defined in the database. This facility is important in allowing the database to ‘grow’ in its ability to recognize finer distinctions between alternative fuelbeds (such as a broader range of times since disturbance, for example).

The "Area Represented" field on this screen will have a default value of one acre. Users are requested to estimate the total area of the U.S.A. in which they would expect to find fuelbeds like the one they have described on this screen. It is understood that the values entered may often be very rough estimates. If the new fuelbed is later saved in the database, however, even order-of-magnitude estimates (such as 10 acres, 100 acres, 1,000 acres or 10,000 acres) will be very useful in helping the database select the most probable fuelbed prototype for the next user (see discussion of Screen Manual #2 above). As explained in section on database maintenance below (Section 7.2), the "Area Represented" estimate will be checked for general consistency before the new fuelbed becomes fully accessible in the database.

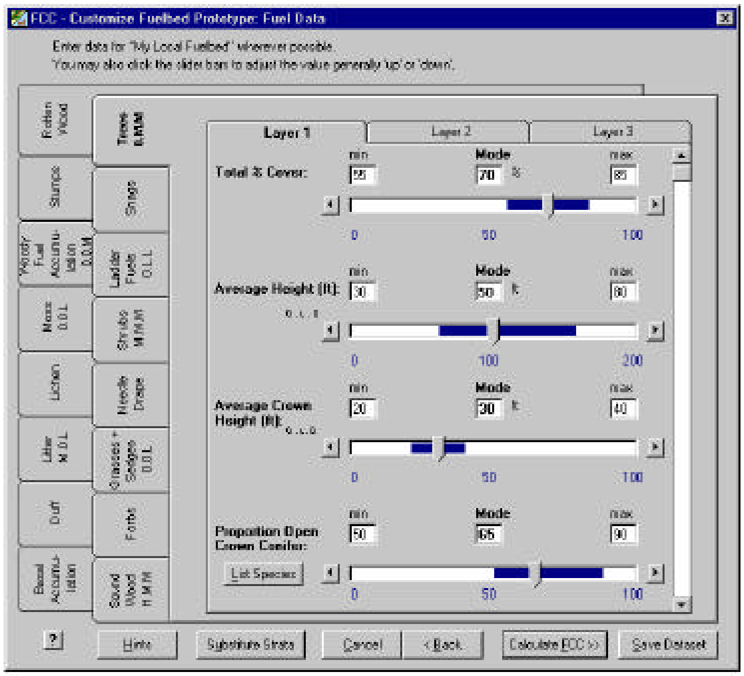


Screen Manual #4: Customize Fuelbed Prototype: Categories Present. This screen allows users to change any of the default assumptions about which strata and categories are present in their fuelbed. Users can click the *Clear All* button for each stratum, or the checked box for each category, to 'turn off' any stratum or any category that is assumed to be present by default. This re-sets all the default values within that stratum or category to zero. Users can also click the *Select All* button or the empty check boxes to 'turn on' strata or categories that were assumed to be absent. The default values will still be zero, however. It is then up to the user to enter values on later screens.

The *Save Dataset* button on this and the following screen allows users to save their customized dataset. This option permits users to back-up their interim dataset at any point (e.g., if they wish to leave the computer before they are ready to proceed to FCC calculation, and will want to return to the same dataset later). The dataset will be stored on their own computer, not in the official system database that is accessed over the internet.

The *Calculate FCC* button on this and the next screen allows users to proceed directly to FCC calculation if they do not wish to make any further changes to the prototypic fuelbed data.

In the screen illustration, asterisks (*) are used to indicate which strata are currently assumed to be present. In the operational system, this should ideally be indicated in a more obvious manner such as by coloring the file tabs differently.



Screen Manual #5: Customize Fuelbed Prototype: Fuel Data. This screen provides access to the gradient variable and physiognomic class data for every category that was indicated to be present on Screen 4. The default values shown on this screen will be the modal values appropriate to the fuelbed prototype. The highlighted area of the slider bar will indicate the expected range of values, from minimum to maximum, for that prototype.

This screen allows users to make as much use as possible of the information they have available, even if that information is qualitative rather than quantitative. Users may either enter their own numeric values in the input boxes, or move the pointer on the slider bar (in which case the numeric values in the input boxes will be automatically updated). Users who do not have precise numeric data values can click on the arrows at the end of the slider bar to indicate that the value for their fuelbed is simply 'higher' (one click), 'much higher' (two clicks), 'lower' or 'much lower' than is typical for the fuelbed prototype. The system will then adjust the default value by a rule-of-thumb, moving the value half-way from the modal default to the expected maximum for the fuel bed in the case of 'higher', and all the way to the maximum in the case of 'much higher'. Users who believe their site exceeds the expected range for the fuelbed will have to specifically indicate the extent of excess. The numeric values in the input boxes will be shown in a neutral color when they are within the expected range, and will be shown in a warning color when the user has specified a value outside the expected range.[14]

Although not shown here, this sample screen will also ask users to rate the quality of the data that they are providing for each category. The rating categories will range from 'no data available' to 'poor data quality', 'fair data quality', and 'good data quality'. These ratings will be included in the output reports, and stored in the database for reference when the new fuelbed is re-used as a prototype fuelbed for other sites. By default, the rating should first display 'no data available'. This rating should be updated automatically to 'poor data quality' if the user edits any of the default values for the category. Higher ratings will only be activated if selected by the user.

[14] Note that the system must be very tolerant of users entering values outside the expected range because, especially in the early phases, there may be circumstances in which the system's "expected" ranges are inappropriate. For example, the user may wish to create a fuelbed for a partially-cut stand by modifying the untreated fuelbed for that stand type.

The *three-character codes* letters on each fuel category file tab indicate the importance of that category in deriving each FCC index (in the case of the fuelbed prototype). In each code (e.g., M.0.L), the left-most character indicates how much influence the category in question has on the spread rate index (‘Moderate’ influence in this case), the middle character indicates how that category influences the crowning potential index (‘Zero’, or no significant influence), and the right-most number indicates how much that category influences the fire effects index (‘Low’ influence). The same codes appearing below some gradient variable values indicate the strength of influence that particular data value has on each FCC index. In the example shown, average tree height and crown height in layer 1 each have ‘Low’ influence on the crowning index but have no influence on any other index. Total % tree cover is shown to have no influence on any of the three indices (no code is shown at all).

A *List Species* button will be shown beside each of the gradient variables for crown cover proportions. These buttons will provide a list of the species that are considered to fall into each crown type (e.g., open crown conifer, closed crown conifer, flammable broadleaf, and ‘other’ broadleaf) in the current ecoregion division.

