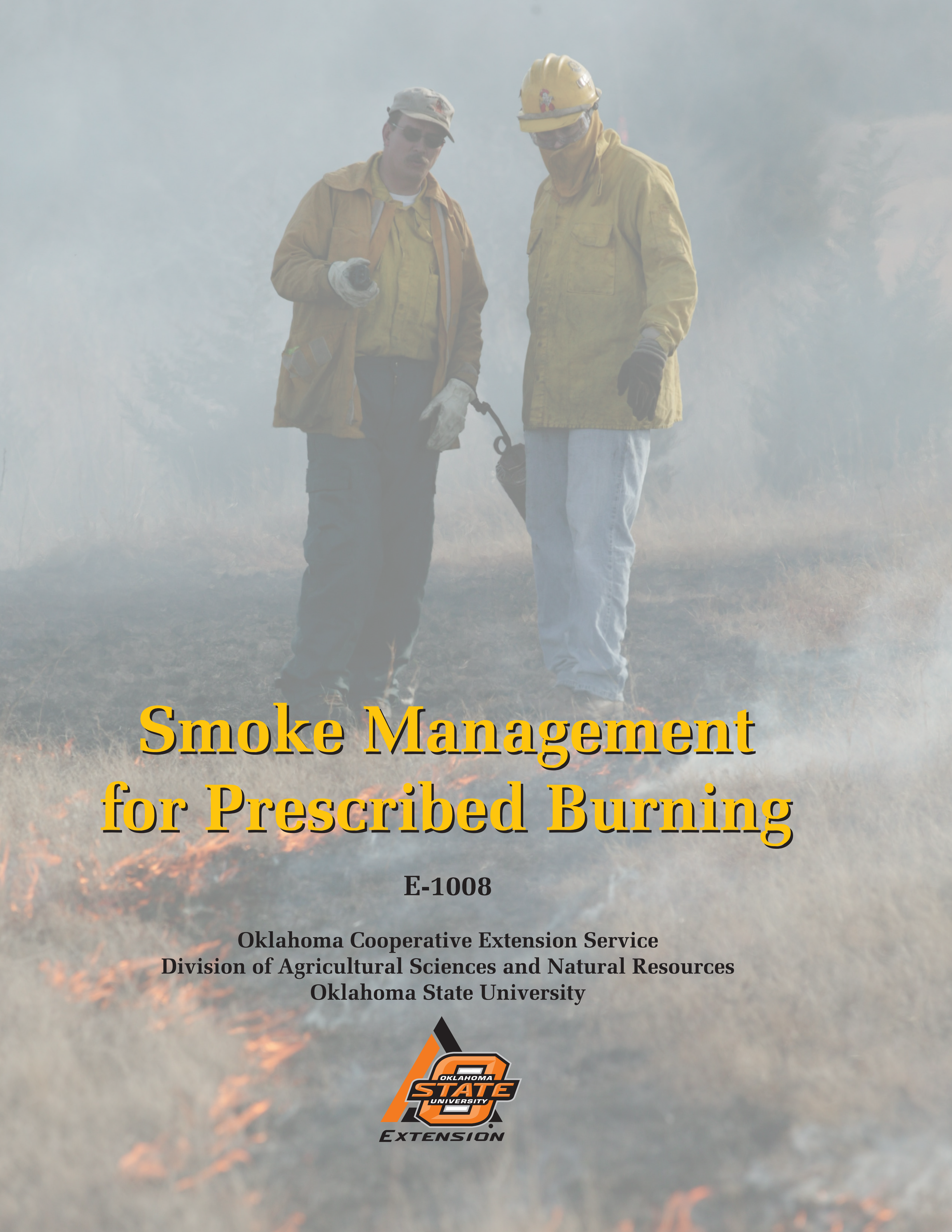

Smoke Management for Prescribed Burning

E-1008

Oklahoma Cooperative Extension Service
Division of Agricultural Sciences and Natural Resources
Oklahoma State University

Smoke Management for Prescribed Burning

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Introduction

Smoke management should be an important consideration when planning all prescribed burns. Smoke can obstruct visibility, which in turn can affect the safety of the personnel conducting the fire, public safety on roadways, and the recreational value of areas. Smoke can also impact public health, along with the public's reaction to prescribed burning in general. Nuisance smoke is smoke that causes problems and is defined as the amount of smoke in the air that interferes with a right or privilege common to members of the public, including the use or enjoyment of public or private resources. That is why it is important to always manage smoke emissions so there are no problems on current or future burns. The main goals of smoke management are to reduce emissions from a fire, improve the dispersion of smoke, and make sure smoke plumes do not affect smoke-sensitive areas.

Smoke is a by-product of incomplete combustion caused by the inefficient mixing of oxygen and fuel. There are four stages of combustion, and the amount of fuel consumed as well as the amount of smoke produced is distinctive for each stage.

- **pre-ignition:** when fuel particles are initially heated, water vapor is expelled into the atmosphere.
- **flaming:** efficiency of combustion is relatively high and the least amount of emissions are produced in relation to the amount of fuel consumed.
- **smoldering:** efficiency of combustion is lower, thus resulting in greater particulate emissions. It has been documented that the amount of particulate emissions produced per amount of fuel consumed during this stage is more than double that of the flaming stage.

Smoke is a by-product of incomplete combustion caused by the inefficient mixing of oxygen and fuel. Ninety percent of smoke emissions from wildland fires are carbon dioxide and water vapor. (photo John Weir).

- **glowing stage:** characterized by minimal smoke because all of the volatile material in the fuel has been driven out and oxygen can now easily reach the fuel particles making combustion more efficient.

