NORTH CAROLINA

DIVISION OF AIR QUALITY

Department of Environment and Natural Resources

MARCH 22, 2007 EXCEPTIONAL EVENT DEMONSTRATION PACKAGE

FOR THE

BRYSON CITY FINE PARTICLE FEDERAL REFERENCE METHOD MONITOR (371730002-88101-1)

December 14, 2007

NCDENR

A Division of the North Carolina Department
of Environment and Natural Resources
Mail Service Center 1641
Raleigh, North Carolina 27699-1641

TABLE OF CONTENTS

Bryson City FRM-$PM_{2.5}$
Swain County, NC
Site ID: 371730002 - 88101
03/22/07
FRM $PM_{2.5}$ Concentration = 43.38 ug/m^3
Recommended Flag - Q: Prescribed Fire

Summary

The North Carolina Division of Air Quality seeks EPA concurrence of the "Q" flag (Prescribed Fire) for an exceedance of the daily PM2.5 standard that occurred at Bryson City on March 22, 2007. The monitor at this location measured a concentration of 43.375 micrograms per cubic meter. It is believed that the elevated concentration on this particular day was due to prescribed burns impacting the monitor. Continuous particulate monitoring revealed the highest concentrations between 1700 March 22nd and 0900 on March 23rd.

The prescribed burn believed to have impacted this monitor on March 22, 2007 was the Shortoff Prescribed Fire in Clay County, NC. This location is on the Tusquitee District of the Nanahala National Forest. The area burned was 1644 acres and the elevation varied from 2000-3900 ft. The coordinates of the prescribed burn were 35.109 degrees latitude and –83.868 degrees longitude. Through the use of trajectory analysis as well as satellite imagery a conclusion can be drawn that the monitor at Bryson City was directly impacted by the Shortoff Prescribed burn. Weather forcasts for March 22nd predicted transport winds from the SW at speeds of 16-20 mph which would have moved smoke from the location of this prescribed burn toward Bryson City. With the distance of the prescribed fire being approximately 30 miles from Bryson City it is estimated that the smoke would have traveled to Bryson City within approximately two hours.

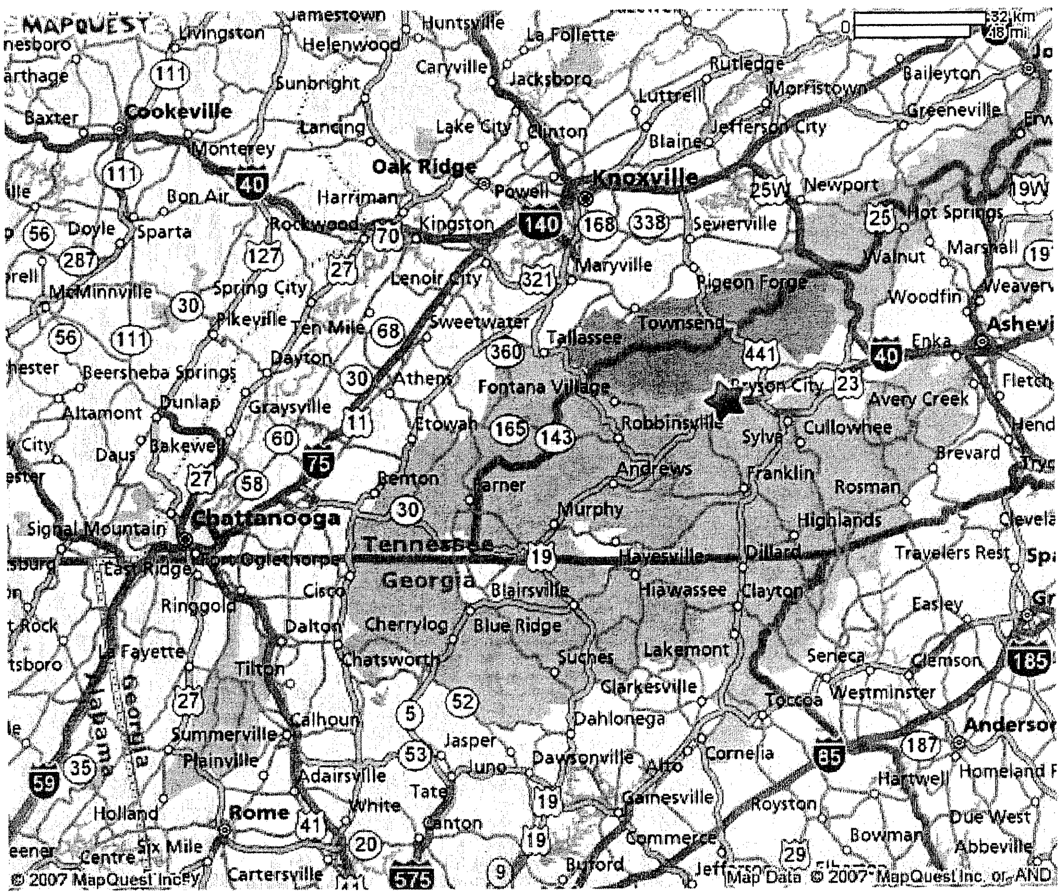
According to the US Department of Agriculture Forest Service the fire began on March 21, 2007 with the use of hand ignition of fuels on the perimeter to provide control lines. This initial burn began at approximately 1200 hours and continued until about 1800 hours. Hand ignition resumed at 1000 on March 22, 2007 burning approximately 300 acres. At approximately 1345-1400 hours an aerial ignition was used to treat the interior of the burn. It is estimated that the maximum emissions occurred between 1500 and 1700 hours on March 22nd.