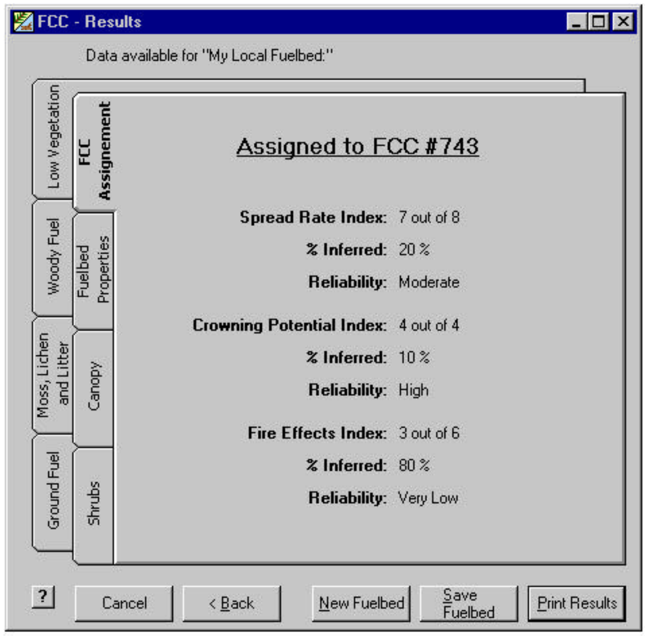
If users click the *Hints* button, the system will consider how the site data provided for the new fuelbed differ from the site data of the fuelbed prototype. Based on this comparison (especially any difference between the ‘change agent’ applicable to each fuelbed), the system will offer suggestions on which fuel data categories are likely to require the most significant revision in order to fit the new fuelbed. For example, the system may suggest “To account for recent partial-cutting, reduce % cover in the affected canopy layers, review the proportions of each crown type to account for any species retention preferences, and increase sound woody fuel loadings in the 0 – 9” size classes to account for slash.”[15]

The *Substitute Strata* button will allow users to specify that all the data values for one or more strata (or categories within a strata) are to be replaced with values from another fuelbed prototype. For example, the user may have chosen an untreated fuelbed prototype to matches their cover type, but need to edit that prototype to reflect conditions after partial-cutting. They may find it convenient to begin by replacing all the woody fuel accumulation, stumps, and sound wood default data in the prototype with data from a partially-cut fuelbed in a different cover type. The *Substitute Strata* button will first ask invite to select the new fuelbed prototype (using screens much like screens Manual #2 and Manual #2-Custom), and then to specify which strata and categories in they wish to replace with the new data (using a screen like Manual #4). The user may repeat this process as many times as they wish, in order to replace data in other strata or categories with data from a third or fourth fuelbed prototype.

Users who are not intending to save their fuelbed in the database need not worry about editing the minimum and maximum values for each gradient variable. Users who do intend to save their fuelbed in the database may nevertheless leave the default minimum and maximum values in place. (As it saves each fuelbed, the database will maintain a record of the source of every value in the fuelbed: derived from the fuelbed prototype, qualitatively adjusted by the user, or numerically input by the user.) The minimum and maximum values are required to display the probable range of data values when a future user selects the new fuelbed as their prototype. (Later phases of system development may also use the minimum and maximum values to estimate the stochastic variation that should be expected between different examples of the same fuelbed type).

When the user has entered all the information they have available, they may direct the system to *Calculate FCC*.

[15] Initially, the system would simply display rules-of-thumb provided by forest scientists. Once the fuelbed database has grown larger, later work could develop additional guidelines from a quantitative comparison of existing fuelbed prototypes. For example, a program could be developed to find all the pairs of fuelbeds that share the same general site characteristics except one (i.e., whether they are undisturbed or have had recent partial-cutting). The program could then compare how each fuelbed category differs between the stands in each pair (between the cut and uncut stands).

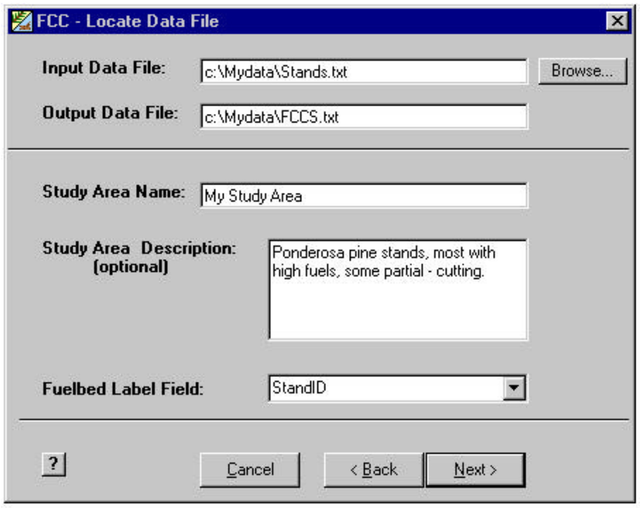


Screen Manual #6: Results. This screen allows users to explore all the data that the system has compiled on their fuelbed. The top page shows the FCC assignment, including the value of each of the three indices and the estimate reliability of each index. Although not illustrated here, this page would ideally include a 3-dimensional illustration (like Figure 1.2 in Section 1 above) showing graphically where the fuelbed falls along each FCC index. The second page on this screen shows other fuelbed-level properties, such as the overall maximum spread component or the combined wind reduction factor. The remaining pages show for each stratum all of the stratum-level gradient variable values (with distinctions made between values based on the fuelbed prototype, values input by the user, and values qualitatively adjusted by the user), inferred physical constants, calculated fuel properties, and assigned fire parameters.

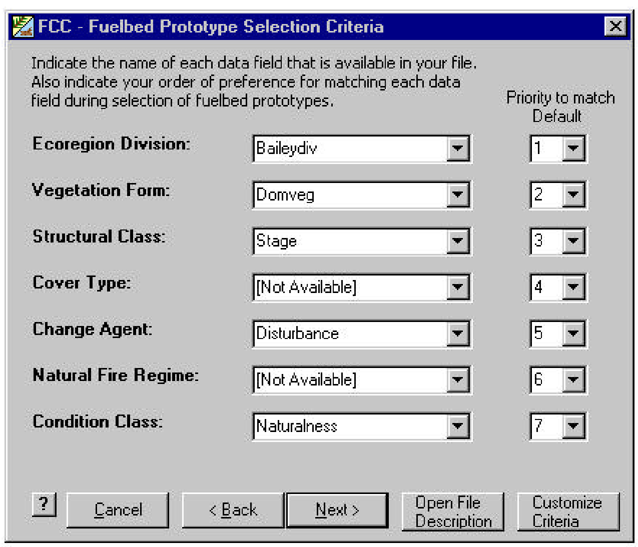
The *Print Results* button will ask users to select one of the available output report formats, and then print the results in that format.

The *Save Fuelbed* button allows users save their new fuelbed in an FCC database on their own computer or – if they are a registered user – in the system database. Before writing the new fuelbed to the selected database, the system will check that the new fuelbed name is unique in the database, and will prompt the user to provide a new name if not. The system will also invite the user to reconsider the total area represented by the new fuelbed ("Area Represented" on screen Manual #3) if the default value of 1 acre has been left in place. Finally, the system will notify the user that new fuelbeds saved in the database are not made commonly available as fuelbed prototypes (i.e., will not be available on screen Manual #2) until quality control procedures have been completed. As this process will be done periodically (perhaps monthly) rather than instantly, the user will be told that their new fuelbed may be accessed in the interim by specifically selecting non-vetted fuelbeds (e.g., fuelbeds with a "Data Reviewed?" field set to "No") on screen Manual #2-Custom.

The *New Fuelbed* button will return users to the Entry screen, allowing them to either begin manual work on a new fuelbed or to select the "Batch Input" interaction type that is described below.



Screen Batch #1: Locate Data File. This screen asks users to locate a tabular data file (such as .dbf file or formatted text file), name the desired output data file, provide a name for the study area, and enter an optional study area description. Once an input data file has been identified, the system will first check that the file is indeed in a suitable format. Next, the system will make a list of all the data field names found in the input file. All the field names will be displayed in the drop-down menu at the bottom of the screen. The user is required to select from this menu the field with which they wish to identify each fuelbed (e.g., a fuelbed name, stand ID, record number, or other unique identifier for each row in the data table).

