Development of fine dead fuel moisture field references for the Southeastern United States: SimpleFFMC

W. Matt Jolly, USFS, RMRS, Fire Sciences Laboratory, Missoula, MT

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Final Report

Abstract

Today's commonly-used fuel moisture field guides were developed decades ago without both the aide of recent technology and without extensive field verifications. As such, these guides often poorly predict fine dead fuel moisture in many areas, particularly those of the humid Southeastern states. Here we present the development a set of fuel moisture field guides that are tailored for use in these areas. We combined field sample collection with laboratory analyses to generate fuel moistures over a range of environmental conditions and modified a physical fuel moisture model to best reflect the influence of environmental conditions on fuel moisture dynamics. We then used this calibrated fuel moisture model to develop a new, highly simplified version of a complex, physically-based fuel moisture model. This new model, called SimpleFFMC, agreed well with the full model while reducing computation time by more than two orders of magnitude. We used this new model to generate field reference tables similar to those found in the Incident Response Pocket Guide (IRPG) but that are more dynamic and that reflect changes in precipitation, humidity and sunshine. These tables will allow the proper calculation of fine dead fuel moisture as a function of temperature, humidity, solar radiation and rainfall. Correlations between the simple and complex models were very high and simple model estimates were unbiased. Finally, we leveraged this new model to create a simple, web-based mobile interface for fuel moisture calculations to simplify fuel moisture calculations in the field. This new model represent a paradigm shift in fine fuel moisture estimation and it will soon be integrated into all computer-based and paper fire behavior field references.

Introduction

The amount of moisture contained in wildland fuels is extremely important in determining expected fire behaviors. Fire behavior prediction models utilize fuel moisture to determine both fire intensity and the heat required to bring the fuel ahead of a spreading fire up to ignition temperature. The moisture content of the fine fuels is of primary importance in moving a fire from point to point. Fuel moisture values are commonly derived using simple tables and field measured weather parameters. The current set of tables was published in 1983 (See example in Figure 1). These tables were found sufficient for most purposes but they have some problems relating to humid conditions of the Southeastern United States. However, new and improved fuel moisture models have been developed that have been shown to better predict daily and seasonal changes in fuel moisture [1]. These models would allow the development of a new set of fine dead fuel moisture tables that are more applicable to a wider range of fuel types. Doing so would require development of a suitable dataset to test and calibrate the model to local conditions.

The purpose of this project is to develop a relevant set of tools that can be used to accurately predict fine dead fuel moisture dynamics in the Southern United States. Fuel moistures derived from these tools would be consistent with existing systems and compatible for use in fire behavior prediction tools such as BehavePlus. These updated fine dead fuel moisture tables will dramatically improve the ability to forecast wildland fire behavior for both wildfire and prescribed fire in the Region.

Table 1 – Reference fine dead fuel moisture table from the Incident Response Pocket Guide (NFES1077)

Dry Bulb Temp (°F)	Relative Humidity (Percent)																				
	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	2	3	4	5	5	6	7	8	8	8	9	9	10	11	12	12	13	13	**14**
30-49	1	2	2	3	4	5	5	6	7	7	7	8	9	9	10	10	11	12	13	13	**13**
50-69	1	2	2	3	4	5	5	6	6	7	7	8	8	9	9	10	11	12	12	12	**13**
70-89	1	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	10	11	12	12	**13**
90-109	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	**13**
109+	**1**	**1**	**2**	**2**	**3**	**4**	**4**	**5**	**6**	**7**	**7**	**8**	**8**	**8**	**9**	**10**	**10**	**11**	**12**	**12**	**12**

Table 2 – Fine dead fuel moisture corrections table from the Incident Response Pocket Guide (NFES1077)

UNSHADED – LESS THAN 50% SHADING OF SURFACE FUELS																			
Aspect	%Slope	0800>			1000>			1200>			1400>			1600>			**1800>**		
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	**A**
N	0-30	2	3	4	1	1	1	0	0	1	0	0	1	1	1	1	2	3	**4**
	31+	3	4	4	1	2	2	1	1	2	1	1	2	1	2	2	3	4	**4**
E	0-30	2	2	3	1	1	1	0	0	1	0	0	1	1	1	2	3	4	**4**
	31+	1	2	2	0	0	1	0	0	1	1	1	2	2	3	4	4	5	**6**
S	0-30	2	3	3	1	1	1	0	0	1	0	0	1	1	1	1	2	3	**3**
	31+	2	3	3	1	1	2	0	1	1	0	1	1	1	1	2	2	3	**3**
W	0-30	2	3	4	1	1	2	0	0	1	0	0	1	0	1	1	2	3	**3**
	31+	4	5	6	2	3	4	1	1	2	0	0	1	0	0	1	1	2	**2**
SHADED – 50% OR MORE SHADING OF SURFACE FUELS																			
N	all	4	5	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	**5**
E	all	4	4	5	3	4	5	3	3	4	3	4	4	3	4	5	4	5	**6**
S	all	4	4	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	**5**
W	**all**	**4**	**5**	**6**	**3**	**4**	**5**	**3**	**3**	**4**	**3**	**3**	**4**	**3**	**4**	**5**	**4**	**4**	**5**

Methods

Field Sampling and Laboratory Analysis

A total of 25 different surface litter and fine fuel samples were collected across seven Southeastern US states (Figure 1). At each location, approximately 2 lbs. of fuel were collected and shipped to the Missoula Fire Sciences Laboratory. These samples underwent a series of artificial moisture content manipulations in an environmental chamber. The environmental chamber allows the absolute control of temperature and relative humidity over a large range of conditions. Fuels were subjected to 12 unique environmental conditions: three unique temperatures (50, 69.8 and 98.6 degrees Fahrenheit) and four unique relative humidity values (20%,60%,80% and 95%). Fuels were allowed to equilibrate to these fixed conditions for 72 hours and then they were weighed. After all 12 set point measurements were completed, fuels were then oven dried to determine moisture content at each set point. A summary of the moisture content of each fuel for each set point is given in Table 3. These moisture contents were then used to calibrate the Nelson dead fuel moisture model [1] saturation vapor pressure function (Figure 2). The calibrated Nelson model accounted for 92% of the variation in all the moisture contents measured in our laboratory environmental chamber trials.

