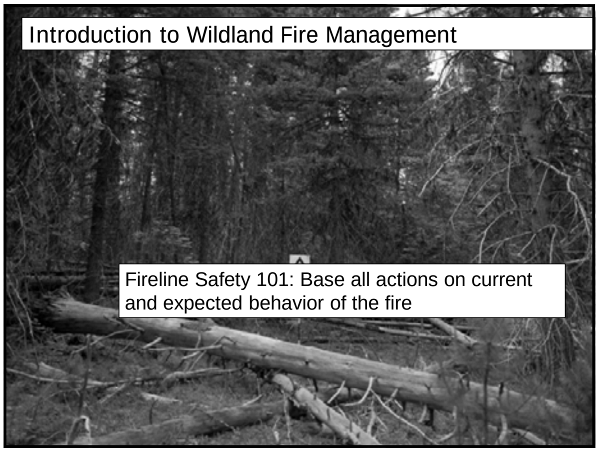
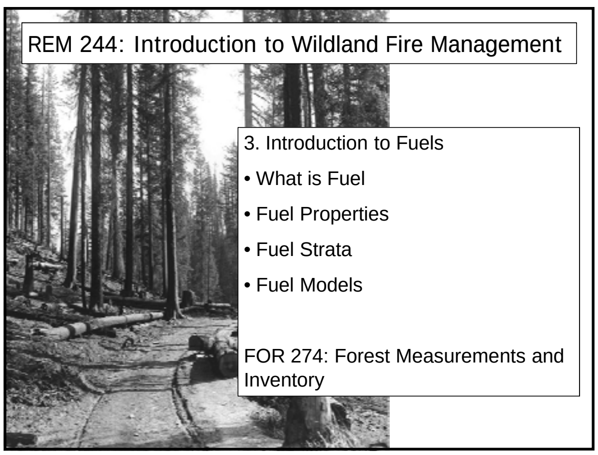
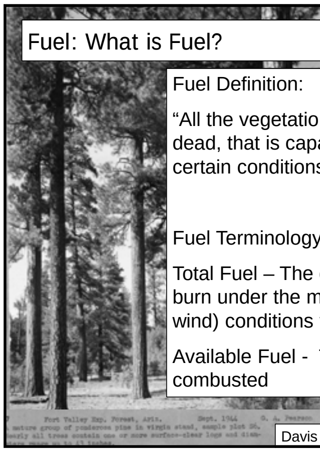

Introduction to Wildland Fire Management
Fireline Safety 101: Base all actions on current and expected behavior of the fire


REM 244: Introduction to Wildland Fire Management
3. Introduction to Fuels
• What is Fuel
• Fuel Properties
• Fuel Strata
• Fuel Models
FOR 274: Forest Measurements and Inventory



Fuel: What is Fuel?

Fuel Definition:

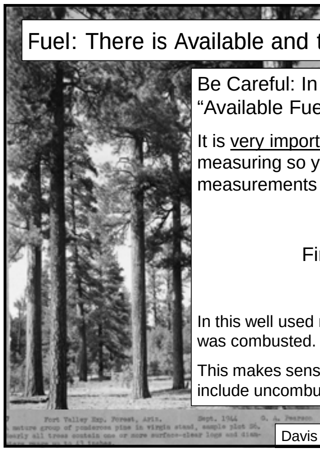
"All the vegetation cover, whether living or dead, that is capable of being burned under certain conditions."

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

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!

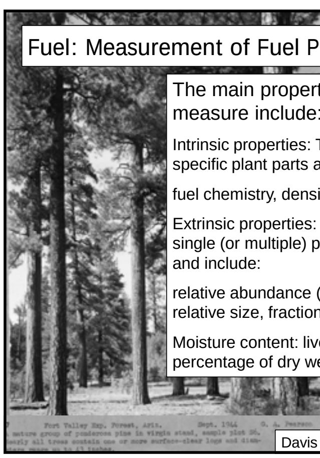
It is very important you know what you are measuring so you use the correct measurements in fire intensity models:

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?

