

*Andrews*

A Publication of the  
National Wildfire  
Coordinating Group

Sponsored by  
United States  
Department of Agriculture

United States  
Department of the Interior

National Association of  
State Foresters



# BEHAVE: Fire Behavior Prediction and Fuel Modeling System-- FUEL Subsystem

Robert E. Burgan  
Richard C. Rothermel

PMS 439-1  
NFES 0275

MAY 1984





## PREFACE

Over the past decade the science of fire modeling has made great advances. The 13 original fire behavior fuel models have been used successfully to represent a wide array of fuel types in the United States. Nevertheless, fire managers, who are using fire predictions in an increasing number of applications, have found that existing fuel models do not adequately match some fuel situations. They therefore have developed a need for techniques that will enable them to modify existing fuel models or to devise entirely new ones. The purpose of this publication is to provide them with this capability.

The FUELS subsystem of BEHAVE contains programs that will enable fire managers to assemble fuel models and test their performance before releasing them for operational use. Fuel modeling is not yet a rigorous process; consequently science and good judgment are both needed. Nevertheless, pilot tests have shown that the methods are ready for application in the field by well-trained personnel.

The programs contain new and simplified procedures for examining fuels in the field and developing fuel models. It is not always necessary to construct new models, however; modifications to existing models may be sufficient in some cases, while in others more rigorous field inventory procedures may be desirable. There are four ways to obtain a fuel model for operational use in BEHAVE:

1. Choose one of the 13 standard models.
2. Modify one of the 13 standard models.
3. Use measured data taken by inventory techniques.
4. Use the new fuel modeling procedures described in this manual.

The fastest solution is choosing one of the standard 13 models (Anderson 1982). If that does not satisfy the user, the most representative model of the 13 can be modified. For example, one can change loading and depth, add green fuel, make it a dynamic model, and so on. If modification is not satisfactory, the next fastest expedient would be to use our new procedures. Although any method of measuring and modeling fuels yields only approximate answers, our new procedures are simple, inexpensive, and rapid to use. But if the user prefers to inventory, or to use previously inventoried data, the programs will

accommodate the fuel loads by size class and will assist the user in providing information needed to assemble a complete fuel model.

Several features built into the modeling program contribute to reasonable fuel models and fire predictions:

1. The system will build either static or dynamic models. This overcomes the problem that the present 13 models are primarily designed for the time of year when fuels are cured.

2. The procedures are designed to combine the data from mixtures of litter, grass, shrubs, and slash to produce a composite model. In this process, depths and loads of each type are adjusted by area covered. Such a model should be carefully examined, tested, and its fire predictions compared with field data and standard models--a task simplified by the FUEL programs.

3. If the fuels occur in individual patches, models may be built to describe the dominant fuel cover and the fuel that interrupts the dominant fuel. BURN will use both in the two-fuel-model concept described by Rothermel (1983).

4. The slash procedures utilize several techniques for estimating load. These are patterned after the research of Brown (1974) and include the number of intercepts as well as load and depth relationships. They also can utilize fuel photo series such as those developed by Fischer (1981a, 1981b, 1981c), Koski and Fischer (1979), and Maxwell and Ward (1978a, 1978b, 1979, 1980).

The site-specific fuel modeling techniques described in this manual are appropriate for constructing fire behavior fuel models only. They are not intended for constructing National Fire-Danger Rating fuel models. Basic differences between the mathematical equations used in the fire danger and fire behavior computer programs preclude this possibility. These differences occur primarily in the procedures for weighting the influence of various fuel size classes, thus producing outputs meant to have different interpretations. As a result, to reasonably represent the same "actual" fuels situation, a fire danger fuel model must be assigned different values than a fire behavior fuel model. Thus, fuel models are applicable only with the fire processor used to construct them, and the fire danger processor is not part of the BEHAVE system.

## THE AUTHORS

**ROBERT E. BURGAN** received his bachelor's degree in forest engineering in 1963 and his master's degree in forest fire control in 1966 from the University of Montana. From 1963 to 1969, he served on the timber management staff of the Union and Bear-Sleds Districts, Wallowa-Whitman National Forest. From 1969 to 1975, he was a research forester on the staff of the Institute of Pacific Islands Forestry, Honolulu, Hawaii. Since 1975, he has been at the Northern Forest Fire Laboratory, Missoula, Mont., first as a member of the National Fire-Danger Rating research work unit, and currently as a research forester in the fire behavior research work unit.

**RICHARD C. ROTHERMEL** received his bachelor of science degree in aeronautical engineering at the University of Washington in 1953 and his master's degree in mechanical engineering at Colorado State University, Fort Collins, in 1971. He served in the U.S. Air Force as a special weapons aircraft development officer from 1953 to 1955. Upon his discharge he was employed at Douglas Aircraft Co. as a designer and trouble shooter in the armament group. From 1957 to 1961 Rothermel was employed by the General Electric Co. in the aircraft nuclear propulsion department at the National Reactor Testing Station in Idaho. In 1961 he joined the Northern Forest Fire Laboratory where he has been engaged in research on the mechanisms of fire spread. He was project leader of the fire fundamentals research work unit from 1966 until 1979 and is currently project leader of the fire behavior research work unit at the fire laboratory.

## RESEARCH SUMMARY

The BEHAVE system is a set of interactive computer programs that (1) permit construction of site-specific fire behavior fuel models, and (2) contain state-of-the-art wildland fire behavior prediction procedures that will be periodically updated. This manual documents the fuel modeling portion of BEHAVE. New and simplified procedures for collecting fuels data are described. Instructions are provided for the use of two programs: (1) NEWMDL, which is used to construct a "first draft" fuel model from raw field data, and (2) TSTMDL, which is used to test new fuel models and adjust them until they produce reasonable fire behavior predictions. An extensive section describes concepts and technical aspects of fuel modeling.

# CONTENTS

|   | Page |  | Page |
|---|------|--|------|
| Introduction .....  | 1    | Definition of Terms in the<br>Spread Equation.....                                 | 31   |
| Fuel Model File--The Common Link<br>for the BEHAVE System ..... | 4    | Reaction Intensity ( $I_r$ ) .....   | 31   |
| Program NEWMDL .....  | 5    | Propagating Flux Ratio ( $\xi$ ) .....   | 35   |
| General Concept .....   | 5    | Wind Coefficient ( $\phi_w$ ) .....  | 36   |
| Structure and Operation.....                                    | 6    | Slope Coefficient ( $\phi_s$ ) .....   | 39   |
| Field Procedures .....  | 9    | Bulk Density ( $\rho_b$ ).....   | 40   |
| General Data Collection Concept ...                             | 9    | Effective Heating Number ( $\epsilon$ )...   | 41   |
| Specific Field Procedures .....                                 | 11   | Heat of Preignition ( $Q_{ig}$ ) .....   | 41   |
| Reconnaissance .....  | 11   | Weighting of Fuel Size Classes.....  | 42   |
| Data Forms .....  | 11   | Response of Fuel Models<br>to Fuel Moisture .....                                  | 45   |
| Individual Data Forms .....                                     | 12   | General Techniques for Adjusting<br>Fuel Models .....                              | 47   |
| Grass Fuel Data Entry Form ...                                  | 12   | Changing Fuel Load .....   | 48   |
| Shrub Fuel Data Entry Form ...                                  | 13   | Changing Fuel Bed Depth .....  | 49   |
| Litter Fuel Data Entry Form ...                                 | 14   | Changing S/V Ratios .....  | 49   |
| Slash Fuel Data Entry Form ...                                  | 15   | Changing Dead Fuel Moisture<br>of Extinction .....                                 | 49   |
| Multiple 1-Hour<br>Data Entry Form .....                        | 16   | Changing Heat Content.....   | 49   |
| Common Data Items .....   | 17   | Recording and Using Site-Specific<br>Fuel Models with the<br>TI-59 Calculator..... | 50   |
| Specific Data .....   | 19   | Modifying the Keyboard Overlay ...   | 51   |
| Grass Component .....   | 19   | Recording a Fuel Model.....  | 52   |
| Shrub Component .....   | 20   | Using a Fuel Model .....   | 53   |
| Litter Component .....  | 21   | References .....   | 53   |
| Slash Component .....   | 21   | Appendix A: Grass and Shrub<br>Fuel Types.....                                     | 56   |
| Multiple 1-Hour Fuels .....                                     | 23   | Appendix B: Example NEWMDL<br>Session .....  | 66   |
| Program TSTMDL .....  | 25   | Appendix C: Example TSTMDL<br>Session .....  | 93   |
| General Concept .....   | 25   | Appendix D: Fuel Model<br>File Structure .....                                     | 123  |
| Program Structure .....   | 25   | Appendix E: Weighting Procedures<br>Used in Program NEWMDL .....                   | 124  |
| Program Operation .....   | 28   |  |      |
| Fuel Modeling Concepts .....                                    | 30   |  |      |
| Introduction.....   | 30   |  |      |
| The Fire Spread Model .....                                     | 30   |  |      |





# BEHAVE: Fire Behavior Prediction and Fuel Modeling System— FUEL Subsystem

Robert E. Burgan  
Richard C. Rothermel

## INTRODUCTION

The site-specific fuel modeling programs described in this manual are part of the BEHAVE System--a series of interactive fire behavior computer programs for estimating wildland fire potential under various fuels, weather, and topographic situations. The field procedures and the two interactive computer programs described here--NEWMDL and TSTMDL--provide fire managers the capability to construct site-specific fuel models and to test their fire behavior characteristics under a variety of simulated environmental conditions. The BURN subsystem of BEHAVE described by Andrews (n.d.) is designed to use the fuel models developed in FUEL along with state-of-the-art fire prediction techniques for predicting fire behavior for operations, planning, or training. The general structure of the BEHAVE system and the relation of these programs to each other are illustrated in figure 1.

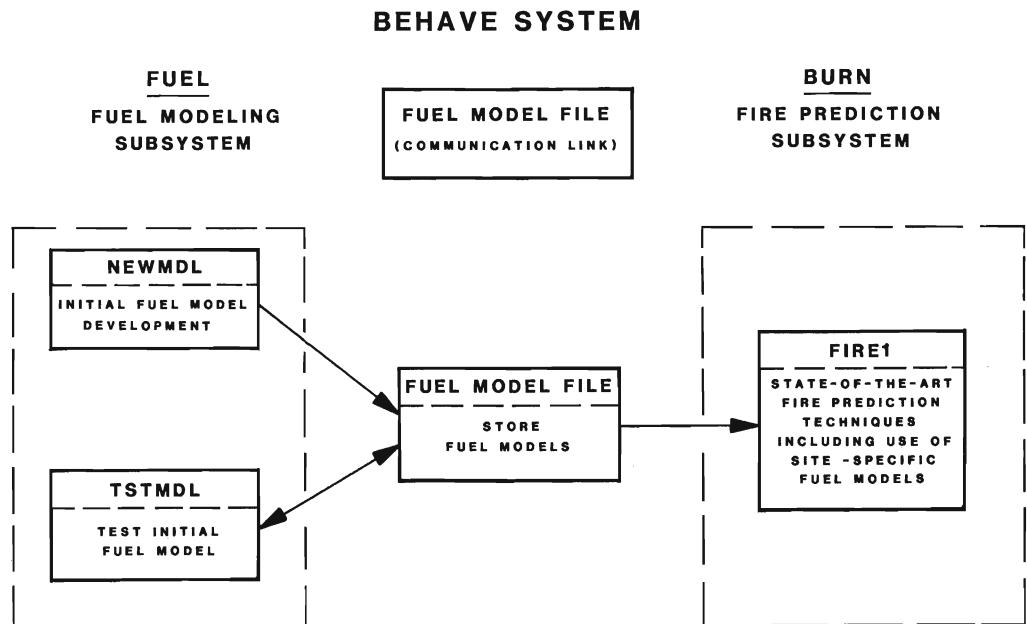


Figure 1.--General structure of the BEHAVE system. The BEHAVE system utilizes a "fuel model file" to give the fire prediction subsystem access to site-specific fuel models constructed in the fuel modeling subsystem.

Until now, the library of fire behavior fuel models available to match fuels situations encountered in the field has been limited to the 13 stylized fuel models developed at the Northern Forest Fire Laboratory (Anderson 1982) or specialized models developed for certain

parts of the country such as the southern California brush models (Rothermel and Philpot 1973; Cohen, review draft) or the southern rough models (Hough and Albini 1978). These fuel models have served well in a variety of applications, but methods are needed to accommodate a wide array of fire management activities.

Careful consideration should be given to the methods of obtaining a fuel model. The matters of cost, time, and values at risk should be considered. The following guidelines are suggested to aid in the choice:

Use the standard 13 models without modification:

- a. To illustrate fire behavior of different fuels in general without reference to any particular site.
- b. For estimating fire behavior when there are no other fuel models for the area and no time to develop them.
- c. When some of the standard models have been found to work well for fuels in an area.
- d. For instruction and training about fuels or fire behavior.

Use one of the standard 13 models with modifications:

- a. When experience indicates better representation of fire behavior requires a change, such as . . .
  - changing a grass model from static to dynamic,
  - adding live fuel to a model such as slash,
  - adjusting load and/or depth to better represent local fuels, i.e., 3-ft brush at 10 tons per acre (T/A) rather than 6-ft at 25 (T/A),
  - increasing the heat content of very flammable brush.

Use inventory techniques as developed by Brown (1974) and Brown and others (1982):

- a. For fuel appraisal, or whenever it is important to compare the relative differences in flammability between fuels complexes.
- b. For developing fuel models where fuels are relatively uniform and values at risk warrant highly accurate fuel models for fire prediction.

Use the new procedures in NEWMDL:

- a. When an estimate of fire behavior is needed but the time and expense of inventory is not cost effective.
- b. For developing a fuel model to produce fire behavior predictions that are consistent with observed behavior in fuels difficult to model by other means.
- c. For constructing fire behavior fuel models to mimic the behavior of the National Fire-Danger Rating System (NFDRS) models used in an area.

If one of the standard 13 models is to be used, it may be called directly in both BURN and TSTMDL.

If one of the standard 13 models is to be modified, follow the TSTMDL instructions.

If the new fuel modeling procedures are to be used, follow the NEWMDL instructions.

If fuel load inventory data is to be used, it is entered in NEWMDL when you are asked for loading by size class.

Successful fuel modeling requires a working knowledge of both the mathematical fire spread model (Rothermel 1972) and the fire behavior characteristics of any given vegetation type, under a variety of environmental conditions. Therefore, fuels and fire behavior specialists are the intended operational users of the BEHAVE system. Nevertheless, the BEHAVE system may also serve as an effective educational tool for those interested in learning more about how fuels and environmental parameters influence fire behavior prediction.

The new procedures introduced in NEWMDL use a few key observations about one or more of four major fuel components: grass,



litter, shrubs, or slash. NEWMDL prompts the user for values of the fuel descriptors in a sequence that gradually assembles the fuel model. Once assembled, the model can be tested in a variety of ways, including comparisons with any of the original 13 fire behavior models.

The philosophy used in developing the new fuel modeling subsystem has been to assemble a fuel model with minimal field sampling. To accomplish this, the programs have the flexibility to allow entry of information from:

- \* previously inventoried fuels data
- \* relationships compiled from past research
- \* new data obtained using field procedures described in this manual.

The new field procedures are simplified through the use of a photo series to help determine general vegetation type and density; ocular assessments of the percentage of area covered by grass, litter, shrubs, or slash; and simple measurements of their approximate depths, or if available from inventory data, loads. Then load/depth relationships defined in NEWMDL are used to determine depths from loads or loads from depths. Load assessment will be most accurate if measured. Depth is more difficult to estimate (Brown 1982). For instructional purposes, where the model will not be keyed to a site, this consideration is not important. Sample load/depth relationships are illustrated in figure 2. The NEWMDL program contains a more complete representation of the data in this figure. The relationships in figure 2 show the distinction between fuel types, but there is, of course, considerable variation in the load/depth relationship for any one fuel type. Consequently, the first approximation may not produce reasonable fire behavior and the values may require adjustment.

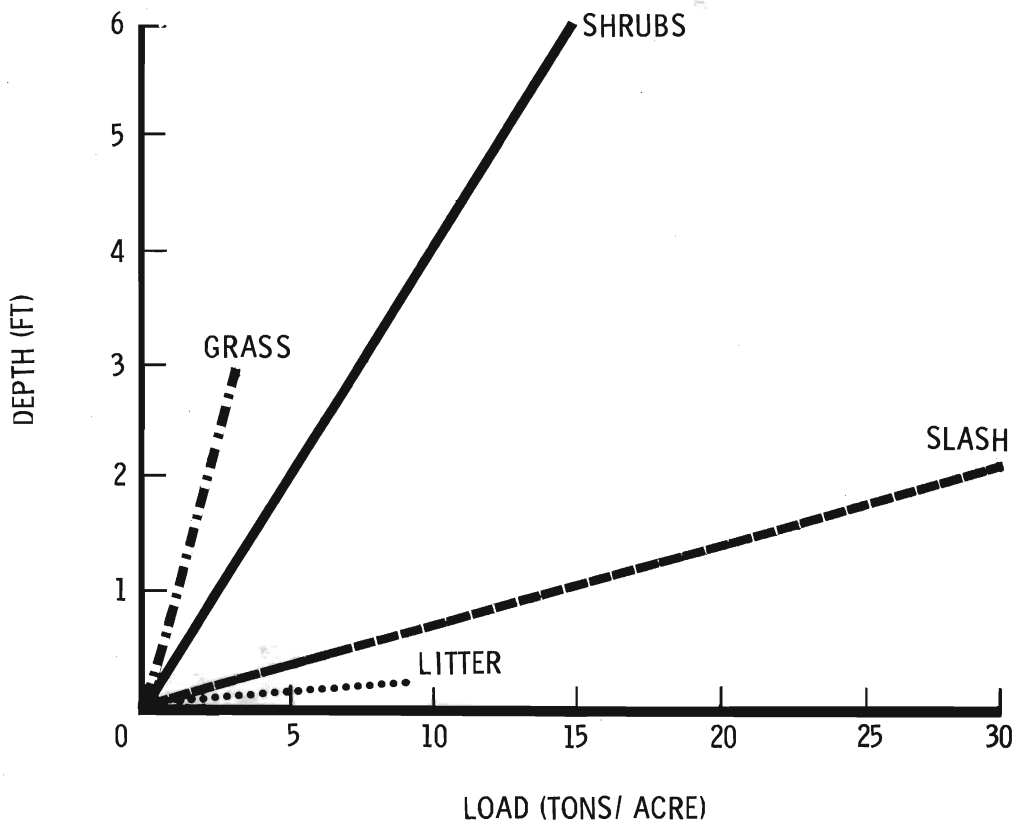


Figure 2.--An example of load/depth relationships established for general fuel types and used in the NEWMDL program.

The interactive computer programs contribute to fuel modeling in several ways: breaking total load into loads by size (timelag) class, estimating heat content, surface-area-to-volume ratios, moisture of extinction, and testing and adjusting a fuel model until it provides fire behavior estimates that closely match known fire behavior for the fuel complex it represents.

Either dynamic or static fuel models can be constructed. Dynamic models transfer fuel between the live herbaceous and the 1-hour timelag categories as appropriate for seasonal changes in the moisture content of herbaceous fuels. This process uses the herbaceous fuel load transfer algorithm developed for the 1978 National Fire-Danger Rating System (Burgan 1979). Static fuel models have fixed loads in all fuel categories. The 13 fire behavior fuel models are an example of static models that were designed for use during the more critical portion of a fire season. The fuel loads in all live and dead classes remain constant regardless of fuel moisture in this type of fuel model.

Both NEWMDL and TSTMDL meet the constraints imposed by 80-column-by-24-row video display terminals and 80-column printing terminals. Although graphics are employed, specialized graphics terminals are not required. This generality was achieved at the expense of graphics resolution.

To increase "user friendliness," the fuel modeling programs are tutorial and have both "wordy" and "terse" response modes. The "wordy" mode provides full prompting, which is helpful for first time or occasional users, while the "terse" mode produces minimal prompting desired by experienced users. In addition, program control is through keywords that are descriptive of the task to be performed. The details of these features are provided in the sections on operating NEWMDL and TSTMDL.

Once an acceptable fuel model has been developed, it can either be used with the BURN subsystem of BEHAVE, or be recorded on a magnetic card and used with the fire behavior program developed for the TI-59 calculator (Burgan 1979). Instructions for using the TI-59 to predict fire behavior are given by Rothermel (1983). Instructions for testing and verifying fire behavior predictions with any fuel model are given by Rothermel and Rinehart (1983).

#### FUEL MODEL FILE--THE COMMON LINK FOR THE BEHAVE SYSTEM

Fuel model files provide a communications link between the NEWMDL, TSTMDL, and BURN programs of the BEHAVE system (fig. 1).

Both NEWMDL and TSTMDL enable you to build and save fuel models in a disk file for easy access. You may manage the contents of the file by listing, adding, replacing, or deleting fuel models. The first record in each fuel model file is a "header" containing (1) a password and (2) a short description of the file.

The password is user-defined and must be matched before fuel models are added to, deleted from, or replaced in a file. This protects users from unauthorized or accidental alteration of their file. Nevertheless, there is no restriction on creating new fuel models for your own file, or listing the names and numbers of models currently in any file.

The file description provides very general information about the models in the file. They might be described as being for a particular Forest, Ranger District, or project.

Use of keyword "FILE" may be made from any of the three programs. TSTMDL will allow you to:

1. Get a previously built site-specific fuel model.
2. List the names and numbers of fuel models in the file.
3. Change a fuel file header.
4. Add the fuel model just built to the fuel model file.
5. Replace a fuel model in the file.
6. Delete a model from the fuel model file.



NEWMDL can perform all of these functions except get a previously built fuel model.

The BURN program is intended to be used with previously constructed fuel models, in an operational mode. It will access models in the file, but cannot alter the file.

The structure of the fuel model file is described in appendix D.

## PROGRAM NEWMDL

### General Concept

Construction of a new site-specific fuel model should begin by using program NEWMDL. NEWMDL defines initial values for fuel model parameters under user control. NEWMDL is especially helpful if extensive fuel inventory information is not available and permits construction of a "composite" fuel model containing any combination of litter, grass, shrub, or slash.

Although most fuel models can be constructed with the standard three dead and two live fuel classes, special cases may arise where it is necessary to enter data for two different sizes of l-h fuels. An example is ponderosa pine (*Pinus ponderosa*) slash, which may have fine needles, but rather coarse twigs.

When such a model is being built, the program assumes measured data is available for direct input. Upon completion of data entry, NEWMDL will "condense" the four-dead, two-live class model to a standard three-dead, two-live class model for use in the BEHAVE system or the TI-59. The "condensed" model should produce fire behavior very similar to a four-dead fuel class model.

Litter, grass, and shrub fuel information can be entered as follows:

1. Direct input of dead fuel loads by timelag class, live loads as woody or herbaceous, and fuel depth for each vegetation type.
2. Total load by vegetation type--depth calculated
3. Total depth by vegetation type--load calculated.

Option 1 is used when fuel inventory data are available for both load by size class and depth by fuel component--grass, litter, or shrub. The program then calculates a mean depth for the composite fuel complex in addition to suggesting reasonable values for heat content, surface-to-volume ratios, and moisture of extinction. Options 2 or 3 are used when only loads or only depths are known. In fuels with poorly defined depths, such as forest litter, option 3 should be used cautiously and the calculated loads checked for reasonableness.

Slash fuels may also be entered directly by load within each time-lag class and depth (option 1) if complete inventory data are available. Otherwise relationships developed for intermountain conifers (Brown 1978; Albin and Brown 1978) are used to estimate the slash fuels. These relationships permit entry of:

1. Total slash load.
2. Total 10-hour timelag load only.
3. Ten-hour timelag load by species.
4. Number of 10-hour intercepts per foot, by species.

The program then assists the user in partitioning the total load into size classes and in reducing slash depth and twig and foliage retention, as a function of harvest method and slash age.

One hundred percent ground coverage is assumed for total litter, grass, shrub, or slash loads initially entered into the program. Such coverage by a single fuel component is possible, but not necessarily the case. When less than 100 percent ground coverage is specified for any fuel component, the load and the depth of that component will be reduced accordingly. Both load and depth must be reduced so the bulk density (amount of fuel [pounds] per cubic foot) of fuel bed will remain the same. In addition, the same ground area may be covered by more than one component (example: grass, litter, and slash). Subsequent program operations sum the loads for each component, and partition them among the size classes.

The final output of NEWMDL is a display of the completed fuel model (fig 3). The model should be exercised in the TSTMDL program to examine its fire behavior characteristics and to possibly adjust some parameters.

A detailed explanation of the weighting procedures used to produce the completed fuel model from the users' input is provided in appendix E.

| CURRENT VALUES OF FUEL MODEL PARAMETERS |      |                   |       |                       |       |
|---|------|-------------------|-------|-----------------------|-------|
| DYNAMIC 14. SAMPLE MODEL                |      |                   |       | BY: BURGAN            |       |
| LOAD (T/AC)                             |      | S/V RATIOS        |       | OTHER                 |       |
| 1 HR                                    | 4.87 | 1 HR              | 1880. | DEPTH (FEET)          | 0.94  |
| 10 HR                                   | 1.00 | LIVE HERB         | 1900. | HEAT CONTENT (BTU/LB) | 8000. |
| 100 HR                                  | 0.89 | LIVE WOODY        | 1700. | EXT MOISTURE (%)      | 17.   |
| LIVE HERB                               | 0.83 | S/V = (SQFT/CUFT) |       |                       |       |
| LIVE WOODY                              | 1.13 |                   |       |                       |       |

Figure 3.--NEWMDL output. The final output of the NEWMDL program is a display of the completed fuel model. At this point the model can be saved in a fuel model file.

## Structure and Operation

The specific procedure for accessing your computer and the NEWMDL program must be obtained from your computer specialist. Once started, you will find the interactive, tutorial nature of NEWMDL eliminates the need for a detailed explanation of program operation. Nevertheless, a general overview of program structure and operation is helpful.

You will first be asked to enter your name (maximum of 20 letters) and indicate whether you want to use the "TERSE" mode (minimal prompting for experienced users) or the "WORDY" mode (full prompting for new users). After accepting or declining a list of keywords used for program control, you will be asked whether you want to build a model with one or two sizes of fine (l-h) fuel. Normally one size of fine fuel should be selected. A number and name must then be entered for the proposed fuel model. Acceptable numbers are 14 through 99. Numbers 1 through 13 are reserved for the 13 fire behavior fuel models (Anderson 1982).

Program control is through the use of keywords. This provides a great deal of operational flexibility. Any keyword above the dashed line in the following tabulation can be entered whenever the message "CONTROL SECTION. KEYWORD?" is printed. There is no specific order in which litter, grass, shrub, or slash fuel loads must be determined. In addition, you can ask for a keyword list, set terse or wordy mode, display current values of the four fuel components, restart the program, access the fuel model file, or quit the session, whenever you are prompted for a keyword. But notice the restrictions associated with the keywords below the dashed lines.



| Keyword  | Function  |
|----------|---|
| KEY      | Prints this keyword list  |
| TERSE    | Set terse mode for minimal prompting  |
| WORDY    | Set wordy mode for full prompting   |
| LITTER   | Determine load and depth of litter fuels  |
| GRASS    | Determine load and depth of grass fuels   |
| SHRUB    | Determine load and depth of shrub fuels   |
| SLASH    | Determine load and depth of slash fuels   |
| COMP     | Display values currently assigned to each of the above four fuel components   |
| FILE     | Access fuel model file  |
| RENUMBER | Renumber the fuel model   |
| QUIT     | Quit session  |
| RESTART  | Start program at beginning again  |
| -----    |   |
| SURF     | Determine surface-to-volume ratios (at least one of the keywords LITTER, GRASS, SHRUB, or SLASH must be used first to assign some fuel loads) |
| HEAT     | Determine heat content (keyword SURF must be used before this keyword)  |
| MODEL    | Display tabulation of completed fuel model (keywords SURF and HEAT must be used before this keyword)  |

Figure 4 reemphasizes the limitations associated with the keywords below the dashed line and also illustrates the general flow of the program. Loads and depth must be defined for at least one of the four fuel components before surface-to-volume (S/V) ratios can be assigned. The S/V ratios must be assigned before heat contents of the fuel components are entered, because S/V ratios are used to calculate a single, weighted heat content for the completed fuel model. Surface-to-volume ratios and heat contents must be **reentered** if a keyword for a fuel model component--LITTER, GRASS, SHRUBS, or SLASH--is used, because you may have modified one or more fuel components.

The program will not accept the keyword "MODEL" until all user-controlled fuel model parameters have been defined, or adjusted if the fuel model has been changed. The fuel model should be added to the file only after you judge that reasonable values have been assigned to all the fuel model parameters under your control. This is best done by looking at the listing obtained from keyword "MODEL". Use of keyword "FILE" will provide an opportunity to save the fuel model on disk. After saving a fuel model, you may either "QUIT" to exit from NEWMDL, or "RESTART" to begin constructing another fuel model. The procedure for accessing any fuel model to test and adjust its fire behavior characteristics is given in the section for operating program TSTMDL.

You should not be able to "crash" the NEWMDL program, so feel free to experiment with it. Appropriate messages are presented and correct actions suggested whenever improper procedures are attempted.

We strongly recommend that you become familiar with the operation and capabilities of NEWMDL before collecting any fuels data in the field. While learning how to construct fuel models, the accuracy of your answers to the questions posed by NEWMDL is much less important than gaining insight into the relationships between the program and the field procedures.

## PROGRAM NEWMDL

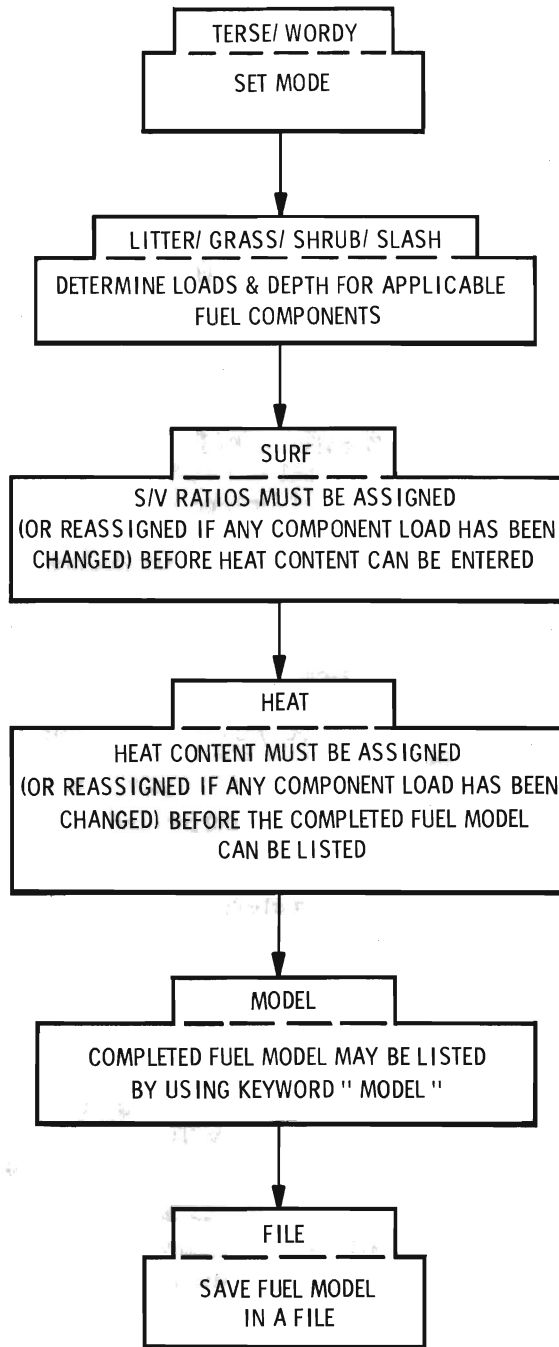


Figure 4.--General flow of program NEWMDL. The general procedure in using the NEWMDL program is to establish fuel load, assign surface-area-to-volume ratios and heat contents, list the model for reference, and save it in a fuel file.



## FIELD PROCEDURES

When building a fuel model the task is more one of describing vegetation as a fuel complex rather than precisely measuring its biomass, although the two are related.

When considering how a particular vegetation type might burn, remember the following limitations of the fire behavior model that will use the fuels data.

1. The fire is assumed to be a line fire burning steadily in **surface** fuels.
2. The fire model is intended to predict fire behavior produced by fine fuels at the perimeter of the fire, usually the fire front.
3. The fire model works best in uniform, continuous fuels such as grass, long-needle pine litter, uniform brushfields, and continuous logging slash.

These limitations have important implications regarding how to view vegetation as a forest or range fuel. For example, because a surface fire is assumed, it is wrong to include vegetation that is in a separate and distinctly higher canopy level than that near the ground. Consider only vegetation that can influence fires before erratic behavior such as crowning or spotting begins.

The fire model predicts behavior on the fire perimeter, normally at the fire front. Inventory only the fine fuel that propagates the fire, that is, dead fuels less than 3 inches in diameter and live fuels of less than 1/4-inch diameter. This is often much less than the **total** fuel load per acre. Ignore fuels that burn long after the fire front has passed. These include deep duff, stumps, large logs, and so on.

The assumption of uniform and continuous fuel means that the fire model will calculate fire behavior as though the fuel components in the model were mixed and distributed uniformly throughout the specified depth.

These are reasonable assumptions when nearly all the fuel is represented by just one component, such as a field of grass or a relatively continuous litter layer. The assumptions still hold even when the fuel complex is composed of more than one component--grass, litter, shrub, or slash--if the components are fairly well mixed. When the data for a mixed fuel complex are entered in NEWMDL it will produce a representative fuel model for the mixture.

But if the fuel components occur in separated patches, and the fire will burn from one to another and back again, consider building separate fuel models. Then the two-fuel-model concept available in BURN can be used to predict rate of spread for this situation.

The fact that the assumptions and limitations do not always match reality accounts in part for differences between predicted and observed fire behavior. Nevertheless, a properly developed and tested fuel model can be used with the fire model to produce surprisingly accurate fire potential estimates.

Perhaps the greatest difficulty in constructing a site-specific fuel model is clearly defining the fuel complex it represents. The infinite variability produced by changes in fuel composition, quantity, depth, continuity, and so on, make it imperative that even site-specific fuel models must represent a rather broad range of conditions. Thus, although the first step in constructing a site-specific fuel model may be to obtain field data, at least the following points should be carefully considered in the planning phase:

1. To what general vegetation type will the model apply? Fire should be a recurring problem in this vegetation type, and the vegetation must be readily identifiable and sufficiently abundant to justify the need for a separate fuel model.
2. Should the model be dynamic or static? Dynamic models are needed only if the model is to be used throughout the growing and curing season.

3. Should the two-fuel-model concept be considered?
4. What are the intended uses of the model?  
This can dictate how accurate the data must be.
5. What is the range of fuel conditions to which the fuel model will apply? Can it be used in similar fuels in other areas? How will it be described so others will know its intended application?

These and other questions arising in your fire management operations will be difficult to answer, but considering such questions in advance is helpful both in the initial collection of field data and in later attempts to apply the model to new situations.

NEWMDL is designed to accept fuel data from a variety of sources. This is not necessarily simpler than a single process, but it does allow the user to utilize data on hand or design field collection procedures to match the needs of the intended application.

If you have discarded the idea of choosing one of the standard 13 models or modifying one of them, you must now select one of the following sources of data:

- utilize inventory data already collected
- collect new inventory data
- use photo series
- use new procedures offered here
- use knowledge about fuels gained from experience
- combination of the above.

The inventory procedures by Brown (1974) are designed to measure fuel load and depth by size class for naturally fallen debris and logging slash. In a later handbook, Brown and others (1982) give more complete procedures for inventorying surface fuels in the interior West. The restriction of their methods to the interior West is necessitated by relating shrub and conifer reproduction measurements to previously measured characteristics of specific species. Their procedures provide estimates of fuel load by size class for duff, litter, grasses and herbs, shrubs, fallen debris, and conifer reproduction. Both living and dead loads are included, but depth of shrubs and duff (not used here) is the only depth tallied.

An ever-expanding photo series is being developed for describing and classifying fuels. Each photographic scene of a fuel complex includes a description of the fuel, a fire potential rating, and data about fuel load by size class.

Fuel inventory procedures and photo series provide data primarily about fuel load. In some cases depth is included, but not always. Brown and others (1982) discuss the difficulty of measuring depth. To construct a fuel model, however, a depth must be provided along with load. The bulk density determined by these two factors is a primary variable needed to drive the fire model (Rothermel 1972). The new procedures presented here overcome this problem by allowing the user to determine a depth that can be used with inventoried loads. The new procedures may also be used to infer fuel loads from estimated fuel depths if inventory data are not available or if the assessment does not warrant the time for inventory.

