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FORECAST GUIDELINES FOR FIRE WEATHER AND FORECASTERS -- HOW NIGHTTIME HUMIDITY AFFECTS WILDLAND FUELS

David W. Goens

Weather Service Office
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David W. Goens
Weather Service Office
Missoula, Montana
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This publication has been reviewed
and is approved for publication by
Scientific Services Division,
Western Region.

Ken Mielke

Ken Mielke, Acting Chief
Scientific Services Division
Salt Lake City, Utah

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I. INTRODUCTION

The forecasting of meteorological elements for the Fire Weather Program presents the meteorologist with a special challenge. In order to make his/her forecast beneficial to the user, it must be presented in terms that are meaningful. When forecasting humidity, especially at night, the forecaster should be cognizant of the effects of humidity on the wildland fuel complex. Some fire weather offices have adopted an adjective rating system in order to describe to users the effects of humidity on wildland fuel. For example, a nighttime humidity recovery rating such as poor or good is often used. Unfortunately, such subjective ratings may have different meanings to different forecasters and wildland managers. Unless the forecaster understands the relationship between relative humidity and fuel moisture, he/she should use caution when assigning adjective ratings to forecast elements. This paper will outline how relative humidity, especially at night, affects different wild land fuels. In so doing, hopefully the field fire weather forecaster can make his/her forecast more useful to the wild land manager. More complete information on fuels and the effects of humidity on fuel moisture can be found in the National Wildfire Coordinating Group (NWCG) S-390 Fire Behavior Course.

The fuel component of the wildland fire environment has been modeled by fire scientists. Fuel models are comprised of woody and herbaceous elements of distinctive size classes. Some fuel models are composed of only dead fuels; others have a live component. This paper will focus on the relationship between dead fuels and short-term changes in relative humidity. In addition, fuel models are categorized broadly by major component groups, specifically: grass, shrub, timber, and slash. Unfortunately, there are two similar but distinct fuel model sets used by fire management and forestry officials. Forecasters must be familiar with both sets of fuel models used by wildland managers.

II. FUEL MODELS

A. The first set of models is the one outlined by Deeming, et al. (1971) in the publication on the National Fire Danger Rating System (NFDRS). This set of twenty models is commonly referred to as the NFDRS model. Most fire weather forecasters deal with the NFDRS system routinely.

Normally, any fire weather district may be adequately described by two or three of these models. The forecaster must become familiar with which models are used in his/her particular district.

B. The second set of models is best described as the Fire Behavior Prediction System model as illustrated by Anderson (1982). These models are used by the prescribed fire manager and the fire behavior analyst in planning for prescribed burning and wildfire control. These models will be referred to as the FBA models. There are thirteen FBA fuel models. Forecasters will be exposed to these models when on an on site fire assignment, or when forecasting for a prescribed fire.

The NFDRS and FBA models are related but have some significant differences. Figure 1 illustrates how these two systems may be cross referenced.

On a day-to-day basis, managers are concerned with the threat of an initiating fire. Most initiating fires begin in the smaller size classes of fuels. For both NFDRS and FBA systems, the size classes of fuel are the same and are referred to in "Time Lag" categories. The time lag concept is poorly understood by most forecasters. It is defined in various publications, specifically Fosberg (1977). Briefly, it relates to the amount of time it takes for a specific size class of fuel to respond to a change in its environmental equilibrium moisture content. Whenever a fuel element experiences a change in its environmental equilibrium moisture content, the moisture content of the fuel will respond correspondingly but at a slower rate. If, for example, a fuel element had a moisture content of 16% and the environmental moisture content changed and stabilized at a level that would eventually produce a fuel moisture of 7%, then a fuel element in the 1-hour category would respond by two-thirds in one hour. So, after one hour, the fuel moisture would be 10%. It would take a 10-hour fuel ten hours to respond in a like manner. The time-lag classes for dead fuels are shown in Table 1.

Time-lag Class	Fuel Diameter (inches)
1-hour	0 to 1/4
10-hour	1/4+ to 1
100-hour	1+ to 3
1000-hour	3+ to 8

Table 1. Dead Fuel Classes

The 10-hour fuels are the ones that fire weather forecasters are most familiar with. It is the size class represented by the NFDRS fuel stick that is weighed daily for fire danger calculations. Forecasters directly or indirectly forecast this stick weight each day in the NFDRS trend forecast.

