<u>The FLAME (*F*ire*L*ine *A*ssessment *ME*thod) in a Nutshell</u>

Jim Bishop, September 2006

<u>WHY USE SUCH A PROCESS?</u>

It is very clear from fireline fatalities that firefighters can be caught by unforeseen dangerous changes in fire behavior, even though they know about the factors that affect fire behavior. Sudden large changes in fire rate-of-spread (ROS) are a common denominator in such accidents. Less deadly unforeseen changes often reduce the effectiveness of control actions. A generalized expectation that any change will be noticed in time does not provide an adequate assessment of potential fire behavior…seat-of-the-pants impressions are not good enough.

Firefighters are busy with many things to think about as they approach a fire and begin their control operations. They tend to expect, almost unconsciously, fire behavior similar to what they are seeing at present…drawing much more heavily, though unconsciously, on "current" rather than "expected" fire behavior and too often not effectively applying the standard order to "Base all actions on current and expected fire behavior". There are many examples of expectations conditioned by an over-dependence on current fire behavior and a failure to foresee change, but the following six are representative and instructive. Quotes and accounts are from the fatality-incident reports, or in example #3 from a documentary book (Maclean, 1999).

1. Choice of tactics was based on "…benign appearance of the fire, along with no appreciable wind during the decision making process…". Not long after that the fire crept through retardant lines and was driven rapidly by increased winds into firefighters on an indirect dozer line. Spanish Ranch Fire, 1979, California, 4 fatalities

2. Crews worked on a line at the base of a slope with the fire backing down on the slope above them: "…burnout was conditioned upon light upslope winds holding…". They were surprised and caught by a rapid increase in fire intensity and spread rate when thunderstorm outflow winds drove crown fire down the slope and over them (even though thunderstorms in the vicinity were essentially 'a given' on that day). Dude Fire, 1990, Arizona, 6 fatalities

3. A decision to begin the West Flank fireline was based in large part on current fire behavior: "Look at what it's doing now."; "…the fire 'didn't look that bad'…". South Canyon Fire, 1994, Colorado, 14 fatalities

4. Firefighters deployed shelters too late, though they had 10s of minutes to prepare: "…assuming they would see the fire coming at the same rate they had all day." 30-mile Fire, 2001, Washington, 4 fatalities

5. Firefighters were caught on a ridge when fire spread rapidly up the drainage below them: "…intensity and rate-of-spread were much greater than had been anticipated…" Cramer Fire , 2003, Idaho, 2 fatalities

6. Firefighters were constructing a short piece of indirect line on the apparently 'safe' side of the fire: "…right flank was backing into a light up-canyon wind."; " …numerous observers reported that the wind had remained light and steady…" A short-lived turbulent increase in wind from nearly the opposite direction pushed the backing fire up the slope and right at them. Tuolumne Fire, 2004, California, 1 fatality

It is clear in every single one of the above fatality fires that firefighters were caught by a dangerous change in fire behavior that they did not foresee. Despite decades of teaching the Standard Firefighting Orders, and of providing fire behavior training courses, too often firefighters do not adequately "base their actions on expected fire behavior". It can probably be safely said that all wildfire-caused accidents were a result of firefighters' failure to expect the change in fire behavior that threatened them. True, other operational failures often compounded the problem to various degrees, but at its root the problem was caused by unanticipated, dangerous fire behavior. And in most cases it would have been quite possible for them to anticipate that change well enough to move to safety.

FLAME provides a method of evaluating potential change that considers the major drivers of large, short term changes in fire behavior—the kinds of change that threaten firefighter safety. Here the meaning of "short term" is change that can encompass minutes or 10s of minutes (even though the change may be gradual or may not take place for hours more). The *FLAME* focus is on factors that make for big changes that happen in a short time.

A key aspect of using it is that it leads a firefighter to make a structured, complete evaluation of the key fire behavior factors; seeking a numerical result requires careful attention to those critical factors. The <u>process</u> of "filling in the blanks" (and acknowledging missing information) is as important as is the final answer. The goal is a system simple enough to be practical and still accurate enough to be helpful.

