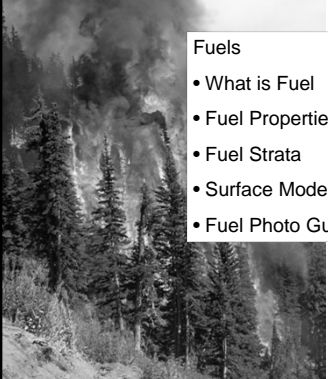
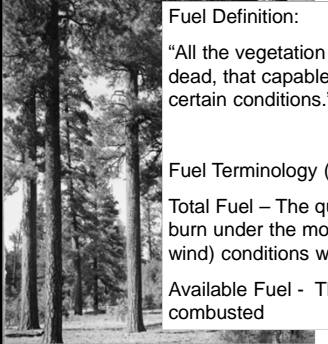


FOR 274: Forest Measurements and Inventory



- Fuels
 - What is Fuel
 - Fuel Properties
 - Fuel Strata
 - Surface Models
 - Fuel Photo Guides

Fuel: What is Fuel?



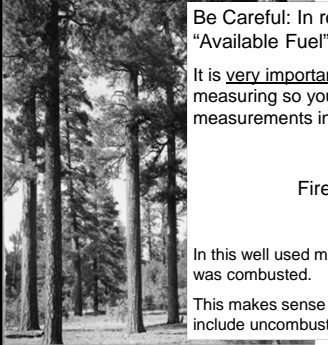
Fuel Definition:
 "All the vegetation cover, whether living or dead, that capable of being burned under certain conditions."

Fuel Terminology (Byram 1959/Davis 1974):
 Total Fuel – The quantity of fuel that would burn under the most extreme (dry and high wind) conditions with the highest-intensity fire
 Available Fuel - The quantity of fuel actually combusted

Port Valley Red Forest, AZ. 1961. 1964. Nature group of ponderosa pine in single stand, middle class. 1961. 1964. Nature group of ponderosa pine in single stand, middle class. 1961. 1964. Nature group of ponderosa pine in single stand, middle class.

Davis (Forest Fire: Control and Use) Chapter 4

Fuel: There is Available and there is Available!



Be Careful: In recent years, the term "Available Fuel" has been used incorrectly!
 It is very important you know what you are measuring so you use the correct measurements in fire intensity models:

Fire Intensity = Hwr

In this well used model, w = available fuel = fuel that was combusted.
 This makes sense as why should fire intensity include uncombusted (but available to burn) fuels?

Port Valley Red Forest, AZ. 1961. 1964. Nature group of ponderosa pine in single stand, middle class. 1961. 1964. Nature group of ponderosa pine in single stand, middle class. 1961. 1964. Nature group of ponderosa pine in single stand, middle class.

Davis (Forest Fire: Control and Use) Chapter 4

Fuel: Measurement of Fuel Properties

The main properties of fuels that we often measure include:

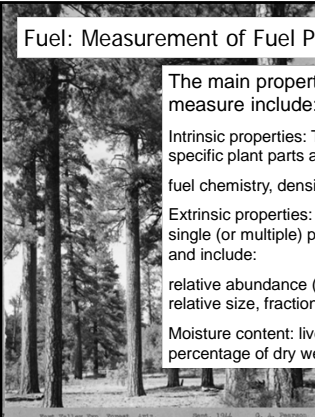
Intrinsic properties: These refer to the properties of the specific plant parts and include:

- fuel chemistry, density, and heat content (Lab analysis)

Extrinsic properties: These refer to the properties of single (or multiple) plant parts in relation to each other and include:

- relative abundance (measurements in this class!), relative size, fraction dead, fuel compaction, etc

Moisture content: live and dead fuels – measured as a percentage of dry weight




Fort Valley State Forest, Ariz. Sept. 1944. J. A. Paddock.
 nature group of positions that is visible stand, which also in, nearly all trees contain one or more horizontal-branch logs and clump
 Davis (Forest Fire: Control and Use) Chapter 4

Fuel: Measurement of Fuel Properties

Measuring Fuel Moisture Content:

1- 1000 hour fuel moisture content are in general measured by clipping representative samples just prior to a fire.