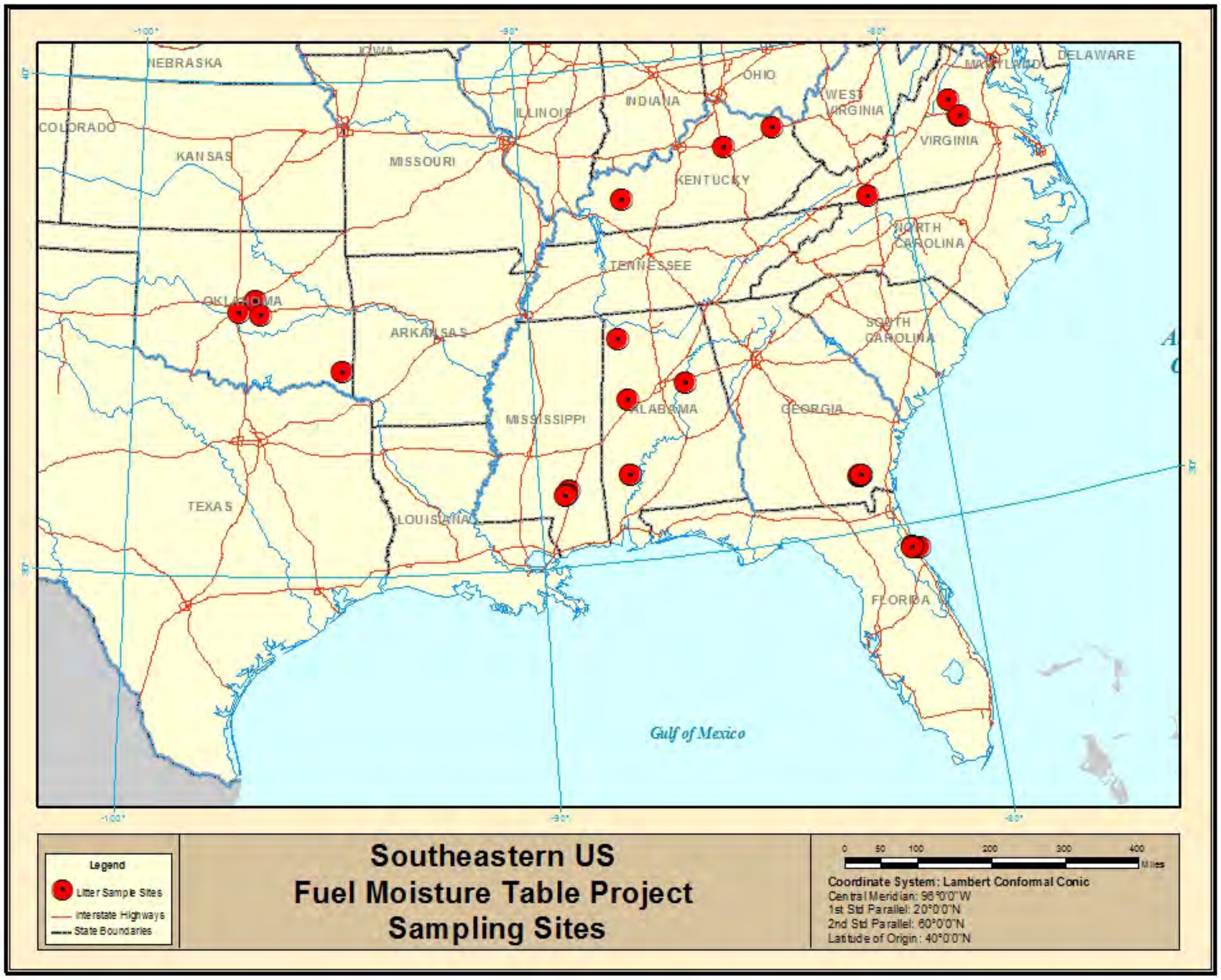


Figure 1 – Locations of surface litter and fine fuel sample sites across the Southeastern United States.

Table 3 – Fuel moistures across a range of Southeastern US fuel types. Fuel moisture values were derived using field-collected fuels exposed to a four humidity levels and three air temperatures that represent a the broad, typical environmental conditions of these states.

	Set RH (%)		20			60			80			95	
	Set Temp (°C)	10	21	37	10	21	37	10	21	37	10	21	37
	Actual Temp/RH	11.1/19.5	22/17.5	34.5/15.8	11.4/55	22.3/53.7	34.2/52.4	11.7/75.2	22.2/73.6	34.4/72.6	11.8/90.7	22.4/88.1	37.4/86
Alabama	Sample Type*	7.02	5.63	4.33	10.30	9.50	9.10	15.27	14.62	14.12	19.27	19.07	17.69
1	N	6.77	4.62	4.29	10.23	9.74	9.24	15.11	14.58	14.21	19.80	19.47	17.66
2	N,L	7.00	5.47	4.16	9.85	9.19	8.75	15.66	14.54	13.65	18.60	18.60	17.29
3	N,L	7.30	6.80	4.53	10.83	9.57	9.32	15.35	14.83	14.32	19.40	19.14	18.14
Florida		6.41	5.39	4.15	10.01	9.28	8.79	15.34	14.63	14.01	19.53	19.17	17.82
4	N	6.86	5.67	4.26	10.40	9.69	9.10	15.90	14.94	14.22	20.09	19.39	17.97
5	O	5.77	4.98	3.93	9.17	8.65	8.06				19.00	18.48	16.78
6	N,L	6.76	5.77	4.37	10.54	9.94	9.34	16.06	15.24	14.84	20.28	20.08	18.89
7	G	6.25	5.15	4.04	9.93	8.82	8.64	14.07	13.70	12.96	18.75	18.75	17.65
Georgia		6.83	5.37	4.27	9.86	9.35	8.89	15.03	14.49	13.94	19.14	18.92	17.79
8	N,L	6.82	5.54	4.26	10.02	9.38	8.96	14.89	14.42	13.82	18.98	18.98	17.91
9	N	6.05	5.17	4.04	9.58	8.95	8.45	14.92	14.40	14.07	18.79	18.54	17.78
10	G	6.78	4.91	3.97	9.35	9.11	8.53	14.76	14.05	13.33	18.69	18.22	16.59
11	N,L	7.65	5.87	4.80	10.50	9.96	9.61	15.82	15.27	14.55	20.11	19.93	18.86
Kentucky		7.26	6.05	4.81	9.89	9.65	9.11	15.06	14.69	14.08	18.58	19.61	19.38
12	L	8.43	6.63	5.12	10.54	10.54	9.94	16.46	15.79	14.75	19.88	19.88	18.07
13	G,N	6.08	5.47	4.50	9.25	8.76	8.27	12.25	12.50	12.75	17.27	19.34	20.68
Mississippi		6.76	5.67	4.28	9.83	9.48	8.95	14.13	13.90	13.79	18.87	18.77	17.50
14	N,L	6.53	5.63	4.05	9.68	9.46	8.67	14.35	13.90	13.67	18.24	18.02	16.67
15	N	6.53	5.15	3.95	9.45	8.93	8.33	13.91	13.91	13.91	17.35	18.21	18.21
16	L	6.88	5.96	4.36	10.32	9.63	9.52				19.72	19.50	18.12
17	G	7.11	5.93	4.74	9.88	9.88	9.29				20.16	19.37	17.00
Oklahoma		7.12	5.87	4.84	10.41	9.85	9.29	16.56	15.42	15.08	19.80	19.38	16.63
18	L	7.39	5.84	5.06	10.89	10.51	9.73	16.73	16.33	15.94	21.01	20.23	16.73
19	G	6.73	5.83	4.48	10.31	9.42	8.30				19.28	18.39	16.14
20	G	6.98	5.43	4.65	10.08	9.30	9.69	17.74	15.32	15.32	19.38	19.38	15.50
21	N,L	7.37	6.37	5.18	10.36	10.16	9.46	15.21	14.60	14.00	19.52	19.52	18.13
Virginia		7.93	6.48	4.99	10.80	10.39	9.55	15.62	15.25	14.45	19.99	19.56	17.28
22	L	8.70	7.73	5.80	11.59	11.59	9.90	16.75	16.26	14.78	21.26	20.29	16.43
23	N,L	8.05	6.49	4.92	10.96	10.29	9.84	15.60	15.37	14.68	20.13	20.13	18.12
24	N,L	7.57	6.01	4.70	10.18	9.92	9.27	14.75	14.21	13.67	19.06	18.54	16.97
25	N	7.38	5.71	4.52	10.48	9.76	9.17	15.40	15.16	14.67	19.52	19.29	17.62
Set Pt Avg		7.03	5.77	4.51	10.17	9.65	9.10	15.31	14.73	14.20	19.36	19.19	17.62
	*Primary litter type: N-Needle, L-Hardwood Leaf, G-Grass, O-Other (Palmetto)												