<u>WHAT MAKES FOR BIG CHANGES?</u>

The measure of "change" used by FLAME is the degree of speedup or slowdown in fire ROS after "the next big change". That change in ROS is expressed by the "ROS-ratio"; simply the bigger ROS divided by the smaller ROS. Many of the important factors in fire behavior either change fairly slowly, or make only a minor contribution to short term variations in fire behavior. For examples, fuel structure, live/dead ratio, live fuel moisture (FM), and the FM of 10-hour and larger fuels change fairly slowly. Over the course of a few hours, changes in ROS due to variation in those factors are generally less than about 10%. While current fire behavior reflects the important overall influence of those longer-term factors, their contribution to <u>changes</u> that happen fast enough to threaten firefighters is minor.

On the other hand, a couple of factors drive huge and rapid changes in ROS. Wind (effective wind speed, or EWS) can drive changes of 200X. And changes between the major fuel types (litter, crown-foliage, and grass) account for another factor of 15X or so. Litter is the "slowest" fuel, crown foliage is about 4X faster, and grass another 3X or 4X faster than crowns (with other factors constant). Considering fuels in easily identified fuel types simplifies the consideration of fuel changes while retaining sufficient accuracy in assessing significant developments in fire behavior.

The fine-fuel moisture (FFM) variation over short periods can introduce ROS changes of 10s of %, but the main contribution of FFM to large changes is via its influence on the potential for crown fire and spotting. (And there is a way in *FLAME* to fine tune the output for the direct effects of FFM on ROS in fine dead fuels.)

ESTIMATING BIG CHANGES IN ROS

An increase in wind by a given factor gives rise to a certain relative increase in ROS, regardless of the actual "before and after" wind speeds in mi/hr. For example, a 4X increase in wind speed will produce about a 5X increase in ROS, whether that increase in wind is from 2 to 8, or from 5 to 20 (both cases represent an increase in EWS of 4X). That greatly simplifies the estimation of the effect of a wind change on fire spread.

If the fire undergoes a change in wind speed and a change in fuel type (the biggest two change-makers by far) the effects of each change will be compounded. In most cases, the wind speed is higher in the "faster" fuel, for example wind at flame level in crown fire is invariably faster than at flame level in litter. So, for example, if the fire moves from litter into crown foliage, it will move 4X faster due to the change in fuel type. If it also feels the effect of an 8X increase in wind, it will move another 12X faster due to the faster wind (ROS increases faster than the wind does). The combined effects of that fuel-type change and an 8X wind-speed increase would be approximately a 4 x 12 = 48X increase in ROS (or an ROS-ratio of "48").

The kind of calculation described above makes up the main part of the FLAME ROS-ratio table (Table 1). If you look up, for example, in the "no fuel change" column an EWS-ratio of 12X you see that the increase in ROS would be about 20X. If you look across the top of the table for EWS-ratio of "1" (which means no change in EWS) and a fuel change from litter to grass you see that the increase in ROS would be about 14X. If those changes were combined (a fire moving from litter into grass and feeling a 12X increase in EWS), you'd get a net change of 14 x 20 = 280X in ROS. And that is about the right answer. Looking in the table with EWS-ratio of 12X and under the "litter-to-grass" column shows an ROS-ratio of "300". The reason those answers are slightly different is that the table accounts for a more detailed dependence of ROS on wind speed for each different fuel type. But it illustrates the general idea. If the change had been in the opposite direction, it would mean a slowdown of 300X rather than a speedup of 300X.

What if the EWS actually increases in the "slower" fuel? That is less common, but it can happen. For example, suppose a fire burns in grass at the base of a slope sheltered from the wind, with an EWS of only 3 mi/hr, and then becomes a crown fire on the windier upper slope with EWS of 15 mi/hr. The 5X increase in EWS would lead to a 7X increase in ROS. But the change from grass to crown fuel would result in about a 4X decrease in ROS. The two factors would not reinforce, but would oppose each other, with the increase in wind being the winning influence. So the ROS-ratio would be about 7/4 = 2X. On balance the fire would move about 2X faster in the crown fuels on the upper slope. The right side of the ROS-ratio table (which is used for such "opposing" changes) shows ROS-ratio = "2".