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

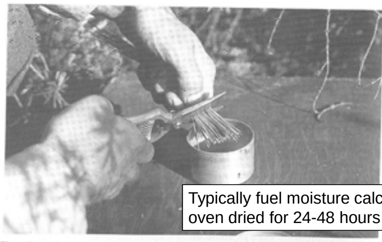
Moisture content: live and dead fuels – measured as a percentage of dry weight

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).

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

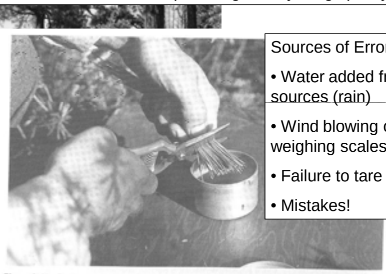
Figure 3.18. Fuel samples are clipped into a can, weighed, dried, and weighed again to determine moisture content. Photo by Melanie Miller. From Norum and Miller (1984).

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 3.18. 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).

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 ½” cookies

1000 hr Dead Fuels (3” + duff):

- Select logs between 3-8” and collect ½” cookies from at least 6” away from the end of the logs

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

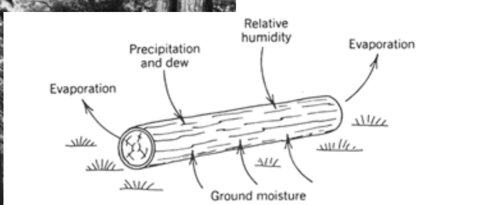


Figure 3.12. Factors influencing moisture exchange in wildland fuels.

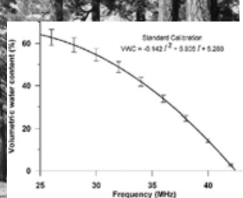
Pyne et al (Intro. Wildland Fire) Chapter 3

Fuel: Measurement of Fuel Properties

Measuring Fuel Moisture Content:

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

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



Fuel: Measurement of Fuel Properties

Live Fuels:

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

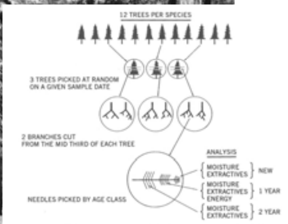


Figure 3.19. A foliage sampling scheme used for ponderosa pine and Douglas fir. From Philpot and Mutch (1971).

Steps:

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

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.

- Ignitability (the time it takes for ignition and ignition from one plant to the next)

- Sustainability (how well a fire will continue to burn after ignition and thus the rate of spread to the fire front)

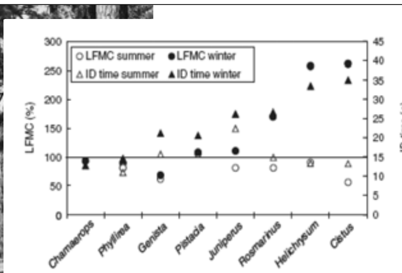
- Consumability (the speed at which a fire burns) and the % of mass or volume consumed by the fire. This is related to the fire intensity.

Flammability is dependent on moisture content, cellulose, lignin content, presence of volatiles, leaf thickness, surface area to volume ratio, particle size, and many more.

Anderson (1970) and Martin et al (2004)

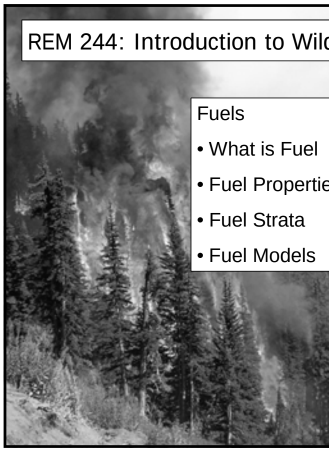
Fuel: Measurement of Fuel Properties

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



Anderson (1970) and Martin et al (2004)