The 1-hour fuels and the 10-hour fuels are the ones most critical in an initiating fire. They are also the ones that are most responsive to diurnal changes in humidity and, specifically, to nighttime humidity recovery.

III. FUEL MOISTURE

As previously discussed, fuels respond to changes in atmospheric moisture in a somewhat predictable manner. From here forward we will concern ourselves only with the 1-hour and 10-hour fuels, since their sensitivity to moisture changes are the most critical in the diurnal cycle.

The concept of "moisture of extinction" (Anderson, 1982) needs to be understood at this point. The moisture of extinction is simply defined as the fuel moisture level at which fire will no longer sustain itself. In other words, it is the point at which the fuel becomes too wet to burn. Table 2 shows the 13 FBA fuel models, along with a fuel complex description, and the moisture of extinction for each model. The values of the moisture of extinction take into account all size classes (if present) but are heavily weighted to the fine fuels (1/4" or less in diameter).

This concept now gives us a starting point to look at how changes in relative humidity (and corresponding changes in temperature) affect the wildland fuel complex. We will want to key on the moisture of extinction and how the fuels reach this moisture level.

IV. RELATIVE HUMIDITY VS. FINE FUEL MOISTURE

Relative humidity tends to follow a definite diurnal cycle during the typical western fire season. Highest values are normally observed around sunrise with the minimum temperature, lowest values during the late afternoon with the maximum temperature. Forecasters must be able to predict the relative humidity (and the temperature) for any specific time. With this information, fire managers may then be able to derive a fuel moisture for calculations of either a NFDRS index, or for a prediction of the behavior of a wild fire or a prescribed fire.

Fosberg and Deeming (1971) derived tables for field use for calculating both 1-hour and 10-hour fuel moisture. These are shown here as Tables 3 and 4.

Table 2 - Descriptions of FBA Fuel Models

Fuel model	Typical fuel complex	Fuel loading 1 hour	10 hours	100 hours	Live	Fuel bed depth	Moisture of extinction dead fuels
		Tons/acre				*Feet*	*Percent*
	Grass and grass-dominated						
1	Short grass (1 foot)	0.74	0.00	0.00	0.00	1.0	12
2	Timber (grass and understory)	2.00	1.00	.50	.50	1.0	15
3	Tall grass (2.5 feet)	3.01	.00	.00	.00	2.5	25
	Chaparral and shrub fields						
4	Chaparral (6 feet)	5.01	4.01	2.00	5.01	6.0	20
5	Brush (2 feet)	1.00	.50	.00	2.00	2.0	20
6	Dormant brush, hardwood slash	1.50	2.50	2.00	.00	2.5	25
7	Southern rough	1.13	1.87	1.50	.37	2.5	40
	Timber litter						
8	Closed timber litter	1.50	1.00	2.50	0.00	0.2	30
9	Hardwood litter	2.92	.41	.15	.00	.2	25
10	Timber (litter and understory)	3.01	2.00	5.01	2.00	1.0	25
	Slash						
11	Light logging slash	1.50	4.51	5.51	0.00	1.0	15
12	Medium logging slash	4.01	14.03	16.53	.00	2.3	20
13	Heavy logging slash	7.01	23.04	28.05	.00	3.0	25

Table 3 - One-hour timelag fuel moisture (percent)

State of weather[1/]			Relative humidity (percent)																				
	Code 0-1 Temperature	Code 2-9 Temperature	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–99	100
SUNNY	10–29		1	2	2	3	4	5	5	6	7	8	8	8	9	9	10	11	12	12	13	13	14
SUNNY	30–49		1	2	2	3	4	5	5	6	7	7	7	8	9	9	10	10	11	12	13	13	13
SUNNY	50–69		1	2	2	3	4	5	5	6	6	7	7	8	8	9	9	10	11	12	12	12	13
SUNNY	70–89		1	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	10	11	12	12	13
SUNNY	90–109		1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	13
SUNNY	109+		1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	13
CLOUDY		10–29	1	2	4	5	5	6	7	8	9	10	11	12	12	14	15	17	19	22	25	25+	25+
CLOUDY		30–49	1	2	3	4	5	6	7	8	9	9	11	11	12	13	14	16	18	21	24	25+	25+
CLOUDY		50–69	1	2	3	4	5	6	6	8	8	9	10	11	11	12	14	16	17	20	23	25+	25+
CLOUDY		70–89	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13	15	17	20	23	25+	25+
CLOUDY		90–109	1	2	3	3	4	5	6	7	8	9	9	10	10	11	13	14	16	19	22	25	25+
CLOUDY		109+	1	2	2	3	4	5	6	6	8	8	9	9	10	11	12	14	16	19	21	24	25+