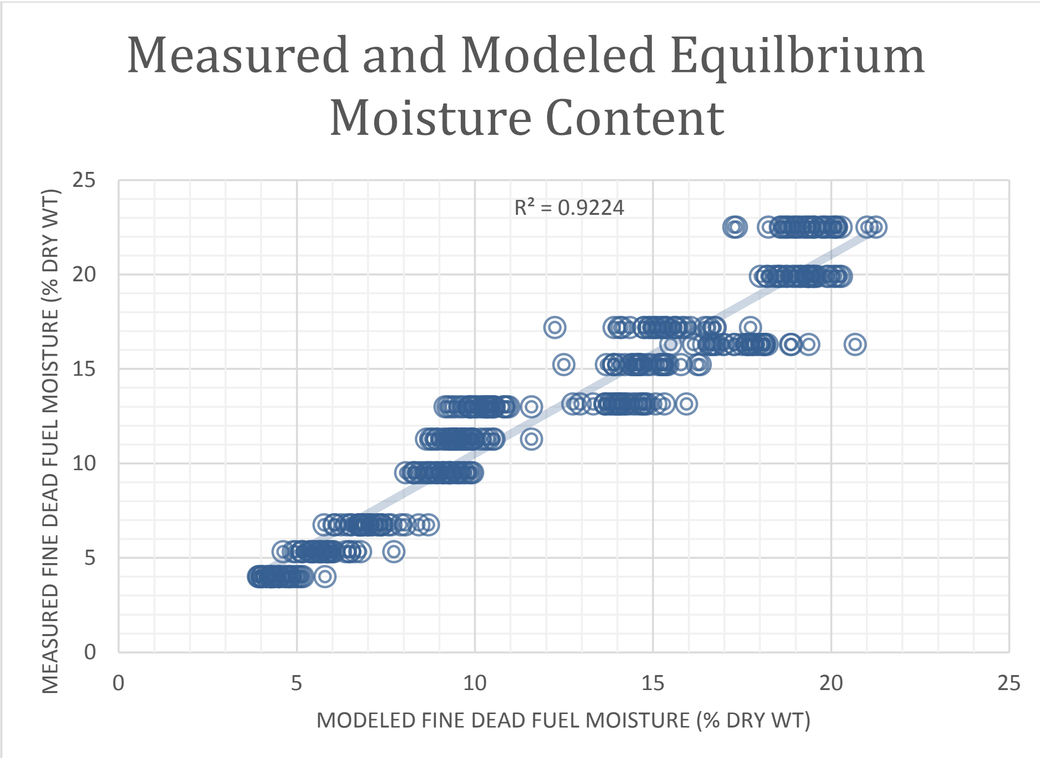


Figure 2 – Comparison of modeled fine dead fuel moisture at equilibrium to measure equilibrium moisture content across the range of fuel moistures generated using the condition chamber.

Field reference development

The Nelson dead fuel moisture model is a complex set of partial differential equations that account for the movement of water liquid and vapor through a porous media, such as a leaf or conifer needle. Our aim was to simplify this logic into a set of tables that can be used to estimate fine dead fuel moisture content in the field but that are consistent with the logic used in the full model. The model has already been extensively validated against field measurements (e.g. Figure 4), therefore we can use the modeled values as verification data for our simplified logic. For this project, we condensed the logic of fine dead fuel moisture calculations from partial differential equation to a simple linear model that calculates fine dead fuel moisture based on the measured fine dead fuel moisture from the previous time step plus corrections evaporation, moisture movement and rainfall (Figure 3). We subscribed to the principle of keeping things as simple as possible but while also maintaining close agreement with the modeled values from the fuel resolution Nelson model.

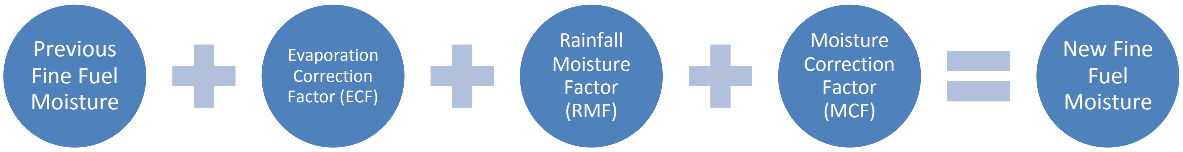


Figure 3 – Model for calculating fine dead fuel moisture.

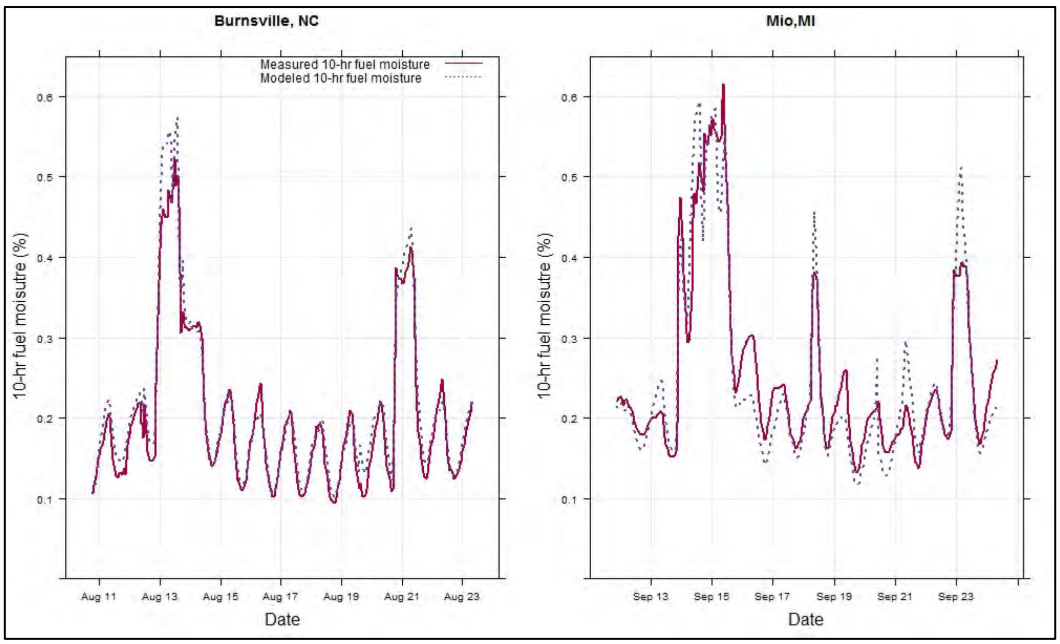


Figure 4 -- Comparison of modeled and measured fine dead fuel moisture for two sampling sites (From Nelson 2000).

Fine Dead Fuel Moisture Tables

The fuel moisture tables are meant to be used with hourly observations of fire weather in the field. These can be derived from handheld weather meters, belt weather kits or local RAWS observations. The calculation flowchart, all appropriate reference tables and a computation worksheet are given in the attached PDF to simplify distribution of the new tables. Any tables referred to as 'Reference Tables' are included in the PDF. The process for fuel moisture calculation is as follows:

1. Measure the air temperature and relative humidity and estimate the solar radiation and local rainfall, for tables, round all temp and rh values to the nearest 5 and solar radiation to the nearest 100.
   a. Use Reference Table 1 to estimate fuel Surface Temperature from measured air temperature and estimated solar radiation (Table 4 this document).

   b. Use Reference Table 2 to estimate equilibrium moisture content (EQMC) from estimated Surface Temperature and measured Relative Humidity (Table 5 this document).
   c. If this is the first observation, record EQMC as the starting fuel moisture.
2. If it rained over the last hour, look up the Rainfall Moisture Factor (RMF) (Reference Table 3) otherwise record 0 for the RMF (Table 7 this document).
3. If the fuel moisture from the previous hour is greater than 30%, look up the Evaporation Correction Factor (ECF) (Reference Table 3) otherwise record 0 for the ECF (Table 6 this document).
4. If it hasn't rained and the moisture content from the previous observation is less than 30%, Lookup the Moisture Correction Factor (MCF) from the Desorption tables (Reference Table 5) (Previous MC is greater than or equal to the EQMC value calculated in Step 3) or the Adsorption tables (Reference Table 6) (Previous MC is less than the current EQMC calculated in Step 3) (See Table 8 for example).
   a. Note: To use Tables 5 and 6, first determine whether you are in an desorption or adsorption phase, then find the table for the appropriate Previous MC value recorded on the datasheet and lookup the MCF based on the appropriate Surface Temperature and Relative Humidity.
5. Calculate the new fine fuel moisture content by adding the previous moisture content (or starting moisture content), the Rainfall Moisture Factor, the Moisture Correction Factor and the Evaporation Correction Factor: New FMC = Previous FMC + RMF + MCF + ECF***. If the new moisture content is greater than 60%, record 60% as the final moisture content.***

A flowchart of this process is given in Figure 5 and a complete worked example using hourly data from the St. Mark (West) RAWS station for a single day is given in Table 10. This example shows the impacts of the various mechanisms such as wetting and drying through both diffusion and evaporation.