Figure 2 illustrates the heart of the new procedures, which rely upon the fact that if the bulk density of a fuel component can be estimated, then its load can be calculated using a measurement of the depth, or the depth can be determined from a load measurement. (Bulk density is the fuel load [ $\text{lb}/\text{ft}^2$ ] divided by the depth [feet].) Note that in figure 2, the bulk densities are the inverse of the slopes of the lines. There is, of course, scatter about these lines for different fuels. The specific field procedures in the next section allow you to choose a bulk density most appropriate for grass or shrub data. Figure 2 illustrates relationships used within the program in greater detail, and is used to define the load/depth relationships needed.

Data forms described in the next section have been designed to record the data needed to develop a fuel model. They will accommodate data obtained by any of the methods described above. As you work with the forms and procedures, you will find that only part of the data can be obtained from the field; other data regarding particle size and heat content must be provided after prompting by the computer.

Some fuel factors essential to the fire model are held constant because they either have a small effect over their naturally occurring range or would be very difficult for the user to determine.

These are:

| Fuel factor                   | Assumed value         |
|-------------------------------|-----------------------|
| Particle density              | 32 lb/ft <sup>2</sup> |
| Total mineral content*        | 0.0555                |
| Effective mineral content*    | 0.010                 |
| 10-h surface-to-volume ratio  | 109                   |
| 100-h surface-to-volume ratio | 30                    |

\*Fraction of dry weight.

### SPECIFIC FIELD PROCEDURES

#### Reconnaissance

The first step is to conduct a field reconnaissance to obtain a general impression of the fuels to be modeled. A fire that covers a significant area will often be influenced by considerable fuel variability. Try to develop an impression of the "typical" situation by looking at the vegetation in broad terms. During your reconnaissance, consider the following questions about the fuel:

1. Which fuel components--litter, grass, shrubs, and slash--are present in significant quantity?
2. How continuous are the various fuel components?
3. What fuel stratum is most likely to carry fire?
4. Are there large variations in the amount of one or more fuel components?
5. What proportion of the fuel is in the 1-h, 10-h, 100-h, live herbaceous, and live woody categories?
6. How many grass and shrub types must be dealt with?
7. Which bulk density photos best represent the bulk densities of the important grasses and shrubs in the area?
8. What is a representative depth of the grasses, shrubs, litter, or slash in the area?
9. Are the fuels sufficiently intermixed that they can be represented by a single model, or do they occur in independent "patches" that may require use of the two-fuel-model concept?

Field measurements are time consuming and expensive; therefore the new procedures described here have been made as simple as possible. The equipment needed is limited to data forms, a tape measure, a grass clipper, and a photo series, if applicable.

#### Data Forms

A separate data form is provided for each fuel component--grass, shrubs, litter, and slash. These four forms are for entering data on a single size of 1-h fuels--that is, the familiar three-dead-class, two-live-class fuel model. Each form is divided into two sections: one for summarizing existing inventory data that include both fuel load and depth ("previously inventoried fuel data"), and the other for recording new observations or inventory data that do not contain both load and depth ("new fuel data"). If you have complete information for either portion, you will be able to answer all the questions NEWMDL will ask. Depth may not be available from your existing fuels data. In that case you can use the new fuel data portion of the form by supplying the additional required information. Note that this

gives you the option of entering **either** load or depth. Enter load and let NEWMDL calculate a depth for you, but be sure to check it for reasonableness. You will also have to enter percentages of loads in the various size classes rather than the actual values.

A fifth form is for entering data on two sizes of l-h fuels. Such data have to come from either detailed field measurements or from supplemental computed programs that analyze or predict debris.

## Individual Data Forms

### GRASS FUEL DATA ENTRY FORM

#### I. Previously Inventoried Fuel Data

A. Model type (1 - 2) \_\_\_\_\_

1. Dynamic
2. Static

B. Total grass load (0-30 tons/acre) \_\_\_\_\_

C. Depth (0-10 ft) \_\_\_\_\_

D. For dynamic models enter maximum percentage that can be live (0-100%) \_\_\_\_\_

E. For static models enter current percentage live (0-100%) \_\_\_\_\_

F. Percentage of area covered by grass (0-100%) \_\_\_\_\_

#### II. New Fuel Data

A. Model type (1 - 2) \_\_\_\_\_

1. Dynamic
2. Static

B. Grass type (1 - 4) \_\_\_\_\_

1. Fine--e.g., cheatgrass
2. Medium--e.g., rough fescue
3. Coarse--e.g., fountaingrass
4. Very coarse--e.g., sawgrass

C. Bulk density class (1 - 6)  
(refer to photos in user's manual) \_\_\_\_\_

D. Total grass load (0-30 tons/acre) \_\_\_\_\_

or

E. Grass depth (0-10 ft) \_\_\_\_\_

F. For dynamic models enter maximum percentage that can be live (0-100%) \_\_\_\_\_

G. For static models enter current percentage live (0-100%) \_\_\_\_\_

H. Percentage of area covered by grass (0-100%) \_\_\_\_\_

SHRUB FUEL DATA ENTRY FORM

I. Previously Inventoried Fuel Data

- A. Loads (tons/acre)
  - 1. 1-HR (0-30) \_\_\_\_\_
  - 2. 10-HR (0-30) \_\_\_\_\_
  - 3. 100-HR (0-30) \_\_\_\_\_
  - 4. Leaves and live twigs (0-30) \_\_\_\_\_
- B. Depth (0-10 ft) \_\_\_\_\_
- C. Percentage of area covered by shrubs (0-100%) \_\_\_\_\_
- D. Oils and waxes (circle one) Yes  
No

II. New Fuel Data

- A. Shrub type (1-5) \_\_\_\_\_
  - 1. Fine stems, thin leaves--e.g., huckleberry
  - 2. Medium stems, thin leaves--e.g., ninebark
  - 3. Medium stems, thick leaves--e.g., ceanothus
  - 4. Densely packed fine stems and leaves--e.g., chamise
  - 5. Thick stems and leaves--e.g., manzanita
- B. Bulk density class (1-6) (refer to photos in user's manual) \_\_\_\_\_
- C. Total shrub load (0-80 tons/acre) \_\_\_\_\_

or

- D. Shrub depth (0-10 ft) \_\_\_\_\_
- E. Percentage of total shrub load in each size class. Enter as whole percentile (must total 100%)
  - 1. 1-HR (0-1/4 inch) \_\_\_\_\_
  - 2. 10-HR (1/4-1 inch) \_\_\_\_\_
  - 3. 100-HR (1-3 inches) \_\_\_\_\_
  - 4. Live leaves and twigs (0-1/4 inch) \_\_\_\_\_
- F. Percentage of area covered by shrubs (0-100%) \_\_\_\_\_
- G. Oils and waxes (circle one) Yes  
No



LITTER FUEL DATA ENTRY FORM

I. Previously Inventoried Fuel Data

A. Loads (tons/acre)

1. 1-HR (0-30) \_\_\_\_\_

2. 10-HR (0-30) \_\_\_\_\_

3. 100-HR (0-30) \_\_\_\_\_

B. Depth (0-5 ft) (ft = cm ÷ 30.48) \_\_\_\_\_

C. Area coverage (0-100%) \_\_\_\_\_

II. New Fuel Data

A. Litter source (1 - 3) \_\_\_\_\_

1. Conifers

2. Hardwoods

3. Both, but at least 30% of lesser type

B. Needle length if conifers or both (1 - 2) \_\_\_\_\_

1. Medium/long--e.g., lodgepole or ponderosa pine

2. Short--e.g., Douglas-fir

C. Litter compactness (1 - 3) \_\_\_\_\_

1. Loose (freshly fallen)

2. Normal

3. Compact (older compressed litter)

D. Total litter load (0-100 tons/acre) \_\_\_\_\_

or

E. Litter depth (0-5 ft) (ft = cm ÷ 30.48) \_\_\_\_\_

F. Percentage of total litter load in each size class. Enter as whole percentile (must total 100%)

1. 1-HR (0-1/4 inch) \_\_\_\_\_

2. 10-HR (1/4-1 inch) \_\_\_\_\_

3. 100-HR (1-3 inches) \_\_\_\_\_

G. Percentage of area covered by litter (0-100%) \_\_\_\_\_

SLASH FUEL DATA ENTRY FORM

I. Previously Inventoried Fuel Data

A. Loads (tons/acre)

- 1. 1-HR (0-30) \_\_\_\_\_
- 2. 10-HR (0-30) \_\_\_\_\_
- 3. 100-HR (0-30) \_\_\_\_\_

B. Depth (0-10 ft) \_\_\_\_\_

C. Area coverage (0-100%) \_\_\_\_\_

II. New Fuel Data

A. Logging method (1 - 3) \_\_\_\_\_

- 1. Commercial timber cut, high lead skidding
- 2. Commercial timber cut, ground lead skidding
- 3. Precommercial thinning

B. Age (0-5 yr) \_\_\_\_\_

C. Total component load (0.01-100 tons/acre) \_\_\_\_\_

D. Total 10-h load (0.01-30 tons/acre) \_\_\_\_\_

| <u>Major species</u> | <u>Crown class</u><br>(1-Dom)<br>(2-Int) | <u>Ave d.b.h.</u> | <u>Species % foliage retention</u> | <u>% by species if C or D</u> | <u>E</u><br><u>Species</u><br><u>10-HR load</u><br><u>per acre</u> | <u>F</u><br><u>Species</u><br><u>intercepts</u><br><u>per foot</u> |
|----------------------|--|-------------------|------------------------------------|-------------------------------|--|--|
| _____                | _____                                    | _____             | _____                              | _____                         | _____  | _____  |
| _____                | _____                                    | _____             | _____                              | _____                         | _____  | _____  |
| _____                | _____                                    | _____             | _____                              | _____                         | _____  | _____  |
| _____                | _____                                    | _____             | _____                              | _____                         | _____  | _____  |
| _____                | _____                                    | _____             | _____                              | _____                         | _____  | _____  |
| _____                | _____                                    | _____             | _____                              | _____                         | _____  | _____  |

G. Average percentage twig retention, all species \_\_\_\_\_

H. Area coverage (0-100%) \_\_\_\_\_

MULTIPLE 1-HOUR DATA ENTRY FORM

I. LITTER COMPONENT

| Loads (0-30 tons per acre) | S/V ratios (800-3,500 ft <sup>2</sup> /ft <sup>3</sup> ) |
|----------------------------|--|
| 1-HR _____                 | _____  |
| 1-HR _____                 | _____  |
| 10-HR _____                |  |
| 100-HR _____               |  |
| Depth (0-5 ft) _____       |  |
| Area coverage (%) _____    |  |

II. SLASH COMPONENT

| Loads (0-30 tons per acre) | S/V ratios (800-3,500 ft <sup>2</sup> /ft <sup>3</sup> ) |
|----------------------------|--|
| 1-HR _____                 | _____  |
| 1-HR _____                 | _____  |
| 10-HR _____                |  |
| 100-HR _____               |  |
| Depth (0-10 ft) _____      |  |
| Area coverage (%) _____    |  |

III. SHRUB COMPONENT

| Loads (0-30 tons per acre) | S/V ratios (800-3,500 ft <sup>2</sup> /ft <sup>3</sup> ) |
|----------------------------|--|
| 1-HR _____                 | _____  |
| 1-HR _____                 | _____  |
| 10-HR _____                |  |
| 100-HR _____               |  |
| Live woody _____           |  |
| Depth (0-10 ft) _____      |  |
| Area coverage (%) _____    |  |
| Waxes or oils _____        |  |
| (yes/no) _____             |  |

IV. GRASS COMPONENT

| Loads (0-30 tons per acre) | S/V ratios (800-3,500 ft <sup>2</sup> /ft <sup>3</sup> ) |
|----------------------------|--|
| 1-HR _____                 | _____  |
| 1-HR _____                 | _____  |
| 10-HR _____                |  |
| Live herbaceous _____      |  |
| Depth (0-10 ft) _____      |  |
| Area covered (%) _____     |  |
| Model type _____           |  |
| (dynamic/static) _____     |  |

**COMMON  
DATA ITEMS**

Four items that occur in several places on the data forms will be defined prior to subsequent use in the detailed explanation of data entries for each fuel component.

**Total component load.**--This is the total load for an individual fuel component (grass, shrub, litter, or slash). It can be any combination of 1-, 10-, and 100-h dead fuels, live herbaceous material, and the leaves and 1/4-inch or smaller twigs of live shrubs. This fuel generally occurs within 6 feet of the F layer surface. Record in tons per acre.

**Individual live and dead loads.**--These loads are most commonly available from existing inventory data. Record in tons per acre for each of the following loads that should be included in the fuel model:

Dead fuels: 1-h ( less than 1/4-inch diameter)  
              10-h (1/4- to 1-inch diameter)  
              100-h (1- to 3-inch diameter)

Live fuels: Leaves and live twigs less than 1/4-inch diameter.  
              Enter zero for those that are inappropriate.

**Percent of the loads in individual classes.**--When using the "New Fuel Data" portion of the shrub and litter forms, estimate as necessary the percentage of the total load in the 1-h, 10-h, 100-h, and/or live fuel classes. These percentages are used to break the total load into individual live and dead loads. Record the percentages of live and dead fuels to the nearest whole percentile. The percentages must sum to 100 for each component.

**Depth.**--Record the average depth of the fuel model component in feet. If the litter component is shallow, it may be measured in centimeters, then converted to feet. Review the definition of depth in the section "General Field Observation Concepts" for "Grass and Shrubs" if there is any question about what depth is. See also figures 5 and 6. Experience has shown that 70 percent of the maximum depth gives a reasonable estimate of depth for grass, shrubs, and slash, while maximum depth is more appropriate for fallen litter fuels that are lying horizontally.

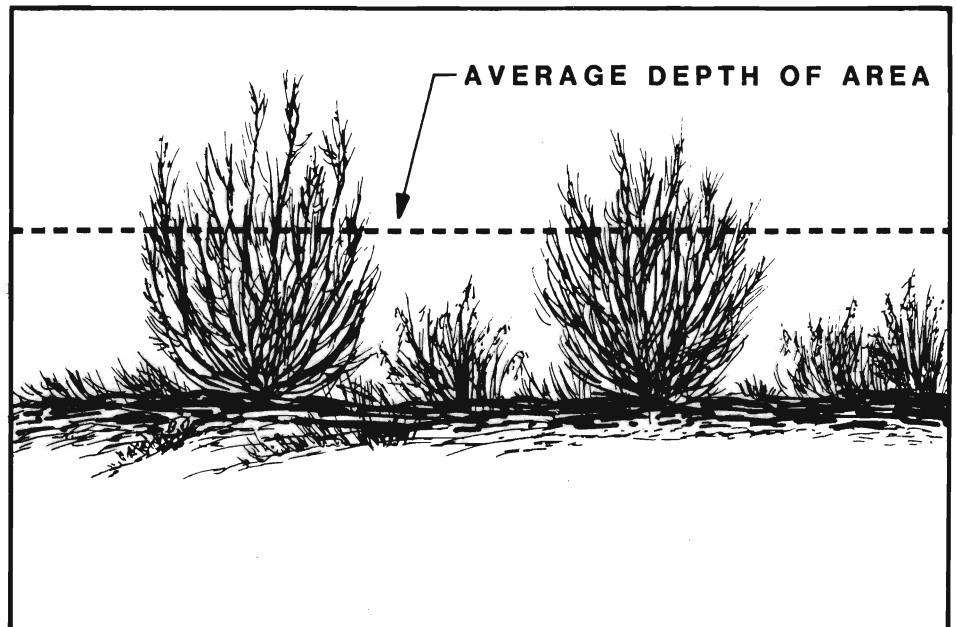


Figure 5.--Concept of grass and shrub depths. Average grass or shrub depth is about 70 percent of the maximum leaf or stalk height. It can be visualized as the average height of a pliable sheet draped over the fuel particles.

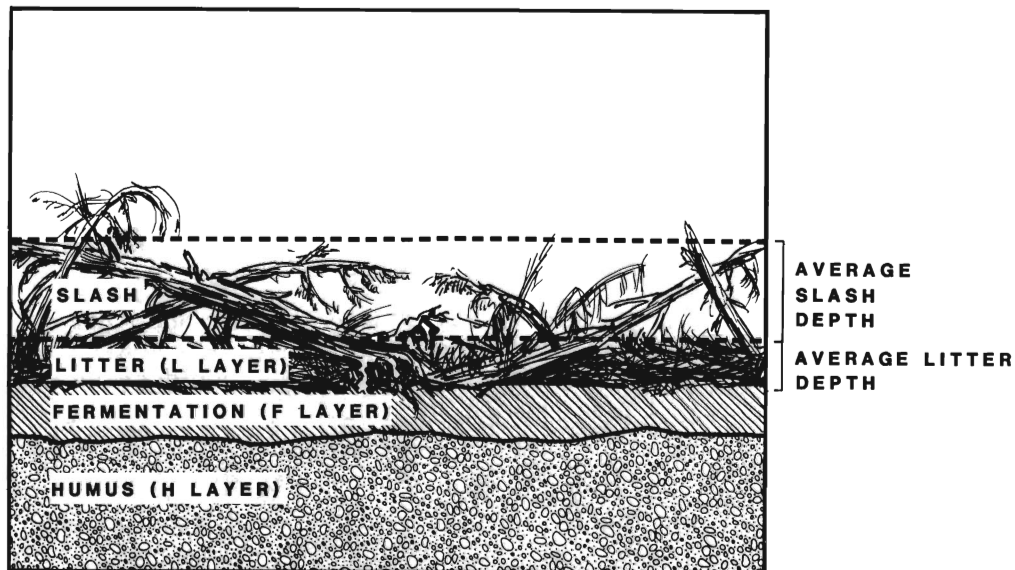


Figure 6.--Concept of slash and litter depth. Litter depth is the vertical distance from the top of the F layer to the general upper surface of the L layer. Slash depth is about 70 percent of the distance from the top of the natural litter layer to the average high intercept. It can be visualized as the average depth of a pliable sheet draped over the fuel particles.

**Percentage of the area covered by each fuel component.**--Initial fuel load estimates are based on the assumption that 100 percent of the area is covered by the fuel component in question. If your inventory procedure was to sample the entire area, both where fuel existed and where it did not exist, enter 100 for the percentage of area covered. Then your inventoried load will not be reduced. If you used the inventory procedure presented here for collecting "new" fuel data, enter your estimate of the percentage of the area actually covered by each fuel component. Then fuel loads will be reduced from the assumed 100 percent coverage to actual coverage.

**Estimating bulk density classes for grasses and shrubs.**--Appendix A provides photo sets to help visualize bulk densities for different grass and shrub types, ranging from fine to very coarse.

First select the photo set that best represents the morphology of the grass or shrub type that will most effectively carry the fire. Then select the photo within that type that best represents its bulk density. If the grasses or shrubs occur in clumps, select a photo that best represents the bulk density of a typical clump, rather than trying to estimate the average bulk density that would exist if all the vegetation in the clumps were spread evenly over the entire area.

Once the bulk density for grasses and shrubs (or both) has been estimated, then either their average loads or depths must be determined. Grass and shrub loads per acre can be estimated by clipping and weighing 3-inch diameter and smaller material from sample plots of known size, oven-drying it, weighing it, and expanding the average sample plot load to a per-acre basis. In this process it must be assumed that the grasses and shrubs cover 100 percent of the area, even if that is not true. NEWMDL reduces these loads for the percentage of the area you state is actually covered by grasses or shrubs.

Estimating the grass or shrub load from its depth is a much faster procedure. The depth of any fuel component is the vertical distance from the bottom of the fuel component layer to the appropriate height at which the bulk density begins to rapidly decrease; or alternatively



about 70 percent of the average maximum leaf or stalk height. Figure 5 illustrates this definition for grass and shrub components. Depth must be estimated with the assumption that the shrub or grass type under consideration covers 100 percent of the area. From that, NEWMDL will first estimate the load per acre based on 100 percent area coverage, then reduce that load for actual area coverage.

**Estimating load and depth for litter and slash.**--Bulk density photos for litter are impractical; therefore the bulk densities are based on litter source (hardwoods, conifers, or both), conifer needle length (long, medium, or short), and litter compactness (loose, normal, or compact). These data are used by NEWMDL, along with a depth value, to determine litter load. Litter depth is defined as the vertical distance from the top of the F layer to the general upper surface of the L layer. Scattered protruding fuel particles are to be ignored. Figure 6 illustrates the definition of depth for slash and litter.

By far the most research has been done on slash, so the relationships developed in these studies have been used to simplify field observations for estimating slash loads and depths. The required information includes logging method, slash age, and one of several expressions of slash load. If estimating slash load is difficult, the data sheets which accompany photo series often provide an excellent source of information. These data are most conveniently recorded as "previously inventoried fuel data." A partial list of available photo series is included in the "References" section.

A note of caution is advised when using photo series. The l-h load given on the data sheet will probably not account for needles still retained on slash. This is because the standard fuel inventory technique used to develop these data (Brown 1974) does not include measurements on needle loads. Brown recognizes this and has provided multiplying ratios to calculate needle quantity based on estimated branch wood weight. These ratios are presented in his appendix III for several species of western conifers. Modification of the l-h load presented in a photo series is appropriate for "red needle" slash.

Alternatively, fuel loads for litter or slash may be determined directly using inventory techniques described by Brown (1974). His publication provides excellent documentation and detailed instructions that need not be repeated here. NEWMDL does not require an inventory as described by Brown, but use of his procedures will provide all the load and depth information required for litter and slash loads. Again, remember to account for needle load when inventorying "red" slash. If you have never measured fuels, some practice will be helpful in understanding and utilizing the methods described here.

## **SPECIFIC DATA**

Specific instructions for completing the data forms for individual fuel components follow.

### **Grass Component**

- I. Previously inventoried fuel data
  - A. Model type - Record whether the model is to be dynamic or static.
  - B. Total grass load - Record total grass load (live and dead) in tons per acre.
  - C. Depth - Record adjusted grass depth in feet.
  - D. Maximum percentage that can be live - For dynamic fuel models, indicate the greatest proportion of the total grass load that is live at any time during the year, regardless of how green the grass may be at the present time. Accumulation of dead grass from previous seasons will generally keep this number below 50 percent. Leave blank if you are building a static fuel model.

- E. Current percentage live - For static fuel models enter the proportion of the grass, by volume, that is live at the time of year for which the model is being designed. It can be estimated by clipping a few pounds of grass, separating all the live material into one pile and all dead material into a number of piles equal in size to the pile of live material. Then the percentage value to enter is:

$$\frac{100}{(\text{total number of piles})}$$

Make no entry if you are building a dynamic model.

- F. Area coverage - Record percentage of area covered by grass.

II. New fuel data

- A. Model type - Record "dynamic" or "static" as explained under I-A above.
- B. Grass type - Compare each page of grass type (1, 2, 3, and 4) photos with your field situation. Record the number of the grass type which is most similar morphologically. The purpose of this step is to just select a general grass type category.
- C. Bulk density class - The bulk density is defined by matching bulk density photos of the appropriate grass type with your field observations. Record the density class number (1-6).
- D. Total grass load - Record if available from a "clip and weigh" inventory, otherwise leave blank.
- E. Grass depth - Record adjusted depth in feet. That is, 70 percent of maximum depth. See figure 5.
- F. Maximum percentage live - See I-E above.
- G. Current percentage live - See I-F above.
- H. Area coverage - Record percentage of the area covered by grass.

**Shrub Component**

I. Previously inventoried fuel data

- A. 1-, 10-, and 100-h dead fuel loads, leaf and live twig loads - Record the load for each of these fuel categories that should be included in the fuel model. Enter zero for those that are inappropriate.
- B. Depth - Record the adjusted shrub depth in feet.
- C. Area coverage - Record percentage of the area covered by shrubs.
- D. Oils and waxes - Some shrubs contain oils and waxes that significantly increase the contribution of the live foliage to the fire intensity and also increase the moisture content at which these fuels will burn. Record whether such material is or is not present in the shrubs.

II. New fuel data

- A. Shrub type - Compare each page of shrub type (1, 2, 3, 4, and 5) photos with your field situation. Circle the number of the shrub type which is most similar morphologically.
- B. Bulk density - Select by matching bulk density photos of the appropriate shrub type with the field situation. Record the bulk density class number (1-6).

- C. Total shrub load - Record total shrub load in tons per acre if available from a clip-and-weigh inventory, otherwise leave blank.
- D. Depth - Record shrub depth in feet.
- E. Percentage of shrub load in each size class - Estimate to nearest whole percentile.
- F. Area coverage - Record percentage of area covered by shrubs.
- G. Oils and waxes - Review I-D for shrubs if necessary; then record yes or no.

**Litter Component**

- I. Previously inventoried fuel data
  - A. 1-, 10-, and 100-h loads - Record in tons per acre for each of those fuel categories that should be included in the fuel model. Enter zero for those that are inappropriate.
  - B. Depth - Record average litter depth in feet. If the litter is shallow it may be measured in centimeters, then converted to feet by dividing by 30.48.
  - C. Area coverage - Enter percentage of area covered by litter.
- II. New fuel data
  - A. Litter source - Record whether the litter results from hardwoods, conifers, or both.
  - B. Needle length - Needle length affects the bulk density of conifer litter, with medium- to long-needle species such as lodgepole or ponderosa pine producing a litter bed having a lower bulk density than short-needle conifers such as larch or Douglas-fir. Record as medium/long or as short.
  - C. Litter compactness - NEWMDL will use different bulk densities for loose, normal, or compact litter. Hardwood litter particularly is most likely to be loose or fluffy when it first falls, but compact after it has been on the ground for at least one winter.
  - D. Total litter load - Record total litter load in tons per acre if available from an inventory. Skip this entry if it is unknown.
  - E. Depth - Record litter depth in feet. If the litter is shallow it may be measured in centimeters, then converted to feet by dividing by 30.48.
  - F. Percentage of litter load in each size class - Estimate to nearest whole percentile.
  - G. Area coverage - Record percentage of area covered by litter fuels.

**Slash Component**

- I. Previously inventoried fuel data. Data obtained by comparing photo series with the field situation should be entered here.
  - A. 1-, 10-, and 100-h loads - Record in tons per acre for each of those fuel categories to be included in the fuel model. Enter zero for those that are not appropriate.
  - B. Depth - Record slash depth in feet.
  - C. Area coverage - Record percentage of the area covered by slash.

II. New fuel data

- A. Logging method - Record as 1, 2, or 3 to define the slash origin as follows:
1. Commercial timber cut, high lead skidding
  2. Commercial timber cut, ground lead skidding
  3. Precommercial thinning
- B. Age - Record slash age as number of winters it has existed.

Slash load data can be recorded in the most convenient form as expressed by C, D, E, or F below. In any case, record the **major species** comprising the slash, the **crown class code** (dominant [1] or intermediate [2]), and the **average d.b.h.** of each species. You may record the percentage of foliage retention by species if you would rather use your own data than have the program make these estimates for you.

- C. Total slash load - If the total slash load is available, enter as tons per acre; otherwise leave blank. If entered, record percentage of slash contributed by each species.
- D. Total 10-h load - If the total 10-h load is known, enter as tons per acre; otherwise leave blank. If entered, record percentage of the slash contributed by each species.
- E. Species 10-h load per acre - Record the major species comprising the slash and the 10-h load per acre for each species. Enter as tons per acre. Entry of percentage slash by species is not required.
- F. Species intercepts per foot - Record the species name and the number of 10-h intercepts per foot for each major species comprising the slash. Entry of percentage slash by species is not required.
- G. Average twig retention, all species. Enter the percentage of twigs less than 1/4-inch diameter still retained on the slash. Estimate an average value for all the slash, rather than for each species.
- H. Area coverage - Enter percentage of area covered by slash.

## Multiple 1-Hour Fuels

Although the familiar 3-dead-class, 2-live-class fuel model should be adequate for most fuel modeling jobs, there may be situations where two distinctly different sizes of 1-h fuels exist. One example might be dead leaves and twigs on frost- or drought-killed shrubs; another example is red coniferous slash such as ponderosa pine where the needles have a much smaller average size than the twigs.

The NEWMDL program contains a section that will accept data on the load and surface-to-volume ratios for two sizes of 1-h fuels plus the 10-h, 100-h, and live fuels. This is called a 4-dead-class, 2-live-class fuel model. You are given the option of selecting this capability early in the NEWMDL program when you are asked whether you want to build a model with one or two sizes of fine fuels. Select the option for two sizes of fine fuels if you have the data for the "Multiple 1-Hour Data Entry Form." Appropriate data can be obtained from option 2 of the DEBMOD program (Puckett and Johnson 1979), or from a fuels inventory you conduct in the field to get the data. This section of NEWMDL requires that you have the data on hand for direct entry. The program will not give any tutorial assistance on values to enter.

On completion of data entry, the program will change your 4-dead-class, 2-live-class model to a 3-dead-class, 2-live-class model so that it will be compatible with the rest of the BEHAVE system and the TI-59. The 1-h load and fuel bed depth must be altered in this process to preserve the fire behavior characteristics of the model, so do not be concerned about that. The resultant 3-dead-class, 2-live-class model should be tested with the TSTMDL program where you can make any necessary adjustments.

The "Multiple 1-Hour Data Entry Form" is simple enough that detailed explanation should not be necessary. Just record and enter the data for those components that contribute significantly to the fuel model. Remember, this section of the program expects direct entry of your data. It will not suggest values to enter.

**Estimating surface-area-to-volume ratios.**--When using NEWMDL to enter your data, you will be asked for surface-area-to-volume (S/V) estimates. The following tabulation presents three broad ranges of S/V ratios for grass, broadleaf, and coniferous plants. Although the specific plant(s) you are concerned with may not be listed, you should be able to find a plant similar enough to select among the three S/V ratio ranges. The midpoint of the appropriate range would be a good initial value. You may adjust this value later when using the TSTMDL program to modify your initial fuel model.

**Estimating heat content.**--Heat content estimates are requested when you enter your fuel model data into NEWMDL. Guidelines are provided by the program and will not be repeated here.



Surface-Area-to-Volume Ratio Ranges for Various Plants

| 500-1,500 ft <sup>2</sup> /ft <sup>3</sup>   | 1,500-2,500 ft <sup>2</sup> /ft <sup>3</sup>   | More than 2,500 ft <sup>2</sup> /ft <sup>3</sup>   |
|--|--|--|
| <b>Grasses</b>   |  |  |
| Jamaica sawgrass<br>( <i>Mariscus jamaicensis</i> )  | Fountaingrass<br>( <i>Pennisetum setaceum</i> )<br>Molassesgrass<br>( <i>Melinis minutiflora</i> )   | Medusahead<br>( <i>Taeniatherum asperum</i> )<br>Cheatgrass<br>( <i>Bromus tectorum</i> )<br>Pinegrass<br>( <i>Calamagrostis rubescens</i> )<br>Idaho fescue<br>( <i>Festuca idahoensis</i> )<br>Crested wheatgrass<br>( <i>Agropyron spicatum</i> )<br>Broomsedge<br>( <i>Andropogon virginicus</i> )   |
| <b>Broadleaved plants</b>  |  |  |
| Yellow beadlily<br>( <i>Clintonia borealis</i> )<br>Sonoma manzanita<br>( <i>Arctostaphylos densiflora</i> ) | Palmetto<br>( <i>Sabal</i> spp.)<br>Common pearleverlasting<br>( <i>Anaphalis margaritacea</i> )<br>Gallberry<br><br>Spreading dogbane<br>( <i>Apocynum androsaemifolium</i> )<br>Bigleaf aster<br>( <i>Aster macrophyllus</i> )<br>Marsh peavine<br>( <i>Lathyrus palustris</i> )<br>Interrupted-fern<br>( <i>Osmunda claytoniana</i> )<br>Eucalyptus<br>( <i>Eucalyptus obliqua</i> )                                      | Wild sarsaparilla<br>( <i>Aralia nudicaulis</i> )<br>Bunchberry dogwood<br>( <i>Cornus canadensis</i> )<br>Brackenfern<br>( <i>Pteridium aquilinum</i> )<br>Serviceberry<br>( <i>Amelanchier</i> spp.)<br>Roundleaf dogwood<br>( <i>Cornus rugosa</i> )<br>Willow<br>( <i>Salix</i> spp.)<br>Showy mountainash<br>( <i>Sorbus decora</i> )<br>Ninebark<br>( <i>Physocarpus malvaceus</i> )<br>Oceanspray<br>( <i>Holodiscus discolor</i> )<br>Mountain alder<br>( <i>Alnus sinuata</i> )<br>Menziesia<br>( <i>Menziesia ferruginea</i> )<br>Snowberry<br>( <i>Symphoricarpos albus</i> )<br>Blue huckleberry<br>( <i>Vaccinium globulare</i> )<br>Quaking aspen<br>( <i>Populus tremuloides</i> )<br>Red maple<br>( <i>Acer rubrum</i> )<br>White oak<br>( <i>Quercus alba</i> )<br>Scrub oak<br>( <i>Quercus dumosa</i> )<br>Oregon-grape<br>( <i>Berberis repens</i> ) |
| <b>Conifer needles</b>   |  |  |
| Eastern hemlock<br>( <i>Thuja canadensis</i> )<br>Northern white-cedar<br>( <i>Thuja occidentalis</i> )      | Jack pine<br>( <i>Pinus banksiana</i> )<br>Balsam fir<br>( <i>Abies balsamea</i> )<br>Ponderosa pine<br>( <i>Pinus ponderosa</i> )<br>Engelmann spruce<br>( <i>Picea engelmannii</i> )<br>Lodgepole pine<br>( <i>Pinus contorta</i> )<br>Douglas-fir<br>( <i>Pseudotsuga menziesii</i> )<br>Grand fir<br>( <i>Abies grandis</i> )<br>Loblolly pine<br>( <i>Pinus taeda</i> )<br>Western redcedar<br>( <i>Thuja plicata</i> ) | Eastern white pine<br>( <i>Pinus strobus</i> )<br>Western white pine<br>( <i>Pinus monticola</i> )<br>Western hemlock<br>( <i>Tsuga heterophylla</i> )<br>Western larch<br>( <i>Larix occidentalis</i> )   |

## PROGRAM TSTMDL

### General Concept

The purposes of TSTMDL are to: (1) provide a means to examine the fire behavior characteristics of the initial fuel model under a variety of environmental conditions, and (2) provide a convenient method to examine the effect on fire behavior when individual fuel model parameters are modified. Although the NEWMDL and TSTMDL programs systematize fuel modeling, it is far from a mechanical process that produces incontrovertible results. It is **extremely important to test every fuel model for the broadest range of environmental conditions to which it may be applied.** Otherwise you may find, for example, that a fuel model that works well for low fuel moistures or windspeeds produces unrealistic fire behavior for high moistures or windspeeds. These tests can and should be performed with the TSTMDL program, but you are also encouraged to test any new model with the BURN program to verify that it will not produce spurious results when used operationally.

The initial verification of a fuel model rests upon your judgment of whether the rate of spread, flame length, and other values are reasonable for a range of environmental conditions. Field verification can only be attained by using the model and comparing its predictions with actual observations. Rothermel and Rinehart (1983) define techniques for observing fire behavior that can be used to assess whether your fuel model produces reasonable values.

TSTMDL has both a "normal" and a "technical" version. The program defaults to the normal version when you first begin. The normal version is for those situations in which a model can be built rather easily, without a need for extensive examination. It provides three graphs and a table. The graphs are: (1) rate of spread versus midflame windspeed, (2) flame length versus midflame windspeed, and (3) the fire characteristics chart (Andrews and Rothermel 1982). Rate of spread and flame length are graphed for either one or three values of l-h fuel moisture over a midflame windspeed range of 0 to 18 mi/h. This chart enables comparison of your fuel model's behavior characteristics plots to one or two of the 13 NFFL fuel models for currently defined environmental conditions.

The tabular output is identical in both the normal and technical versions. It allows you to assign three values to any environmental parameter, then lists the fuel model and the values calculated for five fire behavior parameters: (1) rate of spread, (2) flame length, (3) reaction intensity, (4) heat per unit area, and (5) fireline intensity.

The technical version provides additional graphic output. It allows you to place any fuel or environmental parameter on the x-axis and examine its affect on any appropriate fire behavior parameter. Thus the technical version provides a great deal of flexibility, and a powerful means to examine the influence of the fuel model parameters on fire behavior calculations. The interactions between the fuel model, fire model, and environmental parameters are exceedingly complex. You will undoubtedly get some mystifying plots, but the educational value of this program lies in understanding them.

### Program Structure

The TSTMDL program has three sections, each controlled by keywords. The first section is the "control," which permits task selection and general program control; the second section is the "fuel and environment manipulation" section for changing values of individual parameters, and the third section is the "fuel and environment modification" section, which provides for data entry and listing (fig. 7).