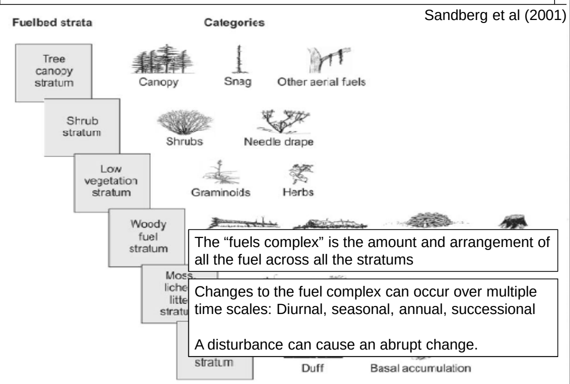
REM 244: Introduction to Wildland Fire Management



Fuels
- What is Fuel
- Fuel Properties
- Fuel Strata
- Fuel Models

Fuel Strata: Example Classifications

Sandberg et al (2001)

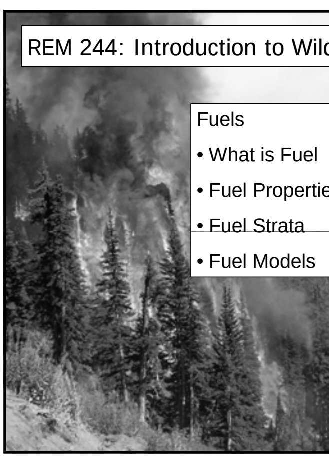


The "fuels complex" is the amount and arrangement of all the fuel across all the stratums

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

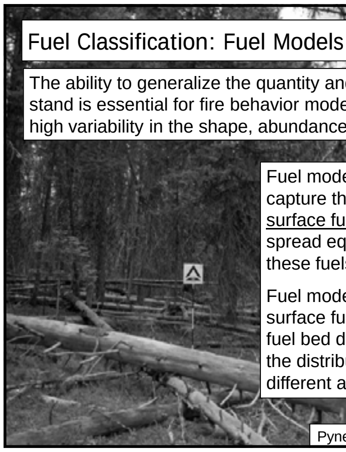
A disturbance can cause an abrupt change.

REM 244: Introduction to Wildland Fire Management



Fuels
- What is Fuel
- Fuel Properties
- Fuel Strata
- Fuel Models

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 ...

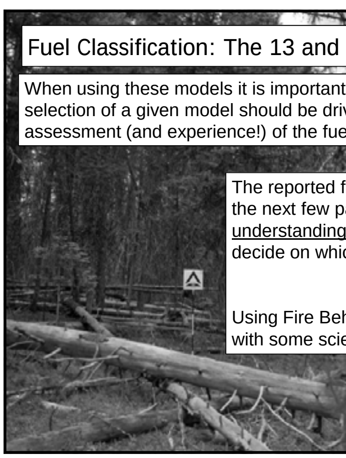
Using fuel models you can model fire spread without a detailed field inventory. The 13 and 40 fuel models are interchangeable.