Smoke is found in all stages of combustion, but it is greatest in the smoldering phase. Smoke is also more prevalent during smoldering combustion of duff, decaying logs, and organic soils than in grass, shrub, and small diameter wood.

Smoke Emissions

Carbon dioxide is the largest single emission from wildland fire. Although it is not considered an air pollutant, carbon dioxide is an important greenhouse gas. Water vapor is the second largest emission from wildland fire. It is also not considered an air pollutant, but it does contribute to the total smoke load and causes reduction in visibility. Ninety percent of smoke emissions from fires are carbon dioxide and water vapor.

The remaining ten percent of smoke emissions consist of other compounds such as carbon monoxide, hydrocarbons, nitrogen oxides and particulate matter (PM). Particulate matter consists of small airborne particles. In wildland fire smoke, 70 percent of these are less than 2.5 microns in diameter. These particles degrade air quality by reducing visibility, absorbing harmful gases and aggravating respiratory problems in susceptible individuals, along with collecting on surfaces, causing damage and reducing aesthetic appeal.

How to Minimize Smoke Problems

There are many methods that can be used to reduce the impact of smoke outside of the burn unit. Some of the methods are easy to accomplish, while others may require additional

Smoke management should be an important consideration when planning all prescribed burns. Smoke can obstruct visibility, which can affect public safety on roadways. (photo John Weir)

labor and can add expense to the burn. The simplest method to reduce smoke problems is to burn smaller units; reduced fuel loads create less smoke. This may require land managers to conduct more burns which can increase cost and take more time, but if it is the only way smoke problems can be mitigated, then it is the best method. The following are additional methods that can be used to reduce smoke problems:

Burn when weather conditions are likely to produce the best dispersion:

- Burn when atmospheric conditions are best for rapid smoke dispersal; this is normally after the morning inversion layer has broken and before the evening inversion layer forms. An inversion is a stable layer of air in which temperature increases with height and in which smoke dispersion is poor.
- Burn when the atmosphere is neutral to unstable, which enhances plume rise and the horizontal and vertical dispersing of smoke.
- Burn at nighttime only if you have a favorable forecast, because nighttime temperature inversions will cause smoke to hold at ground level.
- Consider air pollution regulations and do not burn during pollution alerts, stagnant conditions, or ozone alert days because smoke will then aggravate an already bad situation.
- Burn only if minimal parameter values are met for acceptable smoke dispersal; these include minimum surface and upper level wind speeds, desired wind direction, minimum mixing height, category day, and dispersion index.
- Take into account down-drainage smoke flow, especially in complex terrain where downslope winds prevail at nighttime under light wind conditions.
- Burn only after evaluating smoke dispersion with a computer model (see OK-FIRE website, to be discussed later) or smoke plume trajectory plot. (see OSU Extension publication E-927, "Using Prescribed Fire in Oklahoma").

Burn when fuel conditions are likely to produce the least amount of smoke:

- Burn with proper fuel moisture conditions. This can be accomplished by selecting the correct combination of fuel moisture and fuel size class that need to be removed to meet the burn objectives. For removal of fine fuels, burn when the relative humidity is low enough for these fuels to burn and larger fuels are too wet to ignite. Consult the OK-FIRE website for fuel moisture conditions in a specific area.
- Use test fires prior to burning to confirm fuel conditions and smoke behavior before igniting the entire unit. This is accomplished by igniting a small area inside the burn unit that can be easily contained and extinguished, then observing how well the smoke lifts and disperses. If conditions are not favorable, extinguish the test burn and wait for better atmospheric conditions.
- Estimate the amount of smoke fuels will

Conducting burns when atmospheric conditions are best for rapid smoke dispersal or when the atmosphere is neutral to unstable will aid with the smoke rising and dispersing (top photograph). The fire in the bottom photograph was conducted on a day when atmospheric conditions were not favorable for smoke dispersal. Notice how the smoke is trapped near the surface. (photos by John Weir)

Fuel type will make a difference in smoke emission. Hardwood leaf litter will typically produce more smoke than grass fuels. (photo by John Weir)

produce. This is sometimes difficult to determine and comes with experience. An area that has not been burned in years will create greater amounts of smoke than areas that are frequently burned.

- Fuel type will make a difference in emission rates; fuels that have high moisture contents, high concentration of oils, or large fuel particle size will have higher rates of smoke emissions.

Utilize suitable ignition techniques for smoke management:

- Consider burning using backfires to reduce the amount of smoke produced. Backfires consume higher amounts of fuel in the flaming rather than the smoldering stage of combustion and thus produce less smoke per unit of time.
- Use mass ignition techniques like ring firing and headfires to create greater amounts of heat which will create more lift for the smoke column. (see OSU Extension video VT112, “Using Prescribed Fire in Oklahoma” for examples)
- Utilize mass ignition devices such as heli-torch, DAIDS, or terra-torch to create high intensity fires that can limit the duration of smoke impacts and increase convection.

Conduct post-burn mop-up to reduce nuisance smoke:

- Outline what actions will be taken after the burn to reduce residual smoke, like prompt mop-up, mop-up of certain fuels, or complete mop-up of all smoking fuels.
- If residual smoke problems from logs, brush piles, snags or stumps may be a problem, take steps to keep them from burning. If they do ignite, extinguish them quickly.
- If post-burn smoke could be a problem, be sure to monitor the burn unit and have personnel in place to suppress any fuels that begin to smolder.