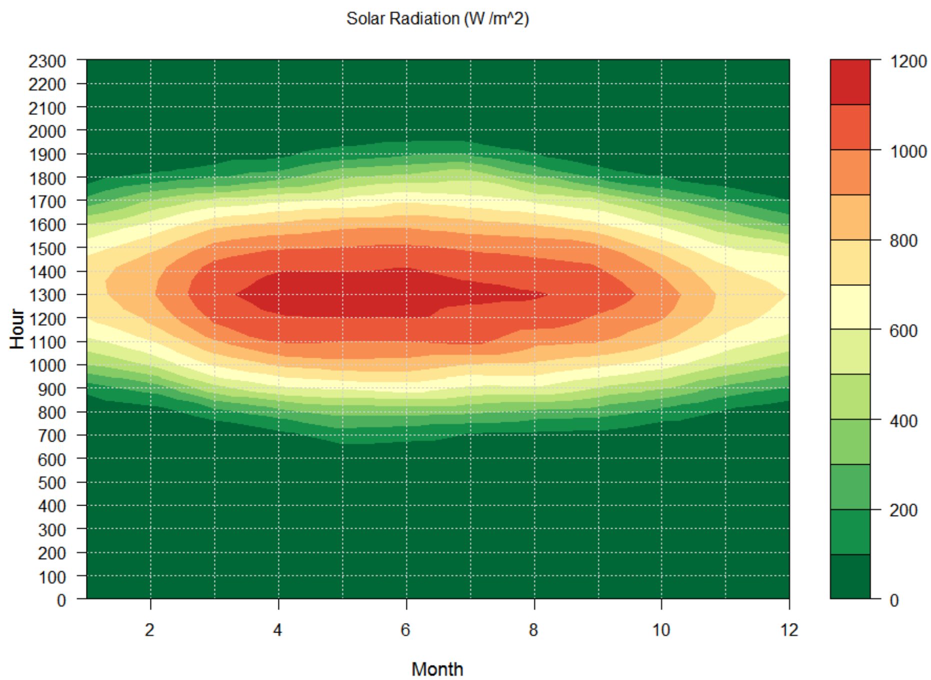


Figure 5 – Example solar radiation atlas for the Sanborn RAWS station in Wakulla Country, FL.

Table 4 – Fuel surface temperature as a function of solar radiation and measured air temperature.

		Solar Radiation (W/m2)														
Temperature (F)		***0 (Dark)***	***100***	***200***	***300***	***400***	***500***	***600***	***700***	***800***	***900***	***1000***	***1100***	***1200***	***1300***	***>1300***
	<15	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
	15	37	38	40	42	44	46	48	50	52	54	56	58	60	62	64
	20	41	43	45	47	49	51	53	55	57	59	60	62	64	66	68
	25	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73
	30	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77
	35	54	56	58	60	62	64	66	68	69	71	73	75	77	79	81
	40	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86
	45	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90
	50	67	69	71	73	75	76	78	80	82	84	86	88	90	92	94
	55	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
	60	75	77	79	81	83	85	87	89	91	93	95	97	99	101	103
	65	80	82	84	85	87	89	91	93	95	97	99	101	103	105	107
	70	84	86	88	90	92	94	96	98	100	102	104	106	108	109	111
	75	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116
	80	93	94	96	98	100	102	104	106	108	110	112	114	116	118	120
	85	97	99	101	103	105	107	109	111	113	115	116	118	120	122	124
	90	101	103	105	107	109	111	113	115	117	119	121	123	125	127	129
	95	105	107	109	111	113	115	117	119	121	123	125	127	129	131	133
	100	110	112	114	116	118	120	122	124	125	127	129	131	133	135	137
	105	114	116	118	120	122	124	126	128	130	132	134	136	138	140	142
	110	118	120	122	124	126	128	130	132	134	136	138	140	142	144	146
	115	123	125	127	129	131	133	134	136	138	140	142	144	146	148	150
	120	127	129	131	133	135	137	139	141	143	145	147	149	151	153	155
	>120	131	133	135	137	139	141	143	145	147	149	151	153	155	157	159

Table 5 – Equilibrium Moisture Content estimation table based on fuel Surface Temperature (Table 4) and relative humidity (%).

Equilibrium Moisture Content (%)																						
		Relative Humidity (%)																				
Surface Temperature (F)		**2**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**99**
	10	3	5	7	8	10	11	12	13	13	14	15	16	17	18	19	21	22	23	25	28	34
	15	3	5	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22	23	25	28	34
	20	3	5	6	8	9	10	11	12	13	14	15	15	16	17	19	20	21	23	25	28	34
	25	3	4	6	7	8	10	10	11	12	13	14	15	16	17	18	19	21	22	24	27	33
	30	3	4	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22	24	27	33
	35	3	4	6	7	8	9	10	11	12	13	13	14	15	16	17	19	20	22	24	27	33
	40	2	4	5	6	8	9	9	10	11	12	13	14	15	16	17	18	20	21	23	26	32
	45	2	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	21	23	26	32
	50	2	3	5	6	7	8	9	10	11	11	12	13	14	15	16	17	19	20	22	26	32
	55	2	3	5	6	7	8	8	9	10	11	12	13	14	15	16	17	18	20	22	25	31
	60	2	3	4	5	6	7	8	9	10	11	12	12	13	14	15	17	18	19	22	25	31
	65	2	3	4	5	6	7	8	9	9	10	11	12	13	14	15	16	17	19	21	24	31
	70	2	3	4	5	6	7	8	8	9	10	11	12	13	14	15	16	17	19	21	24	30
	75	1	2	4	5	6	6	7	8	9	10	10	11	12	13	14	15	17	18	20	23	30
	80	1	2	4	4	5	6	7	8	8	9	10	11	12	13	14	15	16	18	20	23	29
	85	1	2	3	4	5	6	7	7	8	9	10	11	11	12	13	14	16	17	19	22	29
	90	1	2	3	4	5	6	6	7	8	9	9	10	11	12	13	14	15	17	19	22	28
	95	1	2	3	4	5	5	6	7	8	8	9	10	11	12	13	14	15	16	18	21	28
	100	1	2	3	4	4	5	6	7	7	8	9	9	10	11	12	13	14	16	18	21	27
	105	1	2	3	3	4	5	6	6	7	8	8	9	10	11	12	13	14	15	17	20	26
	110	1	2	2	3	4	5	5	6	7	7	8	9	9	10	11	12	13	15	17	20	26
	115	1	1	2	3	4	4	5	6	6	7	8	8	9	10	11	12	13	14	16	19	25
	120	1	1	2	3	4	4	5	5	6	7	7	8	9	10	10	11	13	14	16	19	25
	125	1	1	2	3	3	4	5	5	6	6	7	8	8	9	10	11	12	13	15	18	24

Rainfall (inches)	Rainfall Moisture Factor (%)
0	0
0.01	8
0.02	15
0.03	19
0.04	22
0.05	25
0.06	26
0.07	28
0.08	29
0.09	29
0.1	30
0.11	30
0.12	30
0.13	31
>0.13	31