Fuel model	Typical fuel complex	Surface-area-to-volume ratio(ft⁻¹)/ fuel loading (tons/acre) 1-h	10-h	100-h	Live	Fuel bed depth	Moisture of extinction dead fuels	Characteristic surface area-to-volume ratio	Packing ratio
						Ft	Percent	Ft^{-1}	
	Grass and grass-dominated								
1	Short grass (1 ft)	3,500/0.74	—	—	—	1.0	12	3,500	0.00106
2	Timber (grass and understory)	3,000/2.00	109/1.00	30/0.50	1,500/0.50	1.0	15	2,784	.00575
3	Tall grass (2.5 ft)	1,500/3.01	—	—	—	2.5	25	1,500	.00172
	Chaparral and shrub fields								
4	Chaparral (6 ft)	2,000/5.01	109/4.01	30/2.00	1,500/5.01	6.0	20	1,739	.00383
5	Brush (2 ft)	2,000/1.00	109/0.50	—	1,500/2.00	2.0	20	1,683	.00252
6	Dormant brush, hard-wood slash	1,750/1.50	109/2.50	30/2.00	—	2.5	25	1,564	.00345
7	Southern rough	1,750/1.13	109/1.87	30/1.50	1,500/0.37	2.5	40	1,562	.00280
	Timber litter								
8	Closed timber litter	2,000/1.50	109/1.00	30/2.50	—	.2	30	1,889	.03594
9	Hardwood litter	2,500/2.92	109/0.41	30/0.15	—	.2	25	2,484	.02500
10	Timber (litter and understory)	2,000/3.01	109/2.00	30/5.01	1,500/2.00	1.0	25	1,764	.01725
	Slash								
11	Light logging slash	1,500/1.50	109/4.51	30/5.51	—	1.0	15	1,182	.01653
12	Medium logging slash	1,500/4.01	109/14.03	30/16.53	—	2.3	20	1,145	.02156
13	Heavy logging slash	1,500/7.01	109/23.04	30/28.05	—	3.0	25	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

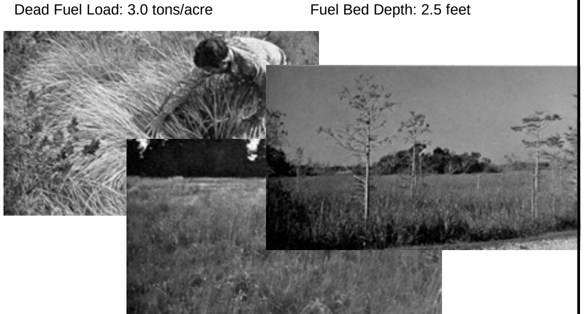
Total Fuel Load: 4.0 tons/acre
Live Foliage Load: 0.5 tons/acre
Dead Fuel Load: 2.0 tons/acre
Fuel Bed Depth: 1.0 feet

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

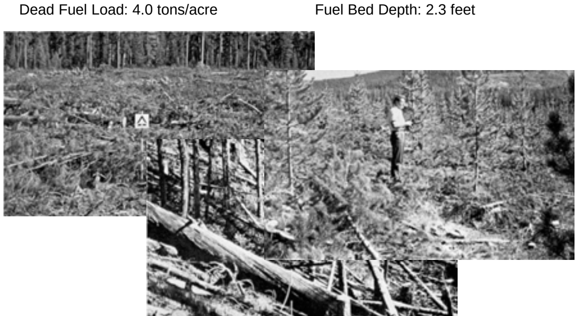
Anderson (1982) from Albini 1976

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

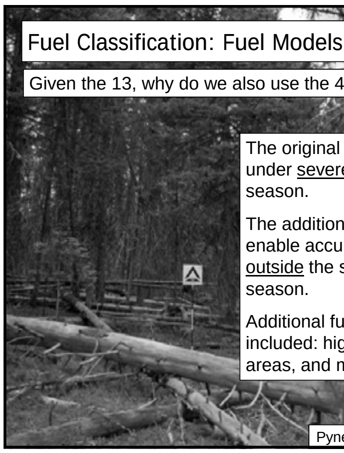
Total Fuel Load: 58.1 tons/acre — Live Foliage Load: 0.0 tons/acre

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)

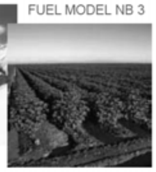
Scott et al (2005)

The 40: Non Burned Examples

FUEL MODEL NB1

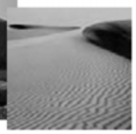
FUEL MODEL NB 2

FUEL MODEL NB 3



FUEL MODEL NB 8

FUEL MODEL NB 9

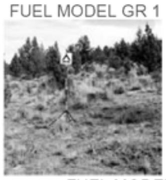


Pictures from: Scott, Joe H.; Burgan, Robert E. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p.