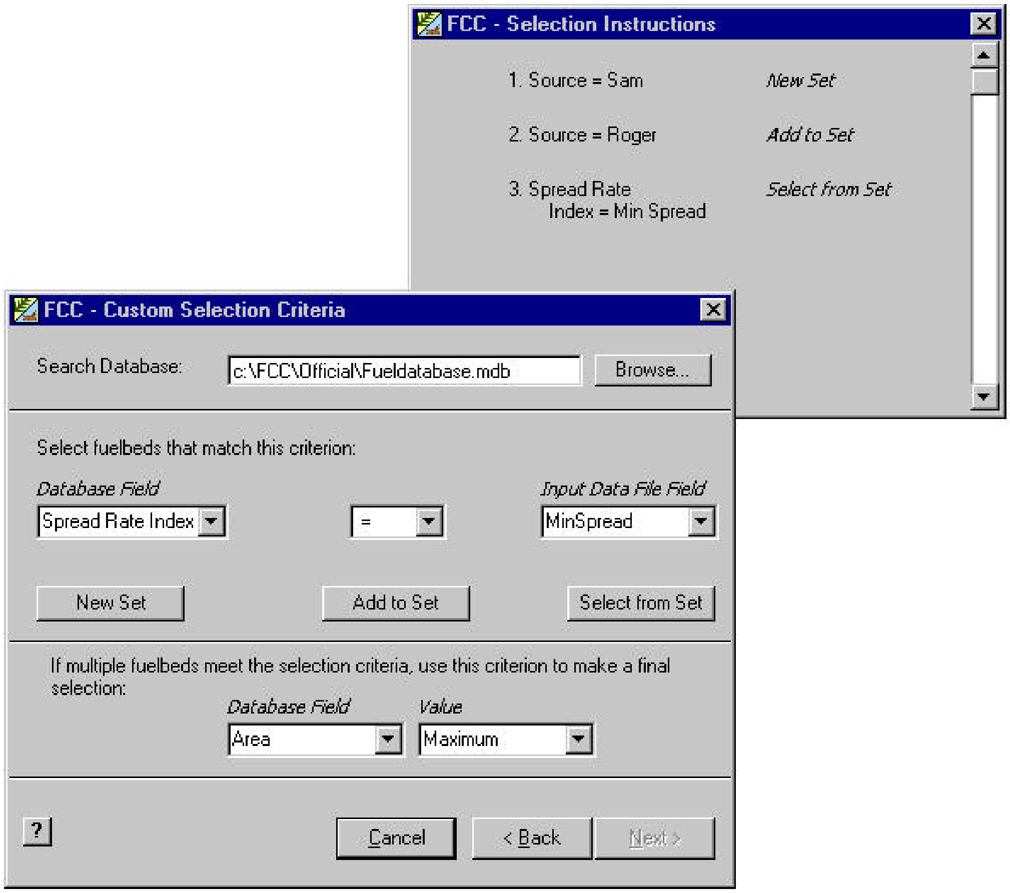


Screen Batch #2: Fuelbed Prototype Selection Criteria. Like Screen Manual #2, this screen allows users to specify the criteria by which the system will choose a fuelbed prototype. In this case, however, rather than selecting a desired value for each criterion, the user must select the name of the data field that should be matched. That is, the user must tell the system which data field contains the ecoregion division value that they wish to match during prototype selection for each of their sites. By default, all the input boxes will display "[Not Available]" when the screen is first entered. The drop-down menus for each input box will list all of the data fields that are available in the specified input file, except for fields that the user has already assigned to another variable. The numbers to the right of each variable allow users to control the order in which each selection criterion is applied. By default, the system would first select the database fuelbeds that match the ecoregion division field (if specified), then the fuelbeds from within the first set that also match the vegetation form field (if specified), and so on. The selection process for each site in their data file will stop when only a single database fuelbed remains selected or when all the specified criteria have been applied. If more than one database fuelbed remains selected in the latter case, the system will choose the selected fuelbed that represents the largest total area of the USA. This is the fuelbed most likely to be representative of the site in question.

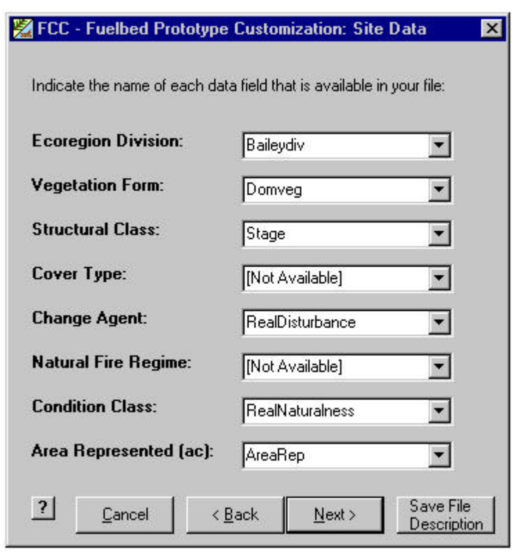
It is not necessary for users to have already adopted in their input data file the same data coding system used in the FCC database (e.g., to designate the shrubland vegetation form with the code “SL” rather than “shrub”, “SH”, “57” or any other code that they prefer). Users will have an opportunity to clarify the meaning of their data codes on screen Batch #6.

The *Open File Description* button allows users to recall a previously-created input data file description, including the field name of each data value that is available in the file. Opening an existing data file description will put a default field name in place for every data value that was available in the data file for which the description was created (unless the specified field name does not occur in the current data file, in which case the window will again show “[Not Available]”). Moreover, default field names and other values from the existing file description will be put in place for every value that was available on screens Batch #2-Custom to Batch #6. The option to re-use stored file descriptions in this way will be wanted 1) when a user has to process numerous files that that were all created with the same field names and data codes; and 2) when a user has to back-up their work before completing an input file description. The option to save a partial or complete file description is provided on screens Batch #3 to Batch #6.

The *Customize Criteria* button allows users to specify that entirely different criteria be used to select the fuelbed type, as is shown on the next screen.



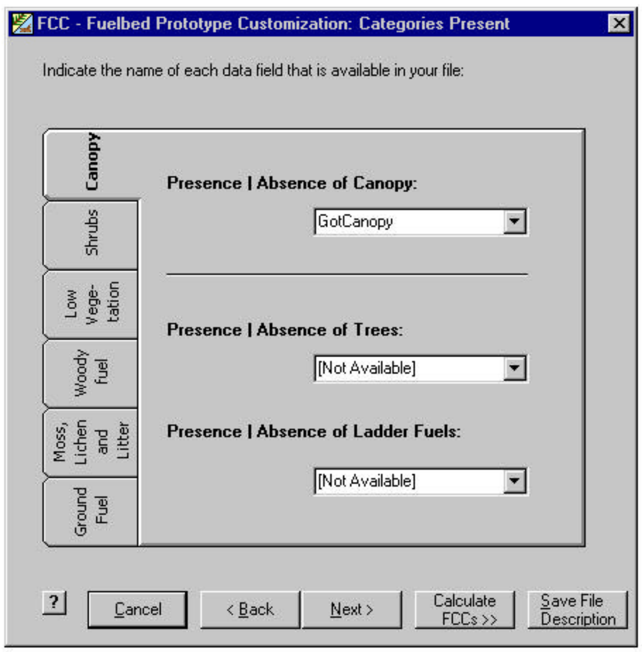
Screen Batch #2-Custom: Custom Selection Criteria. This screen allows users to specify their own criteria for the selection of fuelbed prototypes, just as can be done during Manual interactions (Screen Manual #2-Custom). The only difference here is that users indicate which input data field contains the value that they wish to match for each site, instead of specifying a single target value as is done in Manual interactions.