Table 6 – Rainfall moisture factor (RMF) as a function of hourly rainfall

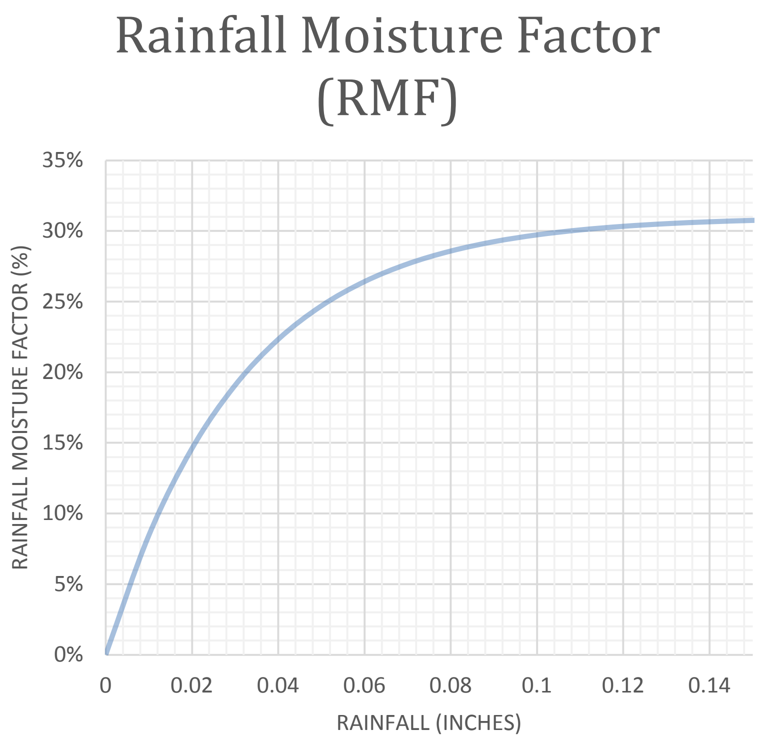


Figure 6 – Rainfall Moisture Factor (RMF) as a function of hourly measured rainfall.

Surface Temperature (F)	Evaporation Correction Factor (ECF) (%)
30	-2
35	-3
40	-3
45	-3
50	-3
55	-3
60	-4
65	-4
70	-4
75	-4
80	-5
85	-5
90	-6
95	-6
100	-6
105	-7
110	-7
115	-8
120	-8
125	-9
130	-9
135	-9
140	-9
145	-9

Table 7 – Evaporation correction factor as a function of fuel surface temperature.

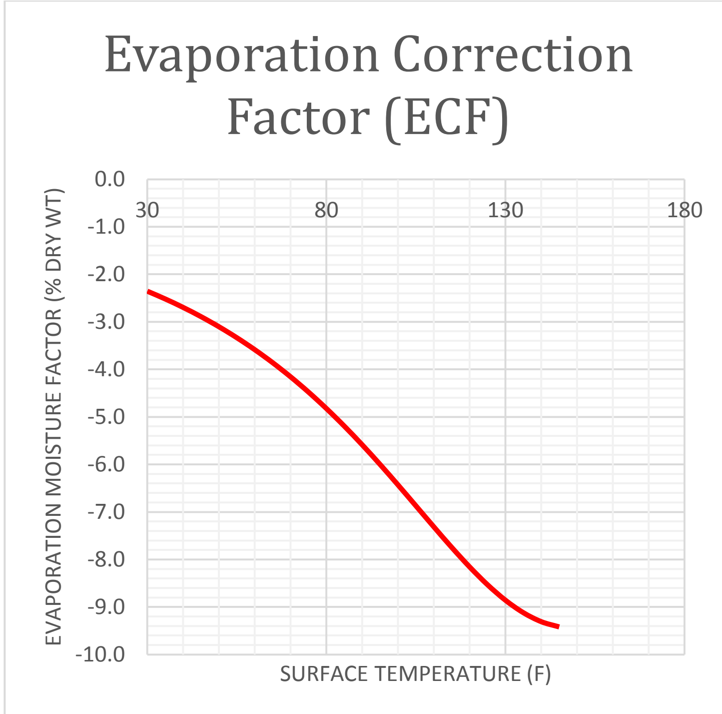


Figure 7 – Relationship between Evaporation Moisture Factor (EMF) and fuel surface temperature.

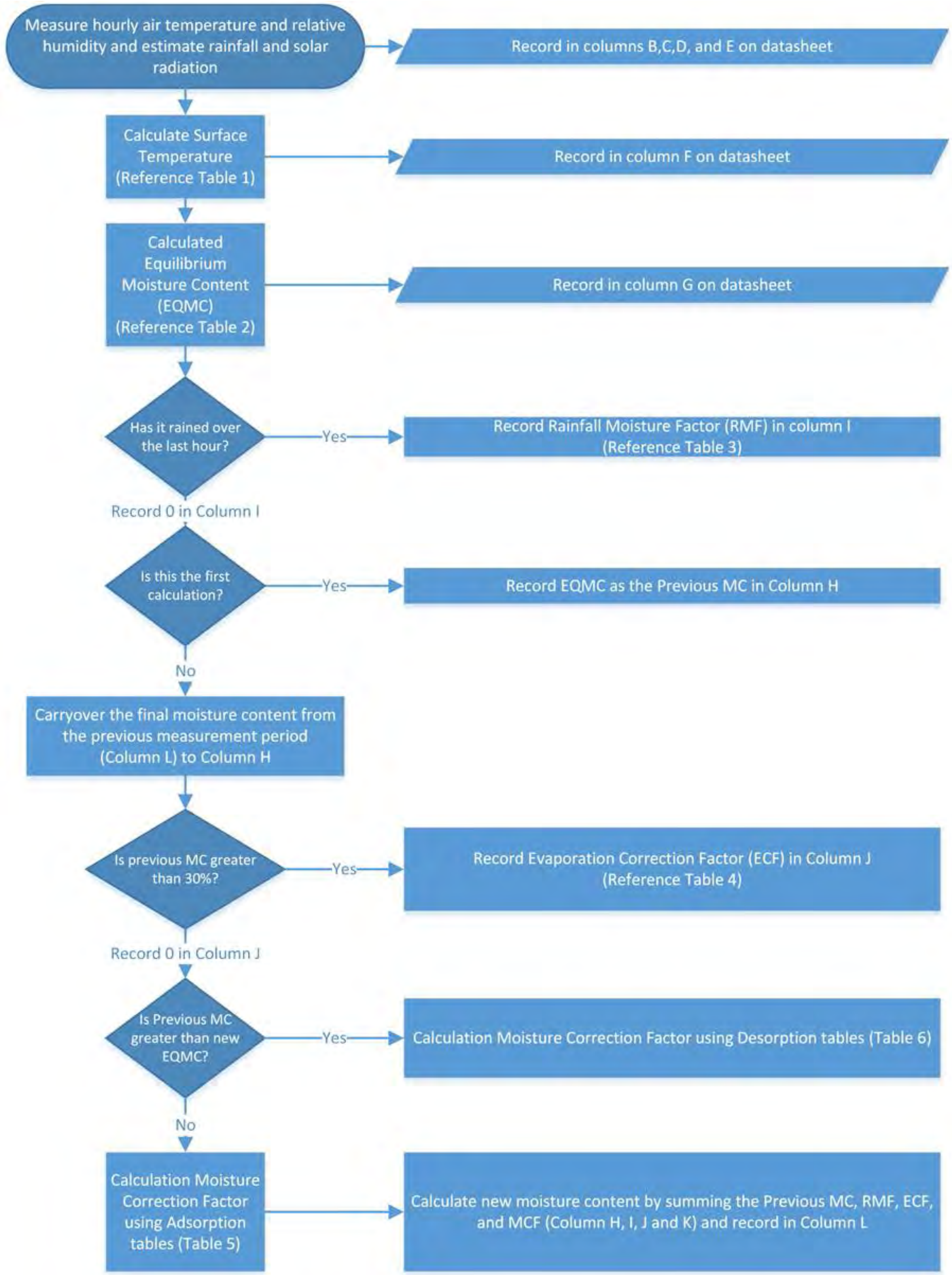


Figure 8 – Flow diagram of the table-based fine dead fuel moisture calculations.

Table 8 – Example Moisture Correction Factor (MCF) table for fuels that are absorbing water.