Table 4 - Ten-hour timelag fuel moisture (percent)

State of weather			Relative humidity (percent)																				
	Code 0-1 Temperature	Code 2-9 Temperature	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–99	100
SUNNY	10–29		1	2	4	5	6	6	7	8	9	9	10	11	12	13	14	14	15	16	17	18	20
SUNNY	30–49		1	2	3	5	6	6	7	8	9	9	10	11	12	12	13	14	15	16	17	18	20
SUNNY	50–69		1	2	3	4	5	6	7	8	8	9	10	11	11	12	13	13	14	15	16	17	19
SUNNY	70–89		1	1	3	4	5	5	6	7	8	8	9	10	11	12	12	13	14	14	16	16	18
SUNNY	90–109		1	1	3	4	4	5	6	7	8	8	9	10	11	11	12	12	13	13	15	16	18
SUNNY	109+		1	1	3	3	4	5	6	7	7	8	9	10	10	11	11	12	13	13	15	15	17
CLOUDY		10–29	1	2	5	6	7	8	9	10	11	12	13	14	15	17	18	20	23	25+	25+	25+	25+
CLOUDY		30–49	1	2	5	6	7	8	9	10	11	12	13	14	15	16	18	20	23	25	25+	25+	25+
CLOUDY		50–69	1	2	4	5	6	7	8	9	10	11	13	13	14	16	17	19	22	24	25+	25+	25+
CLOUDY		70–89	1	2	4	5	6	7	8	9	10	11	12	13	14	15	16	18	21	24	25+	25+	25+
CLOUDY		90–109	1	2	3	4	5	7	8	9	10	11	11	12	13	14	16	18	20	23	25+	25+	25+
CLOUDY		109+	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17	20	22	25	25+	25+

These tables show fuel moisture values for both sunny and cloudy conditions. These tables show what the steady-state fuel moisture would be given the state of the sky (cloudy or sunny), and the ambient temperature and relative humidity. For example, with sunny skies, temperature 75° and relative humidity 47%, the 1-hour fuel moisture would reach a steady-state fuel moisture value of 7%. The portion for cloudy skies may be used for nighttime conditions as well. It has been used in this manner for a number of years and taught at the I-590 Fire Behavior Analyst Course, National Advanced Resource Technology Center, Marana, Arizona. This is meant to be a field guide, and both experience and later research have proven the tables to be quite accurate. They will provide valuable guidance for our purposes.

V. NIGHTTIME HUMIDITY RECOVERY

Some forecasters in Rocky Mountain timber types have developed somewhat intuitive procedures for assigning adjective ratings to the rate and amount of change in relative humidity during the nighttime period. At this time there are no hard rules for assigning ratings, but the following ratings are offered for illustration.

Humidity Recovery Ratings

Rating	Definition
Poor	Humidity slow to increase, values may stay below 40 percent.
Fair	Humidity increases slowly, values may reach of 40 to 60 percent.
Good	Humidity increases at a nearly "normal"rate, values may reach 60 to 75 percent.
Excellent	Humidity increases at a normal or better rate, values exceed 75 percent.

Given the ambient humidity recovery, we need to systematically evaluate the fuel situation and see how different humidity values affect the moisture content of specific fuel models. This will help us devise an adjective rating system that may be more universally applicable.

Since the moisture of extinction is heavily weighted to the fine dead fuel component, we will use this portion of the complex to assess the humidity recovery impacts. Let me suggest the following "Fuel Moisture Recovery" adjective rating for any fuel model:

Fuel Moisture Recovery

Rating	Definition Humidity recovers to value that would produce:
Poor	Less than 50% of Moisture of Extinction
Fair	51% to 70% of Moisture of Extinction
Good	71% to 95% of Moisture of Extinction
Excellent	Greater than 95% of Moisture of Extinction

VI. APPLICATIONS

Tables 5 through 8 have been extracted from the Field Reference Guide developed for students attending the I-590 Fire Behavior Analyst Course. These tables have been modified to graphically display the fuel models with adjective ratings keyed to values of fuel moisture (%).