Typically fuel moisture calculations are oven dried for 24-48 hours at ~70°C


Figure 3.18. Fuel samples are clipped into a can, weighed, dried, and weighed again to determine moisture content. Photo by Melanie Miller. From Norum and Miller (1984).

Fort Valley State Forest, Ariz. Sept. 1944. J. A. Paddock.
 nature group of positions that is visible stand, which also in, nearly all trees contain one or more horizontal-branch logs and clump
 Pyne et al (Intro. Wildland Fire) Chapter 3

Fuel: Measurement of Fuel Properties

Measuring Fuel Moisture Content:

moisture content = (wet weight – dry weight) / dry weight




Important: Weigh the "dry" samples as quickly as possible as they will absorb moisture from the air

Figure 3.18. Fuel samples are clipped into a can, weighed, dried, and weighed again to determine moisture content. Photo by Melanie Miller. From Norum and Miller (1984).

Fort Valley State Forest, Ariz. Sept. 1944. J. A. Paddock.
 nature group of positions that is visible stand, which also in, nearly all trees contain one or more horizontal-branch logs and clump
 Pyne et al (Intro. Wildland Fire) Chapter 3

Fuel: Measurement of Fuel Properties

Fuel Moisture Content Sources of Error:
 $moisture\ content = (wet\ weight - dry\ weight) / dry\ weight$



Sources of Error can Include:

- Water added from other sources (rain)
- Wind blowing on the weighing scales
- Failure to tare the scale
- Mistakes!

Figure 3.10. Fuel samples are clipped into a can, weighed, dried, and weighed again to determine moisture content. Photo by Melanie Miller. From Norum and Miller (1984).

Pyne et al (Intro. Wildland Fire) Chapter 3

Fuel: Measurement of Fuel Properties

1-10hr Dead Fuels (0-1"):

- Select samples that are representative in terms of decay
- Select fuels 1-2 " in size that are not connected to living trees (snags or in litter)
- Remove lichen or moss

100 hr Dead Fuels (1-3"):

- Select a sound unburied and unconnected branch that already has bark that comes off freely and collect 1/2" cookies

1000 hr Dead Fuels (3" + duff):

- Select logs between 3-8" and collect 1/2" cookies from at least 6" away from the end of the logs

Pyne et al (Intro. Wildland Fire) Chapter 3

Fuel: Measurement of Fuel Properties

Measuring Fuel Moisture Content:
 Downed wood moisture content varies due to several interacting factors including: precipitation, wind, solar radiation, temperature/humidity, and interactions with other fuels

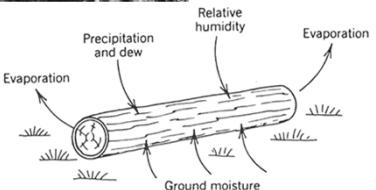


Figure 3.12. Factors influencing moisture exchange in wildland fuels.

Pyne et al (Intro. Wildland Fire) Chapter 3

Fuel: Measurement of Fuel Properties

Measuring Fuel Moisture Content:

Duff moisture content is measured with a duff moisture meter. The device shows a frequency that changes with the moisture content of the sample. Air is 40 MHz.

$$\text{Volumetric Water Content} = 5.288 + 5.905 * \text{freq} - 0.412 * \text{freq}^2$$

Standard Calculator
VWC = -0.142 * F² - 5.925 * F + 5.288

Power Switch
Output Window
Serial Port
DMM00 Base
Compression Plate
Sample Collector
Carrying Case
#4 Mesh Sieve

Fort Valley Stn., Forest, Ariz., Sept. 1944. J. A. Peabody
nature group of ponderosa pine in virgin stand, middle class etc.
mostly all trees outside row or more scattered-older logs and class

Fuel: Measurement of Fuel Properties

Live Fuels:

When sampling moisture content of live fuels a robust sampling strategy should always be followed.