7% Adsorption	Relative Humidity (%) <5	5 to 9	10 to 14	15 to 19	20 to 24	25 to 29	30 to 24	35 to 39	40 to 44	45 to 49	50 to 54	55 to 59	60 to 64	65 to 69	70 to 74	75 to 79	80 to 84	85 to 89	90 to 94	95+
<30	-4	-2	0	1	2	2	3	4	5	6	6	7	8	9	10	11	12	13	15	18
30-49	-3	-2	-1	0	0	1	2	2	3	3	4	4	5	6	6	7	8	9	11	13
50-69	-3	-2	-1	-1	0	0	0	1	1	2	2	2	3	3	4	4	5	5	6	8
70-89	-2	-1	-1	-1	-1	0	0	0	0	0	1	1	1	1	2	2	2	3	3	4
90-99	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2
100-104	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
105-110	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
110-115	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
> 115	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

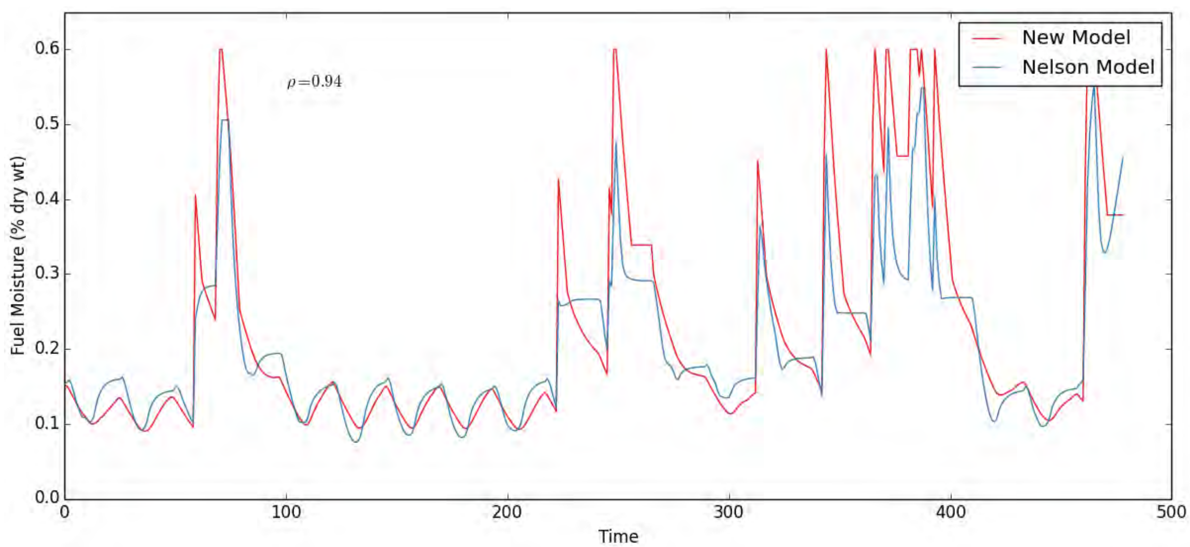


Figure 9 – Comparison of Nelson-calculated fine dead fuel moistures (blue) to SimpleFFMC (red) calculated values calculated from hourly weather data at the Sanborn RAWS . Despite the huge simplifications in model logic, correlations between the complex and simple models are 0.94.

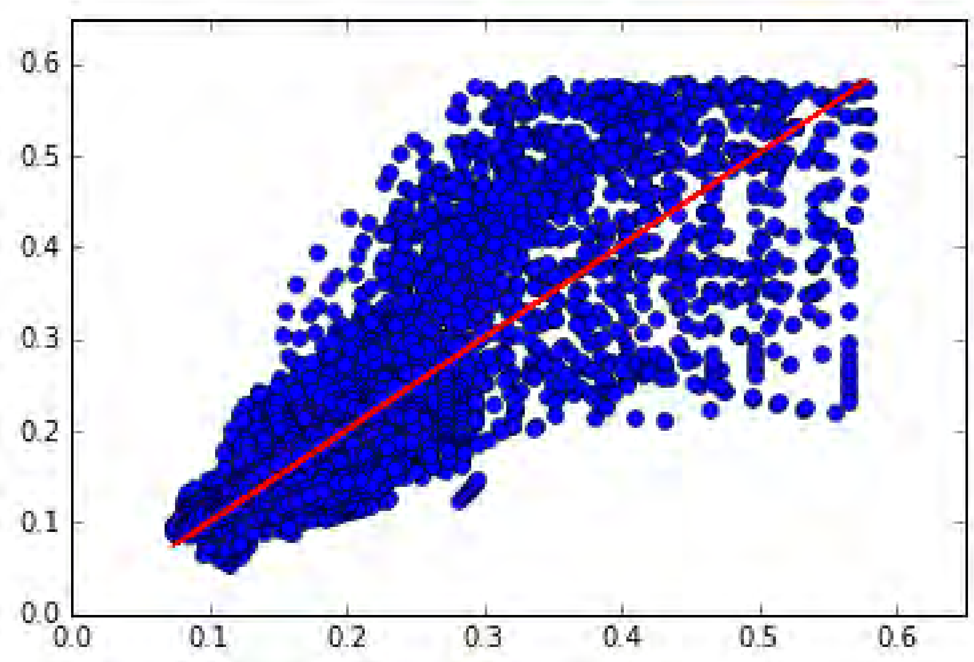


Figure 10 – Comparison of fine dead fuel moistures calculated from the Nelson model (x-axis) to those calculated using SimpleFFMC (y-axis) for an entire year of hourly data at a weather station on the Florida panhandle. Some scatter is to be expected given the simplifications but the observations are unbiased and strongly correlated. r^2 = 0.75, n=8755.

Mobile Application

We have used this simplified Nelson model logic to develop an interactive, web-based mobile fuel moisture calculator. This application simplifies the use of the fuel moisture tables and allows users to quickly calculate fine dead fuel moistures in the field based on measured and estimate fire weather. The application leverages the new SimpleFFMC calculator, along with a mobile-friendly javascript application framework to expose the new fuel moisture calculations as a web-based service and then wraps those calculations in a user-friend mobile form (Figure 11).

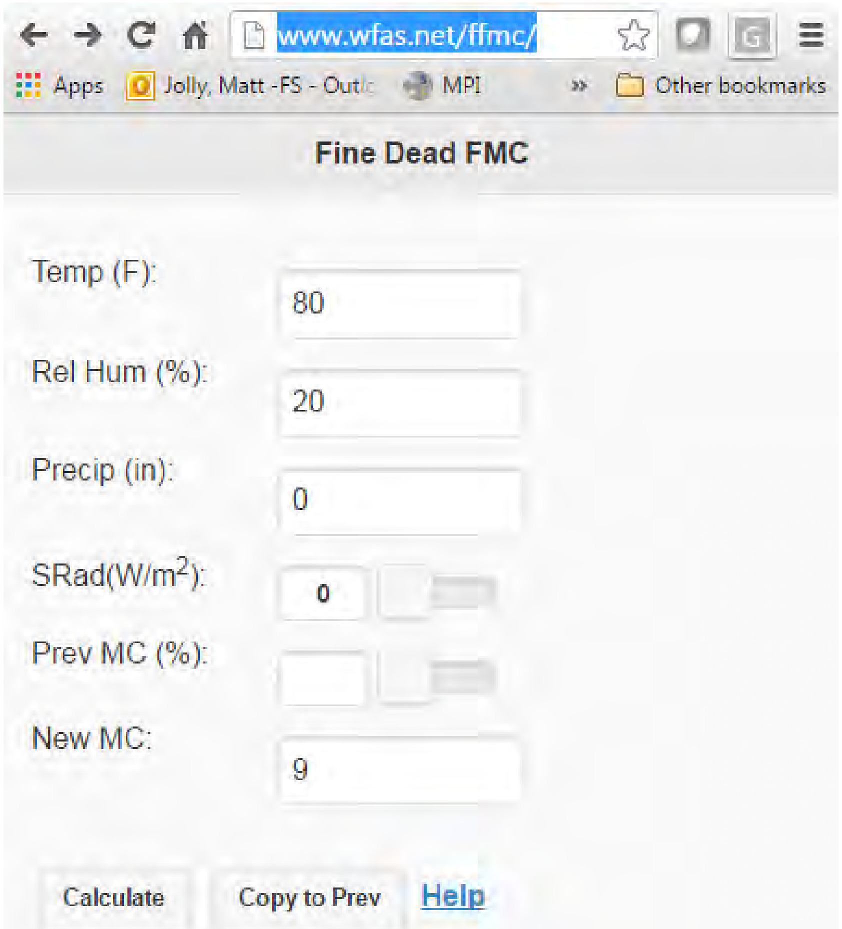


Figure 11 – The Fine Dead Fuel Moisture Content (FMC) calculator that is exposed as a service through the Wildland Fire Assessment System (WFAS) (http://www.wfas.net/ffmc/).