On a daily basis, the forecaster deals with the NFDRS fuel models and needs to be aware of the models represented in his/her area of responsibility. This may be determined by checking the AFFIRMS catalog (Helfman, Straub, & Deeming, 1987), or simply calling the land managers. Once the fuel model is determined, locate the proper table and study how different maximum humidity/minimum temperature levels affect the fuels.

Example:

NFDRS Fuel Model G

Moisture of Extinction = 25%

Minimum Temperature forecast = 45 F

Maximum Humidity forecast = 70%

Humidity Recovery Rating = Good

Fuel Moisture Recovery = Fair

In contrast, if the Fuel Model had been "A" with the same forecast of temperature and humidity, the Fuel Moisture Recovery would have been classified as Excellent.

When making site-specific forecasts for either a wild fire or a prescribed fire, forecasters may be dealing with FBA fuel models. Also, they may be asked to make time-specific forecasts of meteorological elements. In these situations, forecasters may not wish to use adjective descriptors, but they may be helpful as additional information to land managers.

The use of the tables are the same in either case.

Example:

FBA Fuel Model 4

Moisture of Extinction 20%

Temperature Forecast at 2 AM = 65 F

Humidity Forecast at 2 AM = 47%

Humidity Recovery Rating = Fair

Fuel Moisture Recovery = Poor

By studying the tables it is easy to note that fuels are more responsive to humidity than to temperature. Therefore, even though we must have both temperature and humidity to make an assessment of fine fuel moisture, the greatest effort should be directed toward an accurate humidity forecast.

VII. CONCLUSIONS

A good forecast is made up of a combination of meteorological elements, packaged in a manner that is meaningful to the users. Forecasters should use caution when forecasting other than pure meteorological elements. Humidity recovery may be interpreted differently by different fire management clients and, therefore, is not a pure meteorological element in the fire weather forecast.

A forecast product is always inherently better if the forecaster has an understanding of how his/her product impacts the user. This paper was presented to encourage fire weather forecasters to become familiar with one of the critical wildland fire parameters. By understanding the nighttime humidity-fuel moisture relationship, the forecaster can produce a more usable product by putting emphasis where emphasis is due.

The job of the forecaster is to forecast meteorological elements. The land manager is responsible for interpreting the impacts of the forecast.

Forecasters who choose to use the term "Humidity Recovery" along with an adjective rating should do so with caution. The adjective ratings used in this paper were for illustrative purposes only. Local research and coordination with client agencies should be completed before adopting any adjective rating system. If both an adjective rating and an actual numerical value are included in each nighttime humidity forecast, any confusion or false assumptions may be avoided.

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FBA 1
NFDRS A, L, S

NIGHT TIME 2000-0759

MOISTURE OF EXTINCTION 12%

RELATIVE HUMIDITY (PERCENT)

Dry Bulb Temperature (°F)	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100
10 - 29	1	2	4	5	5	6	7	8	9	10	11	12	12	14	15	17	19	22	25	25+	25+
30 - 49	1	2	3	4	5	6	7	8	9	9	11	11	12	13	14	16	18	21	24	25+	25+
50 - 69	1	2	3	4	5	6	6	8	8	9	10	11	11	12	14	16	17	20	23	25+	25+
70 - 89	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13	15	17	20	23	25+	25+
90 - 109	1	2	3	3	4	5	6	7	8	9	9	10	10	11	13	14	16	19	22	25	25+
109+	1	2	2	3	4	5	6	6	8	8	9	9	10	11	12	14	16	19	21	24	25+

FUEL MOISTURE RECOVERY   POOR   FAIR   GOOD   EXCELLENT

TABLE 5.