FLAME ROS-ratio Table

		EWS biggest in faster fuel			EWS less in grass	
EWS-ratio	No fuel change	Litter to/from crown	Litter to/from grass	Crown to/from grass	Crown to/from grass	Litter to/from grass
1	1	4	14	4	*3*	*10*
2	2	10	30	8	1	*5*
3	4	15	60	13	1	*3*
4	5	20	80	20	2	*3*
5	7	30	100	27	2	*2*
6	9	35	130	35	3	*2*
8	12	50	180		4	1
10	16	60	240		5	1
12	20	80	300		6	2
16	30	100	440		8	2
20	40	140	600		10	3
24	50	180	700		13	3
30	60	220	1000		17	4
40	80	300	1300		23	6
50	110	400	1800		30	8
60	140	500	2200		40	10
80	200	700	3100		60	16

Table 1. Rate-of-spread ratios as a function of changes in fuel and changes in effective wind speed. The left-hand column shows the EWS-ratio, the factor by which EWS changes. Each column corresponds to a change between particular fuel types (or to "no change"). Table values express the ROS-ratio that results from the combined change in EWS (left column) and fuel (top row). The three center columns cover cases where wind is greater in the "faster" fuel-type, i.e. that fuel and wind changes reinforce each other. Cases of opposing changes in wind and fuel are handled in the rightmost 2 columns; italicized underlined values indicate faster ROS in the grass. Highlighted entries indicate the field of ROS-ratios that have been associated with fire fatalities.

WHAT IS IT BASED ON?

The FLAME "standard curves" that express ROS as a function of wind speed (EWS) for each of the three main fuel types are shown in Figure 1. They are derived in part from BehavePlus fire model outputs, where the FFM was assumed to be 6% and the live FM to be 80% —the relative changes in ROS due to EWS and fuel type are virtually the same at different but realistic fuel moistures. The FLAME outputs bear the same limitations that characterize the fire models (for example, not accounting for fire spread by firebrands. or smoldering). The grass-fuel data includes fuel models 1 and 3, input from the Australian grass-fire nomograms, and some Australian ROS observations of wind-driven grass fires. The "crown fire" data includes fuel models 5, 6, & 7, and actual ROS observations of both brush and timber fires. The "litter fire" data includes fuel models 8, 9, and 10. ROS is sufficiently similar within each fuel type, and they are sufficiently distinct from each other, to allow the approximation of considering fuels as a simple set of fuel types.

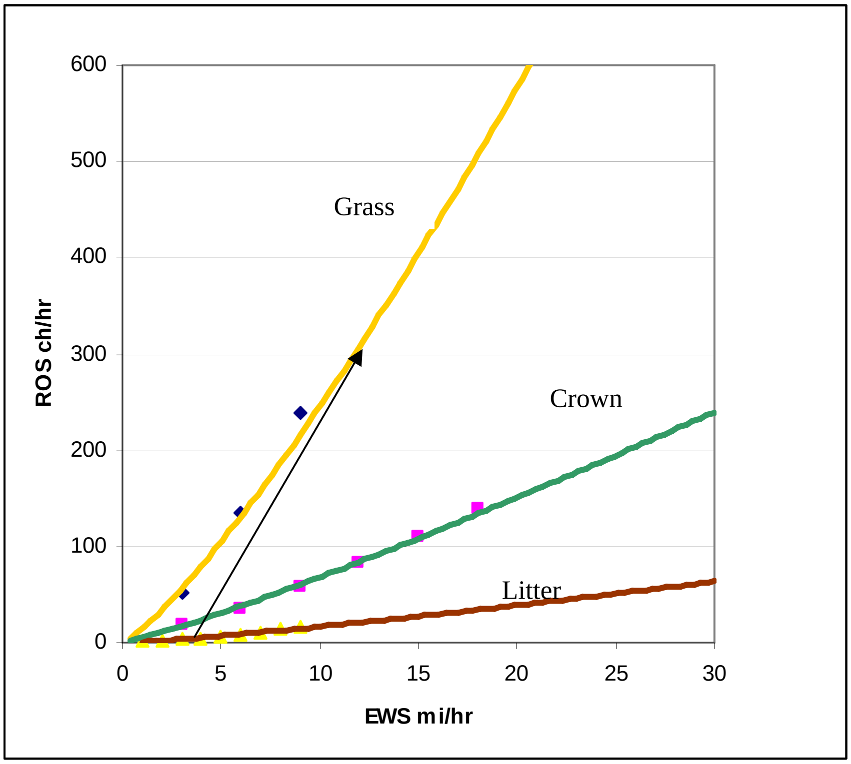


Figure 1. EWS vs. ROS for each of the major fuel types (litter, crown and grass). The arrow depicts an example in which fire in litter with an EWS of about 3 mi/hr changes to fire in grass with EWS about 12 mi/hr. The initial and final ROS would be on the vertical axis, and the larger divided by the smaller would be the ROS-ratio for this change in fire behavior (approx 80X). At very low EWS (as in backing fires) a different curve is used.