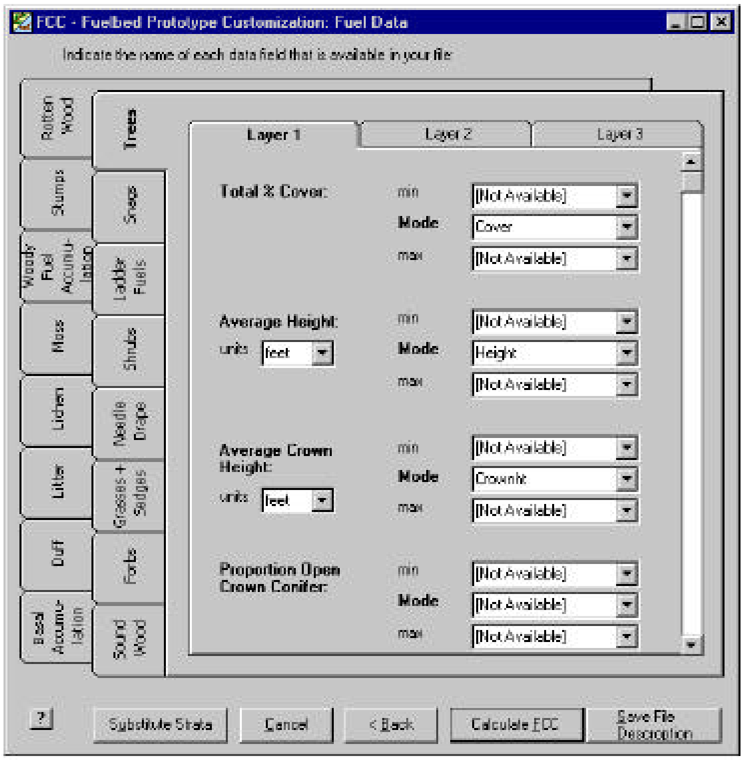
Screen Batch #3: Fuelbed Prototype Customization: Site Data. Like Screen Manual #3, this screen allows users to begin customizing the fuelbed prototypes by specifying the values (or in this case, the data field that contains the values) that accurately describe their own fuelbeds. Again, the purpose of this screen is to allow different criteria to be used for the selection of prototype fuelbeds (for which the available choices may be limited) than the criteria that precisely fit the users fuelbeds. For example, a user may be working with a data file containing information on 10 stands each of which have been subjected to a different form of partial-cutting. The database is unlikely to already contain a fuelbed prototype specific to each form of partial-cutting (in the same cover type, at the same structural stage, etc). Indeed, the same fuelbed prototype may well be selected for all 10 stands. This screen allows the user to specify the new change agents that actually describe each stand (e.g., the values in the data field "RealDisturbance"), instead of the standard form of partial-cutting represented in the prototype. The fuelbed prototype values will be used to estimate the value of any information that is shown as "[Not Available]" on this screen.

This screen also asks users to indicate which data field contains the representative area values for each new fuelbed (see screen Manual #3 for details).

The option to *Save File Description* on this and the following screens allows users to back-up their work if they have to leave the computer, and/or before they proceed to FCC calculation. Screen Batch #2 allows users to recall a saved file description whenever they are working with the same type of data file.



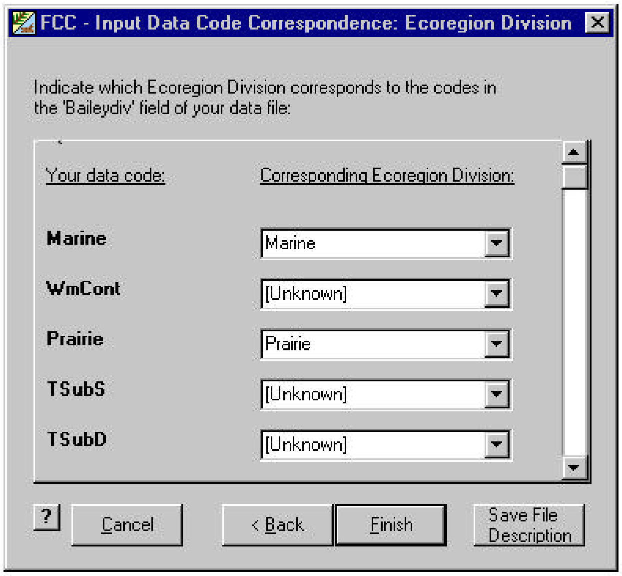
Screen Batch #4: Fuelbed Prototype Customization: Categories Present. This screen gives users a chance to indicate which data fields, if any, provide information on the presence or absence of fuel strata and categories at each of their sites.



Screen Batch #5: Fuelbed Prototype Customization: Fuel Data. This screen lets users indicate which data fields in their input file provide physiognomic data and abundance data for each fuel category. As in Manual interactions, the *Substitute Strata* button allows users to specify that the default data for some strata or categories should be based on one or more alternative fuelbed prototypes. This button will use screens much like Batch #2, Batch #2-Custom, and Batch #4 to let the user identify which data fields contain the criteria to be used in choosing an alternative fuelbed prototype, and which fields identify the strata or categories that are to be based on the alternative prototype. Users may repeat this process as many times as they wish, in order to specify how the system is to select different fuelbed prototypes to replace the data in other fuel strata or categories.

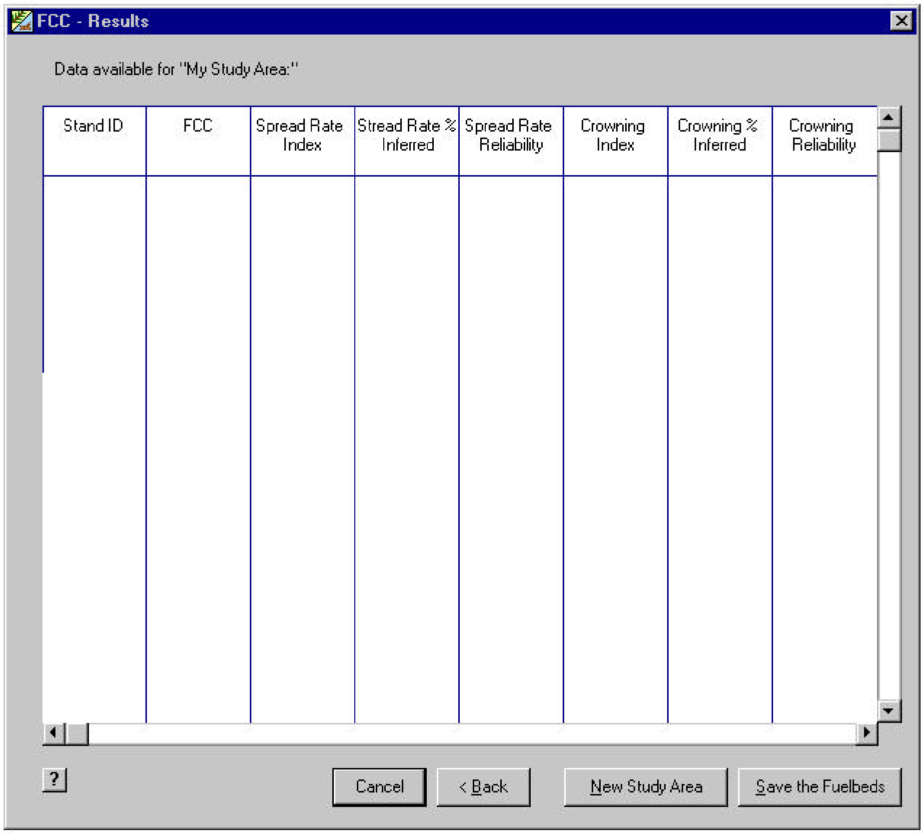
The system will allow the user to designate non-numeric fields as the source of information on quantitative variables like “Average Height”. This is because users may wish to use values such as “Much Higher” or “HH” to indicate that their fuelbed differs from what is typical for the fuelbed prototype, in the same way that they could click on the arrows at the end of each slider bar on screen Manual #5. Users will have an opportunity to clarify the meaning of these data codes on screen Batch #6.