FUEL MODELS
FBA 2, 11
NFDRS C, T, K

NIGHT TIME 2000-0759

MOISTURE OF EXTINCTION 15%

RELATIVE HUMIDITY (PERCENT)

Dry Bulb Temperature (°F)	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100
10 - 29	1	2	4	5	5	6	7	8	9	10	11	12	12	14	15	17	19	22	25	25+	25+
30 - 49	1	2	3	4	5	6	7	8	9	9	11	11	12	13	14	16	18	21	24	25+	25+
50 - 69	1	2	3	4	5	6	6	8	8	9	10	11	11	12	14	16	17	20	23	25+	25+
70 - 89	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13	15	17	20	23	25+	25+
90 - 109	1	2	3	3	4	5	6	7	8	9	9	10	10	11	13	14	16	19	22	25	25+
109+	1	2	2	3	4	5	6	6	8	8	9	9	10	11	12	14	16	19	21	24	25+

FUEL MOISTURE RECOVERY   POOR   FAIR   GOOD   EXCELLENT

TABLE 6.

FBA 4, 5, 23
NFDRS B, J

NIGHT TIME 2000-0759

MOISTURE OF EXTINCTION 20%

RELATIVE HUMIDITY (PERCENT)

Dry Bulb Temperature (°F)	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100
10 - 29	1	2	4	5	5	6	7	8	9	10	11	12	12	14	15	17	19	22	25	25+	25+
30 - 49	1	2	3	4	5	6	7	8	9	9	11	11	12	13	14	16	18	21	24	25+	25+
50 - 69	1	2	3	4	5	6	6	8	8	9	10	11	11	12	14	16	17	20	23	25+	25+
70 - 89	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13	15	17	20	23	25+	25+
90 - 109	1	2	3	3	4	5	6	7	8	9	9	10	10	11	13	14	16	19	22	25	25+
109+	1	2	2	3	4	5	6	6	8	8	9	9	10	11	12	14	16	19	21	24	25+

FUEL MOISTURE RECOVERY — POOR — FAIR — GOOD — EXCELLENT

TABLE 7.

FUEL MODELS
FBA 3, 6, 7, 8, 9, 10, 13
NFDRS N, F, O, H, R, G, I

NIGHT TIME 2000-0759

MOISTURE OF EXTINCTION 25% OR GREATER

RELATIVE HUMIDITY (PERCENT)

Dry Bulb Temperature (°F)	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100
10 - 29	1	2	4	5	5	6	7	8	9	10	11	12	12	14	15	17	19	22	25	25+	25+
30 - 49	1	2	3	4	5	6	7	8	9	9	11	11	12	13	14	16	18	21	24	25+	25+
50 - 69	1	2	3	4	5	6	6	8	8	9	10	11	11	12	14	16	17	20	23	25+	25+
70 - 89	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13	15	17	20	23	25+	25+
90 - 109	1	2	3	3	4	5	6	7	8	9	9	10	10	11	13	14	16	19	22	25	25+
109+	1	2	2	3	4	5	6	6	8	8	9	9	10	11	12	14	16	19	21	24	25+

FUEL MOISTURE RECOVERY — POOR — FAIR — GOOD — EXCELLENT

TABLE 8.

PHYSICAL DESCRIPTION SIMILARITY CHART OF NFDRS AND FBA FUEL MODELS

NFDRS MODELS REALINED TO FUELS CONTROLLING SPREAD UNDER SEVERE BURNING CONDITIONS

NFDRS FUEL MODELS	FIRE BEHAVIOR FUEL MODELS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	
A W. ANNUALS	X													GRASS
L W. PERENNIAL	X													GRASS
S TUNDRA	X					3rd			2nd					GRASS
C OPEN PINE W/GRASS		X							2nd					GRASS
T SAGEBRUSH W/GRASS		X			3rd	2nd								GRASS
N SAWGRASS			X											GRASS
B MATURE BRUSH (6FT)				X										SHRUB
O HIGH POCOSIN				X										SHRUB
F INTER. BRUSH					2nd	X								SHRUB
Q ALASKA BLACK SPRUCE						X	2nd							SHRUB
D SOUTHERN ROUGH						2nd	X							SHRUB
H SRT-NDL CLSD. NORMAL DEAD								X						TIMBER
R HRWD. LITTER (SUMMER)								X						TIMBER
U W. LONG-NDL PINE									X					TIMBER
P SOUTH, LONG-NDL PINE									X					TIMBER
E HRWD. LITTER (FALL)									X					TIMBER
G SRT-NDL CLSD. HEAVY DEAD										X				TIMBER
K LIGHT SLASH											X			SLASH
J MED. SLASH												X		SLASH
I HEAVY SLASH													X	SLASH
	GRASS			SHRUB				TIMBER			SLASH			

FIGURE 1.

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