Before the burn, outline what actions will be taken to reduce residual smoke. Measures such as prompt mop-up, monitoring the burn unit, and having personnel in place to suppress any fuels that begin to smolder are methods to reduce the impact of post-burn smoke. (photo by Stephen Winter)

Reduce the amount of fuels to reduce smoke emissions:

- Use periodic maintenance-type prescribed burns that follow historic natural fire return intervals.
- Consolidate non-merchandisable material in commercial forestry areas, have timber sales of multiple products, use chemical or mechanical treatments, and allow firewood cutting.
- Utilize single or multi-species grazing on rangelands to reduce fine fuels or use haying practices.
- Exercise care when using certain mechanical treatments because they can increase the amount of fuel and volatility of fuels within a burn unit.

Reduce the impact of smoke on people:

- Notify all people that could possibly be affected downwind, such as nearby residents, adjacent landowners, fire departments, and local fire control offices. This is a common courtesy and common sense.
- Inform smoke-sensitive persons how to avoid smoke exposure.
- Re-locate or provide clean-air facilities for sensitive persons until the risk is over.
- Mop-up along roads as soon as possible and pay special attention when roads are in areas where smoke can travel downslope or down drainage.
- Use appropriate signage to inform the public about areas where smoke will impact them, such as highways, secondary roads, trails and campgrounds.
- Initiate public education or public relations prior to conducting burns.

It is up to the fireboss to manage the smoke on each fire. The incorporation of one or more of these smoke impact reduction methods can reduce both current and future problems on most prescribed fires. Remember that even when the smoke leaves the burn unit, it is still our smoke and we should do everything possible to reduce the impacts on people outside of the burn unit.

Use appropriate signage to inform the public about areas where smoke will impact them. This will reduce prescribed fire smoke-related problems and conflicts. (photo by Adam Gourley)

OK-FIRE: Weather-Based Tools for Smoke Management

Wildland fire managers in Oklahoma are fortunate to have a state-of-the-art automated weather station network, the Oklahoma Mesonet. The network is jointly operated by the University of Oklahoma and Oklahoma State University. Operational since 1994, the Oklahoma Mesonet currently consists of 120 weather towers (10 m tall) with an average station spacing of 19 miles (Figure 1). Weather information is relayed every 5 minutes and is available on Mesonet web sites within about 7 minutes of being sent. Thus, fire managers can access current weather conditions critical to smoke management with updates every 5 minutes.

Fire managers can access this Mesonet weather information plus a wealth of other weather-based fire management products on OK-FIRE, a weather-based wildland fire decision support system: ***http://okfire.mesonet.org***

OK-FIRE, a program of Oklahoma State University in conjunction with the Oklahoma Mesonet, was developed as a result of a three-year federal grant from the Joint Fire Science Program. OK-FIRE products focus on three areas: fire weather, fire danger, and smoke dispersion. These products utilize the Oklahoma Mesonet for current and recent conditions, and the North American Model (NAM) of the National Weather Service for forecast conditions. The NAM forecasts, which predict 84 hours in the future, are incorporated by OK-FIRE every six hours, using the 00Z, 06Z, 12Z, and 18Z operational runs of the model.

OK-FIRE products are available in the following formats: (1) dynamic maps of Oklahoma, capable of zooming, animation, and overlays; (2) site-specific charts; and (3) site-specific tables. These products can be viewed from the previous five days through the latest 84-hour forecast period. The

Figure 1. Location of Oklahoma Mesonet sites.

map and chart products require the simple installation of a plug-in, "WeatherScope," available for download on the home page.

Oklahoma Dispersion Model

The Oklahoma Dispersion Model was developed to assess surface dispersion conditions up to several miles downwind. It breaks the atmosphere into six dispersion categories:

6 = Excellent (EX)
5 = Good (G)
4 = Moderately Good (MG)
3 = Moderately Poor (MP)
2 = Poor (P)
1 = Very Poor (VP)

In the map products, dispersion categories 4 through 6 are colored in increasing shades of green, while category 3 is colored in beige, category 2 in orange, and category 1 in red (Figure 2).

The lower end of this scale (1 and 2) typically occurs with inversion conditions, which inhibit mixing and lead to poor dispersion. During such conditions, the smoke plume hangs together as it drifts downwind and anyone caught near the plume centerline could be smoked out. The upper end of this scale (5 and 6) typically occurs with unstable atmospheric conditions, when the dispersion is good, both in the vertical and horizontal directions. The Oklahoma Dispersion Model can be interpreted as follows—for a given distance downwind, smoke concentrations near the plume centerline will be least under the excellent (EX) category and highest under the very poor (VP) category. For further details, consult the OSU Extension publication BAE-1739, "Movement of Odors Off-Farm."

Dispersion Products

Dispersion-related products are found in the "SMOKE" section of the OK-FIRE web site. The map which appears upon entering this section is that of current dispersion conditions based on the latest Mesonet data. Note also that there are three major menu items on the left: "Current/Recent Surface Dispersion," "Forecast Surface Dispersion," and "Forecast Boundary-Layer Conditions."

"Current/Recent Surface Dispersion" contains products based on Oklahoma Mesonet data and relevant to surface smoke dispersion. In "*Site-Specific Dispersion,*" one can click on a nearby Mesonet site to get the latest weather information related to smoke dispersion (Figure 3), including wind speed and direction, the vertical temperature difference if the tower has two levels of temperature sensors (positive values denote a temperature inversion and poor dispersion conditions), and the latest dispersion conditions from the Oklahoma Dispersion Model.

The "*Surface Fire Weather Map*" gives an overall view of the wind, temperature, and relative humidity conditions across the state.