When they have identified as much information as they have available, the user may direct the system to *Calculate FCC*. This button will cause the system to check whether the data fields identified on screens Batch #2 to Batch #5 contain only the data codes normally used in the FCC system. If any other data codes are found, the system will invite the user to match these new codes to defined data values on screen Batch #6 below. If no unusual codes are found, or once all codes have been matched to a defined data value, the system will begin processing each data record in the input file in turn. The system will compile the results in the output data file named by the user on Screen Batch #1.



Screen Batch #6: Input Data Code Correspondence: Ecoregion Division. The FCC system will display a series of screens like the one shown here if any of the data fields previously identified by the user contain data codes other than those used in the system database. These screens will allow the user to specify which of the known data values in the system equate to each of their data codes. In the example illustrated, the user's "Bailydiv" field was identified as the source of ecoregion division information. The system assumes that the "Marine" code equates to the "Marine" division defined in the database. It cannot recognize, however, that the "WmCont" code indicates the "Warm Continental" division. The user will have to select this division from the drop-down list. The *Finish* button will either bring up another screen like this one for the next data field that was found to contain unfamiliar codes, or will tell the system to begin calculating FCC outputs if there are no more unfamiliar codes. This button will not become available until the user has selected a known data value for every code designated "[Unknown]" on the current screen.

The FCC system will also display screens like the one shown here if the user has selected a non-numeric field to provide information on a quantitative variable (such as 'Average Height'). In this case, the system will ask the user to indicate which codes in the designated field equate to the values "higher", "much higher", "lower" and "much lower". These designations will affect the default modal value for that variable in the same manner as clicking on the arrows at the end of the slider bars on screen Manual #5.



Screen Batch #7: Results. After every data record has been processed, the system will show the users the results in a tabular format. This output data table will contain columns for all of the gradient variable values, physiognomic information, inferred and calculated fuel properties, and assigned fire parameters that are provided in Manual interactions (screen Manual #6). Because each row of the output table will be labeled by the Stand ID or other identifier specified by the user (screen Batch #1), users will be able to link this output table back to their original study area polygon files and produces maps of any of the output values.

The *Save Fuelbeds* button will allow users to save the new fuelbeds in either their own or – in the case of registered users – the system database. The button will perform the same functions as described for the *Save Fuelbed* button on screen Manual #6.

The *New Study Area* button will return users to the Entry screen.

6.0 Outstanding Issues

This section discusses two outstanding issues regarding the FCC system's desired output data, proposed input data, and suggested calculation methodologies: 1) the development of procedures to select inferred associated variable values appropriate to each situation; and 2) whether alternative input variables could allow for more accurate output calculation.

6.1 Inferring Associated Variable Values

The selection of appropriate values for inferred associated variables will require some thought during system implementation. It may often be the case that the required values have been measured and reported for particular species and circumstances. The FCC system user, however, may have provided only broad physiognomic class data for a fuelbed in which quite different circumstances apply. For example, available crown bulk density values for conifers may be reported for single species at particular stem diameters, taking into account the usual taper of free-growing crowns. The user may specify only that 60% of crown layer 1 consists of closed-crown conifer. The first question the FCC system will need to resolve is what conifer species composition is likely to be found within the 'closed crown conifers' in the users fuelbed. The second question is what stem diameter the closed crown conifers in layer 1 are likely to have. Variation between different size classes of the same species, and variation due to growing conditions at different densities, are likely to be as great or greater than the variation in average values between different species. The third question is how crown bulk volume calculated as proposed in the FCC system (in this case, by multiplying 60% of the total layer 1 crown cover by the crown length in layer 1) is likely to compare to the total crown volume of the individual closed-crown conifers in that layer. The difficulty in answering this last question is not only that the proposed measure of bulk volume does not account for any crown tapering, but also that percent cover values are non-additive. This latter problem is discussed further in the next section.

6.2 Finalizing the Input Data Requirements

Before finalizing the input data requirements (i.e., Table 2.2 above), it is recommended a plant and fuel biometrician review the required output information and consider how that information might most accurately be derived from readily available input data. The input gradient variables proposed here were selected with the goal of using readily available information wherever possible, but other information (such as average stand diameter, for example) may be equally available. The question should be asked whether any alternative variables would allow for greater accuracy in the output calculations.

The proposed use of percent cover values may turn out to be particularly problematic. The general problem with percent cover data is that they are non-additive. The problem will be described here with reference to tree cover, but the same issues may arise in working with % shrub cover, low vegetation cover, moss cover, lichen cover, and litter cover values in the FCC system. As shown for example in Figure 6.1, two trees of equal size do not necessarily cover twice the area of a sample plot as one of them alone would cover. This means that knowing a stand is composed of conifer and broadleaf crowns in a 50:50 ratio does not allow you to calculate total conifer cover by taking one-half the total stand cover.

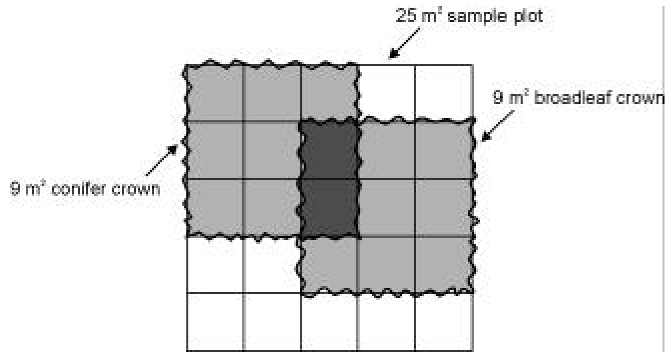


Figure 6.1: *Percent crown cover values are non-additive.* The figure shows a 25 m^2 sample plot containing one 1 m^2 conifer crown and one 9 m^2 broadleaf crown. The tree crowns are shown as approximately square for simplicity. Either tree crown alone would cover 9 or the 25 sample grid squares, providing 36% crown cover. Together, however, the two tree crowns cover only 17 grid squares, providing 68% total crown cover The implication is that the total percent conifer cover cannot be calculated from ½ the total cover. The difference is equal to the amount of overlap between the two crown types.

Care will have to be taken to ensure that this non-additivity does not cause compounding errors in the FCC system. As currently proposed, the system will need to calculate flammable broadleaf bulk volume for each crown layer based on knowing only total % cover in each layer and the proportion of each layer which classified as flammable broadleaf. Whether or not it is reasonable to do this by simply multiplying the two proportions together (which is equivalent to assuming that there is no overlap between flammable broadleaf crowns and other crowns in the stand), depends in part on how crown bulk volume was measured in determining the crown bulk density values that will be used in later calculations (see Section 6.1 above).

Note also that the current system design proposes using % cover to measure horizontal continuity within the tree canopy and other fuelbed categories. Adding the percent cover values of individual tree layers or shrub components will systematically overestimate the total percent cover in the category. This is easy to see by considering a stand in which there is 70% cover in layer 1, 40% cover in layer 2, and 10% cover in layer 3: the sum of these numbers would falsely suggest that total cover in the stand was 120%. It is equally false to assume that 70% cover in layer 1 and 30% cover in layer 2, with no third layer present, means there is 100% cover in the stand.