Once the user has determined the weather conditions for the hour, they can type in the the Temp, RH, Precip and Solar Radition. If it is the first observation, they can double clikc on the Prev MC box and it will calculate the EQMC and enter that value as the carryover fuel moisture and automatically calculate the New MC. The next measurement period, the user can click the Copy to Prev button to copy the New MC to the Prev MC and start a new set of calcualtions.

Comments

While the fuel moisture calculations steps may at first seem somewhat complicated, the calculations are simply based on fuel moisture corrections that are based on three moisture movement states: rainfall wetting, evaporation and moisture transport. Only one of each of these states applies at a given time, based on whether or not it rained in the last hour or whether the previous moisture content was above fiber saturation (30%). The transition period to this new logic should be fairly easy after the user performs just a handful of calculations following the flow chart.

Solar radiation was included in this model to ensure complete compatibility with the original Nelson model inputs and calculations. However, model calculations are not highly sensitive to solar radiation, so a single table of solar radiation by month and hour can be used across large areas and there is little benefit to included shaded and unshaded conditions into these calculations. In the example computation sheet, we suggest using 800 W/m^2 for clear days, 400 W/m^2 for overcast (>50% cloud cover) days and 0 W/m^2 for nighttime. This will give reasonable results until better methods for solar radiation prediction can be derived. Further, any place with a smartphone and internet connectivity can easily obtain solar radiation and hourly precipitation values from nearby RAWS stations using the DRI RAWS data interface (See Appendix A for example).

Until now, carryover fine fuel moistures from the previous observation period have not been a component of the fuel moisture calculations. However, fine fuels that dominate ignition and spread potential of wildland fires typically respond to changes in weather over several hours, rather than just hour to hour. A typical '10-hour fuel' would require 30 hours to reach equilibrium under constant conditions[1], suggesting that our approach of incorporating the fine fuel moisture content from the previous hour has value over previous, single measurement estimates of fine fuel moisture based on fire behavior field reference tables.

The primary benefit of this new approach is that these calculations are based on continuous equations, rather than discrete tables. The continuous equations are then used to derive the appropriate tables. This ensure that these calculations can be included in computer and mobile-based applications. As such, these new equations will be slated for inclusion into the next major release of BehavePlus, the fire modeling system, as well as the next generation of tables for the fireline handbook and other firefighter field references.

Ultimately, this new fine fuel moisture calculator is a paradigm shift in field and device-based fuel moisture calculations. The calculations are more dynamic, allowing the wetting and drying of fuels with rainfall, drying based on humidity and solar radiation and deal with the state changes from saturated to unsaturated flow as well as the hysteresis of the wetting up and drying down of fuels. This new model is exposed as a set of tables to enable field calculation as well as a companion computer code for the quick estimation of fuel moistures in both mobile and desktop applications.

Bibliography

[1] Ralph M Nelson Jr,2000, Prediction of diurnal change in 10-h fuel stick moisture content. Canadian Journal of Forest Research 30(7): 1071-1087.

[1] Anderson HE, Schuette RD, Mutch RW (1978) Timelag and equilibrium moisture content of ponderosa pine needles. Research Paper 202, USDA Forest Service, Intermountain Forest and Range Experimental Station, Ogden, UT, USA

Table 9 – Example measurement and computation worksheet for fuel moisture calculations. Full computation sheet included in printable PDF of tables.

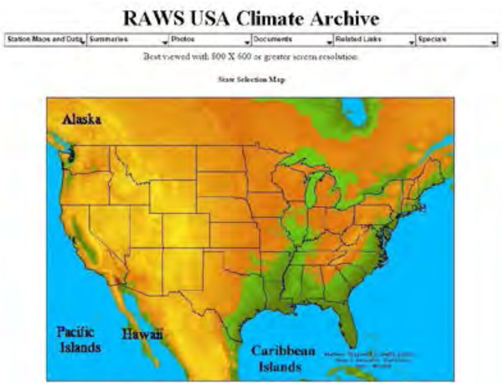
SimpleFFMC Fine Fuel Moisture calculation worksheet											
A	B	C	D	E	F	G	H	I	J	K	L
	Weather Observations					EQM C	Previous MC (t-1)	Rainfall Factor (RMF)	Evaporation Correction Factor (ECF)	Moisture Correction Factor (MCF)	FMC
	Temp	RH	Rainfall	Solar Radiation	Surface Temp						
Units	*(F)*	*(%)*	*(in)*	*(W/m2)*	*(F)*	*(%)*	*(%)*	*(%)*	*(%)*	*(%)*	*(%)*
Table Reference				**Estimated from local table**	**Ref Table 1**	**Ref Table 2**		**Ref Table 3**	**Ref Table 4**	**Ref Tables 5 and 6**	
Notes				If no local table, use 800 for clear days, 400 for overcast days and 0 at night			Moisture content from previous hour or EQMC if first observation	0 if no rainfall over last observation period	0 if FMC (t-1) < 30%	If FMC (t-1) > EQMC use Table 5, otherwise use Table 6	FMC (t -1) + RMF + ECF + MCF
Calculation Ref								**If D = 0, record 0**	**If H < 30, record 0**	**If H > G, use Table 5 else use Table 6**	**H+I+J+K**
Date/Time											

SimpleFFMC Fine Fuel Moisture calculation worksheet											
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
	Weather Observations					**Equilibrium Moisture Content (EQMC)**	**Previous MC (t-1)**	**Rainfall Factor (RMF)**	**Evaporation Correction Factor (ECF)**	**Moisture Correction Factor (MCF)**	**FMC**
	Temp	**RH**	**Rainfall**	**Solar Radiation**	**Surface Temp**						
Units	*(F)*	*(%)*	*(in)*	*(W/m2)*	*(F)*	*(%)*	*(%)*	*(%)*	*(%)*	*(%)*	*(%)*
Table Reference				**Estimated from local table**	**Ref Table 1**	**Ref Table 2**		**Ref Table 3**	**Ref Table 4**	**Ref Tables 5 and 6**	
Notes				If no local table, use 800 for clear days, 400 for overcast days and 0 at night			Moisture content from previous hour or EQMC if first observation	0 if no rainfall over last observation period	0 if FMC (t-1) < 30%	If FMC (t-1) > EQMC use Table 5, otherwise use Table 6	FMC (t -1) + RMF + ECF + MCF
25-Jul-16											
7:00 AM	77	94	0	23.26	90	19	19	0	0	-1	18
8:00 AM	84	76	0	161.657	96	14	18	0	0	-1	17
9:00 AM	82	86	0	123.278	94	16	17	0	0	-1	16
10:00 AM	83	72	0	324.477	103	12	16	0	0	-1	15
11:00 AM	80	79	0	196.547	96	15	15	0	0	-1	14
12:00 PM	80	87	0.09	293.076	98	14	14	21	0	0	35
1:00 PM	77	84	0.02	238.415	92	17	35	7	0	0	42
2:00 PM	87	74	0.01	702.452	111	12	42	4	0	0	46
3:00 PM	88	69	0	846.664	117	11	46	0	-8	0	38
4:00 PM	88	62	0	748.972	115	9	38	0	-8	0	30
5:00 PM	88	67	0	0	111	10	30	0	-7	0	23

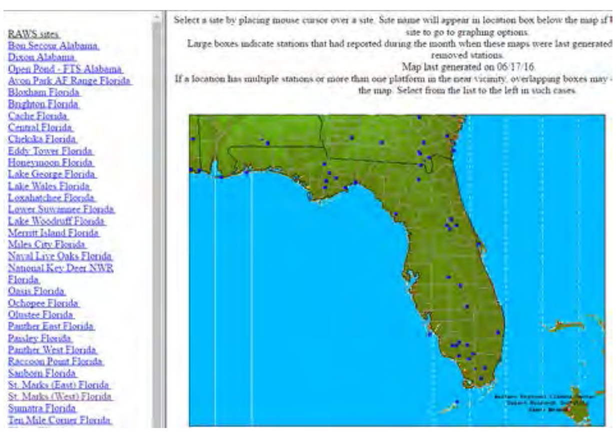
Table 10 – Worked example fuel moisture calculation from the St. Mark (West) RAWS station on 25 July 2016.