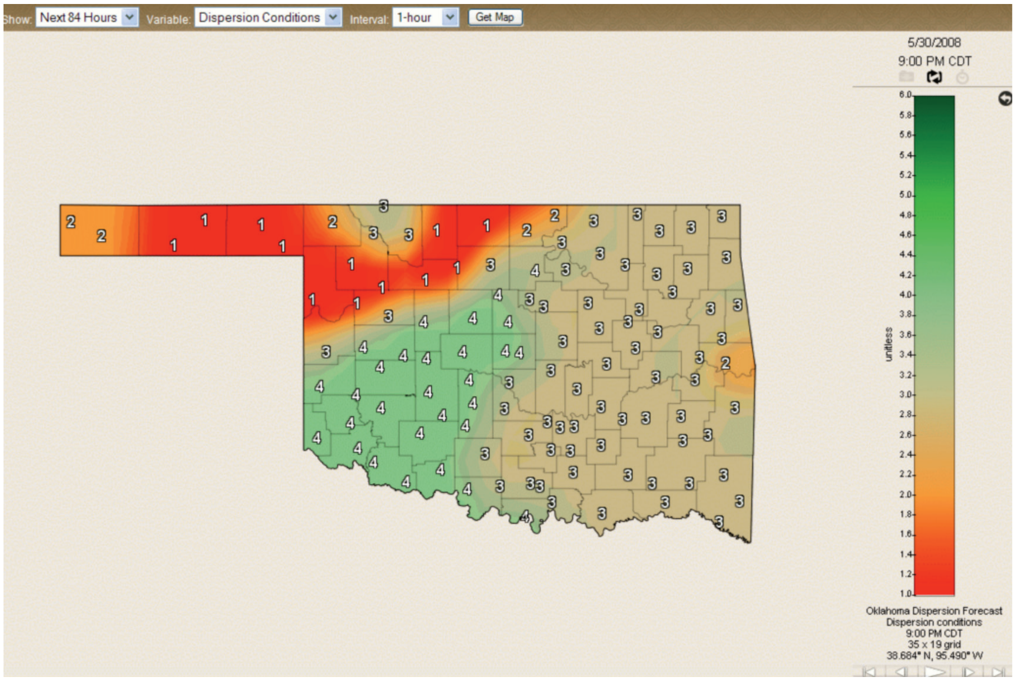


Figure 2. Example of a forecast dispersion conditions map from the Oklahoma Dispersion Model.

The "*Surface Inversion Map*" shows the latest Mesonet tower vertical temperature differences (between 9 m and 1.5 m); again, positive values denote surface inversions, which are indicative of poor dispersion conditions. In the "*Dynamic Dispersion Maps*" section, one can access dispersion condition and wind vector maps from the previous 5 days; of more relevance, using the animation feature, burn managers can see how dispersion conditions and winds have changed over the past number of hours (Figure 4). In "*Site-Specific Dispersion Charts*" and "*Site-Specific Dispersion Tables,*" one can click on a nearby Mesonet site to see current/recent dispersion and wind conditions in chart and table format, respectively.

"Forecast Surface Dispersion" contains products based on the latest 84-hour output of the NAM model. In "*Dynamic Dispersion Maps*" animations are available of the expected dispersion and wind vector conditions for the next 84 hours. In "*Site-Specific Dispersion Charts*" and "*Site-Specific Dispersion Tables,*" forecast dispersion and wind conditions for a specific Mesonet location are viewable in chart and table format, respectively (Figure 5).

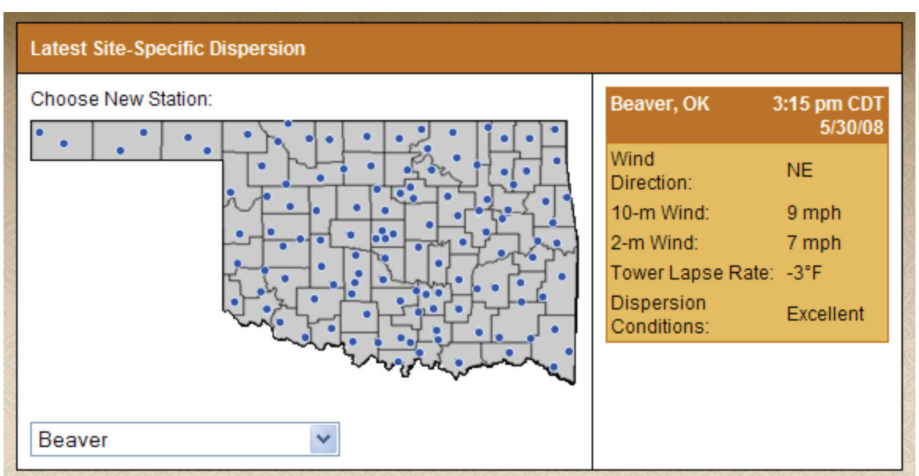


Figure 3. Example showing the latest dispersion conditions for Beaver based on Mesonet data.