APPLICATION OF FLAME

The application of the FLAME process uses a simple field worksheet (see example on last page) that follows 3 stages, proceeding from an initial assessment of the potential for significant change to a complete application that allows prediction of the fire spread over time. Application level depends on the firefighter's needs and available information. It essentially provides a methodical basis on which to "Base all actions on current and expected fire behavior". The worksheet can also provide documentation of the assessment and what occurred. It can be applied to quite realistic situations, and various adjustments can improve its accuracy or allow its application to fairly complex cases.

- **Initial application**: Simply identifies the next big change that will occur; requires the firefighter to depict "current" and "expected" fire behavior situations.

- **Standard application**: Assesses the magnitude of the change in the ROS, via the ROS-ratio, and in the process guides the firefighter to account for the key factors of fuel-type and wind, both "current" and "expected".

- **Complete application**: Combines the expected change in ROS with observation of the ongoing fire spread to predict future fire spread.

The comparison of FLAME "predictions" of ROS-ratio with published fire behavior data from several actual fatality fires shows good agreement with the reconstructed change in ROS that occurred on the incident.

Learning the system

The FLAME application process is currently taught (as an introduction) in Unit 12 of the new (2006) S-290 Intermediate Fire Behavior course. A supplementary addition to Unit 12 can supply the rest of the FLAME course, and a Full FLAME course is available as a stand-alone course. The above brief overview is only intended to provide the general idea of how it works, and is not sufficient to train one on how to use it. Following are some thoughts & perspectives for those instructing and learning FLAME. Keep in mind that S-290 is the fire behavior course that serves most firefighters for most of their careers—one course serves all. Some of the Full FLAME material may seem more detailed than you need right now. But others may need it, and in time you might need it. And in any case, as you work on all of the information in the class you will learn something from it.

The value of dealing in specifics

The material in Unit 12, and learning to apply FLAME, can be challenging and demands some real effort from the students. But there are some points that can help students to appreciate the value of making that effort, and to be comfortable with the time it can take.

Wrestling with the specifics, the key fire behavior factors expressed as numbers, can enhance the value of fire behavior training. You pay more attention to factors that you must evaluate and use in solving a problem. Here is one example. Students will have to figure the difference in wind speed on upper slopes vs. that on lower slopes in doing some of the problems. The exercise of using the adjustment factors will help them understand and to remember such variation in wind speed. Someday out on a ridgetop they may be watching fire progress up the lower slopes below. Having worked a similar problem, they will very likely remember the fact that as the fire moves up the slope it will come under the influence of increasing wind speeds, and could more than double in spread rate on the upper slopes. Even without doing the actual ROS (rate of spread) prediction at the time, they will be better tuned in to the important increase in ROS that is developing.

The application of FLAME in various exercises provides the opportunity to extend and reinforce learning on many of the processes presented in the fire weather sections.

The toughest part, wind adjustments

In applying FLAME the user must address some details of the variations in wind, and that constitutes the most complex part of the process. In fact the wind adjustments in FLAME are as detailed as in more advanced fire model applications. But it is essential that those variations be considered; it is worth the effort. The variations in wind that are due to topographic location and to flame level lead to very large, and often sudden, changes in fire behavior. It is important to anticipate those changes.

A lot to learn, but over time

The course is designed to provide knowledge and methods that can serve the students in situations that demand a full accounting of the fire behavior factors and a fairly accurate prediction of the fire's movement. Even if they do not fully master the process in the first exposure to FLAME, with time and practice their competence will grow and so will the usefulness of the FLAME process. Don't worry if it has not all made perfect sense at the end of the class; keep working on it. For right now, be sure to master at least the most essential aspects of the FLAME approach.