Appendix A

Deriving rainfall and solar radiation data from this model is not difficult when users are within data coverage for a smartphone. The DRI RAWS site, provides quick and easy access to rainfall and solar radiation measurements for all RAWS stations throughout the US (http://www.raws.dri.edu/). Follow these simple steps to get realtime data values:

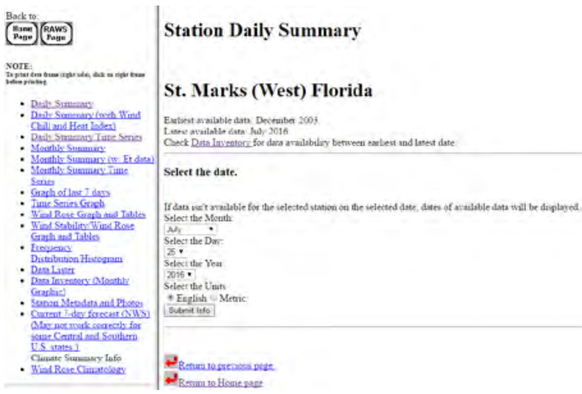


1. **Click on your State**

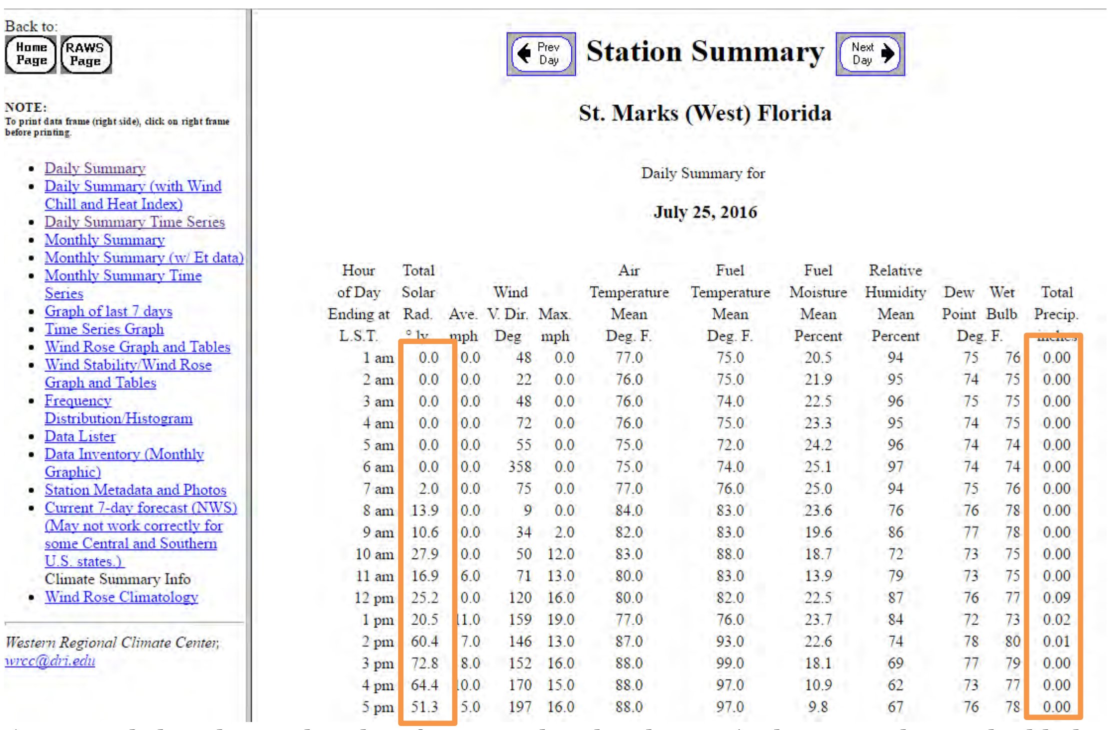


2. **Find the closest weather station and click on the blue square.**

3. **Choose Daily Summary from the links on the left panel.**



4. **If you need data for the current date, just click the "Submit Info" button because the current date is automatically filled in.**


Back to:
Home Page
RAWS Page

NOTE:
To print data frame (right side), click on right frame before printing.

- Daily Summary
- Daily Summary (with Wind Chill and Heat Index)
- Daily Summary Time Series
- Monthly Summary
- Monthly Summary (w/ Et data)
- Monthly Summary Time Series
- Graph of last 7 days
- Time Series Graph
- Wind Rose Graph and Tables
- Wind Stability/Wind Rose Graph and Tables
- Frequency Distribution/Histogram
- Data Lister
- Data Inventory (Monthly Graphic)
- Station Metadata and Photos
- Current 7-day forecast (NWS) (May not work correctly for some Central and Southern U.S. states.)

Climate Summary Info
- Wind Rose Climatology

Western Regional Climate Center, wrcc@dri.edu

Prev Day **Station Summary** Next Day

St. Marks (West) Florida

Daily Summary for

July 25, 2016

Hour of Day Ending at L.S.T.	Total Solar Rad. ° ly	Wind Ave. mph	Wind V. Dir. Deg	Wind Max. mph	Air Temperature Mean Deg. F.	Fuel Temperature Mean Deg. F.	Fuel Moisture Mean Percent	Relative Humidity Mean Percent	Dew Point Deg. F.	Wet Bulb Deg. F.	Total Precip. inches
1 am	0.0	0.0	48	0.0	77.0	75.0	20.5	94	75	76	0.00
2 am	0.0	0.0	22	0.0	76.0	75.0	21.9	95	74	75	0.00
3 am	0.0	0.0	48	0.0	76.0	74.0	22.5	96	75	75	0.00
4 am	0.0	0.0	72	0.0	76.0	75.0	23.3	95	74	75	0.00
5 am	0.0	0.0	55	0.0	75.0	72.0	24.2	96	74	74	0.00
6 am	0.0	0.0	358	0.0	75.0	74.0	25.1	97	74	74	0.00
7 am	2.0	0.0	75	0.0	77.0	76.0	25.0	94	75	76	0.00
8 am	13.9	0.0	9	0.0	84.0	83.0	23.6	76	76	78	0.00
9 am	10.6	0.0	34	2.0	82.0	83.0	19.6	86	77	78	0.00
10 am	27.9	0.0	50	12.0	83.0	88.0	18.7	72	73	75	0.00
11 am	16.9	6.0	71	13.0	80.0	83.0	13.9	79	73	75	0.00
12 pm	25.2	0.0	120	16.0	80.0	82.0	22.5	87	76	77	0.09
1 pm	20.5	11.0	159	19.0	77.0	76.0	23.7	84	72	73	0.02
2 pm	60.4	7.0	146	13.0	87.0	93.0	22.6	74	78	80	0.01
3 pm	72.8	8.0	152	16.0	88.0	99.0	18.1	69	77	79	0.00
4 pm	64.4	10.0	170	15.0	88.0	97.0	10.9	62	73	77	0.00
5 pm	51.3	5.0	197	16.0	88.0	97.0	9.8	67	76	78	0.00

5. **Example hourly weather data for St. Marks, Florida on 25 July 2016. The two highlighted columns are the solar radiation and hourly precipitation needed for the model. Not, solar radiation measurements are reported in Langleys and the SimpleFFMC model needs solar radiation in W/m^2, so multiply the values in the table above by 11.63 to convert to the appropriate units.**