Scott et al (2005)

The 40: Grass Examples

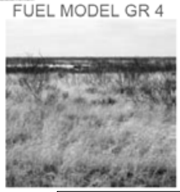
FUEL MODEL GR 1



FUEL MODEL GR 3

FUEL MODEL GR 2

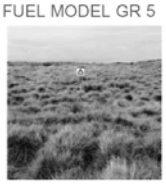
FUEL MODEL GR 4



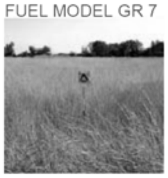
Scott et al (2005)

The 40: Grass Examples

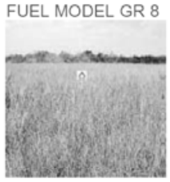
FUEL MODEL GR 5



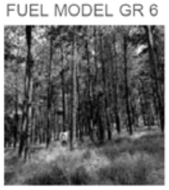
FUEL MODEL GR 7



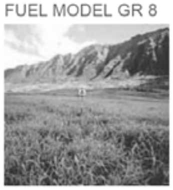
FUEL MODEL GR 8



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

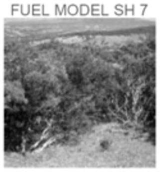
Scott et al (2005)

The 40: Shrub Examples

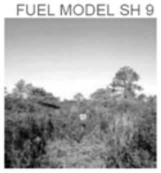
FUEL MODEL SH 6

FUEL MODEL SH 8

FUEL MODEL SH 7



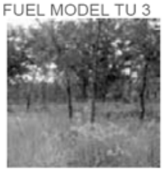
FUEL MODEL SH 9



Scott et al (2005)

The 40: Timber - Understory Examples

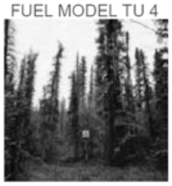
FUEL MODEL TU 1



FUEL MODEL TU 3

FUEL MODEL TU 5

FUEL MODEL TU 2



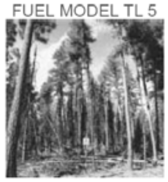
FUEL MODEL TU 4

Scott et al (2005)

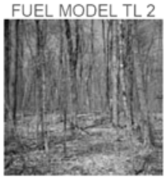
The 40: Timber - Litter Examples

FUEL MODEL TL 1

FUEL MODEL TL 3



FUEL MODEL TL 5

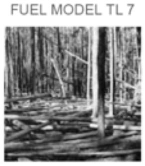


FUEL MODEL TL 2

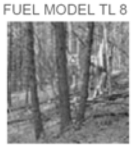
Scott et al (2005)

The 40: Timber - Litter Examples

FUEL MODEL TL 4

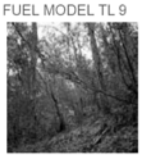


FUEL MODEL TL 7



FUEL MODEL TL 8

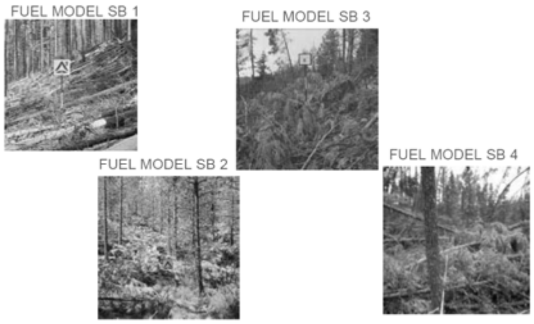
FUEL MODEL TL 6



FUEL MODEL TL 9

Scott et al (2005)

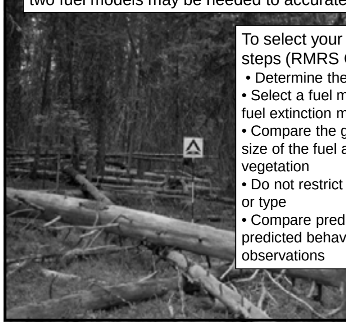
The 40: Timber - Blowdown Examples



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)