12 TREES PER SPECIES
3 TREES PICKED AT RANDOM ON A GIVEN SAMPLE DATE
2 BRANCHES CUT FROM THE MID THIRD OF EACH TREE
NEEDLES PICKED BY AGE CLASS

ANALYSIS
MOISTURE EXTRACTIVES NEW
MOISTURE EXTRACTIVES 1 YEAR
MOISTURE EXTRACTIVES 2 YEAR

Steps:

- Sample twigs and foliage
- Remove flowers, seeds, berries, and dead material
- Represent older and newer growth

Figure 3.18. A foliage sampling scheme used for ponderosa pine and Douglas fir. From Pilgout and Mutch (1971).

Pyne et al (Intro. Wildland Fire) Chapter 3

Fuel: Measurement of Fuel Properties

Flammability is defined as the ease of something to ignite and combust.

Species	LFMIC summer (%)	LFMIC winter (%)	ID time summer (s)	ID time winter (s)
Chamaecyparis	~100	~100	~10	~10
Phyllis	~100	~100	~10	~10
Gambusia	~100	~100	~10	~10
Pistacia	~100	~100	~10	~10
Juniperus	~100	~100	~10	~10
Rosaemorus	~100	~100	~10	~10
Helichrysum	~100	~100	~10	~10
Cactus	~100	~100	~10	~10


Fort Valley Stn., Forest, Ariz., Sept. 1944. J. A. Peabody
nature group of ponderosa pine in virgin stand, middle class etc.
mostly all trees outside row or more scattered-older logs and class

Anderson (1970) and Martin et al (2004)

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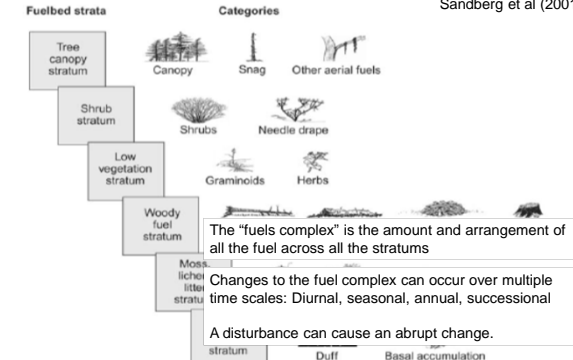
Fuels

- What is Fuel
- Fuel Properties
- Fuel Strata
- Fuel Models
- Fuel Photo Guides



Fuel Strata: Example Classifications

Sandberg et al (2001)



The "fuels complex" is the amount and arrangement of all the fuel across all the stratums

Changes to the fuel complex can occur over multiple time scales: Diurnal, seasonal, annual, successional

A disturbance can cause an abrupt change.

FOR 274: Forest Measurements and Inventory

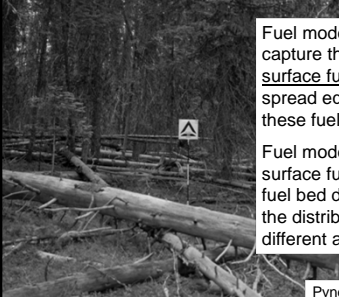
Fuels

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Fuel Classification: Fuel Models

The ability to generalize the quantity and distribution of fuel in a stand is essential for fire behavior modeling. The challenge is the high variability in the shape, abundance, and arrangement.



Fuel models were developed to capture the broad generalities in the surface fuels as fire behavior rate of spread equations typically only use these fuels.

Fuel models seek to generalize the surface fuels by the total fuel load, fuel bed depth, moisture content and the distribution of fuel across the different available sizes.

Pyne et al (Intro. Wildland Fire) Chapter 3

Fuel Classification: The 13 and the 40 ...

Using fuel models you can model fire spread without a detailed field inventory. The 13 and 40 fuel models are interchangeable.