# PROGRAM TSTMDL

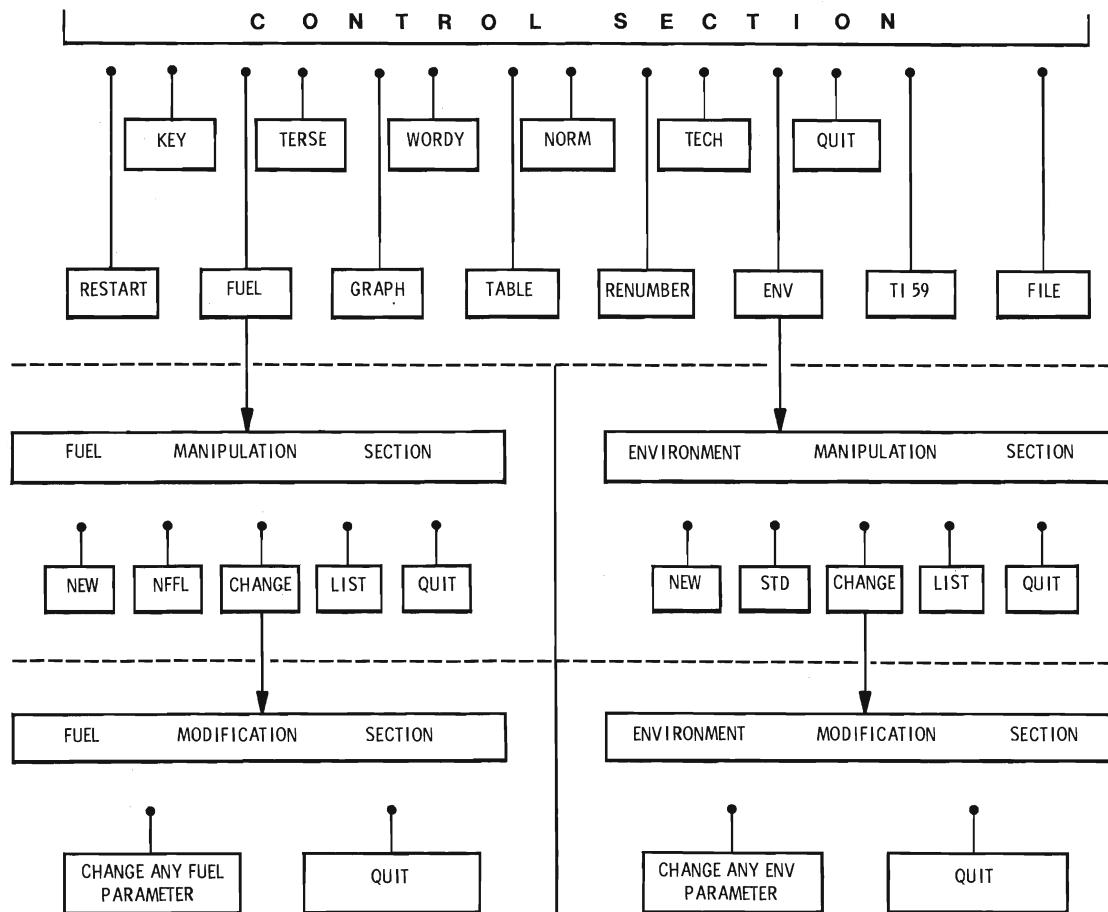


Figure 7.--General flow of program TSTMDL. The TSTMDL program has three sections: control, fuel or environment manipulation, and fuel or environment modification. Keywords associated with each section provide user control.

When you are at the "control" section, you get to the "fuel" or "environment" manipulation section by entering keyword FUEL or ENV, respectively. Then, entry of keyword CHANGE takes you to the third section, the "fuel modification" or "environment modification" section. Each entry of keyword QUIT moves you up one section. Thus you QUIT section three to get to section two and also QUIT section 2 to get back to the "control" section. Entering QUIT from the "control" section terminates operation of the program.

The keyword method of program control permits much flexibility in program operation. For example, whenever prompted for a keyword, you can enter any keyword belonging to the section where you are. Thus program flow does not follow a strict pattern, but allows you to perform tasks defined for each section in any sequence. This capability is symbolized by the dot and short line leading to each keyword. Note that only the keywords FUEL, ENV, CHANGE, and QUIT will move you from one section to another.

A list of keywords and their functions in program control and manipulation of fuels and environmental data is provided in table 1.

Table 2 provides a list of keywords for selecting an environmental variable to which additional values can be temporarily assigned for tabular input, and a list of variables that can be assigned to the X and Y axes when using the technical version's graphics.

Table 1.--TSTMDL keywords and functions

| KEYWORD  | Control Section                                  |  |
|----------|--|--|
|          | FUNCTION   |  |
| KEY      | Prints this keyword list                         |  |
| TERSE    | Set terse mode for minimal prompting             |  |
| WORDY    | Set wordy mode for full prompting                |  |
| NORM     | Implement "normal" version of program            |  |
| TECH     | Implement "technical" version of program         |  |
| FUEL     | Go to "fuel manipulation" section                |  |
| ENV      | Go to "environment manipulation" section         |  |
| GRAPH    | Request graphic output of computed results       |  |
| TABLE    | Request tabular output of computed results       |  |
| RENUMBER | Renumber fuel model and select dynamic or static |  |
| RESTART  | Start program at beginning again                 |  |
| FILE     | Access the fuel model file                       |  |
| TI59     | List fuel model and TI-59 registers              |  |
| QUIT     | Quit this session with TSTMDL                    |  |

Fuels and Environment Manipulation Section

| Fuels   |                                   | Environment |  |
|---------|-----------------------------------|-------------|--|
| KEYWORD | FUNCTION                          | KEYWORD     | FUNCTION                                 |
| NEW     | Enter new fuels data              | NEW         | Enter new environmental data             |
| NFFL    | Enter a fire behavior model       | STD         | Enter standard environmental data        |
| CHANGE  | Go to "fuel modification" section | CHANGE      | Go to "environment modification" section |
| LIST    | List fuel model                   | LIST        | List environmental data                  |
| QUIT    | Go to "control" section           | QUIT        | Go to "control" section                  |

Fuels and Environment Modification Section

| Fuels   |                                   | Environment |  |
|---------|-----------------------------------|-------------|--|
| KEYWORD | FUNCTION                          | KEYWORD     | FUNCTION                                 |
|         | Change the:                       |             | Change the:                              |
| SA1     | 1-HR S/V ratio                    | M1          | 1-HR fuel moisture                       |
| SAH     | Herb S/V ratio                    | M10         | 10-HR fuel moisture                      |
| SAW     | Woody S/V ratio                   | M100        | 100-HR fuel moisture                     |
| DEPTH   | Fuel bed depth                    | MHERB       | Live herb moisture                       |
| HEAT    | Heat content                      | MWOOD       | Live woody moisture                      |
| EXTM    | Extinction moisture               | WIND        | Midflame windspeed                       |
| L1      | 1-HR fuel load                    | SLOPE       | Percent slope                            |
| L10     | 10-HR fuel load                   | QUIT        | Go to "environment manipulation" section |
| L100    | 100-HR fuel load                  |             |  |
| LH      | Herbaceous load                   | KEY         | List these keywords                      |
| LW      | Woody load                        |             |  |
| KEY     | List these keywords               |             |  |
| QUIT    | Go to "fuel manipulation" section |             |  |

Table 2.--TSTMDL keywords for tabular and graphic output

---

Tabular Output Keywords

| KEYWORD | FUNCTION                 |
|---------|--------------------------|
| KEY     | Print this keyword list  |
| M1      | 1-HR fuel moisture       |
| M10     | 10-HR fuel moisture      |
| M100    | 100-HR fuel moisture     |
| MHERB   | Live herb fuel moisture  |
| MWOOD   | Live woody fuel moisture |
| WIND    | Midflame windspeed       |
| SLOPE   | Slope                    |

Graphic Output Keywords

| KEYWORD | MEANING                 |
|---------|-------------------------|
| KEY     | Print this keyword list |
| SA1     | 1-HR S/V ratio          |
| SAH     | Herb S/V ratio          |
| SAW     | Woody S/V ratio         |
| L1      | 1-HR fuel load          |
| L10     | 10-HR fuel load         |
| L100    | 100-HR fuel load        |
| LH      | Herb fuel load          |
| LW      | Woody fuel load         |
| DEPTH   | Fuel bed depth          |
| EXTM    | Extinction moisture     |
| HEAT    | Heat content            |
| M1      | 1-HR fuel moisture      |
| M10     | 10-HR fuel moisture     |
| M100    | 100-HR fuel moisture    |
| MHERB   | Herb fuel moisture      |
| MWOOD   | Woody fuel moisture     |
| WIND    | Midflame windspeed      |
| SLOPE   | Percent slope           |

TSTMDL Technical Version Y-axis Keywords

|       |   |
|-------|---|
| FLINT | Fireline intensity                      |
| RATE  | Rate of spread                          |
| REAC  | Reaction intensity                      |
| FLAME | Flame length                            |
| H/A   | Heat per unit area                      |
| PACK  | Packing ratio                           |
| RSFL  | Rate of spread to<br>flame length ratio |

---

**Program Operation**

The specific procedure for accessing your computer and the TSTMDL program must be obtained from your computer specialist. When you begin, the first message will indicate that you are using the fuel model testing program and ask you to enter your last name. A maximum of 20 characters is allowed. Then you will be asked if you are using a hard copy device such as a printing terminal. The purpose of this question is to indicate whether pauses are necessary in the flow of output, as when a CRT screen is filled.



Your next response will be to indicate whether you want the TERSE mode. Answer "No" unless you are an experienced user.

You will then be asked whether you will be creating a new fuel model or loading a previously built model from your fuel model file. After making this choice you will either be asked to enter a number for your proposed new model or for the previously built model to be selected from the fuel model file. If you are creating a new model you will also be asked to enter a name for the model and whether it is to be "dynamic" or "static."

The next question is whether you want a list of keywords and their functions. Because keywords control the program, this is a good time to list them for reference, or you may decline the list.

If you are using the WORDY version, the next program prompt is a suggestion to enter NORM or TECH to get the version you want. This prompt is not printed in the TERSE version. The NORMAL version is the default, so if this is what you want, keyword NORM does not have to be entered, but doing so will print a message indicating that the NORMAL version is set. You can get the TECHNICAL version only by asking for it.

The next prompt is "CONTROL SECTION. KEYWORD?". Whenever this prompt appears, you can enter any keyword in the control section keyword list, although you will get error messages if the wrong ones are entered first. Such messages will not cause the program to "crash," but return control to the point where you can enter another keyword. The general approach should be to:

1. Define the fuel model. Keyword FILE will give you a chance to get a custom model from the fuel model file. Otherwise keyword FUEL will give you the opportunity to select a fire behavior model, input new fuel model data, change, or list all fuel model data.
2. Define the environmental data. Keyword ENV will allow you to enter, change, or list the environmental data. You can either assign your own values to the environmental parameters, or select one of the "standard" conditions.
3. Define the type of output you want; that is, graphic (keyword GRAPH), or tabular (keyword TABLE). In either case you will be asked a few questions required to set up the graph or table.

After your first time through, in which you set up the fuel and environmental data, you have complete freedom to use the keywords in any order. For example, you can enter keyword FUEL or ENV, change the value of one or more fuel or environmental parameters, then output another graph or table. You can also switch between the TERSE and WORDY modes or the NORMAL and TECHNICAL versions whenever "CONTROL SECTION. KEYWORD?" is printed.

It is not necessary to enter decimal points unless your intention is to enter a decimal fraction. They are not required for integer numbers.

To obtain the list of TI-59 registers and numbers needed to record this fuel model on a magnetic card, enter keyword TI59.

Like NEWMDL, TSTMDL is designed to be a friendly and "difficult to crash" program, so you are encouraged to explore its capabilities until you are completely familiar with its operation.

Remember that although fuel models can be created with the TSTMDL program by entering the data directly, its primary purpose is for testing models initially built with the NEWMDL program.

## FUEL MODELING CONCEPTS

### Introduction

Interactions between fuel model, topography, and environmental parameters, and the mathematical fire spread model are so numerous and complex that attempting to present all the possible results would be an unreasonable task. Yet a basic understanding of the relationships provides valuable insight to the fuel modeling process. Therefore this section is presented for those who are interested in examining in detail the concepts most important to fuel modeling.

The mathematical fire model developed by Rothermel (1972) and amended by Albini (1976) provides a means to estimate the rate at which a fire will spread through a uniform fuel array that may contain fuel particles of mixed sizes. It is basically a rate of spread model, but it also computes an intensity that can be interpreted into the more familiar fireline intensity and flame length developed by Byram (1959).

### The Fire Spread Model

The theoretical basis for the fire spread model was developed by Frandsen (1971). The terms of Frandsen's equation could not be solved analytically, however, so it was necessary to define new terms, reformulate the equation, and design experimental methods to evaluate the individual terms. The final form of the rate of spread equation, derived by Rothermel (1972), which will be examined in depth is:

$$R = \frac{I_r \xi (1 + \phi_w + \phi_s)}{\rho_b \epsilon Q_{ig}}$$

where

R is the forward rate of spread of the flaming front, in feet per minute.

$I_r$  is the reaction intensity--a measure of the energy release rate per unit area of fire front (Btu/ft<sup>2</sup>/min).

$\xi$  ( $\bar{\xi}$ ) is the propagating flux ratio--a measure of the proportion of the reaction intensity that heats adjacent fuel particles to ignition.

$\phi_w$  ( $\bar{\phi}_w$ ) is a dimensionless multiplier that accounts for the effect of wind in increasing the propagating flux ratio.

$\phi_s$  ( $\bar{\phi}_s$ ) is a dimensionless multiplier that accounts for the effect of slope in increasing the propagating flux ratio.

$\rho_b$  ( $\bar{\rho}_b$ ) is a measure of the amount of fuel per cubic foot of fuel bed (lb/ft<sup>3</sup>).

$\epsilon$  ( $\bar{\epsilon}$ ) is a measure of the proportion of a fuel particle that is heated to ignition temperature at the time flaming combustion starts.

$Q_{ig}$  is a measure of the amount of heat required to ignite 1 pound of fuel (Btu/lb).

Basically this equation shows that the rate at which fire spreads is a ratio of the heat received by the potential fuel ahead of the fire, to the heat required to ignite this fuel. Thus if fire can be thought of as a series of ignitions, it will progress through a fuel bed at the rate at which adjacent potential fuel can be heated to ignition temperature. Only a small portion of the heat produced in the flaming front of a wildland fire reaches nearby unignited fuel. The majority of the

heat is carried upward by convective activity or is radiated in other directions. The numerator of the above equation represents the amount of heat actually received by the potential fuel, while the denominator represents the amount of heat required to bring this fuel to ignition temperature.

#### Definition of Terms in the Spread Equation

This section presents a detailed explanation of how fuels, weather, and topographic inputs affect these terms. Your fuel modeling capabilities will be improved by understanding these relationships.

We will explain the concept of the spread equation by first defining the individual terms and briefly discussing what they represent. Then we will look at the terms in greater detail to examine how fuels, weather, and topography affect them.

#### REACTION INTENSITY ( $I_r$ )

Reaction Intensity ( $I_r$ ) is a measure of the energy release rate, per unit area of the fire front. The units assigned to it are: Btu/ft<sup>2</sup>/min. It is affected by:

1. Size of the individual fuel particles. Fuel particle size strongly influences fire spread and intensity. In almost all fire situations, the fire front advances through fine fuels such as grass, shrub foliage, or litter. Both the size of the particles and their compactness are important. The fire model uses a description of the fuel particle surface-area-to-volume ratio as the input describing particle size. The smaller the particle, the larger its surface-area-to-volume ratio. This can be visualized by cutting a fuel particle in half, lengthwise. The total volume of material remains the same, but additional surface area is contributed by each of the two cut surfaces. Thus the surface-area-to-volume ratio increases. This process is amplified as more cuts are made, producing ever smaller particles but more surface area.

For long, cylindrical objects such as conifer needles, twigs, and grasses, the area of the ends can be neglected, so the surface-area-to-volume ratio can be found by dividing the diameter into the number 4. For flat objects such as leaves that have very little area on their edges, the surface-area-to-volume ratio can be found by dividing the thickness into the number 2. The unit of feet is used for all measurements. For example, 1/4-inch diameter sticks have a surface-area-to-volume ratio of 192 ft<sup>2</sup>/ft<sup>3</sup>. The units are often simplified to 1/ft or ft<sup>-1</sup>. Expressing diameter and thickness of small fuels in feet is awkward, but avoids the problem of wondering what units were used in various parts of the model. The mathematical symbol used to represent surface-area-to-volume ratio is the small Greek letter, sigma,  $\sigma$ .

When a fuel array is composed of different size particles, the fire model uses their individual surface areas, and the proportion of the total surface area contributed by each size class, to arrive at a characteristic size that represents the array. It is then assumed that the array would burn as if it were composed of only fuel particles of the characteristic size.

The timelag concept used in the National Fire-Danger Rating System (Fosberg and Deeming 1971) for describing fuel particle size of dead fuels is also used in NEWMDL and TSTMDL. Only the foliage and fine stems of living fuels are considered. These are described as either "herbaceous" for shallow-rooted grasses and herbaceous plants, or "woody" for deep-rooted shrubs. For woody plants, only the foliage and twigs less than 1/4-inch diameter are considered.

2. The compactness of the fuel bed, which is expressed as the packing ratio. At the two extremes, a fuel bed may contain no fuel--packing ratio is 0--or it may be a solid block of wood--packing ratio is 1. Thus, expressed as a percentage, the packing ratio is the percentage of the fuel bed that is composed of fuel, the remainder being air space between the individual fuel particles. A very

compact fuel bed burns slowly because airflow is impeded, and there are so many particles to be heated to ignition in a given length of the bed. A very open or porous fuel bed burns slowly because the individual fuel particles are spaced so far apart there is little heat transfer between them. That is, each particle in the fuel bed would burn as an individual. The maximum reaction intensity occurs at some intermediate packing ratio. The effect of fuel particle size and packing ratio upon the reaction intensity is incorporated in an important intermediate term called the reaction velocity. The reaction velocity is a ratio of how efficiently the fuel will be consumed to the burnout time of the characteristic fuel particle size. Therefore, fine fuel arrays arranged to burn most thoroughly in the shortest time have the largest reaction velocity. Fine fuel particles have higher reaction velocity in fuel arrays that are very loosely packed, whereas larger fuel particles need to be closer together to burn well.

Each size fuel particle has an optimum packing ratio. In the absence of wind the optimum packing ratio for any particle size is determined by a mathematical expression in the fire model. This relationship is illustrated in figure 8. In the presence of wind, the optimum packing ratio shifts to less tightly packed fuel arrays. The reaction velocity is depicted in figure 9 for a range of particle sizes and packing ratios. Note the sharp reduction in reaction velocity on either side of the optimum packing ratio.

Because the reaction intensity depends directly upon reaction velocity, it has the same dependence upon fuel particle size and packing ratio just described for reaction velocity.

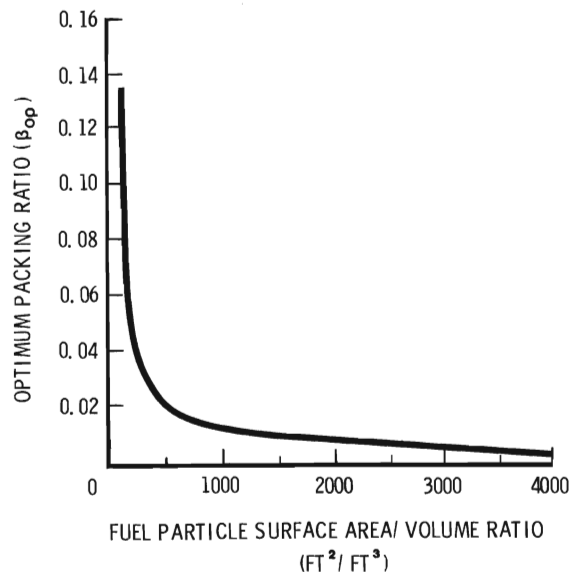


Figure 8.-- Optimum packing ratio. Fuel particle surface-area-to-volume ratio determines the optimum packing ratio for any fuel array.

3. Moisture content of the fuel. Higher moisture contents reduce reaction intensity because more of the heat released during combustion is required to evaporate the moisture. Less heat is available to raise the next fuel particle to ignition temperature.

4. Chemical composition. Although the quantity and type of inorganic material in the fuel affects the rate at which it burns, our primary concern is the heat content--the Btu's of heat released during combustion of 1 pound of fuel. The heat content is lowest for those fuels with few volatiles--oils and waxes--and higher for those

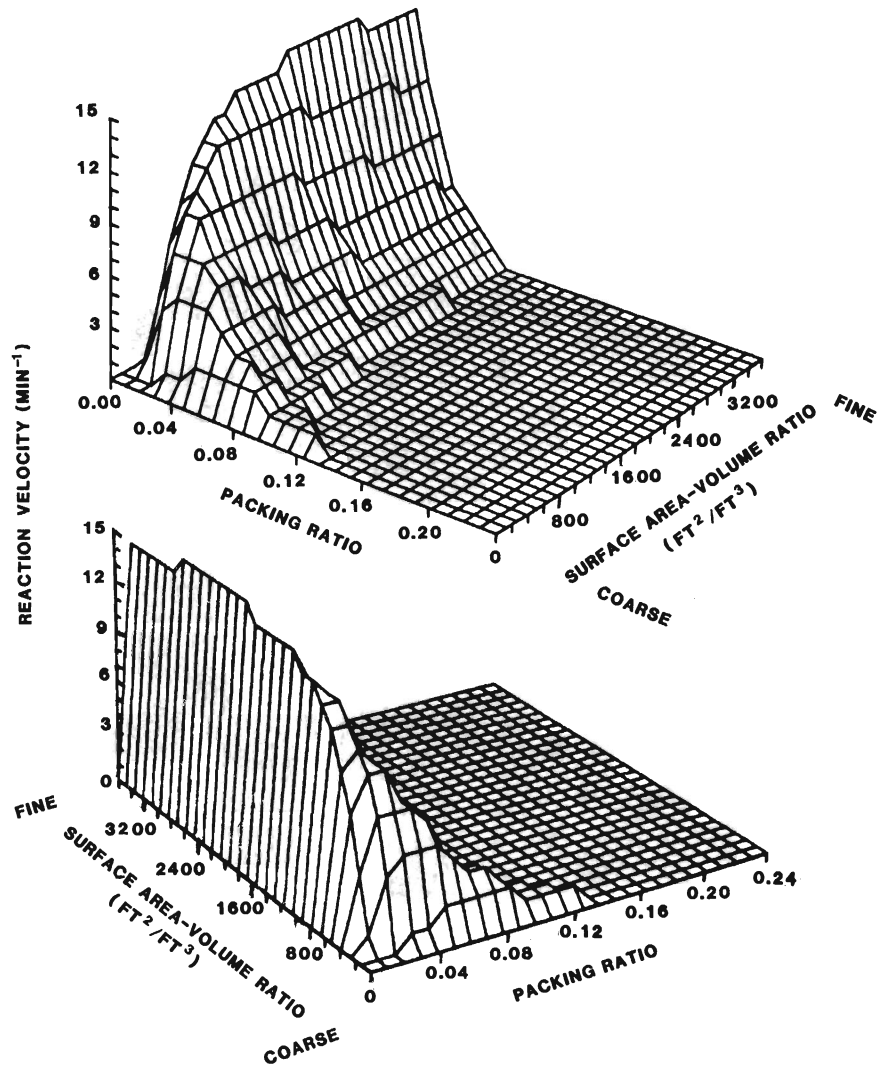


Figure 9.--Reaction velocity. The reaction velocity decreases sharply when the packing ratio is shifted from its optimum value for any given surface-area-to-volume ratio.

with more of them. Fuels having higher heat contents have more heat available per pound of fuel. The rate at which this heat will be released depends on the particle size, the packing ratio, the moisture content, and the mineral content of the fuels. At this time the effect of inorganic materials or minerals associated with salts in the fuel is not adjusted in NEWMDL or TSTMDL although it is variable in the fire model. The total salt content for all fuels is assumed constant at 5.55 percent for all fuel models and the effective salt content is assumed constant at 1.0 percent (Rothermel 1972).

To examine some of these points graphically, figure 10 illustrates that as the size of the individual fuel particles increases (surface-to-volume ratio gets smaller), they must be packed more tightly to maximize the reaction intensity. That is, the maximum reaction intensity for fine fuels occurs at a packing ratio of about 0.03 (3 percent of the fuel bed is wood), while it occurs at a packing ratio of about 0.08 for 1/4-inch sticks and 0.10 for 1/2-inch sticks. The packing ratio producing the maximum reaction intensity for a particular size fuel particle is called the optimum packing ratio. At the optimum packing ratio, the fuel/air mixture is optimized for efficient combustion. Figure 10 also illustrates that reaction intensity decreases

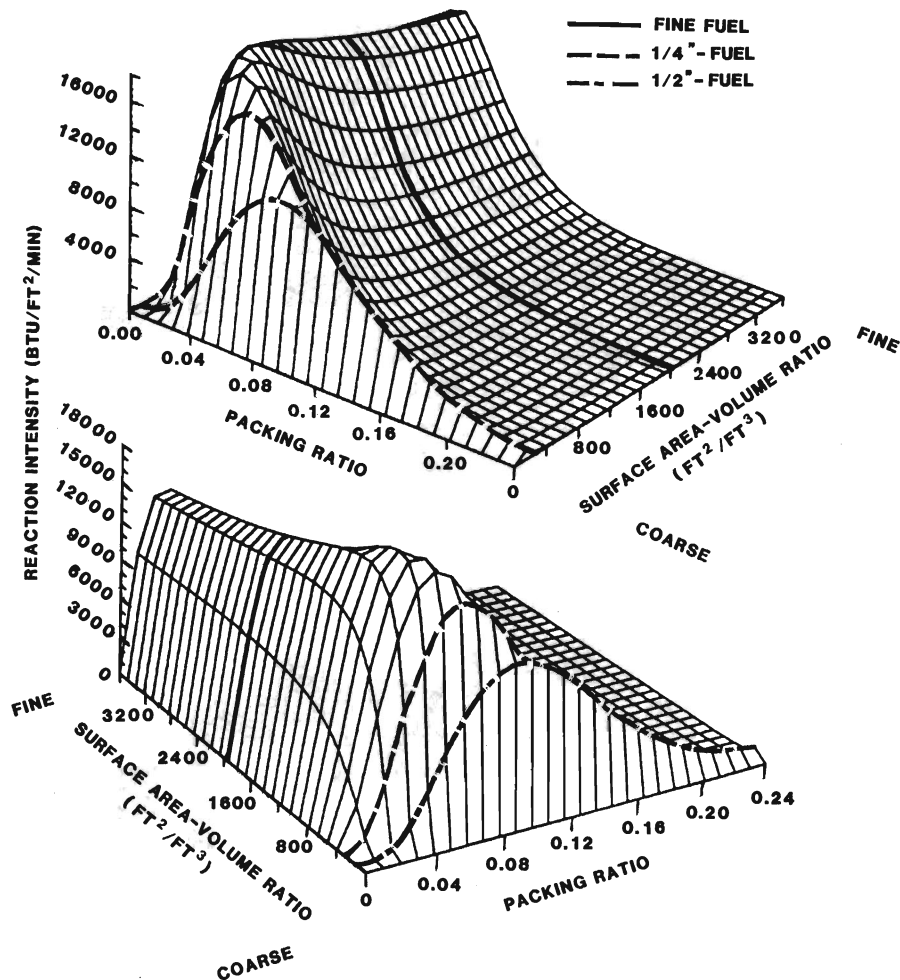


Figure 10.--Reaction intensity. The maximum reaction intensity occurs at higher packing ratios for larger fuel particles than for small ones. The reaction intensity decreases when the packing ratio is either less than or greater than optimum for any given fuel particle size.

when the packing ratio varies from its optimum value for any given fuel particle size.

From a fuel modeling standpoint, it is important to know that although the reaction intensity is maximized at the optimum packing ratio, this does not necessarily hold for rate of spread and flame length. Altering load and depth to adjust the packing ratio also affects the amount of heat required to ignite the fuel, as expressed by the denominator of the spread equation and the proportion of heat transferred to the fuel ahead of the fire as expressed by the propagating flux ratio  $\xi$ . Thus rate of spread and reaction intensity **do not** peak at the same packing ratio.

Tabular output from TSTMDL provides both the packing ratio for the model and a result labeled PR/OPR. The PR/OPR value is the ratio of actual packing ratio to optimum packing ratio. It is **less** than 1 if the packing ratio of the fuel model is less than optimum, 1 if they are equal, and **greater** than 1 if the fuel model packing ratio exceeds the optimum value. There is no rationale for attempting to adjust loads and depth until PR/OPR equals 1. In fact, it normally exceeds 1 for compact "horizontally oriented" fuels such as needle litter, but is usually less than 1 for vertical fuels such as

grass. This number will indicate how tightly your fuel model is packed should you want to make this comparison with one of the more familiar NFFL fuel models. Division of packing ratio by the PR/OPR value yields the optimum packing ratio.

The heat content is the only chemically oriented fuel model parameter users can change. Increasing the heat content always produces a "hotter" fuel model, while decreasing it reduces the calculated fire behavior.

Remember that reaction intensity ( $I_r$ ) is the **total** heat release rate per unit area of fire front, and includes heat convected, conducted, and radiated in **all** directions, not just the direction of the adjacent potential fuel. The next term discussed serves to adjust this total energy release rate down to that portion which **is** effective in propagating the fire.

#### PROPAGATING FLUX RATIO ( $\xi$ )

The propagating flux is that portion of the total heat release rate from a fire, which is transferred and absorbed by the fuel ahead of the fire, raising its temperature to ignition. The propagating flux is calculated under the assumption that the fire is burning on a flat surface and in calm air (no wind, no slope). Effects of wind and slope are discussed later.

The parameter  $\xi$  in the rate of spread equation represents a ratio between this no-wind, no-slope propagating flux [ $(I_p)_o$ ] and the reaction intensity ( $I_r$ ). Mathematically it is defined as:

$$\xi = \frac{(I_p)_o}{I_r}$$

It expresses what proportion of the total reaction intensity ( $I_r$ ) actually heats adjacent fuel particles to ignition. Propagating flux ratios can vary from zero--no heat reaches adjacent fuels--to 1--all of the heat reaches adjacent fuel. Realistically, and expressing the propagating flux ratio in percentage, typical values range from about 1 percent to 20 percent. Multiplying the first two terms in the numerator of the spread equation--reaction intensity times propagating flux ratio ( $I_r \xi$ )--produces the propagating flux, ( $I_p$ ) which is an estimator of the rate of heat transfer that would drive the fire forward in a no-wind, no-slope situation.

The propagating flux ratio is affected by:

1. The average size of the fuel particles in the fuel bed, that is, the characteristic surface-to-volume ratio.
2. The packing ratio, or fuel bed compactness as explained previously.

Figure 11 shows the effect of both packing ratio and average fuel size on the propagating flux ratio. Note that at a constant packing ratio--0.04 is highlighted--the propagating flux ratio is greater for fine fuels than for coarse ones. As shown by figure 11, the propagating flux ratio tends to increase with increasing packing ratio, but the effect is much more pronounced in the finer fuels.

This implies that if fuel bed depth is kept constant and the dead fuel load (1-h, 10-h, and 100-h) is increased, thereby increasing the packing ratio, then a greater proportion of the heat produced by the fire will be effective in preheating the adjacent unburned fuel. This effect is more pronounced in the finer fuels. Remember, however, the reaction intensity is also strongly affected by the packing ratio. Reaction intensity will decrease if the fuel bed is **either** too tightly packed, or too loose. Similarly, the amount of fuel that must be heated to ignition is increased as fuel load is increased, thus illustrating that it is not easy to guess how fuel changes will affect fire behavior.

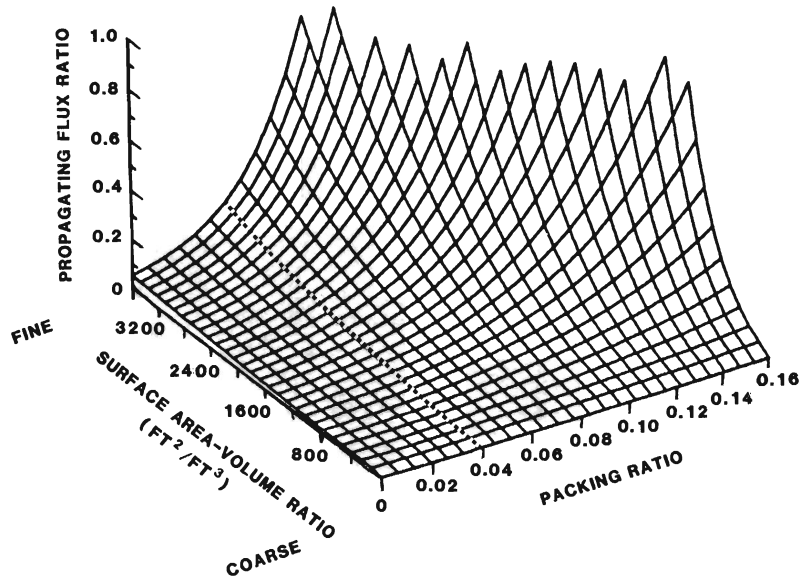


Figure 11.--Propagating flux ratio. The propagating flux ratio increases much faster for fine fuels than coarse ones, as the packing ratio increases. But at any packing ratio, the propagating flux ratio is higher for the finer fuels.

#### WIND COEFFICIENT ( $\phi_w$ )

In the discussion of the no-wind propagating flux ratio ( $\xi$ ) it was assumed there was no ambient wind and the terrain was flat (fig. 12). When this is not the case, wind and slope coefficients ( $\phi_w$ ) and ( $\phi_s$ ) are used by the fire model through the expression  $(1 + \phi_w + \phi_s)$ .

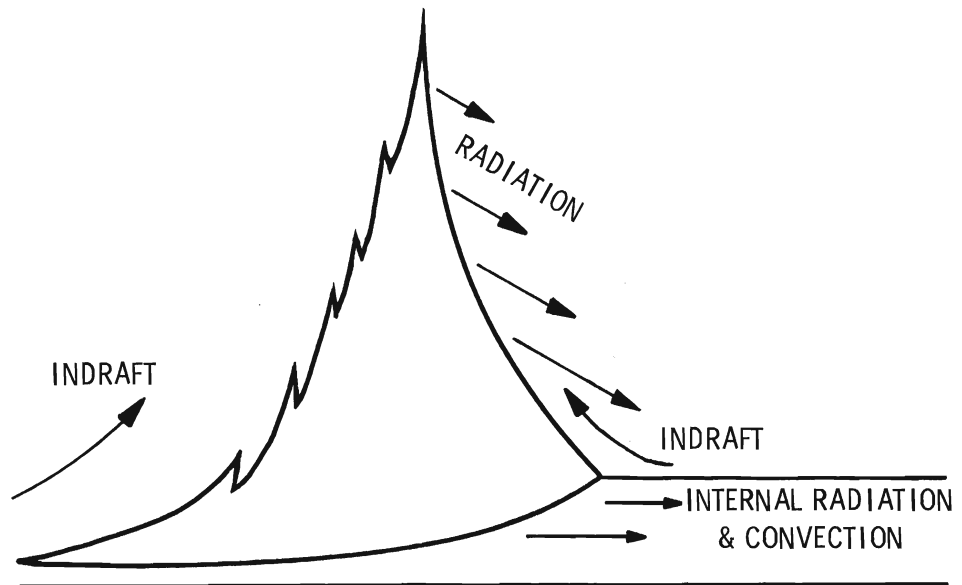


Figure 12.--Schematic of a no-wind fire.

Consider the no-slope case. The wind coefficient increases rapidly with windspeed in loosely packed fine fuels, thus greatly increasing spread rate. This occurs because wind tips the flame forward and causes direct flame contact with the fuel ahead of the fire as well as increased radiation from the flame to the fuel. This greatly increases transfer of radiant and convective heat to unburned fuel ahead of the fire (fig. 13).



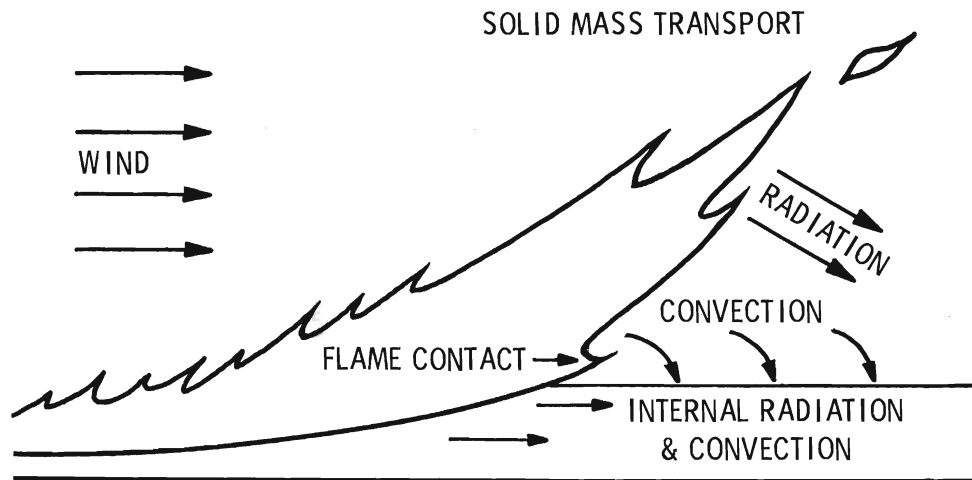


Figure 13.--Wind-driven fire. Increased radiant and convective heat transfer contributes to faster spread rates in wind-driven fires.