7.0 System Implementation

The FCC system is to be made available over the internet. It is anticipated that all of the system interfaces and system code will be stored and maintained centrally, rather than distributed for installation on user's individual computers. This will not only avoid numerous distribution and installation issues that might otherwise arise, but will also facilitate the task of making system updates.

Two types of system users are expected. The first type of user will register on the system, obtain a secure password, and henceforth be permitted to save new fuelbeds to the system database. The second type of user will access the system anonymously (using the username 'guest', for example). Anonymous users will be have access to all of the system functions (including the ability to search the fuelbed database, edit the prototypic fuel data, and ask the system to calculate output fuel values) except the ability to save new fuelbeds to the system database. Both types of users, however, should have the option of saving their new fuelbeds in an FCC database[16] on their own computer.

The following sections consider some issues surrounding implementation of the envisioned system.

7.1 Application Software

The general system design described here was reviewed by Kaldor Interactive Group Ltd, an internet software development group, to ensure that the design was generally suitable for the planned internet application. In addition to verifying that the design did not contain unintentional barriers to internet application, Kaldor provided a discussion of the pros and cons of some alternative application environments. Their complete discussion is shown in Appendix 2. This section briefly describes some of their recommendations.

After describing the drawbacks of 'classic' fat client applications (which must be installed on each user's computer) and HTML applications (which have restricted graphical interface capabilities), Kaldor recommends building the FCC system as *a three-tiered thin client Java application*. They suggest using a Swing-based Java applet for the interface in order to take advantage of the latest graphical capabilities and best speed. This applet may be 'signed' in order to allow the system to write new fuelbeds to the user's local hard drive. For the application layer, they suggest Enterprise Java Beans, which are re-usable components developed to handle issues that arise when an application is running on multiple servers (as may be required if a sufficient number of users seek access to the FCC system at one time).

Kaldors software recommendations surrounding the Java application are summarized in the following table.

Table 7.1: FCC System Software Recommendations from Kaldor Interactive Group Ltd.

	For Intel Hardware	For Sun Hardware
Web Server	Microsoft IIS	Apache
Java Application Server	BEA WebLogic	BEA WebLogic
Database Management System	Microsoft SQL Server or Oracle	Oracle

In finalizing the application environment and component software, the software developers responsible for implementing the FCC system should work closely with the core FCC system designers in the US Forest Service

[16] That is, a database created by the system including a fuelbed data table, fuelbed data source table, and fuelbed data quality table (as described in Section 4.1). When first created, these tables will contain only a single record, for the first fuelbed the user has saved on his/her computer. The user should be able to save any fuelbeds they subsequently create to the same tables.

(David Sandberg, Roger Ottmar, and Geoff Cushon) and with USFS computer-systems people to ensure all objectives are met.

7.2 Database Maintenance & Quality Control

As described in this report, the FCC system is intended to 'learn' and evolve through the addition of new fuelbed prototypes developed by system users. The need to allow registered system users to save fuelbeds to the system database, however, may raise a number of data quality concerns.

It is anticipated that, in order to register on the system, new users will have to provide contact information (including name, email address, work address and phone number, and employer or academic institution) so that they may be contacted if any questions arise concerning the fuelbeds they have created. They may also be asked to volunteer information on their experience or qualifications. This information and the contact information will only be available to FCC system administrators, and not to other users. It is expected that the name of the creator of each fuelbed prototype, however, will be available to all system users.

Data quality control should begin with on-line consistency checking as the user is editing the prototype fuelbed data. For example, the FCC system might be programmed to recognize which cover types can occur in each ecoregion division, and to prevent the user from specifying incompatible combinations (or at least post a warning to the user). With careful consideration, the system might also be programmed to refuse input data values that fall beyond the range of what is considered possible. The system's on-line consistency checking may initially be rudimentary, but it can always be refined during later development work.

Regardless of how much on-line consistency checking has been incorporated in the system, when a user saves a new fuelbed to the database that fuelbed will initially be flagged as not yet having been reviewed. Such fuelbeds will not be available in the general prototype selection screens (Screens Manual #2 and Batch #2) until such time as they have been reviewed. If users wish to access these fuelbeds in the interim, they may do so by specifically requesting non-vetted fuelbeds in the custom-search screens (Screens Manual #2-Custom and Batch #2-Custom).

Two aspects of each new fuelbed will receive particular consideration before the fuelbed is re-classified as vetted and made available to all users through the general search screens. These are:

1. whether the input data values fall within the range of conditions for which the output calculation equations are valid; and
2. whether the estimated total area represented by the fuelbed type has been reviewed.

In reviewing the representative area, data reviewers should consider the general site description of the fuelbed. For example, is the new fuelbed a special case of a broader fuelbed type already defined in the database, or is it a more general example of a specialized fuelbed in the database? The representative area should accordingly be smaller or larger than that of the existing fuelbed. Reviewers should pay particular attention to any new fuelbed that duplicates an existing fuelbed with respect to all of the general site variables (as shown in the general prototype selection screens). Which of these two apparently similar fuelbeds should be taken as the default prototype when both match all the specified criteria?

In addition to review of each new fuelbed, FCC system administrators should schedule periodic reviews of the representative area data for every fuelbed in the system. The actual area represented by each fuelbed type is subject to change over time, as forest disturbance frequencies or management practices change over time. It will likely be adequate to perform these reviews on a 10-year cycle. Ideally, these reviews would be timed to coincide with the release of updated national land-cover or forest inventory data.

8.0 Future Evolution

The following sections describe areas in which the FCC system could be refined, and its coverage expanded, as the system comes into wider use.

8.1 Creation of Fuelbed Prototypes for a Wider Range of Change Agents

Initially, the FCC system will be built to distinguish only a few of the most significant forms of disturbance ("Change Agents"), in order to capture at least the gross variation between fuelbeds with different disturbance histories. It is anticipated that later development work could allow the system to distinguish a greater variety of disturbance types and times since disturbance. Note that the earlier absence of a particular disturbance option in the fuel classification process is only a concern for those users that do not have detailed fuel abundance data with which to check the system's default values.

8.2 Expanded Range of Output Report Formats

As described in Section 3, later development work could provide additional output reporting options, including the option to obtain output reports formatted for input to specific fire models or stand projection models.

8.3 Translation Between Alternative Measurement and Classification Schemes

It is anticipated that a future interface extension could allow additional cover type schemes to be mapped onto the two schemes that will be implemented first. This would then allow users to communicate with the FCC system using other cover type classification schemes. Similarly, an interface extension could allow users to provide fuel abundance measures different than those used internally in the FCC database (such as basal area data instead of percent cover data), and have the system perform the necessary calculations to predict the values it needs internally.

8.4 Facilitation of Fuelbed Customization

The proposed system interface allows users to obtain 'hints' from the FCC system on which prototype fuel values may most need in order to reflect the general site conditions they have described for their own fuelbed (see Screen Manual #5 in Section 5). In future, this capability could be refined such that the user could ask the FCC system to automatically adjusted all the fuel values affected by some specified disturbance type and time frame. The reason this option is not included in the initial system implementation, however, is because it is expected to need a rather large rule base to support it (and much of the required information is not known to have been catalogued to date).