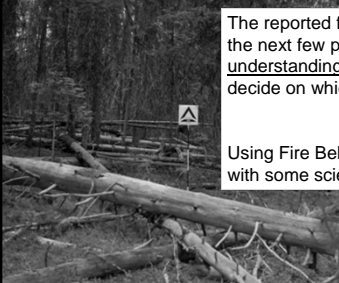
Fuel model	Typical fuel complex	Surface-area-to-volume ratio (ft ² /y ³) fuel loading (tons/acre)			Fuel bed depth	Moisture of extinction (dead fuels)	Characteristic surface area-to-volume ratio	Packing ratio
		1-h	10-h	100-h				
Grass and grass-dominated								
1	Short grass (1 ft)	3,500/0.74	—	—	1.0	12	3,500	0.00198
2	Timber (grass and understorey)	3,500/2.00	109/1.00	30/0.50	1,500/0.50	1.0	2,784	.00875
3	Tall grass (2.5 ft)	1,500/3.01	—	—	1,500	25	1,500	.00172
Chaparral and shrub fields								
4	Chaparral (8 ft)	2,000/5.01	109/4.01	30/2.00	1,500/5.01	6.0	1,739	.00383
5	Shrub (2 ft)	2,000/1.00	109/0.50	—	1,500/2.00	2.0	1,883	.00252
6	Dormant brush, hardwood slash	1,750/1.50	109/2.50	30/2.00	—	2.5	1,564	.00345
7	Southern rough	1,750/1.13	109/1.87	30/1.50	1,500/0.37	2.5	1,562	.00280
Timber litter								
8	Chopped timber litter	2,000/1.50	109/1.00	30/2.50	—	2	1,889	.03594
9	Hardwood litter	2,500/2.92	109/0.41	30/0.15	—	2	2,484	.02500
10	Timber (litter and understorey)	2,000/3.01	109/2.00	30/5.01	1,500/2.00	1.0	1,764	.01725
Slash								
11	Light logging slash	1,500/1.50	109/4.51	30/5.51	—	1.0	1,182	.01653
12	Medium logging slash	1,500/4.01	109/14.03	30/16.53	—	2.3	1,145	.02156
13	Heavy logging slash	1,500/7.01	109/23.04	30/28.05	—	3.0	1,159	.02778

The 13 fuel models are generally described into 4 groups: grasses, brush, timber, and slash

Anderson (1982) from Albini 1976

Fuel Classification: The 13 and the 40 ...

When using these models it is important to understand that the selection of a given model should be driven by your visual assessment (and experience!) of the fuels and how the fire spreads.



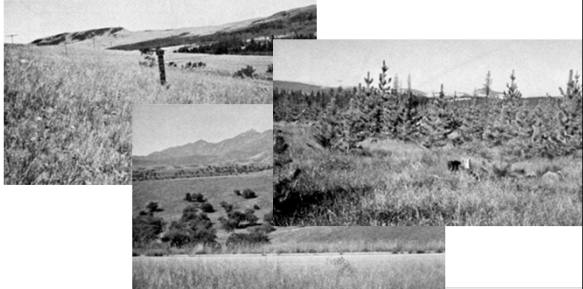
The reported fuel loading numbers (on the next few pages) are only for a general understanding and should not be used to decide on which fuel model to use.

Using Fire Behavior Fuel Models is an Art with some science behind it!

Anderson (1982) from Albini 1976

Fuel Classification: Grasses


Fire Behavior Fuel Model 1: Fine and continuous herbaceous fuels
Total Fuel Load: 0.74 tons/acre Live Foliage Load: 0.0 tons/acre
Dead Fuel Load: 0.74 tons/acre Fuel Bed Depth: 1.0 feet



Anderson (1982) from Albini 1976

Fuel Classification: Grasses


Fire Behavior Fuel Model 2: Herbaceous and surface litter fuels
Total Fuel Load: 4.0 tons/acre Live Foliage Load: 0.5 tons/acre
Dead Fuel Load: 2.0 tons/acre Fuel Bed Depth: 1.0 feet



Anderson (1982) from Albini 1976

Fuel Classification: Grasses


Fire Behavior Fuel Model 3: Tall and open grass stands at risk of high winds
Total Fuel Load: 3.0 tons/acre Live Foliage Load: 0.0 tons/acre
Dead Fuel Load: 3.0 tons/acre Fuel Bed Depth: 2.5 feet