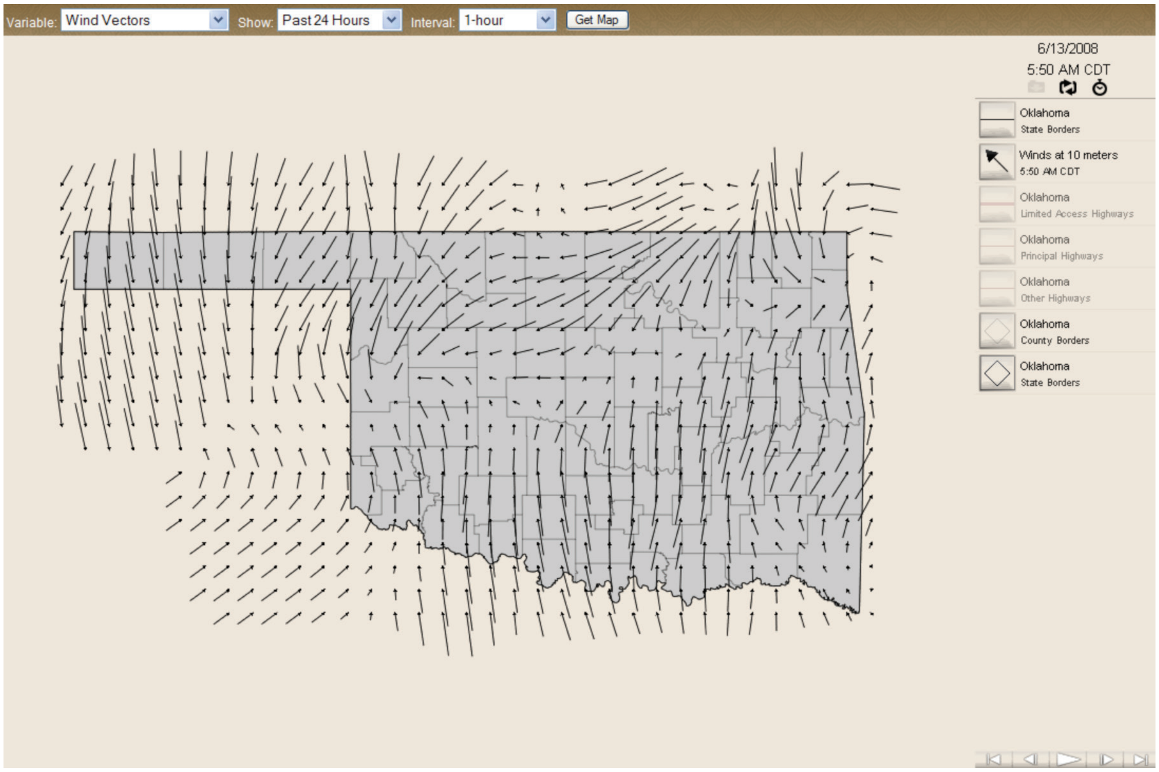


Figure 4. Example of a wind vector plot based on Mesonet data.

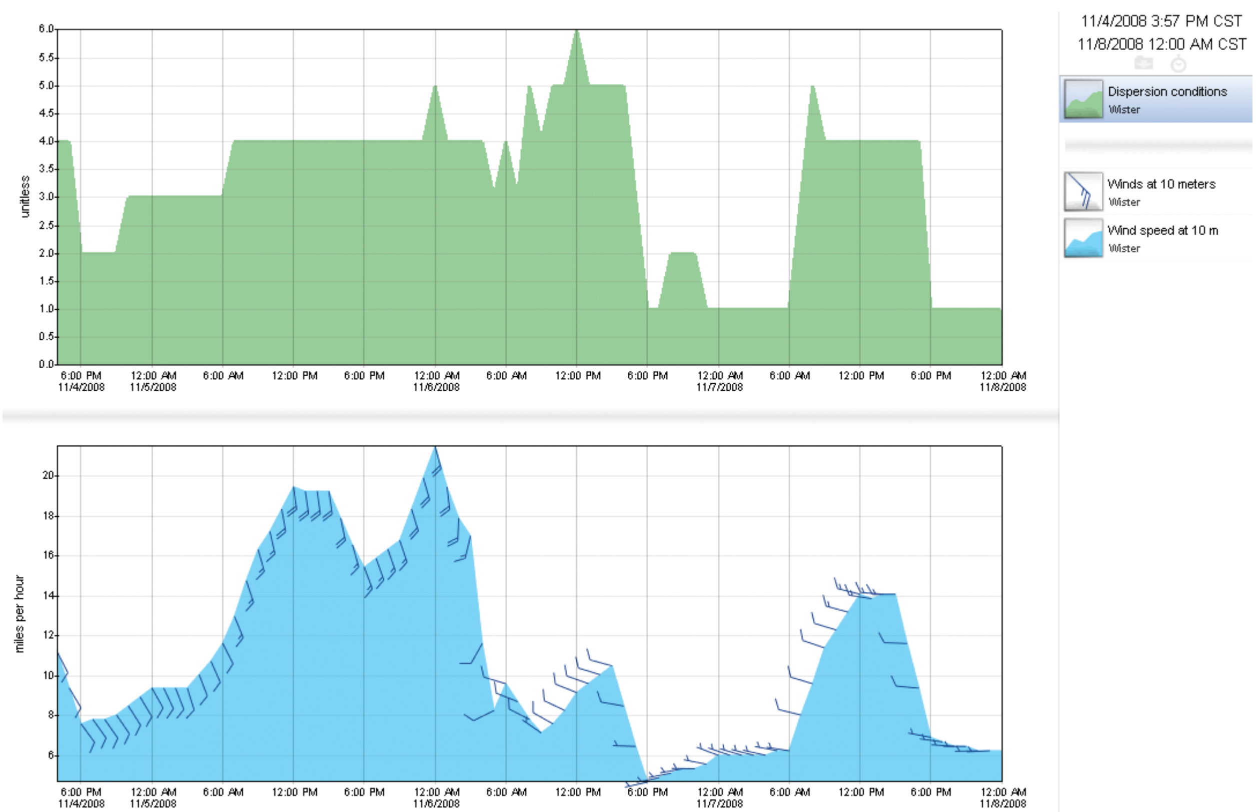


Figure 5. Example of a forecast dispersion chart for Wister. Predicted dispersion conditions (green) are shown in the top graph, and wind speeds (blue) and directions (staff/barb symbols) in the bottom graph.