8.5 Dynamic Gradient Variable Prediction

Ideally every data value entered by the user would potentially shift the default value and narrow the probable range for other variables, both within the same stratum and in other strata. For example, if a user chose to enter woody fuel data first, the input of very high debris values might be used to reduce the default grass cover values. These data sensitivities may be added in later development work. Again, the concern in developing this capability is that many of the required relationships have not yet been well documented (particularly considering that these relationships are likely to vary substantially between different cover types).

8.6 Incorporation of Stochasticity

Another system capability that has been discussed for future development is to provide measures of the range of fuel conditions that are possible given the fuelbed information provided by the user. For example, every fuelbed prototype is designed to reflect a range of conditions (as is evidenced by the maximum and minimum values for every gradient variable). The mid-point of the prototype may fall into a particular Fuel Characteristic Class, but at its extremes fall into different classes. Many users would benefit from knowing the range of fuel conditions that could be associated with the prototype. The range of possible fuel conditions is, of course, even broader if the user has provided only partial site data (such as ecoregion division, vegetation form, and structural stage) and no site-specific fuel abundance data. For users interacting with the system in Batch mode, one possibility is to provide an option whereby each of their fuelbeds is stochastically assigned to one possible FCCs. When these users then mapped the output FCC assignments, they would be able to see on the map the full range of possible fuel conditions. Without the option to get stochastic FCC assignments, the map might only show average, 'median' conditions across the whole study area.

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Appendix 1: Draft Fuelbed Database

The following pages show 3 sample fuelbeds from the draft database (as of 30 January 2001). The abbreviations used in the table are listed following the table. The draft database was compiled by Jennifer Key and Geoff Cushon in the US Forest Service, using information provided by the FCC workshop participants.

Abbreviations Used in the Table

Strata

CA	canopy stratum
SB	shrub (stratum)
LV	low vegetation stratum
WF	woody fuel stratum
ML	moss, lichen, litter stratum
GD	ground stratum

Category

TR	trees
SN	snags
LD	ladder fuels
SB	shrub
NP	needle drape
GS	grass/sedge
FB	forbs
GW	sound wood
RW	rotten wood
ST	stumps
PJW	woody fuel accumulation
MO	moss
LH	lichen
LT	litter
DF	duff
BS	basal accumulation

Vegetation Form

CF	conifer forest
BF	broadleaf forest
MF	mixed forest
SA	savanna
SL	shrubland
GL	grassland
BG	sparsely vegetated
XX	slash

Forest Structural Class

SI	stand initiation
SEOC	stem exclusion open canopy
SECC	stem exclusion closed canopy
UI	understory initiation
YFMS	young-forest multistory
OFMS	old-forest multistory
OFSS	old-forest single story

Change Agent

DD	ditching/draining
EX	introduction of exotic species
FS	fire suppression
FT	residual fertilizer
GZ	grazing
PA	insect and disease
PC	selection cut
RL	salvage logging
RS	restoration work (inc. ground cover, hydrology)
RX	prescribed fire
SW	stumpwooding
TN	thin
TU	turpentining
WD	wildfire
NN	none

History

CC	clearcut
LG	historic logging (specifics unknown)
PL	initial tree planting
RC	stand replacing weather event
RF	stand replacing fire event
RP	stand replacing disease/insect outbreak
SP	site prep (specifics unknown)
SPD	site prep disking
SPF	site prep fire
SPP	site prep pile and burn
UK	unknown

Natural Fire Regime

RN	no natural fire (or very little).
R1	infrequent light surface fire(>25 year intervals).
R2	frequent light surface fires (1-25 year intervals).
R3	infrequent, severe surface fires (>25 year intervals).
R4	short return interval crown fires (25-100 year intervals).
R5	long return interval crown fires and severe surface fires in combination (100-300 year return intervals).
R6	very long return interval crown fires and severe surface fires in combination (>300 year intervals).

Condition Class

C1	condition class 1
C2	condition class 2
C3	condition class 3

Canopy Structure
S1 one layer
S2 two layer
S3 multistory

Trees:Foliage
BD broadleaf deciduous
BE broadleaf evergreen
CO conifer
PF palm frond

Ladder Fuels:Type
AL arboreal lichens and moss
BR dead branches
ES spanish moss
FR climbing ferns
FZ fuzzy bark
VN vines (including draped needles)

Shrub:Foliage
BD broadleaf deciduous
BE broadleaf evergreen
MP microphyllous, xeromorphic
NE needleleaf evergreen
RO rosette
SC evergreen sclerophyllous
SU succulent

Shrub:Growth Habit
SS single-stemmed
MS multi-stemmed
TH thicket forming
PR prostrate

Shrub:Accelerant Potential
A fire accelerating
N fire neutral
R fire retarding

Needle Drape:Component
NO no
M moderately
H highly

Grass/Sedge:Type
GR grass
SG sedge

Grass/Sedge:Growth Habit
BP bunchforming perennial [grass and sedge]
SD sod firming perennial [grass only]
AN annual [grass only]
TK tussock forming [sedge only]

Grass/Sedge:Leaf Blade
F fine (<=0.2"wide)
C coarse (>0.2"wide)

Stump:Decay Class
S predominantly sound (branches remaining)
RT predominantly rotten (branches gone)
L lightered/pitchy

Woody Fuel Accumulation:Type
PI piles
J jackpots
W windrows
SQ squirrel middens

Woody Fuel Accumulation:Clean/Dirty?
CL clean
DT dirty

Litter:Type
BD broadleaf deciduous
BE broadleaf evergreen
LP long needle pine
SH short needle pine
OC other conifer
PF palm fronds
GR grass

Litter:Arrangement
NR normal
FL fluffy (freshly fallen)
PE perched (on grass or forb)

Moss:Type
SM sphagnum moss
OM other moss

Duff-Upper:Derivation
DM dead moss and litter
FP fibric peat

Duff-Lower:Derivation
HM humus or muck
HP humic peat

Basal Accumulation:Type
BD broadleaf deciduous
BE broadleaf evergreen
BK bark slough
BR dead branches
LP long needle pine
SH short needle pine
OC other conifer
PF palm fronds
GR grass

General Information

Canopy

Shrub

Low Vegetation

Woody Fuel

Moss, Lichen, Litter

Ground Fuel

Appendix 2: Software Recommendations and Considerations from Kaldor Interactive Group Ltd.

The following information was prepared by Kaldor Interactive Group Ltd. Comments in square parentheses were added by ESSA Technologies Ltd.

Solutions

There are three possibilities that we would like to discuss:

1. VB server/client application
2. HTML web based
3. Java web based

A classic client/server application is a ‘fat’ client, labeled such because it contains both presentation and business logic. The client program accesses a relational database management system (RDBMS), shared files on a file server or both. A classic Web-based application uses a browser for data presentation, and separate application servers for business logic and database servers for storage.

The main drawback of a fat client is that it requires installation on each user machine. Clients typically have large file sizes and require that each user be provided the application through a distribution channel. Clients often require that certain users update their system prior to installation so they are running the latest libraries necessary for applications to function. Furthermore, each update or patch to the client also requires installation, leading to difficulties where some users run different versions of the client or install the wrong patch, etc. Some users may not even be able to install the client due to IT policy restrictions. This “traditional” software distribution model requires a large amount of technical support resources. The client does offer a slight speed advantage over a Java Swing applet, but this is almost negligible.

A fat client would be suitable for a stand-alone application, however. This could be created with communications occurring over the internet to a remote server. However, having both a stand-alone and web application requires more planning and development than having only one or the other. Having both means that there must be two levels of business logic, two levels of presentation, two levels of database storage, updates to two levels of software, etc. The consistency between the two applications must be maintained, and thus the level of development is much greater to maintain both stand-alone and web applications.