Anderson (1982) from Albini 1976

Fuel Classification: Shrubs


Fire Behavior Fuel Model 4: Nearly continuous secondary overstorey
Total Fuel Load: 13.0 tons/acre Live Foliage Load: 5.0 tons/acre
Dead Fuel Load: 5.0 tons/acre Fuel Bed Depth: 6.0 feet



Anderson (1982) from Albini 1976

Fuel Classification: Shrubs


Fire Behavior Fuel Model 5: Litter grass and forbs with short shrubs
Total Fuel Load: 3.5 tons/acre Live Foliage Load: 2.0 tons/acre
Dead Fuel Load: 1.0 tons/acre Fuel Bed Depth: 2.0 feet



Anderson (1982) from Albini 1976

Fuel Classification: Shrubs


Fire Behavior Fuel Model 6: Flammable shrub foliage (needs moderate winds)
Total Fuel Load: 6.0 tons/acre Live Foliage Load: 0.0 tons/acre
Dead Fuel Load: 1.5 tons/acre Fuel Bed Depth: 2.5 feet



Anderson (1982) from Albini 1976

Fuel Classification: Shrubs


Fire Behavior Fuel Model 7: Surface and shrub strata burn with equal ease
Total Fuel Load: 4.9 tons/acre Live Foliage Load: 0.4 tons/acre
Dead Fuel Load: 1.1 tons/acre Fuel Bed Depth: 2.5 feet



Anderson (1982) from Albini 1976

Fuel Classification: Timber



Fire Behavior Fuel Model 8: Slow moving ground fires – need severe weather
Total Fuel Load: 5.0 tons/acre Live Foliage Load: 0.0 tons/acre
Dead Fuel Load: 1.5 tons/acre Fuel Bed Depth: 0.2 feet



Anderson (1982) from Albini 1976

Fuel Classification: Timber


Fire Behavior Fuel Model 9: Faster moving ground fires and some torching
Total Fuel Load: 3.5 tons/acre Live Foliage Load: 0.0 tons/acre
Dead Fuel Load: 2.9 tons/acre Fuel Bed Depth: 0.2 feet



Anderson (1982) from Albini 1976

Fuel Classification: Timber


Fire Behavior Fuel Model 10: High intensity surface and ground fires
Total Fuel Load: 12.0 tons/acre Live Foliage Load: 2.0 tons/acre
Dead Fuel Load: 3.0 tons/acre Fuel Bed Depth: 1.0 feet



Anderson (1982) from Albini 1976

Fuel Classification: Logging Slash


Fire Behavior Fuel Model 11: Fires active in slash and herbaceous fuels
Total Fuel Load: 11.5 tons/acre Live Foliage Load: 0.0 tons/acre
Dead Fuel Load: 1.5 tons/acre Fuel Bed Depth: 1.0 feet



Anderson (1982) from Albini 1976

Fuel Classification: Logging Slash

Fire Behavior Fuel Model 12: Rapid high intensity fires
Total Fuel Load: 34.6 tons/acre Live Foliage Load: 0.0 tons/acre
Dead Fuel Load: 4.0 tons/acre Fuel Bed Depth: 2.3 feet



Anderson (1982) from Albini 1976

Fuel Classification: Logging Slash

Fire Behavior Fuel Model 13: Continuous layer of slash
 Total Fuel Load: 58.1 tons/acre Live Foliage Load: 0.0 tons/acre
 Dead Fuel Load: 7.0 tons/acre Fuel Bed Depth: 3.0 feet

Anderson (1982) from Albini 1976

Fuel Classification: Fuel Models

Given the 13, why do we also use the 40 fire behavior fuel models?

The original 13 were developed to work under severe fire periods of the fire season.

The additional 40 were developed to enable accurate prediction of fire spread outside the severe period of the fire season.