Fuel Moisture Products

As mentioned earlier, fuel moisture affects smoke production - generally, the more water a given fuel possesses, the more smoke will be given off. With high fuel moisture, most of the energy in the flaming phase will go into vaporizing water rather than burning dry matter, leaving more dry matter to burn in the smoldering phase. Of course, if fuel moisture is too high, the fuel won't burn; if fuel moisture is too low, dangerous and intense fire behavior can result.

Fuel moisture is therefore an important topic both for fire behavior and smoke management. In particular, dead fuel moisture (DFM) is important as it is the dead fuels which are most prominent during the prescribed burn and wildfire seasons in Oklahoma. For purposes of fire modeling, dead fuels are often broken into four categories: 1-hour fuels (less than 1/4-inch in diameter), 10-hour fuels (1/4-inch to 1-inch diameter), 100-hour fuels (1-inch to 3-inch diameter), and 1,000-hour fuels (3-inch to 8-inch diameter). As a general rule, with respect to fire behavior and safety issues, the preferred range of 1-hour DFM should be between 7 percent and 20 percent and 10-hour DFM between 6 percent and 15 percent. Higher fuel moisture values may result in low ignition and very little fire spread, while lower values may result in extreme fire behavior. Consult the OSU Extension publication NREM-2878, "Fire Prescriptions for Maintenance and Restoration of Native Plant Communities," for more details.

OK-FIRE offers a wealth of fuel moisture products for the previous 5 days through the latest 84-hour forecast period. As with other products, they are available in map, chart, and table format (Figure 6). These fuel moisture products can be found in the "FIRE" section of OK-FIRE under "Current/Recent Fire Danger" and "Fire Danger Forecasts."

Fire Prescription Planner

The "Fire Prescription Planner" on OK-FIRE allows the fire manager to specify lower and/or upper limits for various variables pertaining to weather, dispersion conditions, dead fuel moisture, and fire danger. After the prescribed values are entered, the user chooses a Mesonet site. Then, using output based on the latest 84-hour forecast, a table is produced for each hour of the forecast period showing which hours the prescription is met (for each prescribed variable and for all of them combined). Times when the

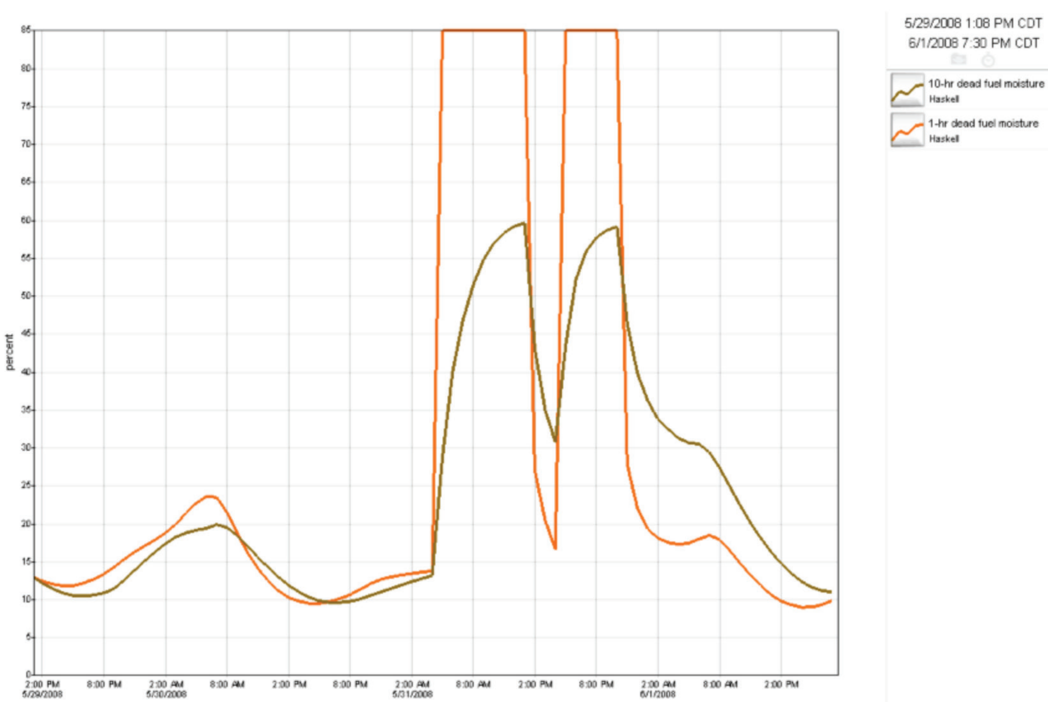


Figure 6. Forecast chart of 1-hour and 10-hour dead fuel moisture for Haskell from OK-FIRE.

criteria are met are shaded green, and those hours when they are not met are shaded red. This product is accessible from the home page as well as from the "WEATHER," "FIRE," and "SMOKE" sections.