The wind coefficient is affected by:

1. The fuel bed's characteristic surface-area-to-volume (S/V) ratio. Figure 14 illustrates the effect of increasing the characteristic S/V ratio of a fuel bed whose packing ratio is half the optimum. Note that increasing the characteristic S/V ratio increases the wind coefficient, and that the effect is greater at higher windspeeds. A similar but less pronounced effect occurs for fuel beds with higher packing ratios.

2. The packing ratio of the fuel bed. For this discussion, a relative packing ratio is introduced. It is the ratio of the actual packing ratio divided by the optimum packing ratio. Its value is 1.0 when beds are packed optimally in the no-wind case. Figure 15 illustrates the effect of increasing packing ratio in a fuel bed whose characteristic S/V ratio is 1,500. Note that the wind coefficient decreases rapidly as the fuel bed is more tightly packed, and that the effect is more pronounced at low packing ratios. A similar but more pronounced effect occurs with finer fuels.

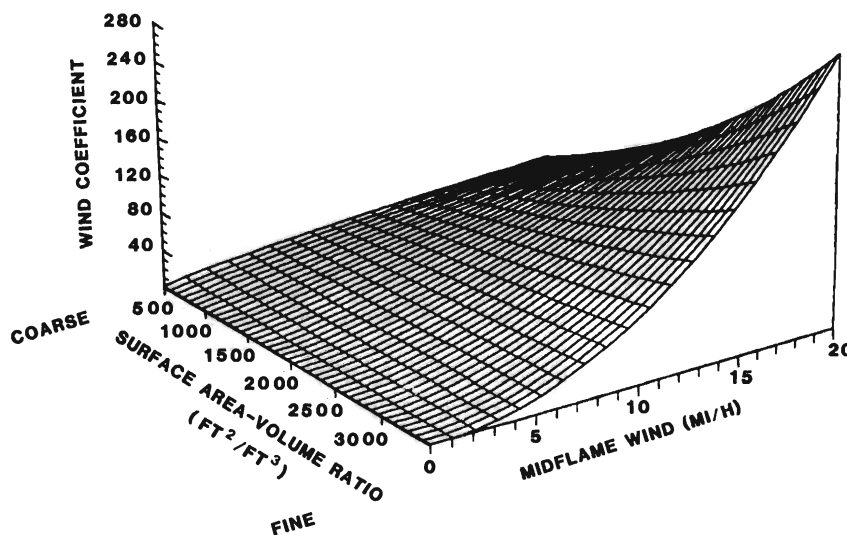


Figure 14.--Effect of fuel particle surface-area-to-volume ratio on wind coefficient. The effect of wind on fire increases more rapidly for fine fuel than for coarse fuel.

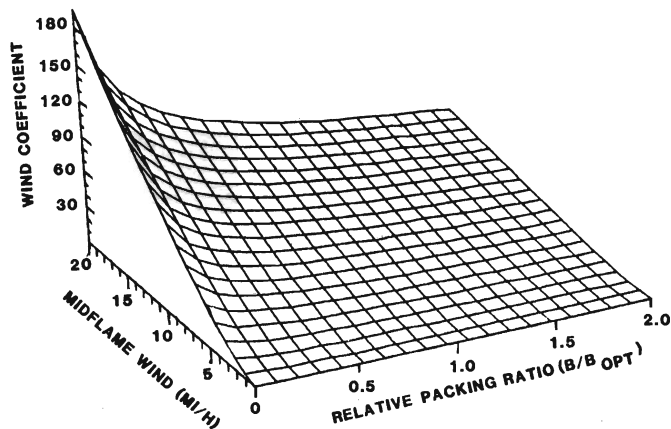


Figure 15.--Effect of packing ratio on the wind coefficient. Wind has a greater effect on fires in loosely packed fuels than tightly packed fuels, with this effect being more pronounced at low packing ratios.

3. The windspeed. Obviously an increase in windspeed will produce an increase in the wind coefficient. Even here there can be a limit which will be discussed soon.

The wind coefficient is increased by increasing the S/V ratio of the l-h, live herbaceous, or live woody fuels. Reducing the packing ratio by either reducing the fuel load or increasing the fuel bed depth also increases the wind coefficient. Remember, however, that packing ratio also affects reaction intensity. So decreasing the packing ratio will increase the wind coefficient, but if the packing ratio falls below optimum, the reaction intensity will decrease even though the wind coefficient may be rather large.

Before leaving this discussion of wind's effect on fire behavior modeling, one note of caution is in order. That is, while wind generally increases fire spread rate and intensity, there is a limit to this effect. McArthur (1969) measured rate of spread on heading grassland fires in Australia and found that **excessive** wind actually **reduced** the spread rate (fig. 16). Although the fire model does not predict reduced spread rate at high windspeed, it does identify when maximum spread is reached. Further increases in windspeed will not give higher spread rates; the model will continue to predict the maximum for those fuel conditions. The effect is caused by the wind forces being stronger than the convective forces of the fire. This will occur when the effective windspeed (mi/h) equals 1/100 of the reaction intensity (Btu/ft<sup>2</sup>/min). Effective windspeed is the no-slope midflame windspeed that produces the same spread rate as for a fire burning upslope and upwind. Effective windspeeds having a magnitude greater than  $0.01I_r$  will not increase the calculated rate of spread. This wind limit may also be expressed as 9/10 of the reaction intensity when the windspeed is in **feet per minute**. This effect is most likely to be noticed with fuel models that represent sparse fuel types. For example, at 1 percent fuel moisture, NFFL model 1 (short grass) produces a maximum spread rate when the effective windspeed is 12 mi/h, while a 42 mi/h effective wind is required to reach the windspeed limit for NFFL model 3 (tall grass) at the same moisture content.

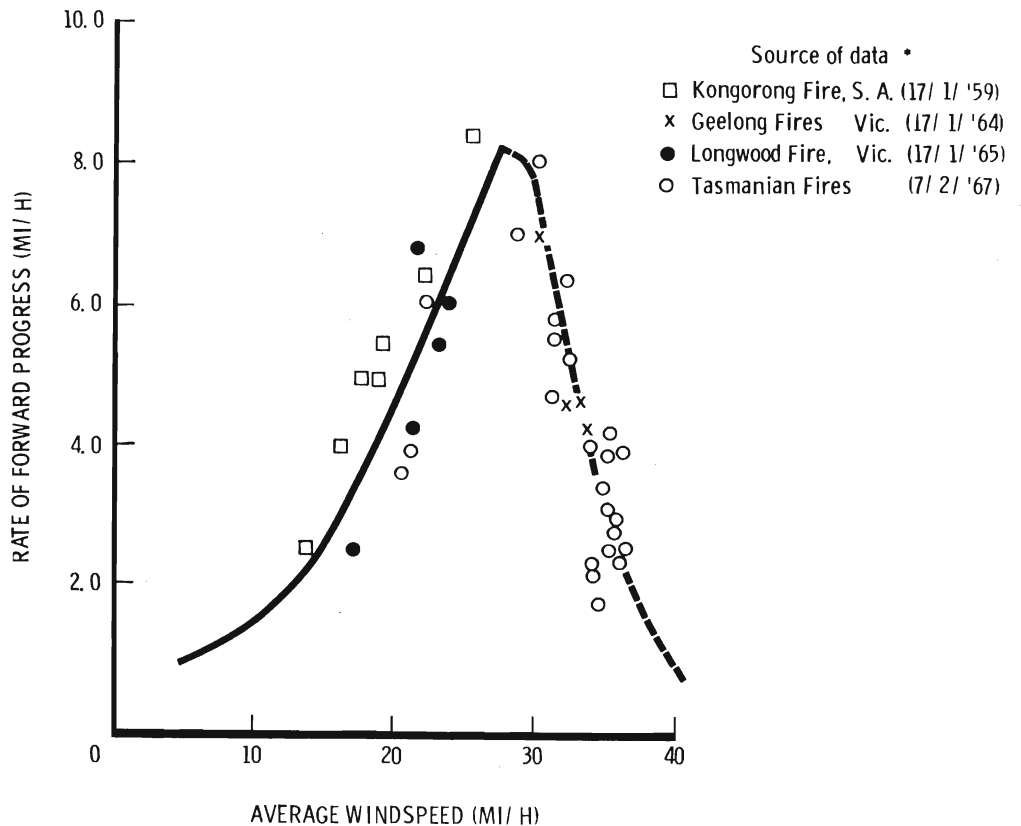


Figure 16.--Reproduction of McArthur's (1969) rate of spread data for grass. The windspeed was measured at a height of 33 feet above the ground in the open.

## SLOPE COEFFICIENT ( $\phi_s$ )

The effect of slope is introduced by the coefficient ( $\phi_s$ ) in the expression  $(1 + \phi_w + \phi_s)$ . Wind is eliminated from this discussion by assuming the wind coefficient ( $\phi_w$ ) is zero. Then as the slope increases from 0 percent, where it does not affect spread rate, to some larger value, the rate of spread steadily increases. The mechanism producing this effect is the same as for wind-improved heat transfer because the flames are closer to unburned fuels on steeper slopes (fig. 17). The effect, however, is not as pronounced as it is with wind.

The slope coefficient is affected by:

1. Slope steepness. The slope coefficient increases as slope steepness increases. Negative slopes are not accepted by the model. A discussion of backing fires on slopes and cross-slope fire spread is given by Rothermel (1983).
2. The packing ratio of the fuel bed. As for the discussion on the wind coefficient, the effect of packing ratio is illustrated (fig. 18) from half to twice the optimum. The slope coefficient was determined for fine fuels, which are largely responsible for fire spread.

The packing ratio of a fuel model will slightly influence its sensitivity to slope steepness. This effect, however, is small relative to the magnitude of other effects produced by changes in packing ratio and so need not be of great concern to the fuel modeler. Changing fuel particle size does not affect the slope coefficient. Wind and slope are both recognized by the fire model, but there is no consideration of interactions between them.

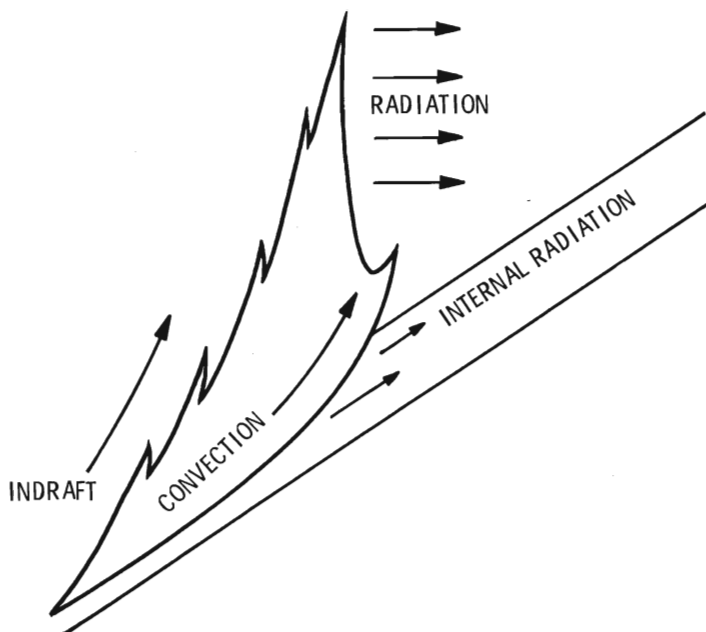


Figure 17.--Schematic of a fire on a slope.

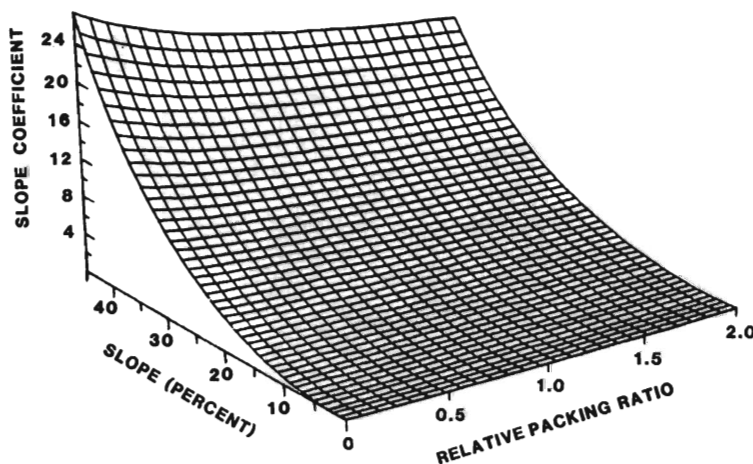


Figure 18.--Effect of packing ratio on the slope coefficient. Although fires spread faster upslope as slope steepness increases, the effect is much less than that of wind. The slope coefficient is affected little by packing ratio.

## BULK DENSITY ( $\rho_b$ )

Bulk density is the first term to be discussed from the denominator of the rate of spread equation. Remember the denominator expresses the amount of heat required to bring the fuel to ignition temperature; that is, it represents a heat sink. Bulk density is the oven-dry weight of fuel per cubic foot of fuel bed. The units are  $\text{lb}/\text{ft}^3$ . It is determined by dividing the fuel load ( $\text{lb}/\text{ft}^2$ ) by the fuel bed depth (feet). Bulk density can be increased by increasing the fuel load or by decreasing the fuel bed depth. It serves as a basis for quantifying how much fuel is potentially available, per cubic foot of fuel bed, to act as a heat sink. Not all the fuel is necessarily heated to ignition; this is discussed in the section on the effective heating number.

It is important to realize the significance of having the bulk density in the denominator of the rate of spread equation. Increasing the bulk density tends to decrease the rate of spread because the total heat sink, as expressed by the denominator, is increased. This

effect, however, is altered by the influence of fuel load on the reaction intensity, and bulk density on the propagating flux ratio. Therefore, no absolute statement can be made with regard to the effect of altering fuel load or bulk density.

**EFFECTIVE HEATING NUMBER ( $\epsilon$ )**

When large logs burn, the center of the log may be cool, relative to the surface that is on fire. That is, only the outer shell of the log has been heated to ignition temperature ( $320^{\circ}\text{C}$ ). The effective heating number ( $\epsilon$ ) provides the means to define what **proportion** of an individual fuel particle is heated to ignition temperature at the time flaming combustion starts. This proportion depends on the size of the fuel particle. Figure 19 shows that nearly the entire fuel particle for fine fuels is heated to ignition temperature at the time of ignition, while a relatively small proportion of larger fuels is heated to this degree. Multiplication of the bulk density by the effective heating number quantifies the amount of fuel, per cubic foot, that must be heated to ignition temperature as the fire progresses. That is, this product defines the **amount** of material in the heat sink.

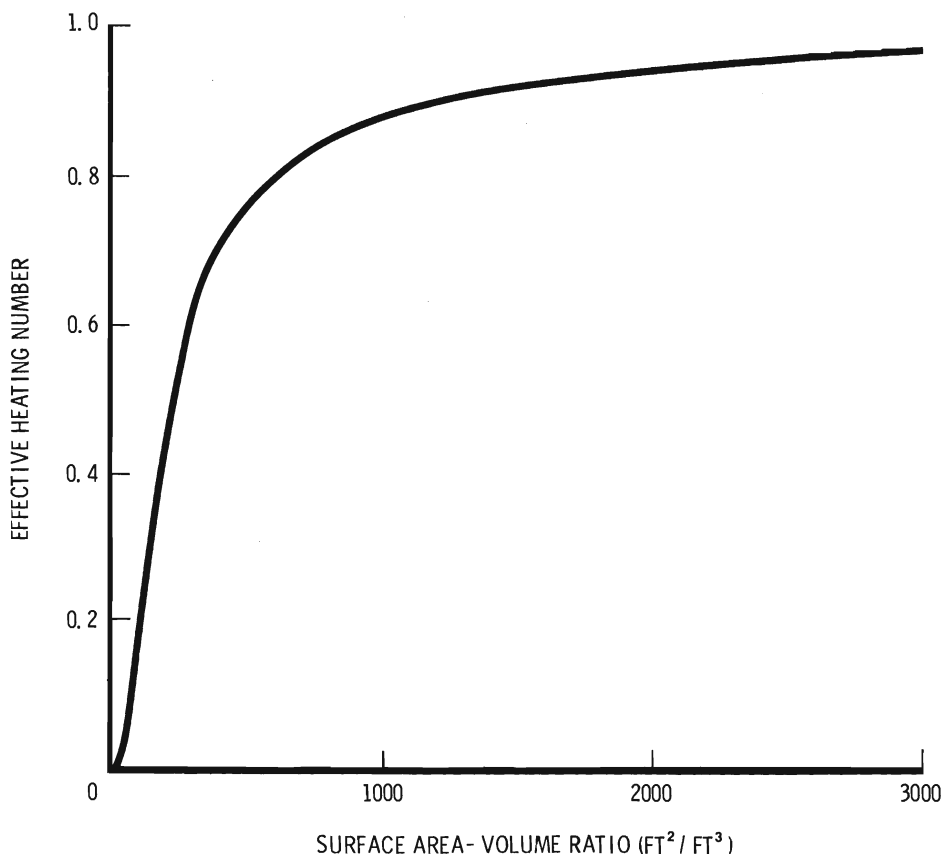


Figure 19.--Heating number. As fuel particle size decreases, a greater portion of the fuel particle is heated to ignition temperature at the time flaming combustion starts.

**HEAT OF PREIGNITION ( $Q_{ig}$ )**

Heat of preignition ( $Q_{ig}$ ) quantifies the amount of heat required to raise the temperature of 1 pound of moist wood from ambient temperature to the temperature at which it will ignite. In this process, first the water is evaporated from the wood, then the dry wood itself is heated. The amount of heat required to raise 1 pound of dry wood from air temperature to ignition temperature is a reasonably constant value that can be calculated in advance. The moisture content of wood, however, is not constant and it strongly affects the amount of

heat required to dry the fuel particle. Figure 20 shows that the heat of preignition increases steadily as the moisture content of the wood increases. Notice that even at zero percent moisture content, 250 Btu's are still required to heat each pound of absolutely dry wood to ignition.

Although the product of bulk density times effective heating number ( $\rho_b \epsilon$ ) quantifies how much **fuel weight**, per cubic foot of fuel bed, must be heated to ignition temperature, the heat of preignition quantifies how much **heat** is required to do this, per pound of moist fuel. Thus the units for  $Q_{ig}$  are Btu/lb. Then the product ( $\rho_b \epsilon Q_{ig}$ ) is the total amount of heat (Btu's) per cubic foot of fuel bed that must be supplied by the propagating flux.

The many interactions produced when fuel parameter values are changed preclude an exact description of how any particular change may affect predicted fire behavior. The technical version of TSTMDL was developed to provide an easy way to examine these changes graphically. You are strongly encouraged to use the technical graphics section of TSTMDL.

This completes a first look at each term in the rate of spread equation; however, additional fuel modeling insight can be gained from looking at some of these terms in greater detail, and from examining the method of weighting the influence of the various fuel size classes.

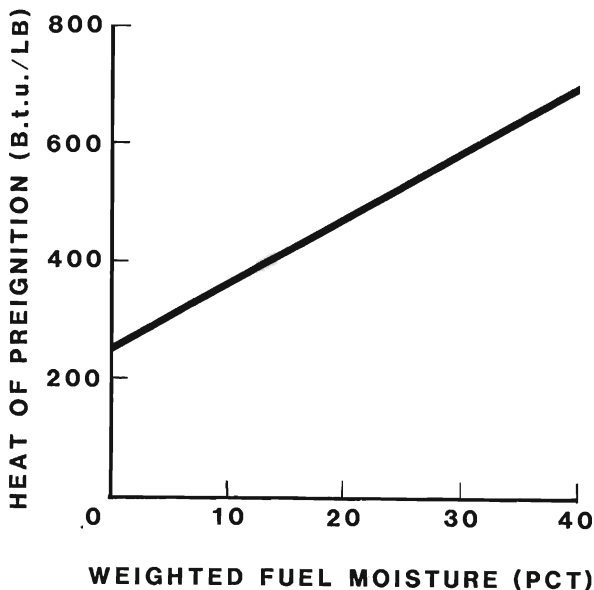


Figure 20.--Heat of preignition. The amount of heat required to ignite woody fuels increases as their moisture content increases.

#### Weighting of Fuel Size Classes

Even though a fuel model may contain several fuel size classes, each having a different surface-area-to-volume (S/V) ratio,  $\sigma$ , the mathematical fire model requires that just one S/V ratio value represent the entire fuel complex being modeled. The method of calculating this value weights the importance of each fuel class by its surface area, thus emphasizing the smaller fuels, which have the most effect on spread rate. A brief discussion of the weighting procedure may clarify some of the graphs produced by TSTMDL. Several tabulations will be used to help illustrate the weighting procedure, by placing an unusually large load in successive fuel classes. For these

tabulations, the S/V ratio of each fuel class will be assigned these constant values:

|   |  |
|---|--|
| 1-h S/V ratio ( $\sigma_{1h}$ )             | = 2,000 ft <sup>2</sup> /ft <sup>3</sup> |
| 10-h S/V ratio ( $\sigma_{10h}$ )           | = 109 ft <sup>2</sup> /ft <sup>3</sup>   |
| 100-h S/V ratio ( $\sigma_{100h}$ )         | = 30 ft <sup>2</sup> /ft <sup>3</sup>    |
| Live herbaceous S/V ratio ( $\sigma_{hb}$ ) | = 1,800 ft <sup>2</sup> /ft <sup>3</sup> |
| Live woody S/V ratio ( $\sigma_{wd}$ )      | = 1,500 ft <sup>2</sup> /ft <sup>3</sup> |

The fuel model loads for the six example cases will be:

| Case number | Fuel model load (tons/acre) |      |       |                 |            |
|-------------|-----------------------------|------|-------|-----------------|------------|
|             | 1-h                         | 10-h | 100-h | Live herbaceous | Live woody |
| 1           | 12                          | 2    | 2     | 2               | 2          |
| 2           | 2                           | 12   | 2     | 2               | 2          |
| 3           | 2                           | 2    | 12    | 2               | 2          |
| 4           | 2                           | 2    | 2     | 12              | 2          |
| 5           | 2                           | 2    | 2     | 2               | 12         |
| 6           | 2                           | 2    | 2     | 6               | 6          |

The first step in the weighting procedure is to determine the square feet of fuel surface area per square foot of fuel bed for each fuel size class. These values are determined for each size class by dividing the fuel particle density into the product of fuel particle S/V ratio times the oven-dry load of that class. That is, the surface area of any given fuel class, per cubic foot of fuel bed, obtained by canceling equivalent units of measure is:

$$\frac{\left( \frac{\text{ft}^2 \text{ of fuel surface area}}{\text{ft}^3 \text{ of fuel volume}} \right) \cdot \left( \frac{\text{lb of fuel}}{\text{ft}^2 \text{ of fuel bed}} \right)}{\left( \frac{\text{lb of fuel}}{\text{ft}^3 \text{ of fuel volume}} \right)} = \left( \frac{\text{ft}^2 \text{ of fuel surface area}}{\text{ft}^2 \text{ of fuel bed}} \right)$$

These surface areas will be referred to as:

$$A_{1h} = \text{ft}^2 \text{ of 1-h fuel surface area per ft}^2 \text{ of fuel bed}$$

$$A_{10h} = \text{ft}^2 \text{ of 10-h fuel surface area per ft}^2 \text{ of fuel bed}$$

$$A_{100h} = \text{ft}^2 \text{ of 100-h fuel surface area per ft}^2 \text{ of fuel bed}$$

$$A_{hb} = \text{ft}^2 \text{ of live herbaceous fuel surface area per ft}^2 \text{ of fuel bed}$$

$$A_{wd} = \text{ft}^2 \text{ of live woody fuel surface area per ft}^2 \text{ of fuel bed.}$$

Then the surface areas for all the fuels in the dead category and the surface areas for all the fuels in the live category are summed separately:

$$A_{\text{dead}} = A_{1h} + A_{10h} + A_{100h}$$

$$A_{\text{live}} = A_{hb} + A_{wd}$$

From these two sets of numbers, individual fuel class weighting factors are calculated by dividing the surface area in each fuel class by the total surface area in its category (live or dead):

$$f_{1h} = A_{1h}/A_{\text{dead}}$$

$$f_{10h} = A_{10h}/A_{\text{dead}}$$

$$f_{100h} = A_{100h}/A_{\text{dead}}$$

$$f_{hb} = A_{hb}/A_{\text{live}}$$

$$f_{wd} = A_{wd}/A_{\text{live}}$$

The first three factors define the proportions of the total dead fuel surface area that are contributed by the 1-, 10-, and 100-h fuel classes, while the last two define the proportions of the total live fuel surface area that are contributed by the live herbaceous and woody fuel classes.

The magnitudes of these weighting factors for the six sample fuel models are shown in the listings below. Note that the heavily loaded fuel component has been underlined in each case.

| Case number | Fuel class weighting factor |             |             |             |             |
|-------------|-----------------------------|-------------|-------------|-------------|-------------|
|             | $f_{1h}$                    | $f_{10h}$   | $f_{100h}$  | $f_{hb}$    | $f_{wd}$    |
| 1           | <u>0.989</u>                | 0.009       | 0.002       | 0.545       | 0.455       |
| 2           | <u>.745</u>                 | .244        | .011        | .545        | .455        |
| 3           | .874                        | <u>.048</u> | <u>.078</u> | .545        | .455        |
| 4           | .935                        | .051        | <u>.014</u> | <u>.878</u> | .122        |
| 5           | .935                        | .051        | .014        | <u>.167</u> | <u>.833</u> |
| 6           | .935                        | .051        | .014        | .545        | <u>.455</u> |

Because the S/V ratio for 1-h fuels is much greater than the S/V ratio for 10- and 100-h fuels,  $f_{1h}$  will generally be much larger than  $f_{10h}$  or  $f_{100h}$ . Thus the 1-h fuels dominate the dead fuel category. Live herbaceous and woody fuels often have similar S/V ratios, however, so  $f_{hb}$  and  $f_{wd}$  may be nearly equal. Note that the sum of the ratios in the live and dead categories of each case is 1.

The fuel class weighting factors are then used to determine a weighted S/V ratio for the dead and live categories by summing the products of the weighting factors for each class times the S/V ratio defined for that class.

$$\sigma_{\text{dead}} = f_{1h} * \sigma_{1h} + f_{10h} * \sigma_{10h} + f_{100h} * \sigma_{100h}$$

$$\sigma_{\text{live}} = f_{hb} * \sigma_{hb} + f_{wd} * \sigma_{wd}$$

The weighted S/V ratios for the dead and live categories of the six sample fuel models are:

| Case number | Weighted S/V ratios by fuel category |                        |
|-------------|--------------------------------------|------------------------|
|             | $\sigma_{\text{dead}}$               | $\sigma_{\text{live}}$ |
| 1           | 1,978                                | 1,663                  |
| 2           | 1,517                                | 1,663                  |
| 3           | 1,755                                | 1,663                  |
| 4           | 1,876                                | 1,763                  |
| 5           | 1,876                                | 1,530                  |
| 6           | 1,876                                | 1,663                  |



To complete the discussion on calculation of a single fuel particle size or S/V ratio to represent the entire fuel bed, a final set of factors is calculated to define the proportion of the total fuel bed surface area that is contributed by each fuel category (dead and live).

$$f_{\text{dead}} = A_{\text{dead}} / (A_{\text{dead}} + A_{\text{live}})$$

$$f_{\text{live}} = A_{\text{live}} / (A_{\text{dead}} + A_{\text{live}})$$

For the sample fuel models, these are:

| Case number | Fuel category weighting factors |                   |
|-------------|---------------------------------|-------------------|
|             | $f_{\text{dead}}$               | $f_{\text{live}}$ |
| 1           | 0.786                           | 0.214             |
| 2           | .449                            | .551              |
| 3           | .410                            | .590              |
| 4           | .148                            | .852              |
| 5           | .165                            | .835              |
| 6           | .178                            | .822              |

Then the weighted S/V ratios for the dead and live categories are combined into a "characteristic" S/V ratio for the entire fuel complex. This is accomplished by adding the products of the weighting factor for each category times the weighted S/V ratio for that category:

$$\bar{\sigma} = f_{\text{dead}} * \sigma_{\text{dead}} + f_{\text{live}} * \sigma_{\text{live}}$$

The "characteristic" S/V ratios for the fuel model examples are:

| Case number | Characteristic S/V ratio for the fuel model |
|-------------|---|
| 1           | 1,911                                       |
| 2           | 1,597                                       |
| 3           | 1,700                                       |
| 4           | 1,780                                       |
| 5           | 1,604                                       |
| 6           | 1,701                                       |

The fire model assumes that fuel complexes composed entirely of particles having a "characteristic" S/V ratio of  $\bar{\sigma}$  would burn the same as the actual fuel complex being modeled, which usually contains several different fuel size classes.

From a fuel modeling standpoint, the "characteristic" S/V ratio,  $\bar{\sigma}$ , is used numerous times in the fire model. In general, larger values suggest a faster combustion rate, therefore faster spread rate, greater flame lengths, increased response to wind and slope, etc. The "characteristic" S/V ratio is printed in tabular output of TSTMDL.

The most useful concept to remember from this discussion is that the relative magnitudes of the individual fuel class weighting factors greatly affect the response of a site specific fuel model to changes in fuel moisture. These weighting factors are primarily affected by the S/V ratios and loads of l h, live herbaceous and live woody loads, all of which can be varied in TSTMDL.

#### Response of Fuel Models to Fuel Moisture

Live and dead fuel moistures, live and dead moistures of extinction, and quantities of fine dead and live fuels all influence the response of a fuel model to fuel moisture changes.

As was described in the previous discussion on S/V weighting of fuel size classes, just one "characteristic" S/V ratio must represent the entire fuel complex. Similarly, a single "characteristic" dead fuel

moisture is determined to represent the average moisture content of the three dead fuel classes. The weighting procedure to determine a "characteristic" dead fuel moisture utilizes the same fuel class weighting factors ( $f_x$ ) as described for the S/V weighting. Therefore the l-h fuel moisture obviously dominates the "characteristic" dead fuel moisture because of the large S/V ratio associated with it.

For any fuel type, there exists a dead fuel moisture of extinction which is the lowest average dead fuel moisture at which a fire will not spread with a uniform front. By this definition, fuel will only burn if the actual moisture is less than the moisture of extinction. As the actual fuel moisture increases and approaches the moisture of extinction the fire will burn less vigorously. When dead fuels are dry enough to produce sufficient heat to desiccate and ignite the live fuels, these too contribute to the predicted fire intensity.

Fuel moistures affect both the numerator and denominator of the spread equation. The denominator is altered by changes in the heat of preignition ( $Q_{ig}$ ); higher moistures increase  $Q_{ig}$ , lower values decrease it. Fuel moistures modify the numerator by altering the reaction intensity through a multiplier called the moisture-damping coefficient. As the "characteristic" dead fuel moisture approaches the dead moisture of extinction, the moisture-damping coefficient approaches zero, thus reducing the reaction intensity. Figure 21 illustrates the general shape of the moisture-damping coefficient curve. Graphs having this general shape are often produced by the

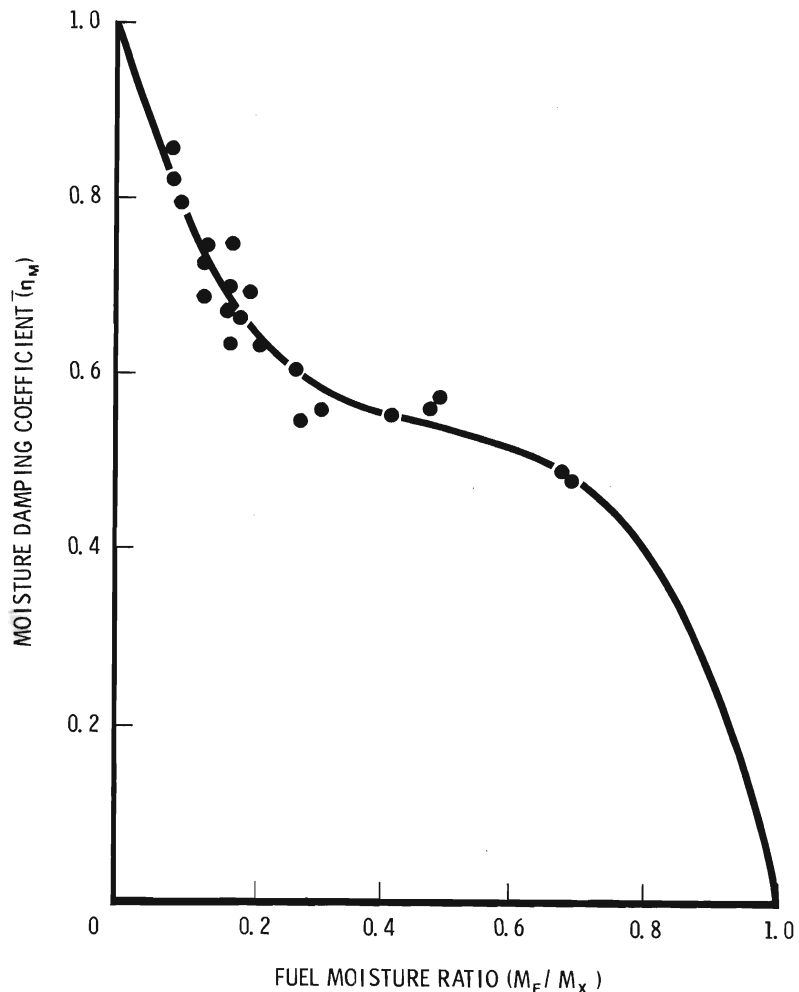


Figure 21.--Moisture damping curve. Fuels typically have an intermediate moisture range over which their sensitivity to changes in fuel moisture is minimized.

technical version of TSTMDL when rate of spread or flame length are plotted for a range of l-h fuel moistures or loads. Increasing the dead moisture of extinction will lengthen the "flat" center portion of the curve indicating the fuel type being modeled will burn well under relatively high fuel moistures. The converse is true for lower dead fuel extinction moistures.

Dynamic fuel models react very differently from static models if they include a significant load of live herbaceous material. In dynamic models, material is transferred between the live herbaceous and the l-h classes as the herbaceous moisture content ranges between 30 and 120 percent. This alters not only the load, but also the weighted moisture content of the live and dead fuel categories. The general result is that rapid changes in fire behavior predicted by static models for critical moisture ranges are less likely in dynamic models.

For fuel modeling, the most important concepts regarding fire behavior response to fuel moisture are:

1. Fuel classes having the highest S/V ratio (l-h, live herbaceous, and live woody) dominate the fuel moisture effects.
2. If the fuel type being modeled burns well at a relatively high moisture content, the model should have a high dead fuel moisture of extinction. If the fuels do not burn well at high moistures, the model should have a low moisture of extinction.
3. When combustion of the dead fuels produces enough heat to desiccate and ignite the live fuels, they too will add to the total fire intensity; otherwise they serve as a heat sink.
4. The dead moisture of extinction defines the "characteristic" moisture of dead fuels at which fire will not spread with a uniform front. Increasing the moisture of extinction will increase predicted fire behavior at all moisture levels--for example, fuels that burn well at high moisture levels should be given high values of moisture of extinction, 30 percent or more.
5. The fire behavior response of a fuel model to changes in fuel moistures is strongly affected by the relative loads in the fuel classes.
6. For dynamic models, herbaceous fuel moisture changes in the range of 30-120 percent produce fuel load transfers between the l-h and the live herbaceous classes, thereby altering the moisture damping curve. The resulting fire behavior may be quite different than a similar static model.

## General Techniques for Adjusting Fuel Models

This discussion section ends with general **guidelines** on how to adjust the fire behavior characteristics of a fuel model. It must be emphasized, however, that **guidelines only** can be provided. Interactions of the fuel model and environmental parameters with the fire model are so complex that "cookbook rules" cannot be substituted for a basic understanding of the fuel modeling process and examination of the models with TSTMDL. Fuel models should first be adjusted to perform well at low fuel moistures, then tested at higher fuel moistures to see if they respond properly there. The standard environmental conditions in the TSTMDL program provide a convenient means to set up low-, medium-, and high-moisture situations. If a fuel model must be adjusted to respond properly at high moistures, check the low-moisture response again to ensure that it is reasonable. All new fuel models should be well tested at all possible environmental conditions for which they may be used. This will help eliminate any undesired surprises in operational situations.

A common fuel-modeling problem is having the spread rate about right, but the flame length too low, or vice versa. The technical version of TSTMDL provides an opportunity to determine whether changing a particular fuel model parameter has a greater effect on the spread rate or the flame length. This can be accomplished by plotting the ratio of spread rate to flame length for a range of any fuel model or environmental parameter. Such a plot will show whether

spread rate will increase faster than flame length (rising curve) or slower (descending curve) as the value of the selected parameter changes (fig. 22). Modifying the fuel model parameters in the following order is a reasonable way to proceed.