1. Understand the role of fire behavior change in firefighter safety, and the need to foresee change.

2. Know the factors that dominate large sudden changes, and how they vary

3. Adopt a systematic approach to assessing fire behavior and potential "big changes"

Even though it does involve some challenges, FLAME provides much of the power of fire behavior prediction in a relatively streamlined form. Most applications of the fire model are not practical for firefighters on the fireline. BehavePlus requires a computer, and employs several tables/charts to determine fuel moisture and midflame wind speed. For non-computer applications, besides the fuel moisture tables, there are 26 nomograms needed or over 100 pages of "Appendix B" tables needed. In contrast FLAME uses only a single essential table (the other two tables only help with some arithmetic) and a few wind-adjustment diagrams, and requires only 2 major fire environment inputs.

Righteous practice vs. practical shortcuts

S-290 Unit 12 is designed to introduce and to exercise the basic steps in the FLAME process. To make sure the students can competently use the system, to handle even complex situations, the class applications require attention to each potential step or detail. But there are practical shortcuts that one can often take advantage of in many real world applications. Don't be confused by the difference between careful steps in learning the process and the shortcuts possible in real world applications. Here are some examples of shortcuts.

1. As a general rule, you can ignore the slope contribution to the EWS (effective wind speed) when the actual mid-flame wind speed (in mph) is half or more of the slope (in %). For example, if the wind speed is 15 mph, and the slope is 30%, the slope would add only 1 mph for a total EWS of 16 mph. An EWS of 16 vs. 15 mph would make no significant difference to the final ROS-ratio and you probably never know the wind to an accuracy of 1 mph anyway.

2. In many cases there is no need to make a specific adjustment for lee-side winds. Most often, except in cases of downslope or foehn winds, the wind on the lee side will on average be light and inconsistent in direction. The fire will primarily be backing down the slope or will be moving upslope mostly driven by the slope itself.