An HTML interface is the second possible solution. This application utilizes a ‘thin’ client that separates presentation from business logic. However, an HTML interface has many drawbacks. It lacks an advanced GUI toolkit so there are no sliders, tabs, etc. DHTML helps can overcome this, but is very time consuming to program and not consistently implemented amongst browsers. Every click on a button forces discontinuity in the interface due to the loading of a new page. Furthermore, an HTML interface cannot respond to user events, so you can’t click a button and have information appear in another area of the screen (unless using frames, although this is considered poor design). Lastly, HTML interfaces give users access to the “BACK” button, which can corrupt the user’s application state or session. The benefit of an HTML interface is that there is no loading time to get the application running.

We recommend the third possibility (i.e., Java interface) for the FFC system - in which there is a client based on a Java web based application. This involves a three tiered system based on a thin rather than fat client. A thin client has the minimum amount of 'presentation' to allow the user to communicate with the system, and we will describe the three tiers below:

Presentation Interface

We recommend a thin client using a Swing-based Java Applet for this layer as opposed to a Visual Basic client application (VB client) or HTML interface. The reason we stress "Swing-based" is because it is the latest Java GUI toolkit and provides the best speed. Previous Java GUI toolkits such as AWT are much slower. A Java applet runs completely inside the users web browser and doesn't require any installation on user machines. It typically takes up to 1 minute to download the first time it is run, but after that, it loads almost instantly as it is cached on the user's machine. Java applets run inside a "sandbox" which means that they don't have access to a user's hard drive by default. However, it is possible to "sign" the applet and thus the Java security manager will allow local hard drive access.

Business Logic

For the business logic, we recommend building Enterprise Java Beans (EJB) to implement the application layer. EJBs are reusable and highly scalable Java components that form the backbone of Sun's Java 2 Enterprise Edition (J2EE) specification. Sun originally invented Java Beans as their component architecture for Java applets and applications, however this original specification did not provide any support for databases or transactions. The EJB spec was created to specifically handle data persistence and scalability issues such as connection pooling and transaction processing. [These are issues that arise if the application is running over multiple servers, as may be required for large applications or if numerous simultaneous users are expected. In this situation, each individual user may connect to a different server each time they interact with the database – i.e., not just when they log-on for a second session, but also every time they send information to the database within a session.]

EJBs take care of all the "plumbing" (i.e., data persistence, optimizations, connection pooling, transaction processing, etc) so that application developers can concentrate on the business logic specific to their application.

Using an application layer with object-oriented EJB components allows developers to reuse components in various areas of the application. Also, maintaining the application is simplified because a change to one EJB is propagated to all areas of the application that use that particular EJB component.

Assumption: users will not be able to access the system if they are not connected to the Internet since all of the application logic will reside on the main Internet server.

Database Management System (DBMS)

The DBMS is the physical database system that manages all the persistent application data. This system includes database tables, security manager, constraints, stored procedures, and other features necessary to ensure that the application data is both accessible and secure at all times. The database server does not need to be connected to the internet, however the machines that run the web server and application must have access to the DBMS.

We recommend a powerful relational, full-featured database as it will support transaction processing, stored procedures, sub-selects and other important database features. Due to the complexity of the data, these features become important with regard to speed and reliability of the system. Either Microsoft SQL Server or Oracle is suitable for the DBMS. [According to Aaron Gladders at Kaldor, either SQL Server or Oracle is suitable for allowing a large number of users to access the FCC system. MySQL, on the other hand, is very fast at those tasks which it can accommodate but it is not a 'transactional' system. It cannot run successive database queries / inserts / deletions without committing the changes as it goes along. In other words, it cannot show the user what the final results of the changes will be without making the process irreversible. Also, instead of just locking the table row on which it is operating, MySQL locks the entire table so that no other user can access the table until the operation is finished.]

Data Management - Output to the User

Due to the complexity of the arrangement of output data, we are recommending XML documents over "tabular" flat files. [XML provides a platform-independent way to exchange information. As in comma- and tab-delimited 'flat' text files, the information in XML files is stored in ASCII text. The XML file, however, is like an HTML page, with identification tags surrounding each data item. With an accompanying style document, the data can be displayed in its original formatted form in any environment. According to Aaron Gladders at Kaldor, all Microsoft applications can transfer data in XML format. Excel, for example, can convert to and from XML.See http://webdevelopersjournal.com/articles/why_xml.html for additional information]. Utilizing XML will make documents more portable, while remaining flexible, as compared to the flat file alternative.

An XML file can be interpreted by multiple disparate and distributed systems automatically. You would need many flat files to store the same information that a single XML document could store. Since XML allows "nesting" or hierarchical organization of information [i.e., individual cells of the table may themselves contain tables, lists, or other sub-sets of information], it provides more flexibility for creating complex documents. Using multiple flat files introduces much unnecessary complexity as a potentially complicated data import tool would have to be built to import data from the flat files.

With XML, data parsers (import/export tools) can be used to exchange information between systems automatically without the need for user intervention. This makes collaboration between teams more efficient.

Data Management - Input from the User

Instead of storing a local fuelbed compilation database and customized fuelbed dataset on each user's PC, it is possible for each user to create their own database of fuelbeds on the main server [with a pre-set limit on the maximum size of each individual database]. The user opts to make this "personal" database available to all users or it could be a private database only accessible by the user who created it. No downloading is required to the local machine for storage and the risk of data loss due to local machine crashes/failures is greatly reduced, as the main Internet server(s) will have multiple redundant backup mechanisms. The customized mapping of each field in the import file to a field in the application is saved as a "data description" record in the main database as opposed to a description file on the local user's machine. This way, the user simply needs to select which data description record to use from a pull-down menu (they may want more than one for different types of data import). Users could also edit their data description records. This will save significant import time and reduce costly data errors.

To ensure proper inserts into the system we recommend the use of a data import tool. It will need to verify each piece of data imported in a file before physically inserting it into the database so that corrupt data is not accidentally inserted.

Additional Issues and Software/Hardware Considerations

General Issues of Consideration

Several issues should be considered in the planning of this application:

1. Security of the server: The server must have its security maintained, and there will be a consistent cost to sustain that. Furthermore, there must be consideration as to how sensitive the data is, and the security needed that would not compromise the data.
2. Database Size and Storage: We recommend very robust relational database systems, however, one must consider scalability of their database based on an expected user number, as well as the maintenance required to maintain their database systems
3. Network Connectivity: The ability of a user to use the system relies on a valid network connection. The user's network connection will have to be considered in data transfers between client/server. As a standard for comparison, a front page for a website should never be larger than 60KB, including images. Interfaces must be designed for a lower common denominator.
4. Testing: Of most imperative importance is budgeting a generous portion of time towards testing of the new application, as well as server load testing, prior to deployment.

Summary of Recommendations

We recommend that for the FCC classification system, a three-tiered thin client architecture utilizing Java would be the most appropriate solution. Java applications allow most control over user interface consistency. A three tiered system permits the user to see only the minimum amount of data required to interact with the interface (presentation tier), and separates the logic (business logic tier) with the information (database tier). Considerations include the level of security needed for the server, the database size and storage required for the future.

Hardware Recommendations:
one (or more) Intel or Sun servers

Software Platform Recommendations (for Intel hardware):
Web Server: Microsoft IIS
Java Application Server: BEA WebLogic
DBMS: Microsoft SQL Server or Oracle

Software Platform Recommendations (for Sun hardware):
Web Server: Apache
Java Application Server: BEA WebLogic
DBMS: Oracle