1. Adjust loads.
  - (a) 1-h timelag
  - (b) live herbaceous
  - (c) live woody
  - (d) 10-h timelag
  - (e) 100-h timelag
2. Adjust fuel bed depth.
3. Adjust surface-area-to-volume ratios.
  - (a) 1-h timelag
  - (b) live herbaceous
  - (c) live woody
4. Adjust the extinction moisture for dead fuels.
5. Adjust the heat content.

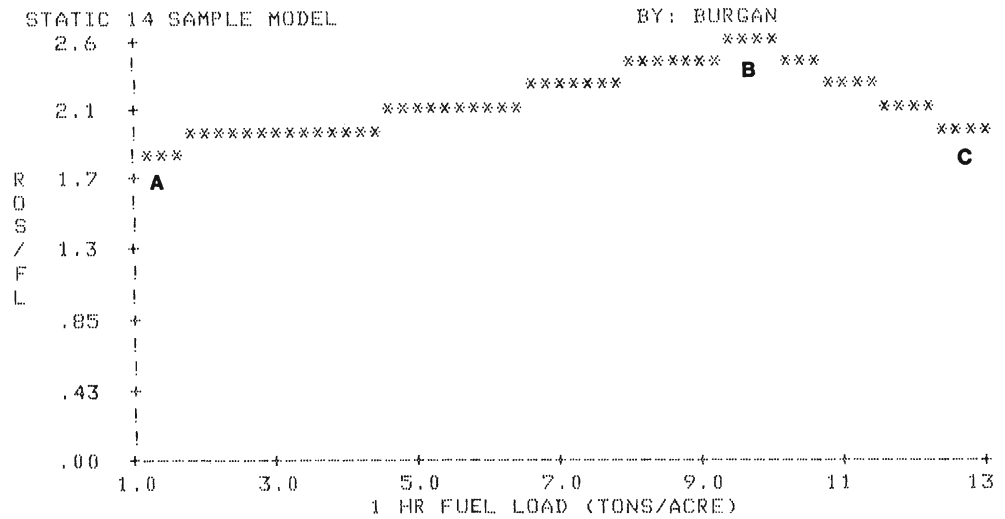


Figure 22.--Relative effect of 1-h timelag load on rate of spread vs flame length for this sample model. From A to B the rate of spread increases faster than flame length. From B to C flame length increases faster than rate of spread.

#### CHANGING FUEL LOAD

Fuel loads have both direct and indirect effects on every variable in the spread equation. Therefore because the load can be changed for any of the three dead and two live classes, a wide variety of responses can be produced. Usually an increase in fuel load will cause reaction intensity to increase more than rate of spread. In fact, the rate of spread may actually decrease because more fuel must be raised to ignition temperature. Addition of live herbaceous or woody fuels increases fuel model sensitivity to seasonal moisture changes in living vegetation. The general effect of live herbaceous fuel in dynamic models is to produce somewhat more intense fire behavior than static models when the live herbaceous moisture is between 30 and 120 percent. Transfer of "fine" fuel between the herbaceous and 1-h classes accounts for this.

The sensitivity of a fuel model to wind and slope can be increased by reducing the fuel load, thereby decreasing the packing ratio.

Because of the complex effects fuel load changes can produce, it is suggested that the technical version be used to plot rate of spread

and flame length over a wide range for any fuel load class you are investigating.

Increasing the l-h load will generally increase the rate of spread and flame length until the fuel model becomes too tightly packed, then the rate of spread will decrease. Additional 10- or 100-h loads will generally decrease the rate of spread, but the flame length may either increase or decrease.

#### CHANGING FUEL BED DEPTH

Increasing fuel bed depth reduces the packing ratio, making a fuel model more sensitive to both wind and slope. Increasing depth also reduces the bulk density, which in turn reduces the heat sink (denominator of the spread equation), thus tending to increase the rate of spread. Increasing depth increases the reaction intensity if the packing ratio is greater than optimum (PR/OPR in TSTM DL tabular output is greater than 1), but decreases it if the packing ratio is less than optimum. Because both rate of spread and reaction intensity affect flame length, no absolute statements can be made about how depth changes will affect it.

#### CHANGING S/V RATIOS

In loosely packed fuels, increasing the S/V ratio of l-h, live herbaceous, or live woody fuels will increase the rate of spread and flame length, and also increases the sensitivity of the fuel model to wind, but not to slope. Increasing the S/V ratio in tightly packed fuels, however, may decrease the spread rate and flame length.

#### CHANGING DEAD FUEL MOISTURE OF EXTINCTION

The greater the difference between the weighted dead moisture of the l-, 10-, and 100-h fuels, and the dead fuel moisture of extinction, the more intense the predicted fire behavior. Dead moisture of extinction not only defines the weighted moisture content for dead fuels at which predicted fire behavior is zero, but also influences the fire intensity predicted at all fuel moisture levels. Increasing dead fuel extinction moisture produces a "hotter" fuel model at all moisture levels and increases the moisture at which the fire is predicted to stop spreading. Changes in moisture of extinction will produce more pronounced fire behavior response at high fuel moisture, however, than at low fuel moisture.

#### CHANGING HEAT CONTENT

Heat content affects all fire behavior outputs directly; higher heat content produces more intensive fire behavior, lower heat content reduces it. Because the effect of heat content is direct and predictable, it provides a means to "fine tune" a fuel model.

**RECORDING AND USING SITE-SPECIFIC  
FUEL MODELS WITH THE TI-59 CALCULATOR**

After developing, refining, and testing a fire behavior fuel model with the NEWMDL, TSTMDL, and BURN programs of the BEHAVE system, it can be recorded on a magnetic card for use in the field with a TI-59 calculator containing a fire behavior CROM. To obtain the values for a fuel model and the TI-59 registers in which to enter them, use program TSTMDL to first "load" the fuel model, either from your fuel model file, or by entering it directly. Entry of keyword TI59 in the "CONTROL" section of TSTMDL will list the values to enter in the TI-59 registers. A sample listing is shown in figure 23. Figure 24 provides a form on which you can record the values for your fuel model if you are not using a hard-copy terminal.

TI-59 Data for Static (Dynamic) Model XX Model Name

| Model parameter | Parameter value | TI Reg. No. |
|-----------------|-----------------|-------------|
| -----Loads----- |                 |             |
| 1-HR            | 0.0689          | 11          |
| 10-HR           | 0.0460          | 12          |
| 100-HR          | 0.0115          | 13          |
| Live herbaceous | 0.0459          | 15          |
| Live woody      | 0.0688          | 16          |
| ---S/V ratio--- |                 |             |
| 1-HR            | 2000.           | 17          |
| 10-HR           | 109.            | 18          |
| 100-HR          | 30.             | 19          |
| Live herb       | 1800.           | 21          |
| Live woody      | 1700.           | 22          |
| ----Others----  |                 |             |
| Heat content    | 8000.           | 23          |
| ROS for IC      | 999999.         | 24          |
| Ext moisture    | 30.             | 25          |
| Depth           | 0.20            | 26          |
| M WS constant   | 1.              | 27          |

To use static models in the TI-59, the live herbaceous and live woody loads have been combined in the live woody class, and the live herb load was set to zero. You must also enter the live herb and live woody S/V ratios as shown in the above listing, even though the herb load is zero.

*Figure 23.--Sample TSTMDL listing needed to produce a fire behavior fuel model card for the TI-59 calculator.*

TSTMDL TI-59 OUTPUT

Model number \_\_\_\_\_

File name \_\_\_\_\_

Wind reduction factor  
for fully exposed fuels \_\_\_\_\_

| Model parameter                          | Parameter value | TI Reg. No. |
|--|-----------------|-------------|
| <i>-----Loads-----</i>                   |                 |             |
| 1-HR                                     | _____           | 11          |
| 10-HR                                    | _____           | 12          |
| 100-HR                                   | _____           | 13          |
| Live herbaceous                          | _____           | 15          |
| Live woody                               | _____           | 16          |
| <i>---S/V ratio---</i>                   |                 |             |
| 1-HR                                     | _____           | 17          |
| 10-HR                                    | _____           | 18          |
| 100-HR                                   | _____           | 19          |
| Live herbaceous                          | _____           | 21          |
| Live woody                               | _____           | 22          |
| <i>----Others----</i>                    |                 |             |
| Heat content                             | _____           | 23          |
| Rate of spread for<br>ignition component | _____           | 24          |
| Extinction moisture                      | _____           | 25          |
| Depth                                    | _____           | 26          |
| M WS constant                            | _____           | 27          |

Figure 24.--Site-specific fuel model recording form for TI-59.

**Modifying the  
Keyboard Overlay**

The fire behavior keyboard overlay was designed to define only one key for entry of LIVE fuel moisture. This key will continue to be used for entry of live fuel moisture for the 13 NFFL fuel models and for all **static** fuel models. For static models, a single average moisture is entered to represent both the live herbaceous and live woody fuels. To use **dynamic** fire behavior fuel models, however, the keyboard overlay must be modified to label a key for entering live

herbaceous fuel moisture. Place the label HERB above the INV key (fig. 25). Live herbaceous moisture can be entered by keying the moisture value into the display, then pressing SBR HERB. It can be recalled by pressing SBR 2nd HERB. Live woody fuel moisture can be entered using the key labeled LIVE.

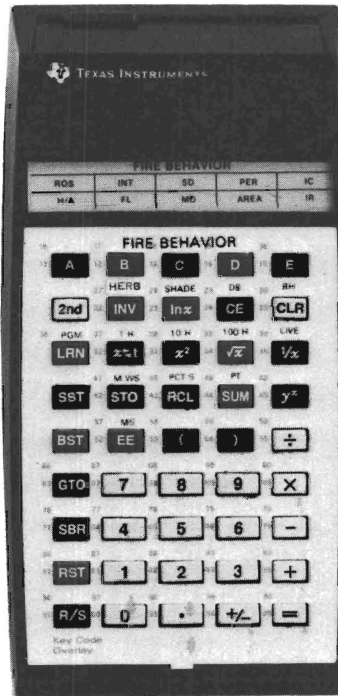


Figure 25.--Modify the fire behavior keyboard overlay by placing the label HERB above the INV key on the calculator.

## Recording a Fuel Model

To record a site-specific fuel model on a TI-59 magnetic card, start with your calculator OFF to ensure all data registers are zeroed. Then perform the following steps:

1. Turn the calculator ON, then press 2nd PGM 2 SBR R/S. A -4. will appear in the display. Successively enter the values of the parameters listed for your fuel model into the display and store them in the indicated registers. For example, to store the 1-h timelag load illustrated in figure 23, enter .0689 in the display, and press STO 11. After all values for your model have been stored, put a -4 in the display, then press 2nd R/S and run a magnetic strip through the read/write slot in the calculator.

If your fuel model is static, that is it has no herbaceous load (register 15 is zero) the fuel model may be used as though it were one of the 13 NFFL models. Live fuel, when it occurs in static models, is stored in register 16 as live woody material. In this situation, step 2 does not apply.



2. If the fuel model is dynamic (register 15 is not zero), press RST LRN and enter the following program:

| Step | Code | Keystrokes |
|------|------|------------|
| 000  | 76   | 2nd SBR    |
| 001  | 53   | (          |
| 002  | 43   | RCL        |
| 003  | 11   | 11         |
| 004  | 42   | STO        |
| 005  | 94   | 94         |
| 006  | 43   | RCL        |
| 007  | 15   | 15         |
| 008  | 42   | STO        |
| 009  | 98   | 98         |
| 010  | 91   | R/S        |
| 011  | 76   | 2nd SBR    |
| 012  | 54   | )          |
| 013  | 43   | RCL        |
| 014  | 94   | 94         |
| 015  | 42   | STO        |
| 016  | 11   | 11         |
| 017  | 43   | RCL        |
| 018  | 98   | 98         |
| 019  | 42   | STO        |
| 020  | 15   | 15         |
| 021  | 91   | R/S        |

Then press LRN 1 2nd R/S, turn the magnetic strip end for end, and run it through the read/write slot again. At this point you have the fuel model recorded on one side of the card and the above program on the other. Label the card.

#### Using a Fuel Model

1. To load any previously recorded fuel model with the TI-59--static or dynamic--press 2nd PGM 2 SBR R/S. A -4. will appear in the display.
2. Run the fuel model side of the card through the card reader.
3. If the model is static, the following steps do not apply; just use the model as though it were one of the 13 NFFL models.
4. If the model is dynamic, press 1 and then run the program side of the card through the card reader.
5. Press RST SBR ( and ignore the number that appears in the display.
6. Press 2nd PGM 2 SBR R/S.
7. Enter or change environmental inputs--including herbaceous moisture.
8. Run the fire behavior program.
9. Press RST SBR )
10. To do another run, go back to step 6.

#### REFERENCES

- Albini, Frank A.; Brown, James K. Predicting slash depth for fire modeling. Res. Pap. INT-206. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1978. 22 p.
- Albini, Frank A. Computer-based models of wildland fire behavior: a user's manual. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976. 68 p.
- Anderson, Hal E. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 22 p.

- Andrews, Patricia L. BEHAVE: fire behavior prediction and fuel modeling system--BURN subsystem. Gen. Tech. Rep. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. Review draft.
- Andrews, Patricia L.; Rothermel, Richard C. Charts for interpreting wildland fire behavior characteristics. Gen. Tech. Rep. INT-131. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 21 p.
- Brown, James K. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1974. 24 p.
- Brown, James K. Weight and density of crowns of Rocky Mountain conifers. Res. Pap. INT-197. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1978. 56 p.
- Brown, James K.; Oberheu, R. D.; Johnston, C. M. Handbook for inventorying surface fuels and biomass in the interior West. Gen. Tech. Rep. INT-129. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 48 p.
- Burgan, Robert E. Estimating live fuel moisture for the 1978 National Fire-Danger Rating System. Res. Pap. INT-226. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 17 p.
- Burgan, Robert E. Fire danger/fire behavior computations with the Texas Instruments TI-59 calculator: users' manual. Gen. Tech. Rep. INT-61. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 25 p.
- Byram, George M. Combustion of forest fuels. In: Davis, Kenneth P., ed. Forest fire control and use. New York: McGraw-Hill; 1959: 90-123.
- Cohen, Jack. FIRECAST user's manual. Riverside, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Forest Fire Laboratory. Review draft.
- Fischer, William C. Photo guide for appraising downed woody fuels in Montana forests: interior ponderosa pine, ponderosa pine-larch-Douglas-fir, larch-Douglas-fir, and interior Douglas-fir cover types. Gen. Tech. Rep. INT-97. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981a. 133 p.
- Fischer, William C. Photo guide for appraising downed woody fuels in Montana forests: lodgepole pine, and Engelmann spruce-subalpine fir cover types. Gen. Tech. Rep. INT-98. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981b. 143 p.
- Fischer, William C. Photo guide for appraising downed woody fuels in Montana forests: grand fir-larch-Douglas-fir, western hemlock, western hemlock-western redcedar, and western redcedar cover types. Gen. Tech. Rep. INT-96. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981c. 53 p.
- Fosberg, Michael A.; Deeming, John E. Derivation of the 1- and 10-hour timelag fuel moisture calculations for fire-danger rating. Res. Note RM-207. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1971. 8 p.

- Frandsen, William H. Fire spread through porous fuels from the conservation of energy. *Combustion and Flame*. 16: 9-16; 1971.
- Hough, W. A.; Albini, F. A. Predicting fire behavior in palmetto-gallberry fuel complexes. Res. Pap. SE-174. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1978. 44 p.
- Koski, W. H.; Fischer, W. C. Photo series for appraising thinning slash in north Idaho western hemlock, grand fir, and western redcedar timber types. Gen. Tech. Rep. INT-46. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 50 p.
- Maxwell, W. G.; Ward, F. R. Photo series for quantifying forest residues in the coastal Douglas-fir hemlock type and coastal Douglas-fir-hardwood type. Gen. Tech. Rep. PNW-51. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1978a. 103 p.
- Maxwell, W. G.; Ward, F. R. Photo series for quantifying forest residues in the ponderosa pine and associated species type, and lodgepole pine type. Gen. Tech. Rep. PNW-52. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1978b. 73 p.
- Maxwell, W. G.; Ward, F. R. Photo series for quantifying forest residues in the Sierra mixed conifer type, Sierra true fir type. Gen. Tech. Rep. PNW-95. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 79 p.
- Maxwell, W. G.; Ward, F. R. Photo series for quantifying forest residues in common vegetation types of the Pacific Northwest. Gen. Tech. Rep. PNW-105. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1980. 230 p.
- McArthur, A. G. The Tasmanian bushfires of 7th February, 1967, and associated fire behavior characteristics. In: Technical cooperative programme mass fire symposium proceedings. Vol. I, Defense Standards Lab., Maribyrnong, Victoria; 1969. 23 p.
- Puckett, John V.; Johnston, Cameron M. Users' guide to debris prediction and hazard appraisal. Revised. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Forest Fire Laboratory, Intermountain Forest and Range Experiment Station and Fire & Aviation Management, Northern Region; 1979 January. 37 p.
- Rothermel, Richard C. A mathematical model for fire spread predictions in wildland fuels. Res. Pap. INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 40 p.
- Rothermel, Richard C. How to predict the spread and intensity of forest and range fires. Gen. Tech. Rep. INT-143. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 161 p.
- Rothermel, Richard C.; Rinehart, George. Field procedures for verification and adjustment of fire behavior predictions. Gen. Tech. Rep. INT-142. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 25 p.
- Rothermel, R. C.; Philpot, C. W. Predicting changes in chaparral flammability. *J. For.* 71(10): 640-643; 1973.

## APPENDIX A: GRASS AND SHRUB FUEL TYPES

The photos in this appendix are meant to illustrate the general morphology for broadly different types of grasses and shrubs. That is, any set (page) of grass or shrub photos represents a **large** variety of grass or shrub species. One must select the photo that best fits the actual conditions at hand.

To help you visualize the general plant morphology each grass and shrub type is meant to represent, the specific species photographed are listed below:

| Photo page   | Species photographed                       | Morphology represented            |
|--------------|--|-----------------------------------|
| Grass Type 1 | Cheatgrass<br><i>Bromus tectorum</i>       | Fine grasses                      |
| Grass Type 2 | Rough fescue<br><i>Festuca scabrella</i>   | Medium coarse grasses             |
| Grass Type 3 | Fountaingrass<br><i>Pennisetum ruppeli</i> | Coarse grasses                    |
| Grass Type 4 | Sawgrass<br><i>Mariscus</i> spp.           | Very coarse grasses               |
| Shrub Type 1 | Huckleberry<br><i>Vaccinium</i> spp.       | Fine stems, thin leaves           |
| Shrub Type 2 | Ninebark<br><i>Physocarpus</i> spp.        | Medium stems, thin leaves         |
| Shrub Type 3 | Ceanothus<br><i>Ceanothus</i> spp.         | Medium stems, thick leaves        |
| Shrub Type 4 | Chamise<br><i>Adenostoma</i> spp.          | Very dense, fine stems and leaves |
| Shrub Type 5 | Manzanita<br><i>Arctostaphylos</i> spp.    | Thick stems and leaves            |

# GRASS TYPE 1



DENSITY 1



DENSITY 2



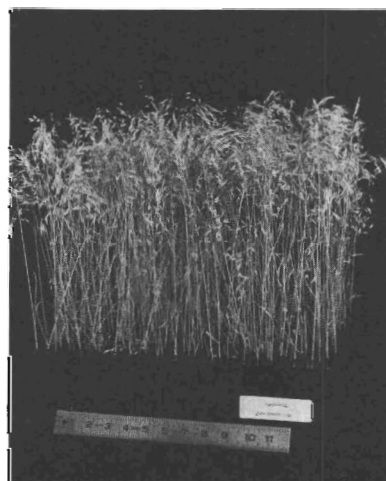
DENSITY 3



DENSITY 4

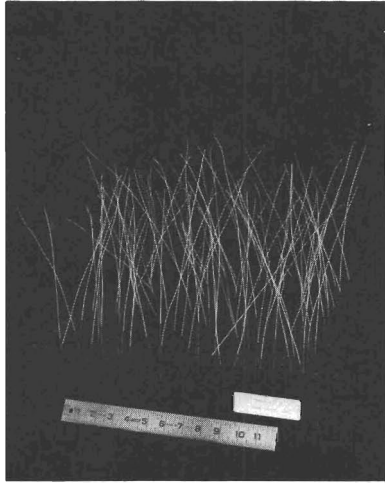


DENSITY 5



DENSITY 6

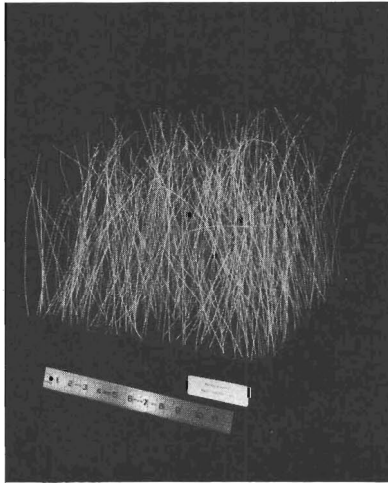
# GRASS TYPE 2



DENSITY 1



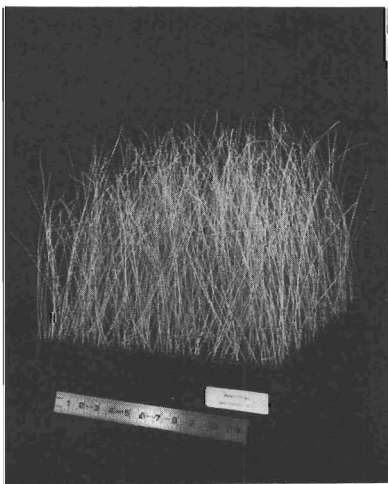
DENSITY 2



DENSITY 3



DENSITY 4



DENSITY 5

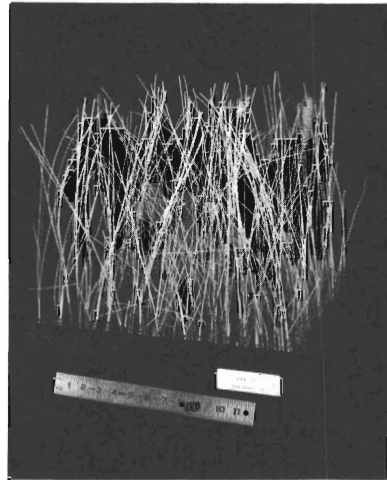


DENSITY 6

# GRASS TYPE 3



DENSITY 1



DENSITY 2



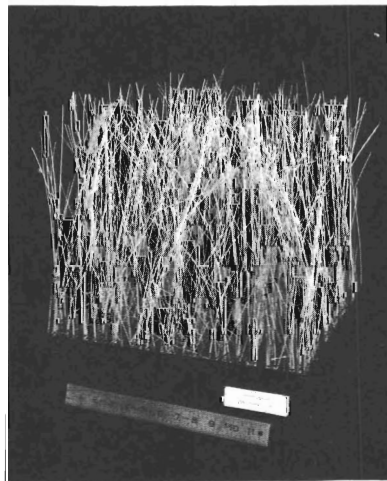
DENSITY 3



DENSITY 4



DENSITY 5



DENSITY 6

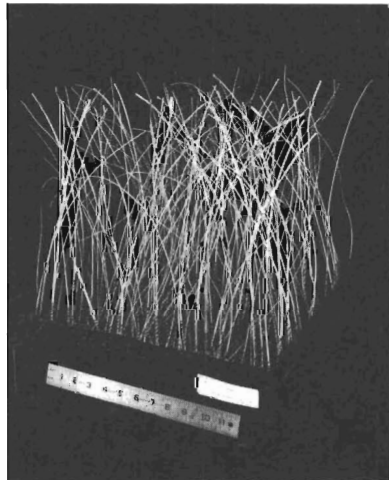
# GRASS TYPE 4



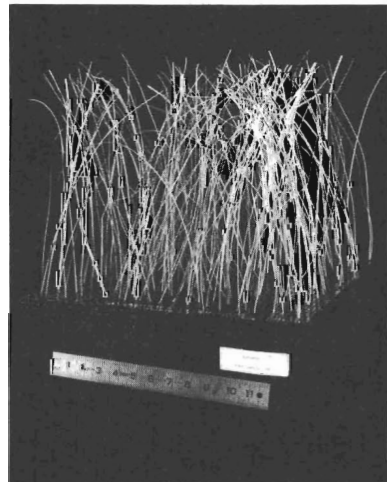
DENSITY 1



DENSITY 2



DENSITY 3



DENSITY 4



DENSITY 5



DENSITY 6



# SHRUB TYPE 1



DENSITY 1



DENSITY 2



DENSITY 3



DENSITY 4



DENSITY 5

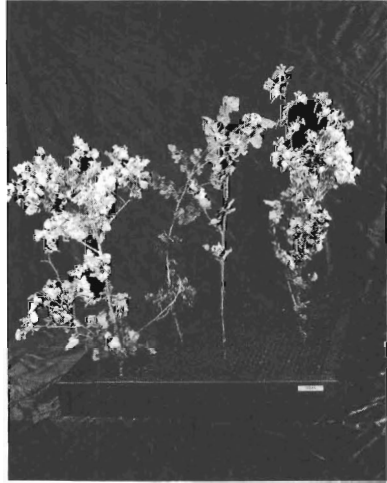


DENSITY 6

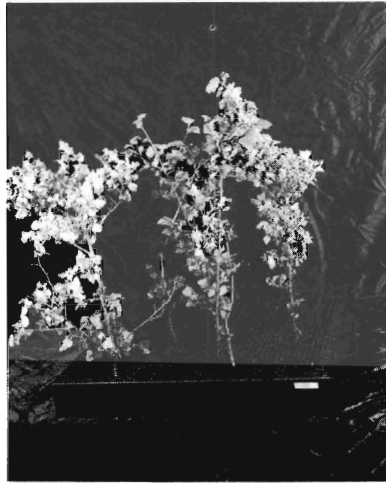
## SHRUB TYPE 2



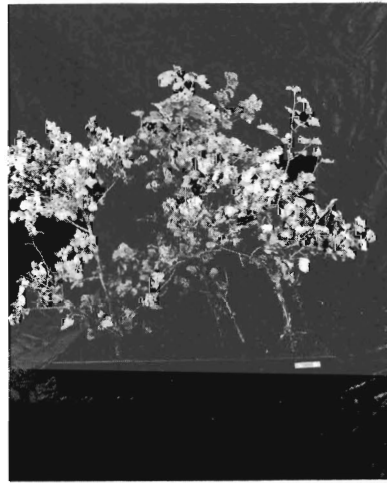
DENSITY 1



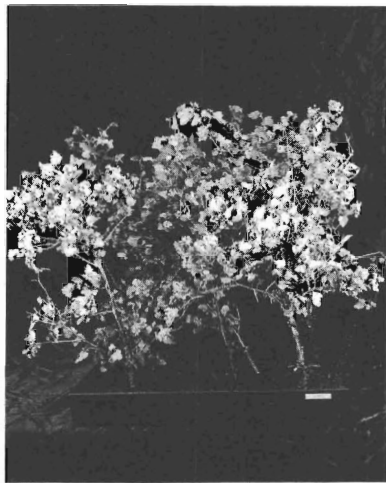
DENSITY 2



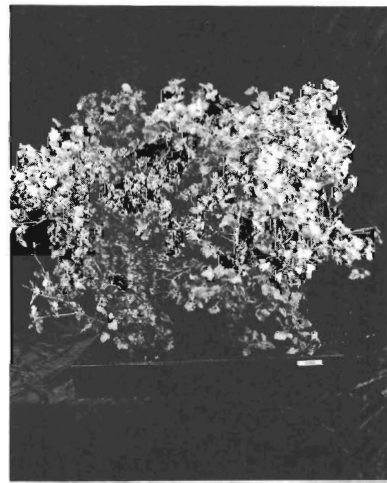
DENSITY 3



DENSITY 4

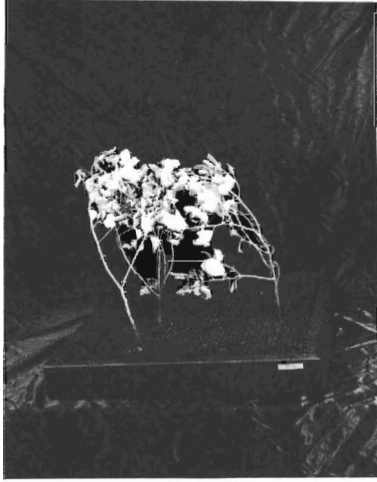


DENSITY 5



DENSITY 6

# SHRUB TYPE 3



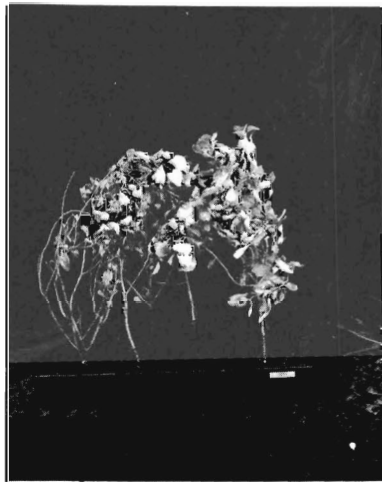
DENSITY 1



DENSITY 2



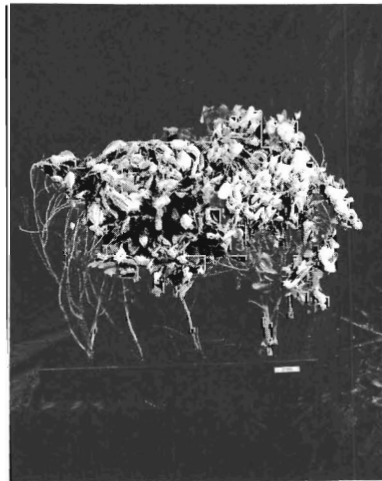
DENSITY 3



DENSITY 4



DENSITY 5



DENSITY 6

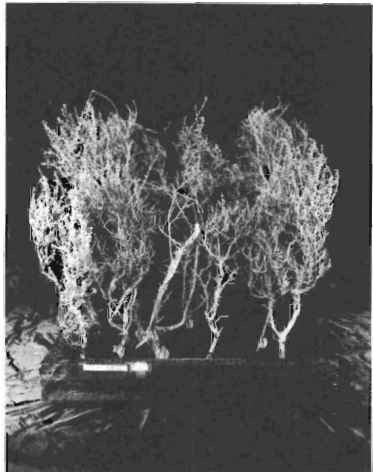
# SHRUB TYPE 4



DENSITY 1



DENSITY 2



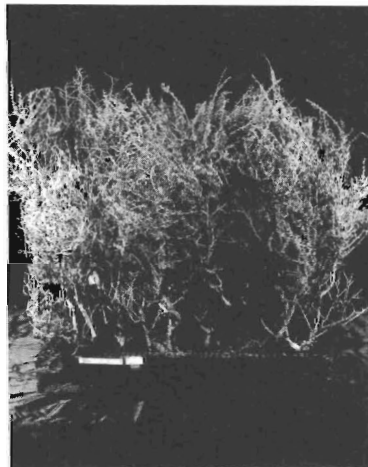
DENSITY 3



DENSITY 4



DENSITY 5



DENSITY 6

# SHRUB TYPE 5



DENSITY 1



DENSITY 2



DENSITY 3



DENSITY 4



DENSITY 5



DENSITY 6

## APPENDIX B: EXAMPLE NEWMDL SESSION

This NEWMDL session provides examples of various ways data can be entered when building a new fuel model. Not all possible data entry combinations are presented, but first-time or occasional users should find this listing helpful.

In this session, data have been entered for most of the fuel components in more than one way. This is to illustrate several procedures so you can refer to those of interest. It is not intended that you sign on to a computer and duplicate this session, although that may certainly be done.

The only fuel model file procedure used in this session is adding a model to the file. Extensive file manipulations are presented in the TSTMDL session (appendix C). Lines that begin with a prompt character (>) were typed by the user. All other lines were printed by the computer.

|  | Page |
|--|------|
| I. Start of session . . . . .  | 67   |
| II. Entering litter data . . . . .                                       | 68   |
| A. By load and size class . . . . .                                      | 68   |
| B. By load only . . . . .  | 69   |
| III. Entering grass data . . . . .                                       | 70   |
| A. By load and depth . . . . .   | 71   |
| B. By depth only . . . . .   | 72   |
| IV. Entering shrub data by depth only . . . . .                          | 73   |
| V. Entering shrub data . . . . .   | 74   |
| A. Direct entry of inventoried data . . . . .                            | 75   |
| B. Entry of total slash load . . . . .                                   | 76   |
| C. Entry of total 10-h load . . . . .                                    | 78   |
| D. Entry of 10-h load by species . . . . .                               | 80   |
| E. Entry of 10-h intercepts per foot by species . . . . .                | 83   |
| VI. Entering surface-area-to-volume ratio data . . . . .                 | 85   |
| VII. Entering heat content data . . . . .                                | 86   |
| VIII. Printing data entered for all fuel components . . . . .            | 87   |
| IX. Printing your completed fuel model . . . . .                         | 87   |
| X. Adding the fuel model to the file . . . . .                           | 88   |
| XI. Building and filing a model with two sizes<br>of fine fuel . . . . . | 89   |

\*NEWMDL

WELCOME TO THE  
BEHAVE SYSTEM  
FUEL SUBSYSTEM  
NEWMDL PROGRAM (VERSION 2.0 -- AUGUST 1983)

DEVELOPED BY THE  
FIRE BEHAVIOR RESEARCH WORK UNIT  
NORTHERN FOREST FIRE LABORATORY  
MISSOULA, MONTANA

ENTER YOUR LAST NAME.  
>BURGAN

THE OBJECTIVE OF THIS PROGRAM IS TO HELP YOU DEVELOP  
A FIRE BEHAVIOR FUEL MODEL THAT REASONABLY CHARACTERIZES A  
FUEL COMPLEX NOT PROPERLY REPRESENTED BY ONE OF THE THIRTEEN  
NFFL FUEL MODELS.

A TERSE MODE IS AVAILABLE FOR EXPERIENCED USERS  
THAT WANT LIMITED PROMPTING. DO YOU WANT TERSE? (Y OR N).  
>N

FULL PROMPT MODE SET.

PROGRAM CONTROL IS THROUGH THE USE OF KEYWORDS.  
DO YOU WANT A LIST OF KEYWORDS AND THEIR FUNCTIONS? (Y OR N)  
>Y

THE PRIMARY KEYWORDS AND THEIR FUNCTIONS ARE:

| KEYWORD  | FUNCTION                             |
|----------|--------------------------------------|
| KEY      | PRINTS THIS KEYWORD LIST             |
| TERSE    | SET TERSE MODE FOR MINIMAL PROMPTING |
| WORDY    | SET WORDY MODE FOR FULL PROMPTING    |
| LITTER   | DETERMINE LOAD OF LITTER FUELS       |
| GRASS    | DETERMINE LOAD OF GRASS FUELS        |
| SHRUB    | DETERMINE LOAD OF SHRUB FUELS        |
| SLASH    | DETERMINE LOAD OF SLASH FUELS        |
| SURF     | DETERMINE SURFACE TO VOLUME RATIOS   |
| HEAT     | DETERMINE HEAT CONTENT               |
| COMP     | DISPLAY VALUES OF FUEL COMPONENTS    |
| MODEL    | DISPLAY FUEL MODEL                   |
| RENUMBER | RENUMBER THE FUEL MODEL              |
| FILE     | ACCESS FUEL MODEL FILE               |
| QUIT     | QUIT SESSION                         |
| RESTART  | START PROGRAM AT BEGINNING AGAIN     |

A FUEL MODEL MAY BE CONSTRUCTED WITH EITHER  
1. 1 SIZE OF FINE FUEL IN ONE OR MORE COMPONENTS  
2. 2 SIZES OF FINE FUEL IN ONE OR MORE COMPONENTS

ENTER 1 OR 2  
>1

*Start of session*

ENTER A NUMBER FOR YOUR PROPOSED FUEL MODEL.

RANGE = 14 TO 99

>60

ENTER FUEL MODEL NAME (32 CHARACTERS MAXIMUM).

-----  
>FIRST SAMPLE MODEL

THE FUEL MODEL WILL BE BUILT UP FROM INDIVIDUAL COMPONENTS -- LITTER, GRASS, SHRUBS, AND SLASH -- EACH CONSIDERED SEPARATELY, BEFORE BEING COMBINED INTO A COMPLETED FUEL MODEL. ENTER THE KEYWORD FOR THE FIRST COMPONENT YOU WISH TO CONSIDER.

CONTROL SECTION, KEYWORD?