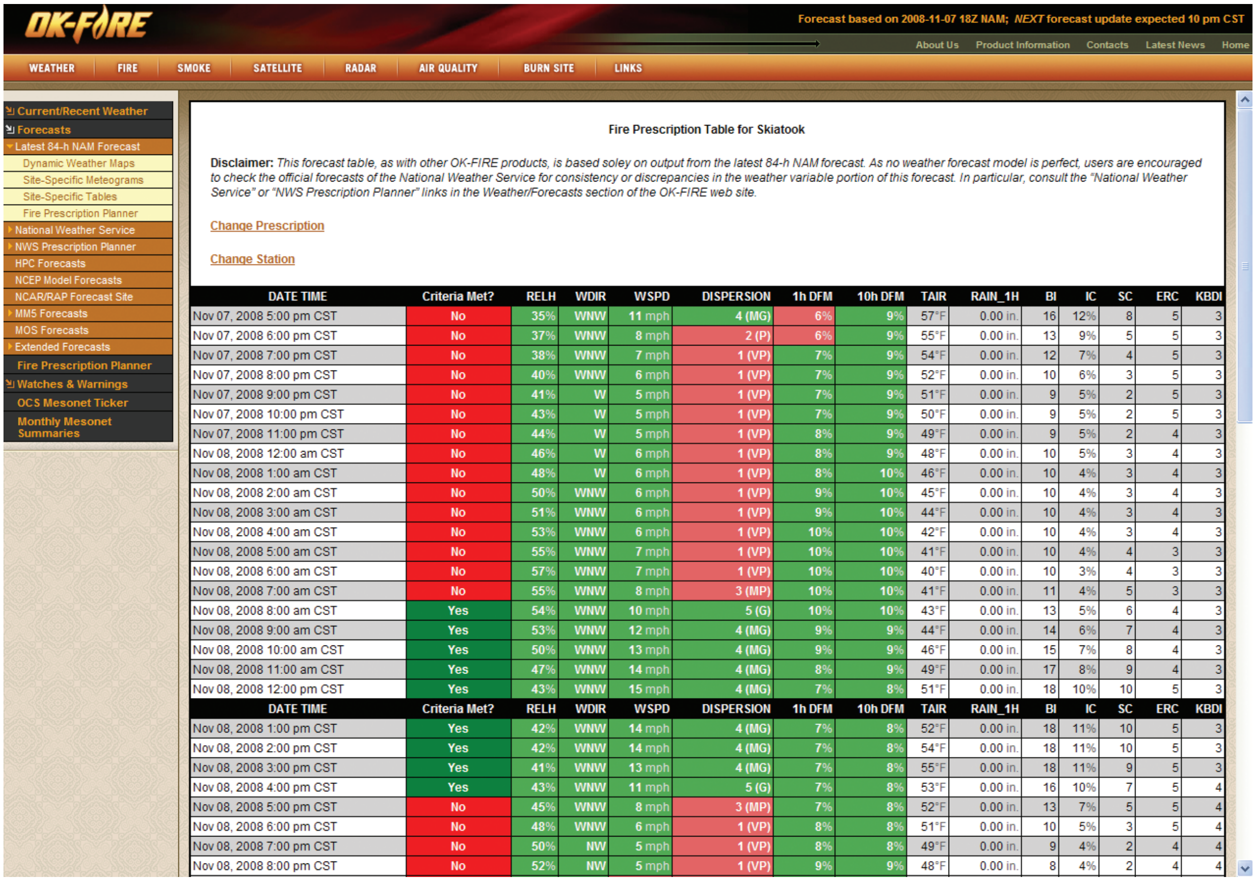
As an example, a fire manager near Skiatook is considering a prescribed burn during the next three days and wishes to see when conditions might be suitable. The burn prescription calls for relative humidity between 30 and 60 percent and wind speeds between 5 and 15 mph. In addition, winds out of the westerly sectors (southwest, west, northwest) are desired. With respect to smoke management, the burn manager puts a lower limit on dispersion conditions of "Moderately Good". Finally, the dead fuel moisture for the burn is prescribed between 7 and 20 percent for 1-hour fuels and between 6 and 15 percent for 10-hour fuels. The first step in the Fire Prescription Planner involves the entry of this information for the prescribed elements. Note that not all data fields need be entered (Figure 7).

After the selection of the Mesonet site Skiatook (not shown), a table is created showing which hours of the 84-hour forecast period meet or do not meet the prescription criteria. The resulting table for Skiatook indicates a suitable period for such a burn between 8 a.m. and 4 p.m. the next day (Figure 8). Note that the first column after the date/time column is entitled "Criteria Met?" and that for these hours those cells are shaded green, indicating all prescribed variable criteria are met during these hours. Also, wind directions are expected to be steady during this period (out of the west-northwest), which is important during prescribed burns.

Smoke Management Products from the National Weather Service

In addition to the Oklahoma Dispersion Model which is designed to model surface dispersion up to several miles downwind, another system can be used for smoke management which deals with the ability of the atmosphere to mix and transport smoke over large distances throughout

Figure 7. Example of selecting values for prescription forecast elements in the Fire Prescription Planner.