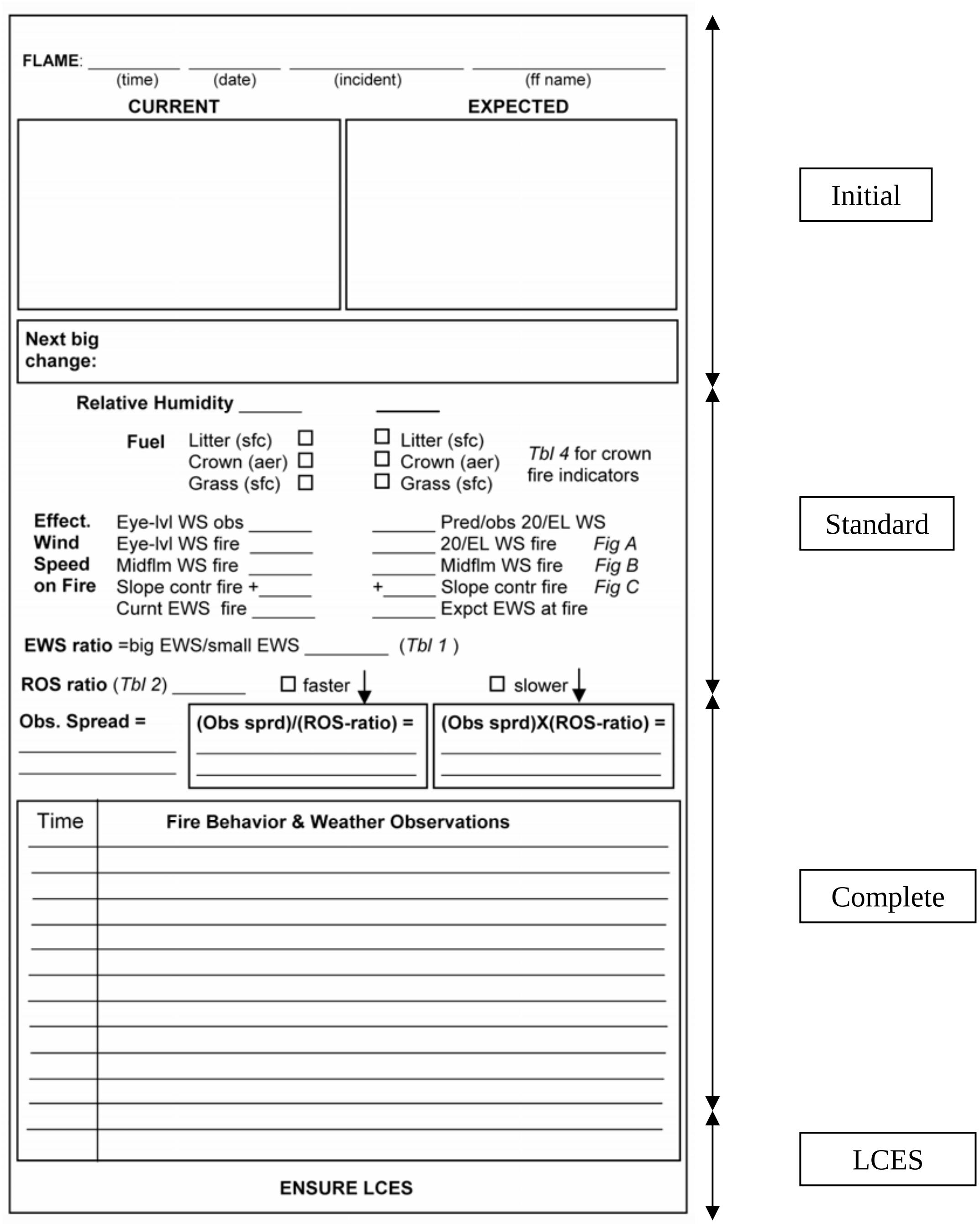
Training potential beyond the classroom

There is value in continuing to train on fire behavior, well beyond the S-290 course that serves most firefighters for most of their careers. FLAME offers a format, a vehicle, for engaging firefighters in ongoing fire behavior training. A fireline incident might be valuable to share with crews as they begin a new fire season. Or an exercise highlighting a particular fire behavior 'event' could be chosen as a way of providing refresher training. The description of the incident situation or fire behavior event and a short lesson plan could be sent out to all crew leaders. They could present the information and work through it using FLAME, arriving at a well-founded safety decision. In the process they would have covered the key fire behavior points and exercised a systematic process for assessing fire behavior.

Also, firefighters pay closer attention to fire behavior and the factors that produce it when they have made a specific prediction of what they expect it to do. And they learn more from each season of experience for having observed more carefully.

The FLAME Worksheet, Stage by Stage

The worksheet is organized to follow the three “application stages” described on page 5, initial, standard, and complete application. A copy of the worksheet is shown below. Where the sheet is divided left-right, the left side records “current” conditions and the right side records “expected” conditions. This brief description is intended to illustrate the FLAME application form, but is not adequate for training on the method.


FLAME: ________ (time) ________ (date) ________ (incident) ________ (ff name)

CURRENT | EXPECTED

Next big change:

Relative Humidity ______ ______

Fuel: Litter (sfc) ☐ Crown (aer) ☐ Grass (sfc) ☐ | ☐ Litter (sfc) ☐ Crown (aer) ☐ Grass (sfc) — *Tbl 4* for crown fire indicators

Effect. Wind Speed on Fire:
Eye-lvl WS obs ______ | ______ Pred/obs 20/EL WS
Eye-lvl WS fire ______ | ______ 20/EL WS fire *Fig A*
Midflm WS fire ______ | ______ Midflm WS fire *Fig B*
Slope contr fire +______ | +______ Slope contr fire *Fig C*
Curnt EWS fire ______ | ______ Expct EWS at fire

EWS ratio =big EWS/small EWS ________ (*Tbl 1*)

ROS ratio (*Tbl 2*) _______ ☐ faster ☐ slower

Obs. Spread = | (Obs sprd)/(ROS-ratio) = | (Obs sprd)X(ROS-ratio) =

Time | Fire Behavior & Weather Observations

ENSURE LCES

FLAME worksheet. Down to the “EWS-ratio” entry the left side is for “current” conditions and the right side for “expected” conditions. Fuels are listed in order from slowest to fastest; the EWS spaces follow the adjustment process from raw values to EWS on the fire. The “LCES” portion allows for notes about how those guidelines will be implemented.