>LITTER

LITTER SECTION

YOU CAN ENTER:

PREVIOUSLY INVENTORIED FUEL DATA

1. LITTER LOAD BY SIZE CLASS (1, 10, 100 HR), AND DEPTH.

NEW FUEL DATA

2. LITTER LOAD ONLY (DEPTH WILL BE ESTIMATED FOR YOU)

3. LITTER DEPTH ONLY (LOAD WILL BE ESTIMATED FOR YOU)

\*\*\* CAUTION \*\*\* LITTER FUELS ARE OFTEN SHALLOW SO THEIR DEPTH (IN FEET) IS USUALLY LESS THAN 1.

EX: 1 INCH = .083 FEET

ENTER 1, 2, OR 3

>1

ENTER LITTER LOAD (TONS/ACRE)

RANGE = 0 TO 30

1 HR?

>3

10 HR?

>4

100 HR?

>1

LITTER DEPTH IN FEET?

RANGE = 0 TO 5

>.2

WHAT PERCENT OF THE AREA IS COVERED BY LITTER?

>80

LITTER LOADS (T/A)

1 HR 2.40

10 HR 3.20

100 HR 0.80

LITTER DEPTH 0.16 FEET

LOADS AND DEPTH NOW REDUCED FOR AREA COVERAGE.

*This procedure can be used to enter previously inventoried fuels data*

*Entering litter data by load and size class.*



DO YOU WANT TO:

1. ACCEPT THESE VALUES
2. START THE LITTER SECTION ALL OVER?

ENTER 1 OR 2

>2

LITTER SECTION

YOU CAN ENTER:

PREVIOUSLY INVENTORIED FUEL DATA

1. LITTER LOAD BY SIZE CLASS (1, 10, 100 HR), AND DEPTH.

NEW FUEL DATA

2. LITTER LOAD ONLY (DEPTH WILL BE ESTIMATED FOR YOU)
3. LITTER DEPTH ONLY (LOAD WILL BE ESTIMATED FOR YOU)

\*\*\* CAUTION \*\*\* LITTER FUELS ARE OFTEN SHALLOW  
SO THEIR DEPTH (IN FEET) IS USUALLY LESS THAN 1.  
EX: 1 INCH = .083 FEET

ENTER 1, 2, OR 3

>2

IS THE LITTER PRIMARILY FROM:

1. CONIFERS
2. HARDWOODS
3. A COMBINATION OF BOTH, BUT AT LEAST 30% OF LESSER TYPE

ENTER 1, 2, OR 3

>3

WHAT IS THE NEEDLE LENGTH?

1. MEDIUM TO LONG (EXAMPLE: LODGEPOLE OR PONDEROSA PINE)
2. SHORT (EXAMPLE: DOUGLAS FIR)

ENTER 1 OR 2

>1

HOW COMPACT IS THE LITTER?

1. LOOSE (FRESHLY FALLEN)
2. NORMAL
3. COMPACT (OLDER LITTER, COMPRESSED BY RAIN OR SNOW.)

ENTER 1, 2, OR 3

>2

ENTER TOTAL LITTER LOAD (TONS/ACRE).

RANGE = 0 TO 100

>7.5

THE CALCULATED AVERAGE LITTER DEPTH (FEET) IS 0.275  
AT A LOAD OF 7.50 TONS/ACRE, FOR ACRES ACTUALLY COVERED WITH LITTER.

DO YOU WISH TO:

1. ACCEPT THIS VALUE
2. ENTER A NEW LITTER LOAD
3. START THIS SECTION ALL OVER AGAIN

ENTER 1, 2, OR 3

>1

*Entering litter data by load only*

WHAT PERCENT, BY WEIGHT, OF THE LITTER LOAD IS 1 HR  
TIMELAG FUEL?

>80

WHAT PERCENT, BY WEIGHT, OF THE LITTER LOAD IS 100 HR  
TIMELAG FUEL?

>5

WHAT PERCENT OF THE AREA IS COVERED BY LITTER?

>90

LITTER LOADS (T/A)

|        |      |
|--------|------|
| 1 HR   | 5.40 |
| 10 HR  | 1.01 |
| 100 HR | 0.34 |

LITTER DEPTH 0.25 FEET

LOADS AND DEPTH NOW REDUCED FOR AREA COVERAGE.

DO YOU WANT TO:

1. ACCEPT THESE VALUES
2. START THE LITTER SECTION ALL OVER?

ENTER 1 OR 2

>1

OTHER FUEL COMPONENTS TO CONSIDER ARE:

GRASS  
SHRUB  
SLASH

IF THESE COMPONENTS ARE NOT PART OF THE FUEL COMPLEX  
ENTER KEYWORD 'SURF'.

CONTROL SECTION, KEYWORD?

>GRASS

GRASS SECTION.

INCLUSION OF HERBACEOUS FUEL PROVIDES THE OPTION OF  
DEVELOPING EITHER A DYNAMIC OR A STATIC FUEL MODEL

DYNAMIC MODELS ADJUST FOR SEASONAL DRYING THROUGH TRANSFER  
OF LIVE HERBACEOUS LOAD BETWEEN LIVE HERBACEOUS AND 1 HOUR  
TIMELAG CLASSES, AS A FUNCTION OF HERBACEOUS FUEL MOISTURE

STATIC MODELS HAVE CONSTANT LOADS IN ALL LIVE AND DEAD  
FUEL CLASSES.

ENTER 1 OR 2

1 = DYNAMIC  
2 = STATIC

>2

*Entering litter data by load only*

*Entering grass data*

YOU CAN ENTER:  
PREVIOUSLY INVENTORIED FUEL DATA  
1. GRASS LOAD AND DEPTH  
NEW FUEL DATA  
2. GRASS LOAD ONLY (DEPTH WILL BE ESTIMATED FOR YOU)  
3. GRASS DEPTH ONLY (LOAD WILL BE ESTIMATED FOR YOU)

ENTER 1, 2, OR 3  
>1

TOTAL GRASS LOAD IN TONS/ACRE?  
RANGE = 0 TO 30  
>3

GRASS DEPTH IN FEET?  
RANGE = 0 TO 10  
>2

WHAT PERCENT OF THE TOTAL GRASS LOAD, BY VOLUME  
IS GREEN?  
PERCENT GREEN RANGE = 0 TO 100  
>75

\*\*CAUTION\*\* MORE THAN 50 PERCENT GREEN MATERIAL IS  
RARE EXCEPT WHERE NO LITTER OR STANDING DEAD STEMS REMAIN  
FROM THE PREVIOUS GROWTH. ENTER PERCENT GREEN AGAIN TO  
VERIFY YOUR ESTIMATE.  
>50

WHAT PERCENT OF THE AREA IS COVERED BY GRASS?  
RANGE = 0 TO 100  
>50

GRASS LOADS (T/A)  
1 HR 0.75  
LIVE GRASS 0.75

GRASS DEPTH 1.00 FEET  
LOADS AND DEPTH NOW REDUCED FOR AREA COVERAGE.

DO YOU WANT TO:  
1. ACCEPT THESE VALUES  
2. START THE GRASS SECTION ALL OVER?

ENTER 1 OR 2  
>2

*Entering grass data by load and depth*

GRASS SECTION.

INCLUSION OF HERBACEOUS FUEL PROVIDES THE OPTION OF DEVELOPING EITHER A DYNAMIC OR A STATIC FUEL MODEL

DYNAMIC MODELS ADJUST FOR SEASONAL DRYING THROUGH TRANSFER OF LIVE HERBACEOUS LOAD BETWEEN LIVE HERBACEOUS AND 1 HOUR TIMELAG CLASSES, AS A FUNCTION OF HERBACEOUS FUEL MOISTURE.

STATIC MODELS HAVE CONSTANT LOADS IN ALL LIVE AND DEAD FUEL CLASSES.

ENTER 1 OR 2  
1 = DYNAMIC  
2 = STATIC  
>1

YOU CAN ENTER:

PREVIOUSLY INVENTORIED FUEL DATA

1. GRASS LOAD AND DEPTH

NEW FUEL DATA

2. GRASS LOAD ONLY (DEPTH WILL BE ESTIMATED FOR YOU)

3. GRASS DEPTH ONLY (LOAD WILL BE ESTIMATED FOR YOU)

ENTER 1, 2, OR 3  
>3

WHICH GRASS TYPE IS MOST LIKE YOURS?

1) FINE --- EX: CHEATGRASS

2) MEDIUM --- EX: ROUGH FESCUE

3) COARSE --- EX: FOUNTAINGRASS

4) VERY COARSE --- EX: SAWGRASS

ENTER 1, 2, 3, OR 4  
>3

WHICH DENSITY CLASS OF THIS TYPE IS MOST LIKE YOURS?

ENTER 1, 2, 3, 4, 5, OR 6  
>5

GRASS DEPTH IN FEET?

RANGE = 0 TO 10

>2

THE CALCULATED TOTAL LOAD FOR ACRES ACTUALLY COVERED WITH GRASS IS 3.27 TONS/ACRE.  
AT A DEPTH OF 2.00 FEET.

DO YOU WANT TO:

1. ACCEPT THIS VALUE

2. ENTER A NEW DEPTH

3. ENTER A NEW DENSITY

4. ENTER A NEW GRASS TYPE

5. START THE GRASS SECTION ALL OVER?

ENTER 1, 2, 3, 4 OR 5  
>1

*Entering grass data by depth only*

WHAT IS THE MAXIMUM PERCENT OF THE TOTAL GRASS FUEL LOAD, BY VOLUME, THAT CAN BE ALIVE (GREEN), REGARDLESS OF HOW GREEN IT IS NOW?

PERCENT GREEN RANGE = 0 TO 100

>50

WHAT PERCENT OF THE AREA IS COVERED BY GRASS?

RANGE = 0 TO 100

>90

GRASS LOADS (T/A)

1 HR 1.47

LIVE GRASS 1.47

GRASS DEPTH 1.80 FEET

LOADS AND DEPTH NOW REDUCED FOR AREA COVERAGE.

DO YOU WANT TO:

1. ACCEPT THESE VALUES
2. START THE GRASS SECTION ALL OVER?

ENTER 1 OR 2

>1

OTHER FUEL COMPONENTS TO CONSIDER ARE:

SHRUB

SLASH

IF THESE COMPONENTS ARE NOT PART OF THE FUEL COMPLEX  
ENTER KEYWORD 'SURF'

CONTROL SECTION. KEYWORD?

>SHRUB

SHRUB SECTION. YOU CAN ENTER:  
PREVIOUSLY INVENTORIED FUEL DATA

1. SHRUB LOAD BY CATEGORY (1, 10, 100 DEAD FUELS, LIVE  
NEW FUEL DATA

FOLIAGE AND TWIGS LESS THAN 1/4 INCH) AND DEPTH.

2. SHRUB LOAD ONLY (DEPTH WILL BE ESTIMATED FOR YOU)

3. SHRUB DEPTH ONLY (LOAD WILL BE ESTIMATED FOR YOU)

ENTER 1, 2, OR 3

>3

*Entering grass data by depth only*

---

*Entering shrub data  
by depth only*

WHICH SHRUB TYPE IS MOST LIKE YOURS?

ENTER 1, 2, 3, 4, OR 5

>2

WHICH DENSITY OF THIS TYPE IS MOST LIKE YOURS?

ENTER 1, 2, 3, 4, 5, OR 6

>4

SHRUB DEPTH IN FEET?

>4

THE CALCULATED AVERAGE SHRUB LOAD IS 6.00 TONS/ACRE.

AT A DEPTH OF 4.00 FEET, FOR ACRES ACTUALLY COVERED WITH SHRUBS.

DO YOU WANT TO:

1. ACCEPT THIS VALUE
2. ENTER A NEW DEPTH
3. ENTER A NEW DENSITY
4. ENTER A NEW SHRUB TYPE
5. START THE SHRUB SECTION ALL OVER?

ENTER 1, 2, 3, 4 OR 5

>1

WHAT PERCENT, BY WEIGHT, OF THE SHRUB LOAD IS:

1 HR?

RANGE = 0 TO 100

>30

10 HR?

RANGE = 0 TO 70.0

>40

100 HR?

RANGE = 0 TO 30.0

>10

LIVING LEAVES AND TWIGS?

RANGE = 0 TO 20.0

>20

WHAT PERCENT OF THE AREA IS COVERED BY SHRUBS?

RANGE = 0 TO 100

>50

DO THE SHRUBS CONTAIN OILS OR WAXES THAT ENABLE THEM TO BURN WHEN THEY ARE QUITE GREEN? (ENTER Y OR N).

>N

SHRUB LOADS (T/A)

1 HR 0.90

10 HR 1.20

100 HR 0.30

LEAVES & TWIGS 0.60

SHRUB DEPTH 2.00 FEET

LOADS AND DEPTH NOW REDUCED FOR AREA COVERAGE.

*Entering shrub data by depth only*

DO YOU WANT TO:

1. ACCEPT THESE VALUES
2. START THE SHRUB SECTION ALL OVER?

ENTER 1 OR 2

>1

OTHER FUEL COMPONENTS TO CONSIDER ARE:  
SLASH

IF THESE COMPONENTS ARE NOT PART OF THE FUEL COMPLEX  
ENTER KEYWORD 'SURF'

CONTROL SECTION. KEYWORD?

>SLASH

SLASH SECTION. YOU CAN:

1. INPUT YOUR INVENTORIED DATA ON LOAD BY SIZE CLASS, AND DEPTH
2. USE RELATIONSHIPS DEVELOPED FROM RESEARCH DATA FOR INTERMOUNTAIN CONIFERS. \*\* CAUTION \*\* THESE RELATIONSHIPS ARE PROBABLY NOT VALID WEST OF THE CASCADES OR EAST OF THE ROCKY MOUNTAINS.

ENTER 1 OR 2

>1

ENTER LOAD (TONS/ACRE) FOR:

1 HR? --- THIS MEANS LOAD OF 0-1/4 INCH TWIGS PLUS AIR  
DRY NEEDLES STILL ATTACHED TO THE BRANCHES.  
RANGE = 0 TO 30

>3

10 HR?

>5

100 HR?

>10

SLASH DEPTH IN FEET?

RANGE = 0 TO 10

>2

WHAT PERCENT OF THE AREA IS COVERED BY SLASH?

RANGE = 0 TO 100

>40

SLASH LOADS (T/A)

|        |      |
|--------|------|
| 1 HR   | 1.20 |
| 10 HR  | 2.00 |
| 100 HR | 4.00 |

SLASH DEPTH 0.80 FEET

*If your inventory procedure was to sample only where the slash existed and not the bare areas, then enter the percent of the area covered by slash. That was assumed to be the case for this example.*

*If your inventory procedure was to sample the entire area, both where the slash existed and where it did not, enter 100 as the percent of area covered by slash. Then your inventoried slash load will not be reduced.*

*Direct entry of previously inventoried slash data*

DO YOU WANT TO:

1. ACCEPT THESE VALUES
2. START THE SLASH SECTION ALL OVER?

ENTER 1 OR 2

>2

SLASH SECTION. YOU CAN:

1. INPUT YOUR INVENTORIED DATA ON LOAD BY SIZE CLASS, AND DEPTH
2. USE RELATIONSHIPS DEVELOPED FROM RESEARCH DATA FOR INTERMOUNTAIN CONIFERS. \*\* CAUTION \*\* THESE RELATIONSHIPS ARE PROBABLY NOT VALID WEST OF THE CASCADES OR EAST OF THE ROCKY MOUNTAINS.

ENTER 1 OR 2

>2

WHICH BEST DESCRIBES THE ORIGIN OF THE SLASH?

1. COMMERCIAL TIMBER CUT, HIGHLEAD SKIDDING
2. COMMERCIAL TIMBER CUT, GROUNDLEAD SKIDDING
3. PRECOMMERCIAL THINNING.

ENTER 1, 2, OR 3

>3

ENTER SLASH AGE IN YEARS.

RANGE = 0 TO 5

>2

TO PROCEED FURTHER YOU MUST HAVE FUEL INFORMATION IN ONE OF FOUR FORMATS, OR ELSE END CONSIDERATION OF SLASH.

1. TOTAL SLASH LOAD IN TONS PER ACRE
2. LOAD OF 10 HR FUELS ONLY, IN TONS PER ACRE
3. 10 HR LOAD IN TONS PER ACRE, BY SPECIES
4. NUMBER OF 10 HR INTERCEPTS PER FOOT, BY SPECIES
5. END SLASH INPUTS, PROPER DATA UNAVAILABLE

ENTER 1, 2, 3, 4, OR 5

>1

ENTER THE TOTAL SLASH LOAD IN TONS PER ACRE.

RANGE = .01 TO 100

>18

FOR EACH SPECIES YOU FEEL CONTRIBUTES SIGNIFICANTLY TO THE SLASH LOAD, YOU WILL BE ASKED ITS PRE-HARVEST AVERAGE CROWN CLASS (DOMINANT OR INTERMEDIATE), AVERAGE DBH, AND PERCENT OF THE SLASH LOAD CONTRIBUTED BY THIS SPECIES.

*Entry of total slash load*



FUEL MODELING ASSISTANCE IS AVAILABLE FOR THESE SPECIES:

| SPECIES CODE | SPECIES NAME       |
|--------------|--------------------|
| GF           | GRAND FIR          |
| WL           | WESTERN LARCH      |
| ES           | ENGELMANN SPRUCE   |
| AF           | SUBALPINE FIR      |
| LP           | LODGEPOLE PINE     |
| WP           | WESTERN WHITE PINE |
| WB           | WHITEBARK PINE     |
| WC           | WESTERN RED CEDAR  |
| PP           | PONDEROSA PINE     |
| DF           | DOUGLAS FIR        |
| WH           | WESTERN HEMLOCK    |

ENTER SPECIES CODE.

>WL

ENTER CROWN CLASS AS:

1. DOMINANT
2. INTERMEDIATE

ENTER 1 OR 2

>1

ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

RANGE = 1 TO 100

>8

ENTER PERCENT OF SLASH CONTRIBUTED BY THIS SPECIES

RANGE = 0 TO 100

>60

IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)

>N

ENTER SPECIES CODE.

>DF

ENTER CROWN CLASS AS:

1. DOMINANT
2. INTERMEDIATE

ENTER 1 OR 2

>2

ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

RANGE = 1 TO 100

>6

*Entry of total slash load*

ENTER PERCENT OF SLASH CONTRIBUTED BY THIS SPECIES  
RANGE = 0 TO 100

>40

IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)  
>Y

YOU CAN EITHER:

1. USE COMPUTER ADJUSTMENTS FOR FOLIAGE AND TWIG RETENTION

2. USE YOUR ESTIMATES OF FOLIAGE AND TWIG RETENTION

ENTER 1 OR 2

>1

WHAT PERCENT OF THE AREA IS COVERED BY SLASH?  
RANGE = 0 TO 100

>30

SLASH LOADS (T/A)

1 HR 1.74

10 HR 1.76

100 HR 0.51

SLASH DEPTH 0.49 FEET

DO YOU WANT TO:

1. ACCEPT THESE VALUES

2. START THE SLASH SECTION ALL OVER?

ENTER 1 OR 2

>2

SLASH SECTION. YOU CAN:

1. INPUT YOUR INVENTORIED DATA ON LOAD BY SIZE CLASS, AND DEPTH

2. USE RELATIONSHIPS DEVELOPED FROM RESEARCH DATA FOR  
INTERMOUNTAIN CONIFERS. \*\* CAUTION \*\* THESE RELATIONSHIPS  
ARE PROBABLY NOT VALID WEST OF THE CASCADES OR EAST OF  
THE ROCKY MOUNTAINS.

ENTER 1 OR 2

>2

WHICH BEST DESCRIBES THE ORIGIN OF THE SLASH?

1. COMMERCIAL TIMBER CUT, HIGHLEAD SKIDDING

2. COMMERCIAL TIMBER CUT, GROUNDLEAD SKIDDING

3. PRECOMMERCIAL THINNING.

ENTER 1, 2, OR 3

>3

ENTER SLASH AGE IN YEARS.

RANGE = 0 TO 5

>2

*Entry of total slash load*

\_\_\_\_\_

*Entry of total 10 hour load*

TO PROCEED FURTHER YOU MUST HAVE FUEL INFORMATION IN ONE OF FOUR FORMATS, OR ELSE END CONSIDERATION OF SLASH.

1. TOTAL SLASH LOAD IN TONS PER ACRE
2. LOAD OF 10 HR FUELS ONLY, IN TONS PER ACRE
3. 10 HR LOAD IN TONS PER ACRE, BY SPECIES
4. NUMBER OF 10 HR INTERCEPTS PER FOOT, BY SPECIES
5. END SLASH INPUTS, PROPER DATA UNAVAILABLE

ENTER 1, 2, 3, 4, OR 5

>2

ENTER TOTAL 10 HR LOAD IN TONS PER ACRE.

RANGE = .01 TO 30

>4.5

FOR EACH SPECIES YOU FEEL CONTRIBUTES SIGNIFICANTLY TO THE SLASH LOAD, YOU WILL BE ASKED ITS PRE-HARVEST AVERAGE CROWN CLASS (DOMINANT OR INTERMEDIATE), AVERAGE DBH, AND PERCENT OF THE SLASH LOAD CONTRIBUTED BY THIS SPECIES.

FUEL MODELING ASSISTANCE IS AVAILABLE FOR THESE SPECIES:

| SPECIES CODE | SPECIES NAME       |
|--------------|--------------------|
| GF           | GRAND FIR          |
| WL           | WESTERN LARCH      |
| ES           | ENGELMANN SPRUCE   |
| AF           | SUBALPINE FIR      |
| LP           | LOGEPOLE PINE      |
| WP           | WESTERN WHITE PINE |
| WB           | WHITEBARK PINE     |
| WC           | WESTERN RED CEDAR  |
| PP           | PONDEROSA PINE     |
| DF           | DOUGLAS FIR        |
| WH           | WESTERN HEMLOCK    |

ENTER SPECIES CODE.

>LP

ENTER CROWN CLASS AS:

1. DOMINANT
2. INTERMEDIATE

ENTER 1 OR 2

>1

ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

RANGE = 1 TO 100

>6

ENTER PERCENT OF SLASH CONTRIBUTED BY THIS SPECIES

RANGE = 0 TO 100

>100

*Entry of total 10 hour load*

IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)  
>Y

YOU CAN EITHER:

1. USE COMPUTER ADJUSTMENTS FOR FOLIAGE AND TWIG RETENTION
2. USE YOUR ESTIMATES OF FOLIAGE AND TWIG RETENTION

ENTER 1 OR 2

>2

ENTER PERCENT FOLIAGE STILL ON LODGEPOLE PINE  
RANGE = 0 TO 100

>50

ENTER AVERAGE PERCENT TWIG (0 TO 1/4 INCH) RETENTION FOR ALL SPECIES  
RANGE = 0 TO 100

>80

WHAT PERCENT OF THE AREA IS COVERED BY SLASH?  
RANGE = 0 TO 100

>50

SLASH LOADS (T/A)

|        |      |
|--------|------|
| 1 HR   | 3.27 |
| 10 HR  | 2.25 |
| 100 HR | 0.29 |

SLASH DEPTH 0.79 FEET

DO YOU WANT TO:

1. ACCEPT THESE VALUES
2. START THE SLASH SECTION ALL OVER?

ENTER 1 OR 2

>2

SLASH SECTION. YOU CAN:

1. INPUT YOUR INVENTORIED DATA ON LOAD BY SIZE CLASS, AND DEPTH
2. USE RELATIONSHIPS DEVELOPED FROM RESEARCH DATA FOR INTERMOUNTAIN CONIFERS. \*\* CAUTION \*\* THESE RELATIONSHIPS ARE PROBABLY NOT VALID WEST OF THE CASCADES OR EAST OF THE ROCKY MOUNTAINS.

ENTER 1 OR 2

>2

WHICH BEST DESCRIBES THE ORIGIN OF THE SLASH?

1. COMMERCIAL TIMBER CUT, HIGHLEAD SKIDDING
2. COMMERCIAL TIMBER CUT, GROUNDLEAD SKIDDING
3. PRECOMMERCIAL THINNING.

ENTER 1, 2, OR 3

>2

*Entry of total 10 hour load*

*Entry of 10 hour load by species*

ENTER SLASH AGE IN YEARS.

RANGE = 0 TO 5

>3

TO PROCEED FURTHER YOU MUST HAVE FUEL INFORMATION IN ONE OF FOUR FORMATS, OR ELSE END CONSIDERATION OF SLASH.

1. TOTAL SLASH LOAD IN TONS PER ACRE
2. LOAD OF 10 HR FUELS ONLY, IN TONS PER ACRE
3. 10 HR LOAD IN TONS PER ACRE, BY SPECIES
4. NUMBER OF 10 HR INTERCEPTS PER FOOT, BY SPECIES
5. END SLASH INPUTS, PROPER DATA UNAVAILABLE

ENTER 1, 2, 3, 4, OR 5

>3

FOR EACH SPECIES YOU FEEL CONTRIBUTES SIGNIFICANTLY TO THE SLASH LOAD, YOU WILL BE ASKED ITS PRE-HARVEST AVERAGE CROWN CLASS (DOMINANT OR INTERMEDIATE), AVERAGE DBH, AND 10 HR LOAD IN TONS PER ACRE.

FUEL MODELING ASSISTANCE IS AVAILABLE FOR THESE SPECIES:

| SPECIES CODE | SPECIES NAME       |
|--------------|--------------------|
| GF           | GRAND FIR          |
| WL           | WESTERN LARCH      |
| ES           | ENGELMANN SPRUCE   |
| AF           | SUBALPINE FIR      |
| LP           | LOGSPOLE PINE      |
| WP           | WESTERN WHITE PINE |
| WB           | WHITEBARK PINE     |
| WC           | WESTERN RED CEDAR  |
| PP           | PONDEROSA PINE     |
| DF           | DOUGLAS FIR        |
| WH           | WESTERN HEMLOCK    |

ENTER SPECIES CODE.

>ES

ENTER CROWN CLASS AS:

1. DOMINANT
2. INTERMEDIATE

ENTER 1 OR 2

>1

ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

RANGE = 1 TO 100

>24

ENTER 10 HR LOAD (TONS PER ACRE) FOR THIS SPECIES.

RANGE = .01 TO 30

>1.5

*Entry of 10 hour load by species*

IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)  
>N

ENTER SPECIES CODE.  
>WL

ENTER CROWN CLASS AS:  
1. DOMINANT  
2. INTERMEDIATE

ENTER 1 OR 2  
>2

INTERMEDIATE CROWN CLASS DATA NOT AVAILABLE FOR THIS SPECIES. DATA FOR DOMINANT CROWN CLASS WILL BE USED.

ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

RANGE = 1 TO 100  
>20

ENTER 10 HR LOAD (TONS PER ACRE) FOR THIS SPECIES.  
RANGE = .01 TO 30  
>.85

IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)  
>Y

YOU CAN EITHER:  
1. USE COMPUTER ADJUSTMENTS FOR FOLIAGE AND TWIG RETENTION  
2. USE YOUR ESTIMATES OF FOLIAGE AND TWIG RETENTION  
ENTER 1 OR 2

>1

WHAT PERCENT OF THE AREA IS COVERED BY SLASH?  
RANGE = 0 TO 100  
>60

SLASH LOADS (T/A)  
1 HR 1.03  
10 HR 1.41  
100 HR 1.69

SLASH DEPTH 0.39 FEET

DO YOU WANT TO:  
1. ACCEPT THESE VALUES  
2. START THE SLASH SECTION ALL OVER?

ENTER 1 OR 2  
>2

*Entry of 10 hour load by species*

SLASH SECTION. YOU CAN:

1. INPUT YOUR INVENTORIED DATA ON LOAD BY SIZE CLASS, AND DEPTH
2. USE RELATIONSHIPS DEVELOPED FROM RESEARCH DATA FOR INTERMOUNTAIN CONIFERS. \*\* CAUTION \*\* THESE RELATIONSHIPS ARE PROBABLY NOT VALID WEST OF THE CASCADES OR EAST OF THE ROCKY MOUNTAINS.

ENTER 1 OR 2  
>2

WHICH BEST DESCRIBES THE ORIGIN OF THE SLASH?

1. COMMERCIAL TIMBER CUT, HIGHLEAD SKIDDING
2. COMMERCIAL TIMBER CUT, GROUNDLEAD SKIDDING
3. PRECOMMERCIAL THINNING.

ENTER 1, 2, OR 3  
>2

ENTER SLASH AGE IN YEARS.  
RANGE = 0 TO 5

>3

TO PROCEED FURTHER YOU MUST HAVE FUEL INFORMATION IN ONE OF FOUR FORMATS, OR ELSE END CONSIDERATION OF SLASH.

1. TOTAL SLASH LOAD IN TONS PER ACRE
2. LOAD OF 10 HR FUELS ONLY, IN TONS PER ACRE
3. 10 HR LOAD IN TONS PER ACRE, BY SPECIES
4. NUMBER OF 10 HR INTERCEPTS PER FOOT, BY SPECIES
5. END SLASH INPUTS, PROPER DATA UNAVAILABLE

ENTER 1, 2, 3, 4, OR 5  
>4

FOR EACH SPECIES YOU FEEL CONTRIBUTES SIGNIFICANTLY TO THE SLASH LOAD, YOU WILL BE ASKED ITS PRE-HARVEST AVERAGE CROWN CLASS (DOMINANT OR INTERMEDIATE), AVERAGE DBH, AND NUMBER OF 10 HR INTERCEPTS PER FOOT.

FUEL MODELING ASSISTANCE IS AVAILABLE FOR THESE SPECIES:

| SPECIES CODE | SPECIES NAME       |
|--------------|--------------------|
| GF           | GRAND FIR          |
| WL           | WESTERN LARCH      |
| ES           | ENGELMANN SPRUCE   |
| AF           | SUBALPINE FIR      |
| LP           | LODGEPOLE PINE     |
| WP           | WESTERN WHITE PINE |
| WB           | WHITEBARK PINE     |
| WC           | WESTERN RED CEDAR  |
| PP           | PONDEROSA PINE     |
| DF           | DOUGLAS FIR        |
| WH           | WESTERN HEMLOCK    |

ENTER SPECIES CODE.  
>WL

*Entry of 10 hour intercepts per foot, by species*

ENTER CROWN CLASS AS:

1. DOMINANT
2. INTERMEDIATE

ENTER 1 OR 2

>1

ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

RANGE = 1 TO 100

>28

ENTER AVERAGE NUMBER OF 10 HR INTERCEPTS PER FOOT FOR THIS SPECIES.

RANGE = .001 TO 10

>4.3

IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)

>N

ENTER SPECIES CODE.

>DF

ENTER CROWN CLASS AS:

1. DOMINANT
2. INTERMEDIATE

ENTER 1 OR 2

>2

ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

RANGE = 1 TO 100

>20

ENTER AVERAGE NUMBER OF 10 HR INTERCEPTS PER FOOT FOR THIS SPECIES.

RANGE = .001 TO 10

>1.2

IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)

>Y

YOU CAN EITHER:

1. USE COMPUTER ADJUSTMENTS FOR FOLIAGE AND TWIG RETENTION
2. USE YOUR ESTIMATES OF FOLIAGE AND TWIG RETENTION

ENTER 1 OR 2

>1

WHAT PERCENT OF THE AREA IS COVERED BY SLASH?

RANGE = 0 TO 100

>50

SLASH LOADS (T/A)

|        |      |
|--------|------|
| 1 HR   | 2.53 |
| 10 HR  | 5.98 |
| 100 HR | 6.28 |

SLASH DEPTH 0.64 FEET

*Entry of 10 hour intercepts per foot, by species*



DO YOU WANT TO:

1. ACCEPT THESE VALUES
2. START THE SLASH SECTION ALL OVER?

ENTER 1 OR 2

>1

CONTROL SECTION. KEYWORD?

>SURF

SURFACE TO VOLUME RATIO SECTION.

TYPICAL SURFACE TO VOLUME RANGES FOR VARIOUS FUEL COMPONENTS ARE:

1 HR FUELS (REDUCE VALUES ABOUT 200 FOR LIVE FOLIAGE)

COARSE 1500-2000

MEDIUM 2000-2500

FINE 2500-3000

SURFACE TO VOLUME RATIOS USED IN THE 13 NFFL MODELS ARE:

| MODEL | 1 HR S/V | LIVE S/V | MODEL | 1 HR S/V | LIVE S/V |
|-------|----------|----------|-------|----------|----------|
| 1     | 3500     | -----    | 8     | 2000     | -----    |
| 2     | 3000     | 1500     | 9     | 2500     | -----    |
| 3     | 1500     | -----    | 10    | 2000     | 1500     |
| 4     | 2000     | 1500     | 11    | 1500     | -----    |
| 5     | 2000     | 1500     | 12    | 1500     | -----    |
| 6     | 1750     | -----    | 13    | 1500     | -----    |
| 7     | 1750     | 1550     |       |          |          |

REFER TO THE USERS MANUAL IF MORE DETAILED S/V DATA IS NEEDED.

USING THE ABOVE GUIDES, ENTER A SURFACE TO VOLUME RATIO FOR:

DEAD GRASS?

RANGE = 192 TO 3500

>2500

1 HR LITTER FUELS?

>1900

1 HR SLASH FUELS?

>1500

1 HR SHRUB FUELS?

>1750

S/V RATIOS FOR LIVE FUELS SHOULD BE ABOUT 200 LESS THAN COMPARABLE DEAD FUELS.

LIVE HERBACEOUS S/V RATIO?

>1500

LIVE WOODY S/V RATIO?

>800

YOUR S/V RATIOS ARE: 1 HR 1923. LIVE HERB 1500. LIVE WOODY 800

*Entry of surface area to volume ratios*

DO YOU WANT TO:

1. ACCEPT THESE VALUES
2. REENTER THESE VALUES
3. START THIS SECTION ALL OVER?

ENTER 1, 2, OR 3

>1

ENTER KEYWORD 'HEAT'

CONTROL SECTION, KEYWORD?

>HEAT

HEAT CONTENT SECTION

TYPICAL HEAT CONTENT RANGES FOR VARIOUS FUEL TYPES ARE:

LOW VOLATILE FUELS 7400-8400 (SOLID WOOD, MOST GRASSES  
AND HARDWOOD LEAVES)

HIGHLY VOLATILE FUELS 8400-9400 (CONIFER FOLIAGE, SAGEBRUSH,  
CHAPARRAL, GALBERRY)

8000 BTU/LB IS USED FOR ALL LIVE AND DEAD FUELS IN THE 13 NFFL MODELS

USE THE LOW END OF THE RANGE FOR FUEL THAT DOES NOT PRODUCE  
VOLATILES THAT CAN BE SMELLED ON HOT DAYS (MOST DEAD FUELS)  
THE HIGH END FOR FUELS THAT DO, OR THAT FEEL OILY OR WAXY.  
(EX: SOME LIVE FUELS SUCH AS GALLBERRY LEAVES OR PINE NEEDLES)

ENTER HEAT CONTENT FOR DEAD FUELS

RANGE = 7000 TO 10000

>8500

ENTER HEAT CONTENT FOR LIVE HERBACEOUS FUELS

RANGE = 7000 TO 10000

>8000

ENTER HEAT CONTENT FOR LEAVES AND TWIGS OF LIVE SHRUBS

RANGE = 7000 TO 10000

>8000

YOUR WEIGHTED AVERAGE HEAT CONTENT (BTU/LB) IS 8440.

DO YOU WANT TO:

1. ACCEPT THIS VALUE
2. START THIS SECTION OVER?

ENTER 1 OR 2

>1

*Entry of heat contents*

CONTROL SECTION. KEYWORD?  
 >COMP

LOADS, S/V RATIOS, AND DEPTHS FOR INDIVIDUAL FUEL COMPONENTS

| FUEL COMPONENT | LOADS |       |       | S/V RATIOS |       | DEPTHS |       |
|----------------|-------|-------|-------|------------|-------|--------|-------|
|                | 1 HR  | 10 HR | 100 H | HERB       | WOODY | 1 HR   | 10 HR |
| LITTER         | 5.40  | 1.01  | 0.34  | 0.00       | 0.00  | 1900.  | 0.    |
| GRASS          | 1.47  | 0.00  | 0.00  | 1.47       | 0.00  | 2500.  | 1500. |
| SHRUBS         | 0.90  | 1.20  | 0.30  | 0.00       | 0.60  | 1750.  | 0.    |
| SLASH          | 2.53  | 5.98  | 6.28  | 0.00       | 0.00  | 1500.  | 0.    |

\*\*\*\*\* FUEL LOAD SUMMARY \*\*\*\*\*

| FUEL COMPONENT | DEAD  | LIVE | TIMELAG CLASS | LOAD  |
|----------------|-------|------|---------------|-------|
| LITTER         | 6.75  | 0.00 | 1 HR          | 10.30 |
| GRASS          | 1.47  | 1.47 | 10 HR         | 8.19  |
| SHRUBS         | 2.40  | 0.60 | 100 HR        | 6.92  |
| SLASH          | 14.78 | 0.00 |               |       |
| TOTAL          | 25.40 | 2.07 | TOTAL         | 25.40 |

CONTROL SECTION. KEYWORD?  
 >MODEL

CURRENT VALUES OF FUEL MODEL PARAMETERS  
 DYNAMIC 60. FIRST SAMPLE MODEL BY: BURGAN

| LOAD (T/AC)     | S/V RATIOS        | OTHER                       |
|-----------------|-------------------|-----------------------------|
| 1 HR 10.30      | 1 HR 1923.        | DEPTH (FEET) 0.81           |
| 10 HR 8.19      | LIVE HERB 1500.   | HEAT CONTENT (BTU/LB) 8440. |
| 100 HR 6.92     | LIVE WOODY 800.   | EXT MOISTURE (%) 13.        |
| LIVE HERB 1.47  | S/V = (SQFT/CUFT) |                             |
| LIVE WOODY 0.60 |                   |                             |

*Data for all fuel components*

*Completed fuel model*

CONTROL SECTION. KEYWORD?  
>FILE

ENTER THE NAME OF YOUR FUEL MODEL FILE.  
>MYFILE

THIS WILL BE A NEW FILE. OK? (Y OR N).