DATE TIME	Criteria Met?	RELH	WDIR	WSPD	DISPERSION	1h DFM	10h DFM	TAIR	RAIN_1H	BI	IC	SC	ERC	KBDI
Nov 07, 2008 5:00 pm CST	No	35%	WNW	11 mph	4 (MG)	6%	9%	57°F	0.00 in.	16	12%	8	5	3
Nov 07, 2008 6:00 pm CST	No	37%	WNW	8 mph	2 (P)	6%	9%	55°F	0.00 in.	13	9%	5	5	3
Nov 07, 2008 7:00 pm CST	No	38%	WNW	7 mph	1 (VP)	7%	9%	54°F	0.00 in.	12	7%	4	5	3
Nov 07, 2008 8:00 pm CST	No	40%	WNW	6 mph	1 (VP)	7%	9%	52°F	0.00 in.	10	6%	3	5	3
Nov 07, 2008 9:00 pm CST	No	41%	W	5 mph	1 (VP)	7%	9%	51°F	0.00 in.	9	5%	2	5	3
Nov 07, 2008 10:00 pm CST	No	43%	W	5 mph	1 (VP)	7%	9%	50°F	0.00 in.	9	5%	2	5	3
Nov 07, 2008 11:00 pm CST	No	44%	W	5 mph	1 (VP)	8%	9%	49°F	0.00 in.	9	5%	2	4	3
Nov 08, 2008 12:00 am CST	No	46%	W	6 mph	1 (VP)	8%	9%	48°F	0.00 in.	10	5%	3	4	3
Nov 08, 2008 1:00 am CST	No	48%	W	6 mph	1 (VP)	8%	10%	46°F	0.00 in.	10	4%	3	4	3
Nov 08, 2008 2:00 am CST	No	50%	WNW	6 mph	1 (VP)	9%	10%	45°F	0.00 in.	10	4%	3	4	3
Nov 08, 2008 3:00 am CST	No	51%	WNW	6 mph	1 (VP)	9%	10%	44°F	0.00 in.	10	4%	3	4	3
Nov 08, 2008 4:00 am CST	No	53%	WNW	6 mph	1 (VP)	10%	10%	42°F	0.00 in.	10	4%	3	4	3
Nov 08, 2008 5:00 am CST	No	55%	WNW	7 mph	1 (VP)	10%	10%	41°F	0.00 in.	10	4%	4	3	3
Nov 08, 2008 6:00 am CST	No	57%	WNW	7 mph	1 (VP)	10%	10%	40°F	0.00 in.	10	3%	4	3	3
Nov 08, 2008 7:00 am CST	No	55%	WNW	8 mph	3 (MP)	10%	10%	41°F	0.00 in.	11	4%	5	3	3
Nov 08, 2008 8:00 am CST	Yes	54%	WNW	10 mph	5 (G)	10%	10%	43°F	0.00 in.	13	5%	6	4	3
Nov 08, 2008 9:00 am CST	Yes	53%	WNW	12 mph	4 (MG)	9%	9%	44°F	0.00 in.	14	6%	7	4	3
Nov 08, 2008 10:00 am CST	Yes	50%	WNW	13 mph	4 (MG)	9%	9%	46°F	0.00 in.	15	7%	8	4	3
Nov 08, 2008 11:00 am CST	Yes	47%	WNW	14 mph	4 (MG)	8%	9%	49°F	0.00 in.	17	8%	9	4	3
Nov 08, 2008 12:00 pm CST	Yes	43%	WNW	15 mph	4 (MG)	7%	8%	51°F	0.00 in.	18	10%	10	5	3
DATE TIME	Criteria Met?	RELH	WDIR	WSPD	DISPERSION	1h DFM	10h DFM	TAIR	RAIN_1H	BI	IC	SC	ERC	KBDI
Nov 08, 2008 1:00 pm CST	Yes	42%	WNW	14 mph	4 (MG)	7%	8%	52°F	0.00 in.	18	11%	10	5	3
Nov 08, 2008 2:00 pm CST	Yes	42%	WNW	14 mph	4 (MG)	7%	8%	54°F	0.00 in.	18	11%	10	5	3
Nov 08, 2008 3:00 pm CST	Yes	41%	WNW	13 mph	4 (MG)	7%	8%	55°F	0.00 in.	18	11%	9	5	3
Nov 08, 2008 4:00 pm CST	Yes	43%	WNW	11 mph	5 (G)	7%	8%	53°F	0.00 in.	16	10%	7	5	4
Nov 08, 2008 5:00 pm CST	No	45%	WNW	8 mph	3 (MP)	7%	8%	52°F	0.00 in.	13	7%	5	5	4
Nov 08, 2008 6:00 pm CST	No	48%	WNW	6 mph	1 (VP)	8%	8%	51°F	0.00 in.	10	5%	3	5	4
Nov 08, 2008 7:00 pm CST	No	50%	NW	5 mph	1 (VP)	8%	8%	49°F	0.00 in.	9	4%	2	4	4
Nov 08, 2008 8:00 pm CST	No	52%	NW	5 mph	1 (VP)	9%	9%	48°F	0.00 in.	8	4%	2	4	4

Figure 8. Resulting forecast table for Skiatook in the Fire Prescription Planner.

the boundary layer (the mixed layer), which can extend upwards of 5,000 feet above the surface. The "Mixing Height" is the depth of the layer above the ground throughout which smoke can be dispersed. "Transport Wind" is the average wind speed through the depth of that layer. Multiplying these two variables gives "Ventilation Rate" (VR), which is an estimate of the ability of the atmosphere to ventilate the area. A variable called "Category Day," which is a function of VR and ranges from 1 to 5, has been developed as a smoke management index to provide guidance as to when and when not to burn. A Category Day value of 1 represents the worst boundary-layer dispersion conditions during which no burning should occur, while a Category Day value of 5 represents the best boundary-layer dispersion conditions. This system is more fully described in the OSU Extension publication E-927, "Using Prescribed Fire in Oklahoma."

Category Day forecasts can be obtained from local National Weather Service (NWS) offices serving Oklahoma (Amarillo, Norman, Tulsa, and Shreveport). Links to their fire weather web pages can be found on the OK-FIRE site in the "SMOKE" section under "Forecast Boundary-Layer Conditions" and "*National Weather Service.*" The fire manager can click on the NWS office serving the area of concern and view predictions of Category Day through the 84-hour period.

It is important to consult both the Oklahoma Dispersion Model, which relates to surface dispersion conditions, and the Category Day system, which relates to the capacity of the boundary layer to disperse the smoke. Under some circumstances the Oklahoma Dispersion Model could show good to excellent conditions at the surface, but the mixing height and/or transport wind could be so low that the smoke is trapped in a relatively small vertical layer above the surface (refer to earlier picture of entrapped smoke in the boundary layer).

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