Additional fuel models in the 40 also included: high humidity areas, barren areas, and more forest litter complexes

Pyne et al (Intro. Wildland Fire) Chapter 3

Fuel Classification: The 40

The 40 fuel model system brought in a new naming convention:

- Nonburnable (NB)
- Grass (GR)
- Grass Shrub (GS)
- Shrub (SH)
- Timber Understory (TU)
- Timber Litter (TL)
- Slash Blowdown (SB)

Fuel type	Fuel model number block	Used in original or new set	Reserved for future standard fuel models	Available for custom fuel models
	1-13	1-13		
	14-89			14-89
NB	90-99	91-93, 98-99 ^a	94-95	90, 96-97
GR	100-119	101-109	110-112	100, 113-119
GS	120-139	121-124	125-130	120, 131-139
SH	140-159	141-149	150-152	140, 153-159
TU	160-179	161-165	166-170	160, 171-179
TL	180-199	181-189	190-192	180, 193-199
SB	200-219	201-204	205-210	200, 211-219
	220-256			220-256

^a The gap in the NB numbering sequence is to retain fuel model numbers 98 as open water and 99 as "rock" (bare ground), as has been convention in FARSITE.

Each fuel type is also assigned a dead fuel extinction moisture (generally assigned as humid or dry)

Scott et al (2005)

The 40: Non Burned Examples

FUEL MODEL NB1

FUEL MODEL NB 2

FUEL MODEL NB 3

FUEL MODEL NB 8

FUEL MODEL NB 9

Pictures from: Scott, Joe H.; Burgan, Robert E. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p.

Scott et al (2005)

The 40: Grass Examples

FUEL MODEL GR 1

FUEL MODEL GR 3

FUEL MODEL GR 2

FUEL MODEL GR 4

Scott et al (2005)

The 40: Grass Examples

FUEL MODEL GR 5

FUEL MODEL GR 7

FUEL MODEL GR 8


FUEL MODEL GR 6

FUEL MODEL GR 8


Scott et al (2005)

The 40: Grass-Shrub Examples


FUEL MODEL GS 1




FUEL MODEL GS 3



FUEL MODEL GS 2




FUEL MODEL GS 4




Scott et al (2005)

The 40: Shrub Examples


FUEL MODEL SH 1




FUEL MODEL SH 3




FUEL MODEL SH 5



FUEL MODEL SH 2




FUEL MODEL SH 4




Scott et al (2005)

The 40: Shrub Examples


FUEL MODEL SH 6




FUEL MODEL SH 8



FUEL MODEL SH 7




FUEL MODEL SH 9




Scott et al (2005)

The 40: Timber - Understory Examples


FUEL MODEL TU 1




FUEL MODEL TU 3




FUEL MODEL TU 5



FUEL MODEL TU 2




FUEL MODEL TU 4




Scott et al (2005)

The 40: Timber - Litter Examples


FUEL MODEL TL 1




FUEL MODEL TL 3



FUEL MODEL TL 5




FUEL MODEL TL 2




Scott et al (2005)

The 40: Timber - Litter Examples


FUEL MODEL TL 4




FUEL MODEL TL 7




FUEL MODEL TL 8



FUEL MODEL TL 6



FUEL MODEL TL 9



Scott et al (2005)

The 40: Timber - Blowdown Examples

FUEL MODEL SB 1

FUEL MODEL SB 2

FUEL MODEL SB 3

FUEL MODEL SB 4

Scott et al (2005)

Fuel Models: Selection

Clearly the fuel complex undergoes changes and selection of a given fuel model one day may not accurately predict fire behavior. In some locations, two fuel models may be needed to accurately represent the fire behavior.

To select your fuel model follow the general steps (RMRS GTR 153):

- Determine the general fire-carrying fuel type
- Select a fuel model which represents the dead fuel extinction moisture in your area (dry or humid)
- Compare the general depth, compactness and size of the fuel and the relative amount of live vegetation
- Do not restrict your selection by fuel model name or type
- Compare predicted fire behavior to be sure the predicted behavior agrees with expectations or observations

Fuel Models: Selection

NOTE: Other fuel model systems do exist – for example the National Fire Danger System Fuel Models (NFDRS)

FUEL MODEL TL 8

Fuel Model TL6

FUEL MODEL 9

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