>Y  
YOU NEED TO CREATE A HEADER FOR THIS FUEL FILE

ENTER FUEL MODEL FILE PASSWORD (4 CHAR MAX)

-----  
>NFFL

ENTER COMMENT TO DESCRIBE THIS FUEL FILE (72 CHAR MAX)

-----  
>SAMPLE FUEL MODEL FILE

DO YOU WANT TO:

- 1) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 2) CHANGE A FUEL FILE HEADER
- 3) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 4) REPLACE A FUEL MODEL IN THE FILE
- 5) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 6) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, OR 6

>3

ENTER PASSWORD

>NFFL

FUEL MODEL 60 WRITTEN TO FUEL MODEL FILE

DO YOU WANT TO:

- 1) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 2) CHANGE A FUEL FILE HEADER
- 3) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 4) REPLACE A FUEL MODEL IN THE FILE
- 5) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 6) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, OR 6

>6

*Adding the fuel model to the file*

CONTROL SECTION. KEYWORD?  
>RESTART

*Start again at the beginning  
of the program*

WELCOME TO THE  
BEHAVE SYSTEM  
FUEL SUBSYSTEM  
NEWMDL PROGRAM (VERSION 2.0 -- AUGUST 1983)

DEVELOPED BY THE  
FIRE BEHAVIOR RESEARCH WORK UNIT  
NORTHERN FOREST FIRE LABORATORY  
MISSOULA, MONTANA

ENTER YOUR LAST NAME.  
>BURGAN

THE OBJECTIVE OF THIS PROGRAM IS TO HELP YOU DEVELOP  
A FIRE BEHAVIOR FUEL MODEL THAT REASONABLY CHARACTERIZES A  
FUEL COMPLEX NOT PROPERLY REPRESENTED BY ONE OF THE THIRTEEN  
NFFL FUEL MODELS.

A TERSE MODE IS AVAILABLE FOR EXPERIENCED USERS  
THAT WANT LIMITED PROMPTING. DO YOU WANT TERSE? (Y OR N).  
>N

FULL PROMPT MODE SET.

PROGRAM CONTROL IS THROUGH THE USE OF KEYWORDS.  
DO YOU WANT A LIST OF KEYWORDS AND THEIR FUNCTIONS? (Y OR N)  
>N

A FUEL MODEL MAY BE CONSTRUCTED WITH EITHER  
1. 1 SIZE OF FINE FUEL IN ONE OR MORE COMPONENTS  
2. 2 SIZES OF FINE FUEL IN ONE OR MORE COMPONENTS

ENTER 1 OR 2  
>2

ENTER A NUMBER FOR YOUR PROPOSED FUEL MODEL.  
RANGE = 14 TO 99  
>61

ENTER FUEL MODEL NAME (32 CHARACTERS MAXIMUM).  
-----  
>SECOND SAMPLE MODEL

EXPANDED FINE FUEL INPUT SECTION.  
THIS SECTION PROVIDES FOR DIRECT ENTRY OF TWO 1 HR LOADS  
AND S/V RATIOS IN LITTER, SHRUB, SLASH, AND GRASS  
FUELS. 10 HR, 100 HR AND LIVE LOADS ARE ALSO ENTERED.  
THE MULTIPLE 1 HR LOADS ARE ADJUSTED TO PROVIDE  
A SINGLE REPRESENTATIVE LOAD AND S/V RATIO.

*Building a fuel model with two sizes of fine fuel*

DO YOU WANT TO ENTER ANY LITTER LOAD? (Y OR N)  
>N

DO YOU WANT TO ENTER ANY SLASH LOADS? (Y OR N)  
>Y

ENTER FIRST LOAD.  
RANGE = 0 TO 30 TONS PER ACRE.

>2  
ENTER FIRST S/V RATIO.  
RANGE = 192 TO 3500

>2000  
ENTER SECOND LOAD.  
RANGE = 0 TO 30 TONS PER ACRE.

>3  
ENTER SECOND S/V RATIO.  
RANGE = 192 TO 3500

>1000

ENTER 10 HR LOAD  
RANGE = 0 TO 30 TONS PER ACRE.

>5

ENTER 100 HR LOAD  
RANGE = 0 TO 30 TONS PER ACRE.

>9

SLASH DEPTH IN FEET?  
RANGE = 0 TO 10

>1

WHAT PERCENT OF THE AREA IS COVERED BY SLASH?  
RANGE = 0 TO 100

>80

YOUR SLASH ENTRIES, REDUCED FOR AREA COVERAGE ARE:

| 1 HRTL FUELS         | LOADS | S/V RATIOS |
|----------------------|-------|------------|
| FIRST ENTRY          | 1.60  | 2000.      |
| SECOND ENTRY         | 2.40  | 1000.      |
| 1 HR LOAD            | 4.00  |            |
| 10 HR LOAD           | 4.00  |            |
| 100 HR LOAD          | 7.20  |            |
| DEPTH (FEET)         | 0.80  |            |
| PERCENT AREA COVERED | 80.   |            |

DO YOU WANT TO:  
1 ACCEPT THESE ENTRIES  
2 REENTER THIS DATA  
ENTER 1 OR 2

>1

DO YOU WANT TO ENTER ANY SHRUB LOAD? (Y OR N)  
>N

DO YOU WANT TO ENTER ANY GRASS LOAD? (Y OR N)  
>N

*Building a fuel model with two sizes of fine fuel*

HEAT CONTENT SECTION

TYPICAL HEAT CONTENT RANGES FOR VARIOUS FUEL TYPES ARE:

LOW VOLATILE FUELS 7400-8400 (SOLID WOOD, MOST GRASSES AND HARDWOOD LEAVES)

HIGHLY VOLATILE FUELS 8400-9400 (CONIFER FOLIAGE, SAGEBRUSH, CHAPARRAL, GALBERRY)

8000 BTU/LB IS USED FOR ALL LIVE AND DEAD FUELS IN THE 13 NFFL MODELS

USE THE LOW END OF THE RANGE FOR FUEL THAT DOES NOT PRODUCE VOLATILES THAT CAN BE SMELLED ON HOT DAYS (MOST DEAD FUELS) THE HIGH END FOR FUELS THAT DO, OR THAT FEEL OILY OR WAXY. (EX: SOME LIVE FUELS SUCH AS GALLBERRY LEAVES OR PINE NEEDLES)

ENTER HEAT CONTENT FOR DEAD FUELS

RANGE = 7000 TO 10000

>8000

YOUR WEIGHTED AVERAGE HEAT CONTENT (BTU/LB) IS 8000.

DO YOU WANT TO:

- 1. ACCEPT THIS VALUE
- 2. START THIS SECTION OVER?

ENTER 1 OR 2

>1

CURRENT VALUES OF FUEL MODEL PARAMETERS

STATIC 61. SECOND SAMPLE MODEL

BY: BURGAN

| LOAD (T/AC) |      | S/V RATIOS        |       | OTHER                 |       |
|-------------|------|-------------------|-------|-----------------------|-------|
| 1 HR        | 1.62 | 1 HR              | 1728. | DEPTH (FEET)          | 0.67  |
| 10 HR       | 4.00 | LIVE HERB         | 0.    | HEAT CONTENT (BTU/LB) | 8000. |
| 100 HR      | 7.20 | LIVE WOODY        | 0.    | EXT MOISTURE (%)      | 28.   |
| LIVE HERB   | 0.00 | S/V = (SQFT/CUFT) |       |                       |       |
| LIVE WOODY  | 0.00 |                   |       |                       |       |

DO YOU WANT TO:

- 1. START ALL OVER
- 2. FILE YOUR FUEL MODEL
- 3. RENUMBER YOUR FUEL MODEL
- 4. QUIT THIS SESSION

ENTER 1, 2, 3 OR 4

>2

*with two eyes of fine fuel*

*Building a model*

DO YOU WISH TO USE THE CURRENT FUEL MODEL FILE (Y OR N)?  
THE CURRENT FILE IS MYFILE  
>Y

DO YOU WANT TO:

- 1) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 2) CHANGE A FUEL FILE HEADER
- 3) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 4) REPLACE A FUEL MODEL IN THE FILE
- 5) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 6) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, OR 6  
>3

ENTER PASSWORD  
>NFFL

FUEL MODEL 61 WRITTEN TO FUEL MODEL FILE

DO YOU WANT TO:

- 1) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 2) CHANGE A FUEL FILE HEADER
- 3) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 4) REPLACE A FUEL MODEL IN THE FILE
- 5) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 6) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, OR 6  
>6

DO YOU WANT TO:

1. START ALL OVER
2. FILE YOUR FUEL MODEL
3. RENUMBER YOUR FUEL MODEL
4. QUIT THIS SESSION

ENTER 1, 2, 3 OR 4  
>4

DO YOU REALLY WANT TO TERMINATE THIS RUN? (Y OR N).  
>Y

NEWMODL RUN TERMINATED.  
\*\*\*\*\*

*Deleting the model with two sizes of fine fuels*



## APPENDIX C: EXAMPLE TSTMDL SESSION

This TSTMDL session provides brief examples of most of the capabilities of this program. It illustrates how to manipulate fuels and environmental data, obtain graphic and tabular output, use both the normal and technical versions, manipulate the fuel model file, and obtain a fuel data listing for the TI-59.

Although the session can be duplicated as presented, it is structured for easy reference to specific activities such as changing values of fuel model parameters, doing technical version graphics, etc.

Lines that begin with a prompt character (>) were typed by the user. All other lines were printed by the computer.

|   | Page |
|---|------|
| I. Start of session . . . . .                       | 94   |
| II. Fuel section . . . . .                          | 96   |
| A. Entering fuel model data directly . . . . .      | 96   |
| B. Listing the fuel model . . . . .                 | 97   |
| C. Getting an NFFL model . . . . .                  | 97   |
| D. Changing the fuel model. . . . .                 | 98   |
| E. Getting a fuel model from your file . . . . .    | 99   |
| III. Environmental section . . . . .                | 100  |
| A. Getting standard data . . . . .                  | 100  |
| B. Entering new data. . . . .                       | 101  |
| C. Changing the environmental data . . . . .        | 102  |
| D. Listing the environmental data. . . . .          | 102  |
| IV. Obtaining tabular output . . . . .              | 103  |
| V. Obtaining graphic output . . . . .               | 105  |
| A. Normal version graphics. . . . .                 | 106  |
| 1. Standard scaling . . . . .                       | 106  |
| 2. Calculated scaling . . . . .                     | 108  |
| B. Technical version graphics . . . . .             | 110  |
| VI. Fuel model file manipulations . . . . .         | 114  |
| A. Getting a model from the file . . . . .          | 114  |
| B. Listing the models in the file . . . . .         | 115  |
| C. Changing the fuel file header . . . . .          | 116  |
| D. Adding a model to the file. . . . .              | 117  |
| E. Replacing a model in the file . . . . .          | 119  |
| F. Deleting a model from the file . . . . .         | 120  |
| VII. Obtaining TI-59 fuel model card data . . . . . | 121  |

\*TSTMDL

WELCOME TO THE  
BEHAVE SYSTEM  
FUEL SUBSYSTEM  
TSTMDL PROGRAM (VERSION 2.2 -- SEPTEMBER 1983)

DEVELOPED BY THE  
FIRE BEHAVIOR RESEARCH WORK UNIT  
NORTHERN FOREST FIRE LABORATORY  
MISSOULA, MONTANA

ENTER YOUR LAST NAME.  
>BURGAN

ARE YOU USING A TERMINAL WITH A SCREEN? (Y OR N).  
>Y

THE INTERACTIVE FUEL MODEL TESTING PROGRAM HAS BOTH A  
'NORMAL' AND A 'TECHNICAL' VERSION. THE NORMAL VERSION  
SHOULD BE USED FIRST, BUT IF YOU WANT MORE DETAIL THE  
TECHNICAL VERSION PERMITS GRAPHIC OR TABULAR DISPLAY OF  
ADDITIONAL FUEL AND FIRE MODEL PARAMETERS.

A 'TERSE' MODE IS AVAILABLE FOR EXPERIENCED USERS  
THAT WANT LIMITED PROMPTING. DO YOU WANT TERSE? (Y OR N).  
>N

FULL PROMPT MODE SET.

WILL YOU BE:

1. CREATING A NEW FUEL MODEL OR USING AN NFFL FUEL MODEL?
2. LOADING A PREVIOUSLY BUILT MODEL FROM A FUEL MODEL FILE?

ENTER 1 OR 2  
>1

ENTER THE NUMBER YOU WANT ASSIGNED TO THIS CUSTOM MODEL  
RANGE = 14 TO 99  
>59

ENTER FUEL MODEL NAME (32 CHARACTERS MAXIMUM).  
-----  
>DUMMY MODEL

IS YOUR PROPOSED FUEL MODEL DYNAMIC(1) OR STATIC(2)?

DYNAMIC MODELS ADJUST FOR SEASONAL DRYING THROUGH TRANSFER  
OF LIVE HERBACEOUS LOAD BETWEEN LIVE HERBACEOUS AND 1 HOUR  
TIMELAG CLASSES, AS A FUNCTION OF HERBACEOUS FUEL MOISTURE.

STATIC MODELS HAVE CONSTANT LOADS IN ALL LIVE AND DEAD  
FUEL CLASSES.  
ENTER 1 OR 2  
>1

*Start of session*

PROGRAM CONTROL IS THROUGH THE USE OF KEYWORDS.  
DO YOU WANT A LIST OF KEYWORDS AND THEIR FUNCTIONS? (Y OR N)

>Y

THE PRIMARY KEYWORDS AND THEIR FUNCTIONS ARE:

| KEYWORD  | FUNCTION   |
|----------|--|
| KEY      | PRINTS THIS KEYWORD LIST                         |
| TERSE    | SET TERSE MODE FOR MINIMAL PROMPTING             |
| WORDY    | SET WORDY MODE FOR FULL PROMPTING                |
| NORM     | IMPLEMENTS 'NORMAL' VERSION OF PROGRAM           |
| TECH     | IMPLEMENTS 'TECHNICAL' VERSION OF PROGRAM        |
| FUEL     | ENTER NEW OR CHANGE EXISTING FUEL MODEL DATA     |
| ENV      | ENTER NEW OR CHANGE EXISTING ENVIRONMENTAL DATA  |
| GRAPH    | IMPLEMENTS GRAPHIC OUTPUT OF COMPUTED RESULTS    |
| TABLE    | IMPLEMENTS TABULAR OUTPUT OF COMPUTED RESULTS    |
| RENUMBER | RENUMBER FUEL MODEL AND SELECT DYNAMIC OR STATIC |
| RESTART  | START PROGRAM AT BEGINNING AGAIN                 |
| FILE     | ACCESS FUEL MODEL FILE                           |
| TI59     | LIST DATA FOR TI59 FUEL MODEL CARD               |
| QUIT     | QUIT SESSION                                     |

WHENEVER 'KEYWORD?' IS PRINTED, TYPE THE KEYWORD FOR  
THE NEXT TASK YOU WANT TO ACCOMPLISH. YOUR FIRST RESPONSE  
SHOULD BE THE KEYWORD 'NORM' OR 'TECH' TO GET THE VERSION  
YOU WANT.

CONTROL SECTION. KEYWORD?

>NORM

NORMAL VERSION SET.

*Start of session*

ENTER KEYWORD 'FUEL' TO DEFINE FUEL MODEL PARAMETERS.  
CONTROL SECTION. KEYWORD?  
>FUEL

FUELS MANIPULATION SECTION.

TO USE ONE OF THE 13 NFFL FUEL MODELS TYPE 'NFFL',  
TO INPUT ALL FUELS DATA TYPE 'NEW',  
TO CHANGE EXISTING FUELS DATA TYPE 'CHANGE',  
TO LIST CURRENT FUELS DATA TYPE 'LIST',  
TO GET OUT OF THE FUELS SECTION TYPE 'QUIT'.

KEYWORD?  
>NEW

NEW FUEL MODEL DATA INPUT SECTION.  
FUELS DATA:

FUEL LOAD (TONS/ACRE):  
RANGE = 0. TO 30.

>2  
1 HR?

>2.5  
10 HR?

>1  
100 HR?

>.8  
LIVE HERB?

>1.4  
LIVE WOODY?

FUEL BED DEPTH IN FEET?  
RANGE = .01 TO 10.  
>1.7

HEAT CONTENT IN BTU/LB?  
RANGE = 7000. TO 12000.  
>8000

MOISTURE OF EXTINCTION?  
RANGE = 10. TO 60.  
>20

SURFACE AREA/VOLUME RATIOS (SQ FT/CU FT):  
RANGE = 192. TO 3500.

>2000  
1 HR S/V?

>1800  
LIVE HERB S/V?

>1600  
LIVE WOODY S/V?

*This is a good way to enter fuel model data if you know exactly what the values are.*

*For example you could re-enter the data for a model that was accidentally deleted from your fuel model file.*

*Entering fuel model data directly*

FUELS MANIPULATION SECTION.  
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'.

KEYWORD?  
>LIST

CURRENT VALUES OF FUEL MODEL PARAMETERS  
DYNAMIC 59. DUMMY MODEL BY: BURGAN

| LOAD (T/AC) |      | S/V RATIOS |       | OTHER        |       |
|-------------|------|------------|-------|--------------|-------|
| 1 HR        | 2.00 | 1 HR       | 2000. | DEPTH        | 1.70  |
| 10 HR       | 2.50 | LIVE HERB  | 1800. | HEAT CONTENT | 8000. |
| 100 HR      | 1.00 | LIVE WOODY | 1600. | EXT MOISTURE | 20.   |
| LIVE HERB   | 0.80 |            |       |              |       |
| LIVE WOODY  | 1.40 |            |       |              |       |

*the fuel model*

FUELS MANIPULATION SECTION.  
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'.

KEYWORD?  
>NFFL

THIS WILL PLACE AN NFFL MODEL IN COMPUTER MEMORY  
IF YOU NOW HAVE A MODEL IN MEMORY, IT WILL BE WIPED OUT  
THIS WILL NOT AFFECT YOUR FUEL MODEL FILE.

ENTER YES IF THIS IS OK  
ENTER NO IF YOU NEED TO STOP AND FILE YOUR CURRENT MODEL.  
>YES

ENTER NFFL MODEL NUMBER (RANGE = 1 TO 13)  
>3

NFFL MODEL 3 ENTERED.

ALL NFFL MODELS ARE STATIC. IF YOU WANT TO PRODUCE A DYNAMIC  
MODEL USEING THE PARAMETERS OF THIS MODEL, TYPE 'LIST', THEN  
'NEW' AND ENTER THE PARAMETERS OF THIS NFFL MODEL.

FUELS MANIPULATION SECTION.  
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'.

KEYWORD?  
>LIST

CURRENT VALUES OF FUEL MODEL PARAMETERS  
STATIC 59. DUMMY MODEL BY: BURGAN

| LOAD (T/AC) |      | S/V RATIOS |       | OTHER        |       |
|-------------|------|------------|-------|--------------|-------|
| 1 HR        | 3.01 | 1 HR       | 1500. | DEPTH        | 2.50  |
| 10 HR       | 0.00 | LIVE HERB  | 0.    | HEAT CONTENT | 8000. |
| 100 HR      | 0.00 | LIVE WOODY | 0.    | EXT MOISTURE | 25.   |
| LIVE HERB   | 0.00 |            |       |              |       |
| LIVE WOODY  | 0.00 |            |       |              |       |

*Selecting*

*Selecting an NFFL model*

FUELS MANIPULATION SECTION.  
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'.

KEYWORD?  
>CHANGE

FUEL MODIFICATION SECTION.  
ENTER KEYWORD 'QUIT' AFTER LAST CHANGE.

DO YOU WANT A LIST OF FUEL MODEL KEYWORDS? (Y OR N)  
>Y

THE FUEL MODEL KEYWORDS AND THEIR MEANINGS ARE:

| KEYWORD | MEANING                        |
|---------|--------------------------------|
| KEY     | PRINT THIS KEYWORD KEY         |
| SA1     | 1 HR S/V RATIO                 |
| SAH     | HERB S/V RATIO                 |
| SAW     | WOODY S/V RATIO                |
| DEPTH   | FUEL BED DEPTH                 |
| HEAT    | HEAT CONTENT                   |
| EXTM    | EXTINCTION MOISTURE            |
| L1      | 1 HR FUEL LOAD                 |
| L10     | 10 HR FUEL LOAD                |
| L100    | 100 HR FUEL LOAD               |
| LH      | HERB LOAD                      |
| LW      | WOODY LOAD                     |
| QUIT    | STOP MAKING FUEL MODEL CHANGES |

KEYWORD?  
>EXTM

MOISTURE OF EXTINCTION?  
RANGE = 10. TO 60.  
>20

KEYWORD?  
>SA1

1 HR S/V RATIO?  
RANGE = 192. TO 3500.  
>1700

KEYWORD?  
>QUIT

FUELS MANIPULATION SECTION.  
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'

KEYWORD?  
>LIST

CURRENT VALUES OF FUEL MODEL PARAMETERS  
DYNAMIC 59. DUMMY MODEL BY: BURGAN

| LOAD (T/AC) |      | S/V RATIOS |       | OTHER        |       |
|-------------|------|------------|-------|--------------|-------|
| 1 HR        | 3.01 | 1 HR       | 1700. | DEPTH        | 2.50  |
| 10 HR       | 0.00 | LIVE HERB  | 0.    | HEAT CONTENT | 8000. |
| 100 HR      | 0.00 | LIVE WOODY | 0.    | EXT MOISTURE | 20.   |
| LIVE HERB   | 0.00 |            |       |              |       |
| LIVE WOODY  | 0.00 |            |       |              |       |

*While any of the items in the above list can be changed, only extinction moisture and 1 hour s/v ratio were.*

*Changing the fuel model*

FUELS MANIPULATION SECTION.  
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'.

KEYWORD?  
>QUIT

*This is just a reminder printed by the 'wordy' mode.  
You will eventually have to do this, but you don't  
have to do it now.*

ENTER KEYWORD 'ENV' TO DEFINE ENVIRONMENTAL PARAMETERS.  
CONTROL SECTION. KEYWORD?  
>FILE

ENTER THE NAME OF YOUR FUEL MODEL FILE.  
>MYFILE

DO YOU WANT TO:

- 1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
- 2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 3) CHANGE A FUEL FILE HEADER
- 4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 5) REPLACE A FUEL MODEL IN THE FILE
- 6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7  
>1

ENTER FUEL MODEL NUMBER  
RANGE = 14 TO 99  
>60

*Again this reminder, but I wanted  
to list the fuel model first.*

MODEL 60 LOADED

ENTER KEYWORD 'ENV' TO DEFINE ENVIRONMENTAL PARAMETERS.  
CONTROL SECTION. KEYWORD?  
>FUEL

FUELS MANIPULATION SECTION.

TO USE ONE OF THE 13 NFFL FUEL MODELS TYPE 'NFFL'.  
TO INPUT ALL FUELS DATA TYPE 'NEW'.  
TO CHANGE EXISTING FUELS DATA TYPE 'CHANGE'.  
TO LIST CURRENT FUELS DATA TYPE 'LIST'.  
TO GET OUT OF THE FUELS SECTION TYPE 'QUIT'.

KEYWORD?  
>LIST

CURRENT VALUES OF FUEL MODEL PARAMETERS  
DYNAMIC 60, FIRST SAMPLE MODEL BY: BURGAN

| LOAD (T/AC) |       | S/V RATIOS |       | OTHER        |       |
|-------------|-------|------------|-------|--------------|-------|
| 1 HR        | 10.30 | 1 HR       | 1923. | DEPTH        | 0.81  |
| 10 HR       | 8.19  | LIVE HERB  | 1500. | HEAT CONTENT | 8440. |
| 100 HR      | 6.92  | LIVE WOODY | 800.  | EXT MOISTURE | 13.   |
| LIVE HERB   | 1.47  |            |       |              |       |
| LIVE WOODY  | 0.60  |            |       |              |       |

*Getting a fuel model from your file.*

FUELS MANIPULATION SECTION.  
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'.

KEYWORD?  
>QUIT

ENTER KEYWORD 'ENV' TO DEFINE ENVIRONMENTAL PARAMETERS.  
CONTROL SECTION. KEYWORD?  
>ENV

ENVIRONMENT MANIPULATION SECTION.  
TO INPUT ALL ENVIRONMENTAL DATA TYPE 'NEW'.  
TO CHANGE EXISTING ENVIRONMENTAL DATA TYPE 'CHANGE'.  
TO LIST CURRENT ENVIRONMENTAL DATA TYPE 'LIST'.  
TO ASSIGN STANDARD ENVIRONMENTAL DATA TYPE 'STD'.  
TO GET OUT OF THE ENVIRONMENTAL SECTION TYPE 'QUIT'.

KEYWORD?  
>STD

| FUEL CLASS | FUEL MOISTURES |      |      | OTHER               |
|------------|----------------|------|------|---------------------|
|            | LOW            | MED  | HIGH |                     |
| 1 HR       | 3.             | 6.   | 12.  | MIDFLAME WINDSPEED  |
| 10 HR      | 4.             | 7.   | 13.  | 4 MPH               |
| 100 HR     | 5.             | 8.   | 14.  |                     |
| LIVE HERB  | 70.            | 120. | 170. | SLOPE = 30. PERCENT |
| LIVE WOODY | 70.            | 120. | 170. |                     |

ENTER 'LOW', OR 'MEDIUM', OR 'HIGH' TO SELECT FUEL ← *The choices*

MOISTURE RANGE  
>LOW ← *The range selected*  
STANDARD ENVIRONMENTAL DATA SET.

ENVIRONMENT MANIPULATION SECTION.  
TYPE 'NEW', 'CHANGE', 'LIST', 'STD', OR 'QUIT'.

KEYWORD?  
>LIST

STANDARD ENVIRONMENTAL PARAMETERS  
DYNAMIC 60. FIRST SAMPLE MODEL BY: BURGAN

| FUEL CLASS | FUEL MOISTURES |      |      | OTHER              |
|------------|----------------|------|------|--------------------|
|            | LOW            | MED  | HIGH |                    |
| 1 HR       | 3.             | 6.   | 12.  | MIDFLAME WINDSPEED |
| 10 HR      | 4.             | 7.   | 13.  | 4 MPH              |
| 100 HR     | 5.             | 8.   | 14.  |                    |
| LIVE HERB  | 70.            | 120. | 170. | SLOPE = 30 PERCENT |
| LIVE WOODY | 70.            | 120. | 170. |                    |

LOW FUEL MOISTURE SET. ← *Proof that the low moisture range is now set.*

*Setting standard environmental data*



ENVIRONMENT MANIPULATION SECTION.  
TYPE 'NEW', 'CHANGE', 'LIST', 'STD', OR 'QUIT'.

KEYWORD?  
>NEW

NEW ENVIRONMENTAL DATA SECTION.

ENVIRONMENTAL DATA:

DEAD MOISTURES(%):  
RANGE = 2. TO 50.  
1 HR?

>4

10 HR?

>5

100 HR?

>6

LIVE MOISTURES (%)  
RANGE = 30. TO 350.  
LIVE HERB?

>100

LIVE WOODY?

>120

MIDFLAME WINDSPEED IN MPH?  
RANGE = 0. TO 18.

>5

SLOPE IN PERCENT?  
RANGE = 0. TO 200.

>30

ENVIRONMENT MANIPULATION SECTION.  
TYPE 'NEW', 'CHANGE', 'LIST', 'STD', OR 'QUIT'.

KEYWORD?  
>LIST

CURRENT USER DEFINED ENVIRONMENTAL PARAMETERS

DYNAMIC, 60. FIRST SAMPLE MODEL

BY: BURGAN

| MOISTURES (%) |      |
|---------------|------|
| -----         |      |
| 1 HR          | 4.   |
| 10 HR         | 5.   |
| 100 HR        | 6.   |
| LIVE HERB     | 100. |
| LIVE WOODY    | 120. |

| OTHER               |     |
|---------------------|-----|
| -----               |     |
| MIDFLAME WIND (MPH) | 5.  |
| SLOPE (PERCENT)     | 30. |

*Entering new environmental data*

ENVIRONMENT MANIPULATION SECTION.  
TYPE 'NEW', 'CHANGE', 'LIST', 'STD', OR 'QUIT'.

KEYWORD?  
>CHANGE

ENVIRONMENTAL DATA MODIFICATION SECTION.

TYPE KEYWORD 'QUIT' AFTER LAST CHANGE.  
DO YOU WANT A LIST OF ENVIRONMENTAL KEYWORDS? (Y OR N)  
>Y

THE ENVIRONMENTAL KEYWORDS AND THEIR MEANINGS ARE:

| KEYWORD | MEANING                           |
|---------|-----------------------------------|
| KEY     | PRINT THIS KEYWORD LIST           |
| M1      | 1 HR FUEL MOISTURE                |
| M10     | 10 HR FUEL MOISTURE               |
| M100    | 100 HR FUEL MOISTURE              |
| MHERB   | LIVE HERB FUEL MOISTURE           |
| MWOOD   | LIVE WOODY FUEL MOISTURE          |
| WIND    | MIDFLAME WINDSPEED                |
| SLOPE   | PERCENT SLOPE                     |
| QUIT    | STOP MAKING ENVIRONMENTAL CHANGES |

KEYWORD?  
>MHERB  
LIVE HERB?  
RANGE = 30. TO 350.  
>90

*Any of the items in the above list  
can be changed, but only live  
herbaceous moisture and slope were.*

KEYWORD?  
>SLOPE  
SLOPE IN PERCENT?  
RANGE = 0. TO 200.  
>35

KEYWORD?  
>QUIT

ENVIRONMENT MANIPULATION SECTION.  
TYPE 'NEW', 'CHANGE', 'LIST', 'STD', OR 'QUIT'.

KEYWORD?  
>LIST

CURRENT USER DEFINED ENVIRONMENTAL PARAMETERS

DYNAMIC, 60. FIRST SAMPLE MODEL

BY: BURGAN

| MOISTURES (%) |       | OTHER               |       |
|---------------|-------|---------------------|-------|
| -----         |       | -----               |       |
| 1 HR          | 4.    | MIDFLAME WIND (MPH) | 5.    |
| 10 HR         | 5.    | SLOPE (PERCENT)     | 35. ← |
| 100 HR        | 6.    |                     |       |
| LIVE HERB     | 90. ← |                     |       |
| LIVE WOODY    | 120.  |                     |       |

*Changing the environmental data*

ENVIRONMENT MANIPULATION SECTION.  
TYPE 'NEW', 'CHANGE', 'LIST', 'STD', OR 'QUIT'.

KEYWORD?  
>QUIT

ENTER KEYWORD 'GRAPH' OR 'TABLE' TO DEFINE TYPE OF OUTPUT.  
CONTROL SECTION. KEYWORD?

>TABLE  
TABLE OUTPUT SET.

TABULAR OUTPUT SECTION.

DO YOU WANT A LIST OF KEYWORDS FOR SELECTING AN ENVIRONMENTAL  
PARAMETER TO VARY? (Y OR N).

>Y

THE KEYWORDS FOR THE ENVIRONMENTAL VARIABLES ARE:

| KEYWORD | VARIABLE                 |
|---------|--------------------------|
| KEY     | PRINT THIS KEYWORD LIST  |
| M1      | 1 HR FUEL MOISTURE       |
| M10     | 10 HR FUEL MOISTURE      |
| M100    | 100 HR FUEL MOISTURE     |
| MHERB   | LIVE HERB FUEL MOISTURE  |
| MWOOD   | LIVE WOODY FUEL MOISTURE |
| WIND    | MIDFLAME WINDSPEED       |
| SLOPE   | PERCENT SLOPE            |

ENTER ENVIRONMENTAL PARAMETER KEYWORD.  
>WIND

YOUR MIDFLAME WINDSPEED IS 5.  
ENTER 2 MORE VALUES.

FIRST VALUE?  
RANGE = 0. TO 18.  
>0

SECOND VALUE?  
>10

*The environmental parameter selected to vary was wind. Any other item could be chosen.*

*Obtaining tabular output.*

FUEL MODEL TEST RUN -- USER DEFINED ENVIRONMENTAL INPUT

DYNAMIC 60. FIRST SAMPLE MODEL

BY: BURGAN

| LOAD (T/AC) |       | S/V RATIOS |       | OTHER        |       |
|-------------|-------|------------|-------|--------------|-------|
| 1 HR        | 10.30 | 1 HR       | 1923. | DEPTH        | 0.81  |
| 10 HR       | 8.19  | LIVE HERB  | 1500. | HEAT CONTENT | 8440. |
| 100 HR      | 6.92  | LIVE WOODY | 800.  | EXT MOISTURE | 13.   |
| LIVE HERB   | 1.47  | SIGMA      | 1790. | PR/OPR       | 6.70  |
| LIVE WOODY  | 0.60  |            |       |              |       |

ENVIRONMENTAL DATA

FIRE BEHAVIOR RESULTS

| ENVIRONMENTAL DATA |      | FIRE BEHAVIOR RESULTS |               |       |       |
|--------------------|------|-----------------------|---------------|-------|-------|
|                    |      | FIRE VARIABLE         | MIDFLAME WIND |       |       |
| 1 HR FM            | 4.   |                       | 0.            | 5.    | 10.   |
| 10 HR FM           | 5.   |                       |               |       |       |
| 100 HR FM          | 6.   | ROS (FT/M)            | 3.            | 9.    | 20.   |
| LIVE HERB FM       | 90.  | FL (FT)               | 2.            | 4.    | 6.    |
| LIVE WOODY FM      | 120. | IR (BTU/SQFT/M)       | 4212.         | 4212. | 4212. |
|                    |      | H/A (BTU/SQFT)        | 904.          | 904.  | 904.  |
| SLOPE (%)          | 35.  | FLI (BTU/FT/SEC)      | 39.           | 137.  | 306.  |

RUN ANOTHER TABLE? (Y OR N)  
>N

*Obtaining tabular output*

CONTROL SECTION. KEYWORD?

>GRAPH

GRAPHIC OUTPUT SET.

NORMAL VERSION GRAPHICS SECTION.

DO YOU WANT GRAPH 1 - RATE OF SPREAD? (Y OR N).

>Y

DO YOU WANT GRAPH 2 - FLAME LENGTH? (Y OR N).

>Y

DO YOU WANT TO USE:

- 1) STANDARD
- 2) CALCULATED

SCALING OF THE Y-AXIS?

ENTER 1 OR 2

>1

YOUR 1 HR FM IS 4.

DO YOU WANT TO PLOT CURVES FOR 2 MORE 1 HR MOISTURES? (Y OR N)

>Y

FIRST VALUE?

RANGE = 2. TO 50.

>8

SECOND VALUE?

RANGE = 2. TO 50.

>12

DO YOU WANT GRAPH 3 - FIRE CHARACTERISTICS CHART? (Y OR N).

>Y

DO YOU WANT TO COMPARE YOUR MODEL WITH 1 OR 2 NFFL MODELS? (Y OR N).

>Y

ENTER FIRST NFFL MODEL NUMBER

RANGE = 1. TO 13.

>8

DO YOU WANT TO SELECT A SECOND NFFL MODEL? (Y OR N).

>Y

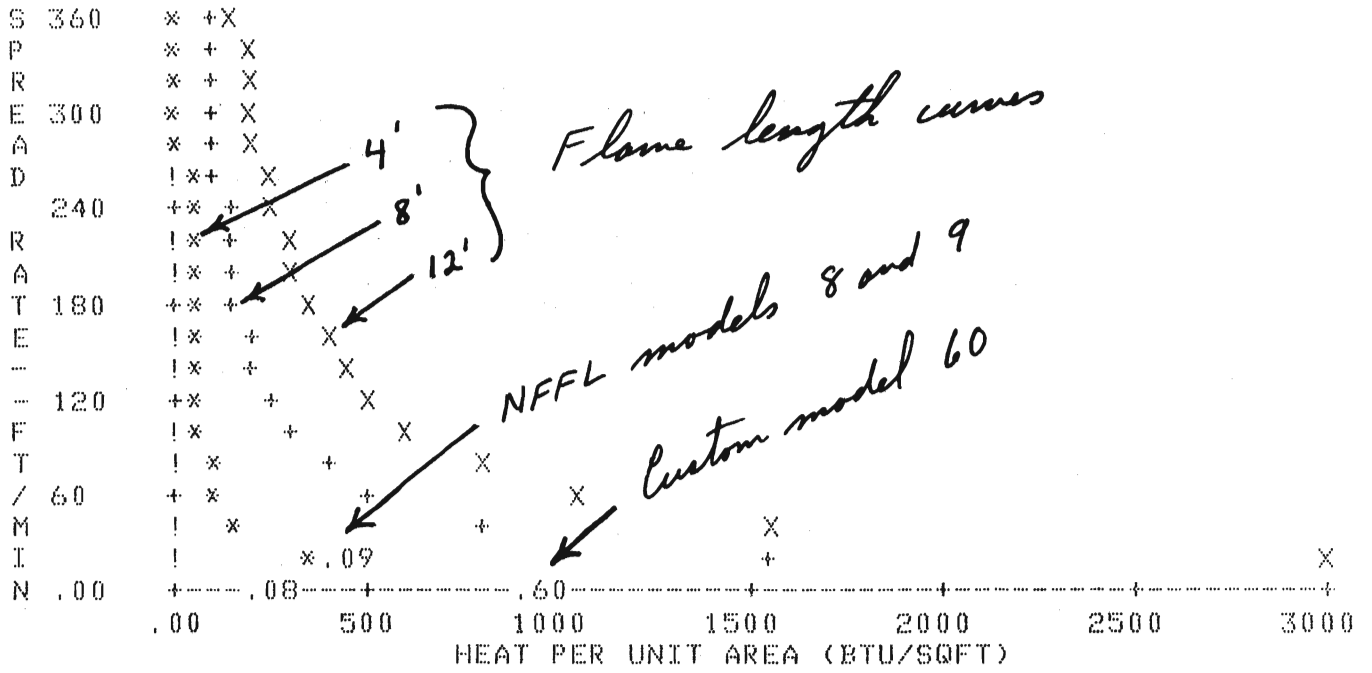
ENTER SECOND NFFL MODEL NUMBER

RANGE = 1. TO 13.

>9

*obtaining graphic output, normal version, standard scaling*





NORMAL VERSION GRAPHICS SECTION.

DO YOU WANT GRAPH 1 - RATE OF SPREAD? (Y OR N).  
>Y

DO YOU WANT GRAPH 2 - FLAME LENGTH? (Y OR N).  
>Y

DO YOU WANT TO USE:  
1) STANDARD  
2) CALCULATED  
SCALING OF THE Y-AXIS?

ENTER 1 OR 2  
>2

YOUR 1 HR FM IS 4.  
DO YOU WANT TO PLOT CURVES FOR 2 MORE 1 HR MOISTURES? (Y OR N).  
>Y

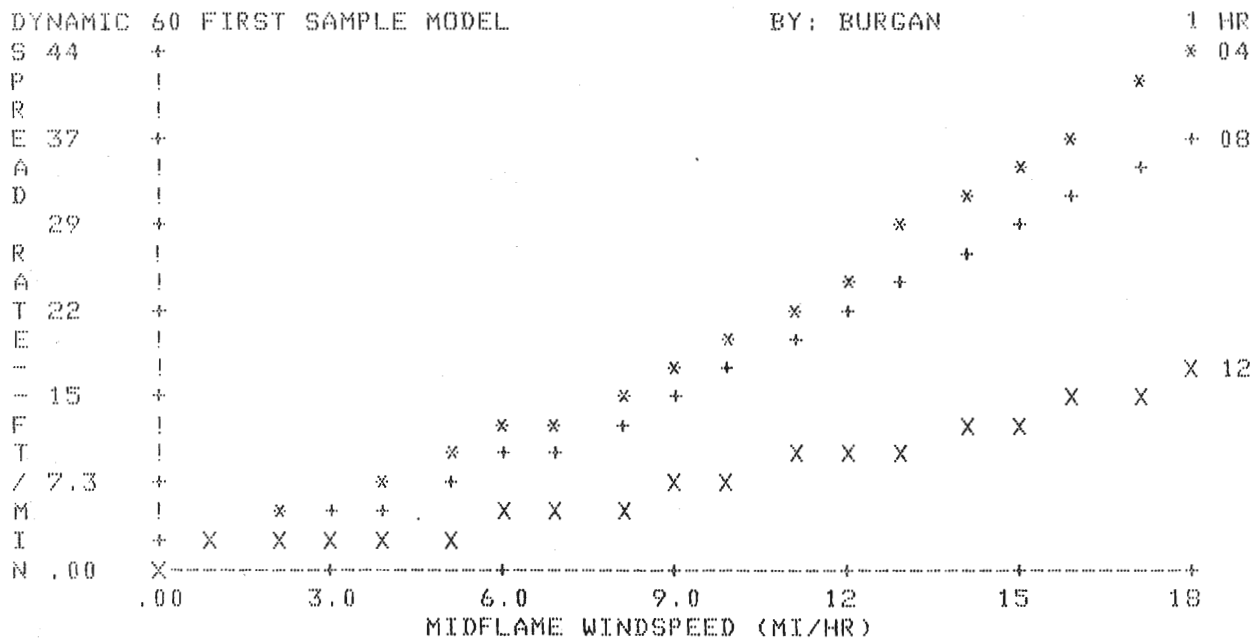
FIRST VALUE?  
RANGE = 2. TO 50.  
>8

SECOND VALUE?  
RANGE = 2. TO 50.  
>12

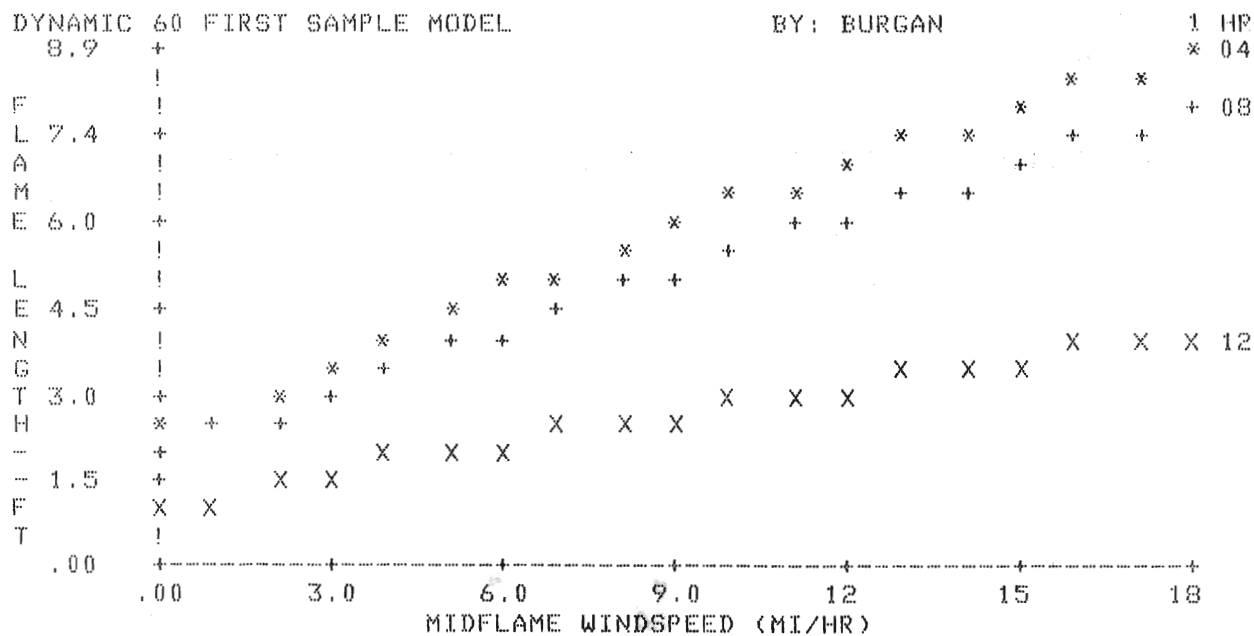
DO YOU WANT GRAPH 3 - FIRE CHARACTERISTICS CHART? (Y OR N).  
>N

*Normal version graphics, calculated scaling*





PRESS RETURN TO CONTINUE



PRESS RETURN TO CONTINUE

RUN MORE GRAPHS? (Y OR N)

>N

*Calculated scaling uses the full y-axis range*

CONTROL SECTION. KEYWORD?  
>TECH

TECHNICAL VERSION SET.  
CONTROL SECTION. KEYWORD?  
>GRAPH  
GRAPHIC OUTPUT SET.

TECHNICAL VERSION GRAPHICS SECTION.

DO YOU WANT KEYWORDS FOR X AXIS? (Y OR N)  
>Y

THE KEYWORDS FOR THE X AXIS AND THEIR MEANING ARE:

| KEYWORD | MEANING                 |
|---------|-------------------------|
| KEY     | PRINT THIS KEYWORD LIST |
| SA1     | 1 HR S/V RATIO          |
| SAH     | HERB S/V RATIO          |
| SAW     | WOODY S/V RATIO         |
| L1      | 1 HR FUEL LOAD          |
| L10     | 10 HR FUEL LOAD         |
| L100    | 100 HR FUEL LOAD        |
| LH      | HERB FUEL LOAD          |
| LW      | WOODY FUEL LOAD         |
| DEPTH   | FUEL BED DEPTH          |
| EXTM    | EXTINCTION MOISTURE     |
| HEAT    | HEAT CONTENT            |
| M1      | 1 HR FUEL MOISTURE      |
| M10     | 10 HR FUEL MOISTURE     |
| M100    | 100 HR FUEL MOISTURE    |
| MHERB   | HERB FUEL MOISTURE      |
| MWOOD   | WOODY FUEL MOISTURE     |
| WIND    | MIDFLAME WINDSPEED      |
| SLOPE   | PERCENT SLOPE           |

*Any of these items can  
be placed on the X-axis*

*Technical version graphics*

DO YOU WANT KEYWORDS FOR Y AXIS? (Y OR N)  
>Y

THE KEYWORDS FOR THE Y AXIS AND THEIR MEANING ARE:

| KEYWORD | MEANING            |
|---------|--------------------|
| FLINT   | FIRELINE INTENSITY |
| RATE    | RATE OF SPREAD     |
| REAC    | REACTION INTENSITY |
| FLAME   | FLAME LENGTH       |
| H/A     | HEAT PER UNIT AREA |
| RSFL    | ROS/FL RATIO       |
| PACK    | PACKING RATIO      |

*Any of these items can  
be placed on the Y-axis*





TECHNICAL VERSION GRAPHICS SECTION.

DO YOU WANT KEYWORDS FOR X AXIS? (Y OR N)

>N

DO YOU WANT KEYWORDS FOR Y AXIS? (Y OR N)

>N

X AXIS KEYWORD?

>L10

← Selected 10 hour load

ENTER MINIMUM 10 HR FUEL LOAD IN TONS/ACRE

RANGE = .001 TO 30.

>1

*It is a good idea to use a large - even unrealistic - range for your first plot, to see how a parameter can affect the behavior of your model*

ENTER MAXIMUM 10 HR FUEL LOAD

>30

ENTER Y AXIS KEYWORD.

>RATE

YOU CAN EITHER:

- 1) SET THE Y AXIS RANGE
- 2) USE THE CALCULATED Y AXIS RANGE

CALCULATED Y AXIS RANGE FOR RATE OF SPREAD : (0. TO 16.)

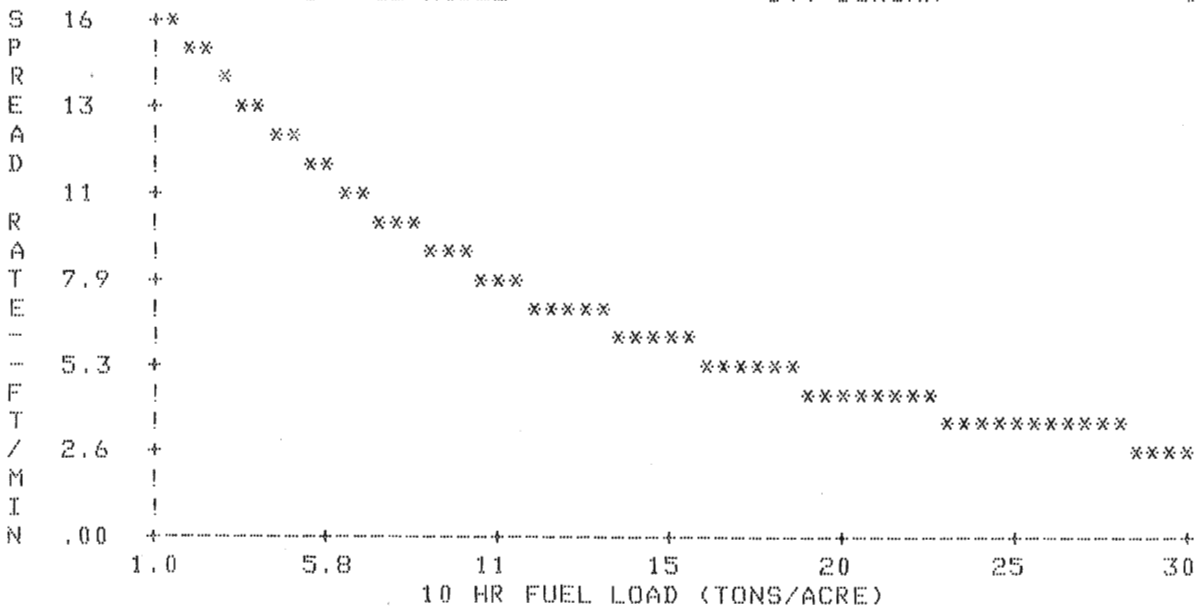
ENTER 1 OR 2

>2

DYNAMIC 60 FIRST SAMPLE MODEL

BY: BURGAN

1 HR



*Technical version graphics*

PRESS RETURN TO CONTINUE

>

DO YOU WANT TO CHANGE THE X AXIS, THE Y AXIS OR QUIT?

ENTER X, Y, OR QUIT

>QUIT

CONTROL SECTION. KEYWORD?  
>FILE

DO YOU WISH TO USE THE CURRENT FUEL MODEL FILE (Y OR N)?  
THE CURRENT FILE IS MYFILE  
>Y

DO YOU WANT TO:

- 1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
- 2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 3) CHANGE A FUEL FILE HEADER
- 4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 5) REPLACE A FUEL MODEL IN THE FILE
- 6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7  
>1

ENTER FUEL MODEL NUMBER  
RANGE = 14 TO 99  
>61

MODEL 61 LOADED  
CONTROL SECTION. KEYWORD?

*After 'getting' a model, you  
are automatically put back  
in the 'control' section*

*Getting a fuel model from the file*

>FILE

*Get back to the file section*

DO YOU WISH TO USE THE CURRENT FUEL MODEL FILE (Y OR N)?  
THE CURRENT FILE IS MYFILE

>Y

DO YOU WANT TO:

- 1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
- 2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 3) CHANGE A FUEL FILE HEADER
- 4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 5) REPLACE A FUEL MODEL IN THE FILE
- 6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7

>2

SAMPLE FUEL MODEL FILE

60 FIRST SAMPLE MODEL  
61 SECOND SAMPLE MODEL

} ←

*Fuel model file description from the file 'header'*

*List of models in the file*

*Listing the models in the file*

DO YOU WANT TO:

- 1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
- 2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 3) CHANGE A FUEL FILE HEADER
- 4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 5) REPLACE A FUEL MODEL IN THE FILE
- 6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7

>3

ENTER PASSWORD

>NFFL

ENTER NEW PASSWORD (4 CHAR MAX)

>LFFN

*{ Password changed in this case, but you could enter the same password (NFFL) if you didn't want to change it.*

THE CURRENT FUEL FILE DESCRIPTION IS:

SAMPLE FUEL MODEL FILE

DO YOU WANT TO CHANGE IT? (Y OR N)

>Y

ENTER COMMENT TO DESCRIBE THIS FUEL FILE (72 CHAR MAX)

>EXAMPLE FUEL MODEL FILE

*← Changed the file description, but you don't have to if you say NO to the above question*

FUEL FILE HEADER CHANGED

DO YOU WANT TO:

- 1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
- 2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 3) CHANGE A FUEL FILE HEADER
- 4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 5) REPLACE A FUEL MODEL IN THE FILE
- 6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7

>2

EXAMPLE FUEL MODEL FILE

*← New fuel file descriptor*

60 FIRST SAMPLE MODEL

61 SECOND SAMPLE MODEL

*Changing a fuel file header*



DO YOU WANT TO:

- 1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
- 2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 3) CHANGE A FUEL FILE HEADER
- 4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 5) REPLACE A FUEL MODEL IN THE FILE
- 6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7

>4

A FUEL MODEL WITH THIS NUMBER ALREADY EXISTS IN THE FILE  
RETURNING TO THE CONTROL SECTION SO YOU CAN RENUMBER THE MODEL  
CONTROL SECTION. KEYWORD?

>RENUMBER

*← Must change fuel model number*

ENTER THE NUMBER YOU WANT ASSIGNED TO THIS CUSTOM MODEL  
RANGE = 14 TO 99

>62

*← New number*

ENTER FUEL MODEL NAME (32 CHARACTERS MAXIMUM).

>SECOND COPY OF MODEL 61

*Called it this because it really is  
the same model*

IS YOUR PROPOSED FUEL MODEL DYNAMIC(1) OR STATIC(2)?

DYNAMIC MODELS ADJUST FOR SEASONAL DRYING THROUGH TRANSFER  
OF LIVE HERBACEOUS LOAD BETWEEN LIVE HERBACEOUS AND 1 HOUR  
TIMELAG CLASSES, AS A FUNCTION OF HERBACEOUS FUEL MOISTURE.

STATIC MODELS HAVE CONSTANT LOADS IN ALL LIVE AND DEAD  
FUEL CLASSES.

ENTER 1 OR 2

>2

*Renumbering a model provides a chance to  
change its status as static or dynamic*

PROGRAM CONTROL IS THROUGH THE USE OF KEYWORDS.

DO YOU WANT A LIST OF KEYWORDS AND THEIR FUNCTIONS? (Y OR N)

>N

WHENEVER 'KEYWORD?' IS PRINTED, TYPE THE KEYWORD FOR  
THE NEXT TASK YOU WANT TO ACCOMPLISH. YOUR FIRST RESPONSE  
SHOULD BE THE KEYWORD 'NORM' OR 'TECH' TO GET THE VERSION  
YOU WANT.

*↑ Just a reminder. You don't have to do  
this unless you want the other version.*

*Adding a model to the file*

CONTROL SECTION. KEYWORD?  
>FILE

DO YOU WISH TO USE THE CURRENT FUEL MODEL FILE (Y OR N)?  
THE CURRENT FILE IS MYFILE  
>Y

DO YOU WANT TO:

- 1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
- 2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 3) CHANGE A FUEL FILE HEADER
- 4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 5) REPLACE A FUEL MODEL IN THE FILE
- 6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7  
>4

ENTER PASSWORD  
>LFFN

FUEL MODEL 62 WRITTEN TO FUEL MODEL FILE

*This time the model was  
added OK*

*Adding a model to the file*

DO YOU WANT TO:

- 1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
- 2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 3) CHANGE A FUEL FILE HEADER
- 4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 5) REPLACE A FUEL MODEL IN THE FILE
- 6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7  
>7

CONTROL SECTION. KEYWORD?  
>FUEL

FUELS MANIPULATION SECTION.  
TO USE ONE OF THE 13 NFFL FUEL MODELS TYPE 'NFFL'.  
TO INPUT ALL FUELS DATA TYPE 'NEW'.  
TO CHANGE EXISTING FUELS DATA TYPE 'CHANGE'.  
TO LIST CURRENT FUELS DATA TYPE 'LIST'.  
TO GET OUT OF THE FUELS SECTION TYPE 'QUIT'.

KEYWORD?  
>CHANGE

FUEL MODIFICATION SECTION.  
ENTER KEYWORD 'QUIT' AFTER LAST CHANGE.

DO YOU WANT A LIST OF FUEL MODEL KEYWORDS? (Y OR N)  
>N

KEYWORD?  
>EXTM

MOISTURE OF EXTINCTION?  
RANGE = 10. TO 60.  
>30

*Decided to change model 62  
slightly before replacing it  
in the file*

KEYWORD?  
>QUIT

FUELS MANIPULATION SECTION.  
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'

KEYWORD?  
>LIST

CURRENT VALUES OF FUEL MODEL PARAMETERS  
STATIC 62. SECOND COPY, OF MODEL 61 BY: BURGAN

| LOAD (T/AC) |      | S/V RATIOS |       | OTHER        |       |
|-------------|------|------------|-------|--------------|-------|
| 1 HR        | 1.62 | 1 HR       | 1728. | DEPTH        | 0.67  |
| 10 HR       | 4.00 | LIVE HERB  | 0.    | HEAT CONTENT | 8000. |
| 100 HR      | 7.20 | LIVE WOODY | 0.    | EXT MOISTURE | 30.   |
| LIVE HERB   | 0.00 |            |       |              |       |
| LIVE WOODY  | 0.00 |            |       |              |       |

FUELS MANIPULATION SECTION.  
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'

KEYWORD?  
>QUIT

*Replacing a model in the file*

CONTROL SECTION, KEYWORD?  
>FILE

DO YOU WISH TO USE THE CURRENT FUEL MODEL FILE (Y OR N)?  
THE CURRENT FILE IS MYFILE  
>Y

DO YOU WANT TO:

- 1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
- 2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 3) CHANGE A FUEL FILE HEADER
- 4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 5) REPLACE A FUEL MODEL IN THE FILE
- 6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7  
>5

*Model 62 was found in  
the file and replaced.*

ENTER PASSWORD  
>LFFN

FUEL MODEL 62 WRITTEN TO FUEL MODEL FILE

DO YOU WANT TO:

- 1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
- 2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 3) CHANGE A FUEL FILE HEADER
- 4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 5) REPLACE A FUEL MODEL IN THE FILE
- 6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7  
>6

HOW MANY MODELS DO YOU WANT TO DELETE?  
RANGE = 0 TO 5  
>1

ENTER NUMBER OF FIRST MODEL TO BE DELETED  
>62

FUEL MODEL 62 DELETED

*Replacing a model in the file*

---

*Deleting a model from the file*

DO YOU WANT TO:

- 1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
- 2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
- 3) CHANGE A FUEL FILE HEADER
- 4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
- 5) REPLACE A FUEL MODEL IN THE FILE
- 6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
- 7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7

>1

ENTER FUEL MODEL NUMBER

RANGE = 14 TO 99

>60

MODEL 60 LOADED

CONTROL SECTION, KEYWORD?

>TI59

\*\* TI-59 DATA FOR DYNAMIC MODEL 60. FIRST SAMPLE MODEL

MODEL PARAMETER      PARAMETER VALUE      TI REG NO

----- LOADS -----

|            |        |    |
|------------|--------|----|
| 1 HR       | 0.4729 | 11 |
| 10 HR      | 0.3760 | 12 |
| 100 HR     | 0.3177 | 13 |
| LIVE HERB  | 0.0675 | 15 |
| LIVE WOODY | 0.0275 | 16 |

--- S/V RATIO ---

|            |       |    |
|------------|-------|----|
| 1 HR       | 1923. | 17 |
| 10 HR      | 109.  | 18 |
| 100 HR     | 30.   | 19 |
| LIVE HERB  | 1500. | 21 |
| LIVE WOODY | 800.  | 22 |

--- OTHERS ---

|               |         |    |
|---------------|---------|----|
| HEAT CONTENT  | 8440.   | 23 |
| ROS FOR IC    | 999999. | 24 |
| EXT MOISTURE  | 13.     | 25 |
| DEPTH         | 0.81    | 26 |
| M WS CONSTANT | 1.      | 27 |

PRESS RETURN TO CONTINUE

>

THE WIND ADJUSTMENT FACTOR TO REDUCE 20 FOOT WINDSPEED  
TO MIDFLAME WINDSPEED FOR FULLY EXPOSED FUELS IS 0.4  
CONSULT ROTHERMEL'S HOW TO PREDICT . . . . BOOK  
FOR PARTIALLY OR FULLY SHELTERED FUELS.  
CONTROL SECTION, KEYWORD?

>QUIT

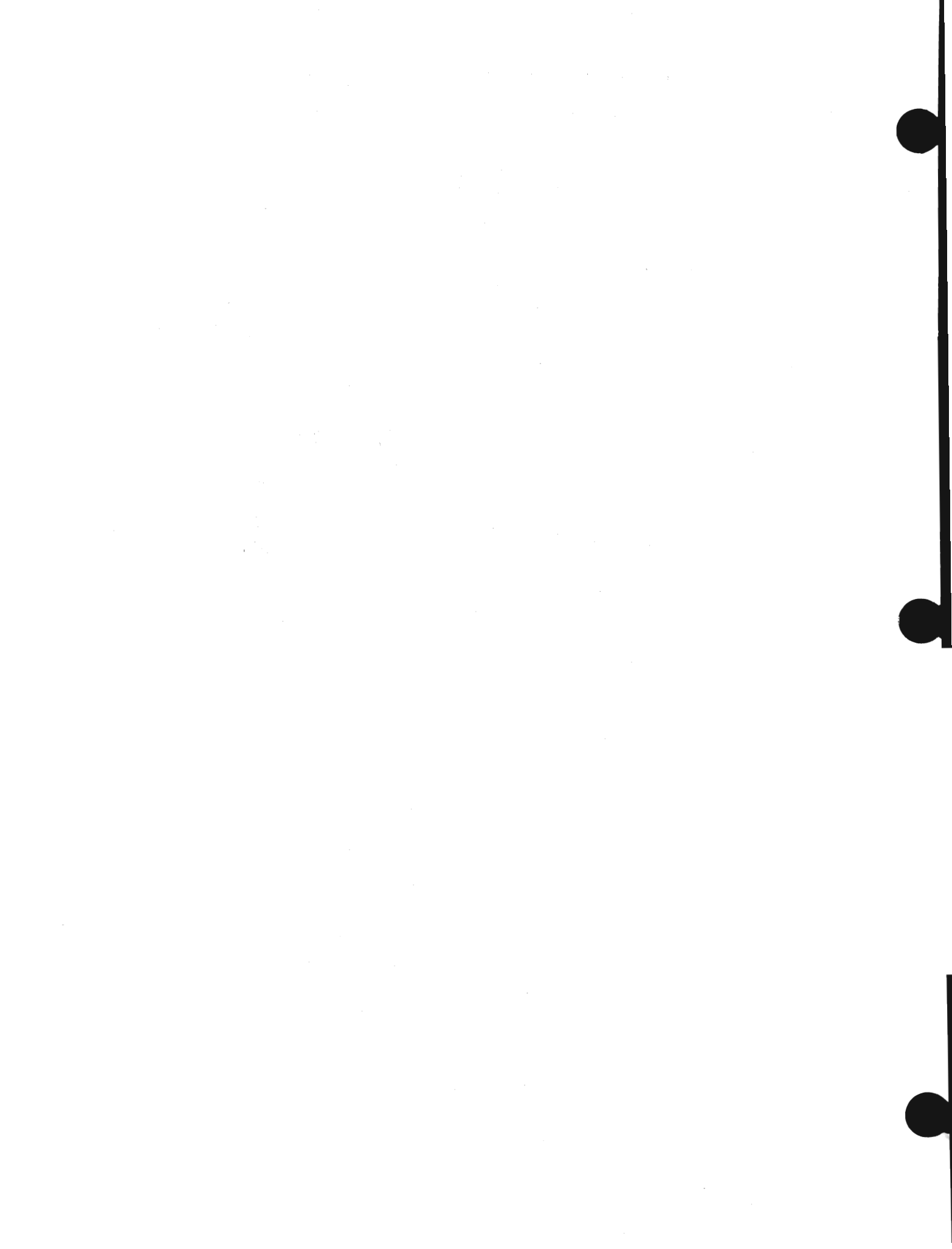
DO YOU REALLY WANT TO TERMINATE THIS RUN? (Y OR N).

>Y

TSTMDL RUN TERMINATED.

\*\*\*\*\*

*Obtaining TI-59 fuel model card data*



## APPENDIX D: FUEL MODEL FILE STRUCTURE

The fuel model file serves as the basic means of communication between the programs of the BEHAVE system. The structure of the file is:

1. A "header" record containing the user's password and a general description of the models in the file.
2. One record for each fuel model in the file.
3. An end of file mark.

If fuel models have been deleted from a file, you may find some extraneous records after the first end of file mark. They should not be a cause for concern. With some computers you may see these records if you look at the file with the editor. Other computers may delete them.

The records of the file are described in detail below.

### "Header" Record

| Column(s) | Data recorded            |
|-----------|--------------------------|
| 1 - 4     | User's password          |
| 5 - 6     | Blank                    |
| 7 - 78    | File description         |
| 79        | Blank                    |
| 80        | A letter of the alphabet |

The letter in column 80 will be used to check whether or not the fuel model has the current format. When BEHAVE is implemented this letter will be A. If the format changes in the future, the letter will be changed to B, then C, etc.

### Fuel Model Card Records

| Column(s) | Data recorded                   |
|-----------|---------------------------------|
| 1 - 2     | Fuel model number               |
| 3         | Wind reduction factor           |
| 4 - 35    | Fuel model name                 |
| 36 - 39   | 1-h load                        |
| 40 - 43   | 10-h load                       |
| 44 - 47   | 100-h load                      |
| 48 - 51   | Live herbaceous load            |
| 52 - 55   | Live woody load                 |
| 56 - 59   | Fuel bed depth                  |
| 60 - 64   | Heat content                    |
| 65 - 66   | Extinction moisture             |
| 67 - 70   | 1-h S/V ratio                   |
| 71 - 74   | Live herbaceous S/V ratio       |
| 75 - 78   | Live woody S/V ratio            |
| 79        | Letter                          |
| 80        | Dynamic (1),<br>static (2) code |

The formats used to write and read these records are:

"Header" record:

Write format (A4,2X,18A4, 1X, A1))  
Read format (A4,2X,18A4, 1X, A1))

Fuel model records:

Write format (I2,I1,32A1,6I4,I5,I2,3I4,A1,I1)  
Read format (F2.0,I1,32A1,6F4.2,F5.0,F2.0,3F4.0,A1,I1)

## APPENDIX E: WEIGHTING PROCEDURES USED IN PROGRAM NEWMDL

Field data are usually collected for more than one of the fuel components--litter, grass, shrubs, or slash. The data collected for each component will differ. For example, the 1-h S/V ratio for litter will not likely be the same as for shrubs or grass. And the heat content may be different for slash than for the live leaves and twigs of shrubs. Therefore, while the NEWMDL program will accept the diversity of data collected on the various fuel components, it must eventually be condensed to "average" values that represent the entire fuel complex. This appendix describes the weighting procedures used to calculate average heat content, 1-h S/V ratio, dead fuel extinction moisture, and fuel bed depth for the "first cut" fuel model produced by the NEWMDL program.

### Heat Content

1. Calculate the mean total surface area of fuel in the  $j^{\text{th}}$  class of the

$$\text{dead category: } A_{1j} = \frac{(\sigma)_{1j}(W_o)_{1j}}{(\rho_p)_{1j}}$$

and the

$$\text{live category: } A_{2j} = \frac{(\sigma)_{2j}(W_o)_{2j}}{(\rho_p)_{2j}}$$

where

$\sigma$  = surface-area-to-volume ratio of the  $j^{\text{th}}$  class of the dead fuel category

$W_o$  = oven-dry load in the  $j^{\text{th}}$  class of the dead fuel category

$\rho_p$  = particle density (32 lb/ft<sup>3</sup>)

2. Calculate the mean total surface area of the

$$\text{dead category: } \bar{A}_{1j} = \sum_{j=1}^3 A_{1j}$$

and the

$$\text{live category: } \bar{A}_{2j} = \sum_{j=1}^2 A_{2j}$$

and the mean total surface area of the complex

$$\bar{A}_T = \sum_{i=1}^2 \bar{A}_i$$

3. Determine the fraction of the total surface area in the

$$\text{dead category: } f_1 = \frac{\bar{A}_1}{\bar{A}_T}$$

$$\text{live herbaceous class: } f_{2,1} = \frac{\bar{A}_{2,1}}{\bar{A}_2}$$



$$\text{live woody class: } f_{2,2} = \frac{\bar{A}_{2,2}}{\bar{A}_2}$$

4. Calculate the weighted heat content for all fuel classes and categories

$$H_w = f_{1,1}H_{1,1} + f_{2,1}H_{2,1} + f_{2,2}H_{2,2}$$

where

$$H_{1,1} = \text{dead fuel heat content (Btu/lb)}$$

$$H_{2,1} = \text{live herbaceous heat content (Btu/lb)}$$

$$H_{2,2} = \text{live woody heat content (Btu/lb)}$$

#### One-Hour Timelag Surface-to-Volume Ratio

1. Calculate weighting factors for each component

$$f_i = W_i \sigma_i / 32$$

where

$$W_i = \text{ovendry load of each component}$$

$$\sigma_i = \text{1-h S/V ratio of each component}$$

2. Calculate the "characteristic" 1-hour S/V ratio for the fuel complex

$$\bar{\sigma}_{1,1} = \frac{\sum_{i=1}^4 f_i \sigma_i / \sum_{i=1}^4 f_i}{\sum_{i=1}^4 f_i}$$

#### Dead Fuel Extinction Moisture and Fuel Bed Depth

1. Convert total load of each component from tons per acre to pounds per square foot
2. Calculate the packing ratio for litter, grass, and slash components as

$$\beta_{cp} = \frac{w_{cp}}{32 \delta_{cp}}$$

where

$$\beta_{cp} = \text{component packing ratio}$$

$$w_{cp} = \text{component load (lb/ft}^2\text{)}$$

$$\delta_{cp} = \text{component depth}$$

3. Calculate the extinction moisture (%) for litter, grass, and slash components

$$M_{xcp} = 100(0.12 + 4.8\beta_{cp})$$

where

$$M_{xcp} = \text{component extinction moisture}$$

Component extinction moisture ( $M_{xcp}$ ) estimates are based on the relationship of extinction moisture to packing ratio for the 13 NFFL fuel models (fig. 26). These models can be separated into two groups:

- shrubs and tall coarse grass (models 3-7)
- shorter, finer grasses (models 1 and 2) and fuels that are primarily horizontal (models 8-13)

The two groups were considered separately. The extinction moisture of the first group is set, in subroutine SHRUB, as 0.35 if the leaves are said to contain oils and waxes, 0.20 if not.

The extinction moisture of the second group is calculated using the regression line fitted to the points plotted for models 1-2, and 8-13.

4. Calculate extinction moisture for the fuel model

$$M_x = \frac{\sum_{i=1}^4 M_{xcp} W_{cp}}{W_o}$$

where

$$w_o = \text{total oven-dry load}$$

5. Depth for the fuel complex is similarly calculated

$$\delta = \frac{\sum_{i=1}^4 \delta_{cp} W_{cp}}{W_o}$$

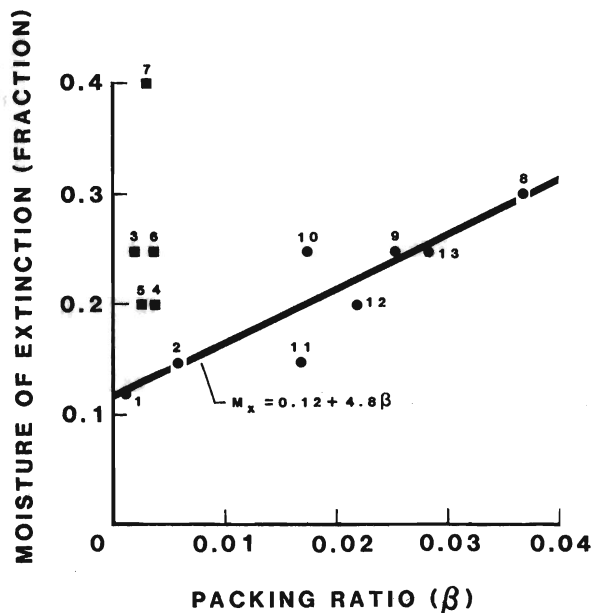


Figure 26.--Moisture of extinction is assigned for shrub-type fuels (models 3-7), but calculated from the extinction moisture equation for other fuel types (models 1-2 and 8-13).

---

Burgan, Robert E.; Rothermel, Richard C. BEHAVE: fire behavior prediction and fuel modeling system--FUEL subsystem. General Technical Report INT-167. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 126 p.

This manual documents the fuel modeling procedures of BEHAVE--a state-of-the-art wildland fire behavior prediction system. Described are procedures for collecting fuel data, using the data with the program, and testing and adjusting the fuel model.

---

KEYWORDS: fire, fuels, fire behavior prediction

---

Sponsored for NWCG publication by NWCG Prescribed Fire and Fire Effects Working Team, August 1989, in cooperation with USDA Forest Service Intermountain Research Station, Ogden, Utah.

---

Additional copies of this publication may be ordered from:

National Interagency Fire Center  
ATTN: Supply  
3833 S. Development Ave.  
Boise, Idaho 83705

Order NFES # 0275