Trajectories, GIS maps and satellite imagery are attached. These items provide visual evidence that the Shortoff prescribed burn directly impacted the monitor at Bryson City, NC.

The "But For" analysis shows distinctly that the Shortoff prescribed burn contributed to the exceedance on March 22, 2007. It also demonstrates that had the burn not impacted the monitor an exceedance would not have occurred at the Bryson City monitoring site on that day.

Bryson City NC
US

Notes:
Only text visible within note field will print.



"Atypical" Analysis for Bryson 22 March 2007 Exceedance

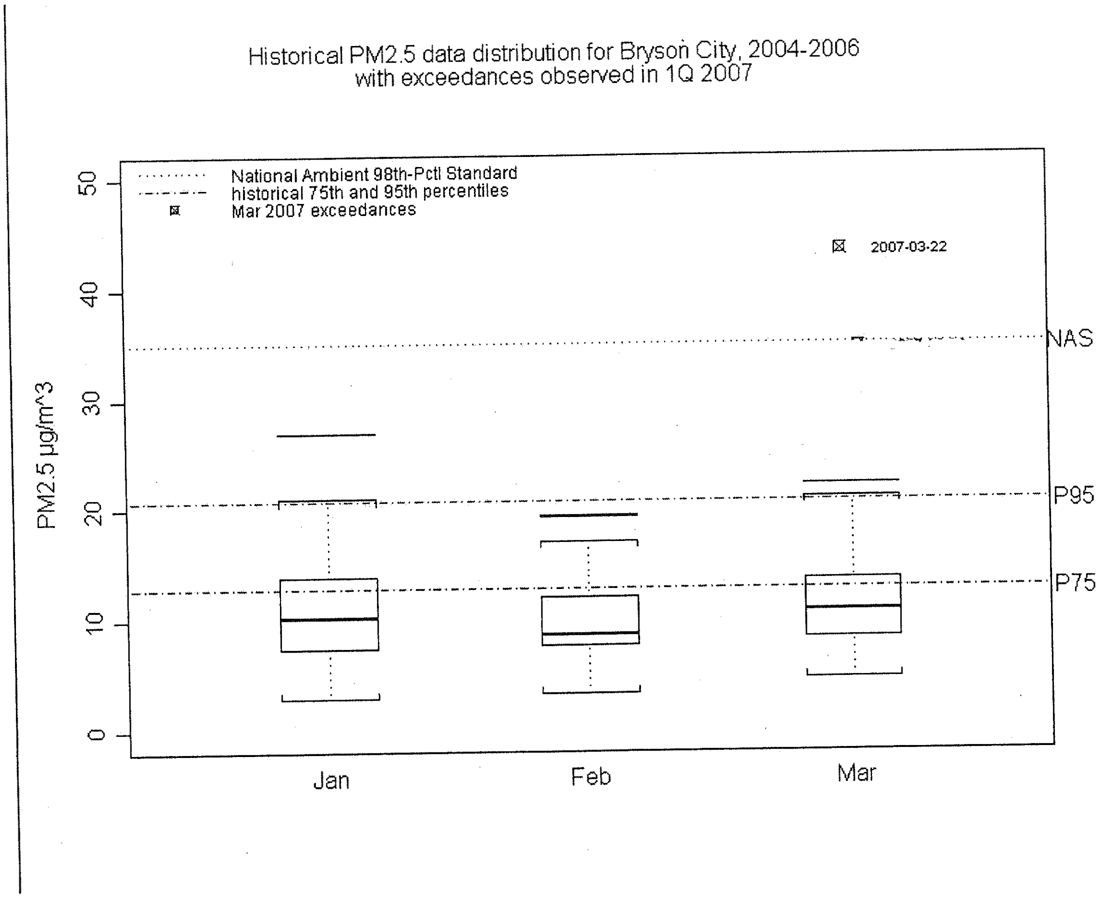


Figure 3.1 - shows "normal historical fluctuations" of PM2.5 data for the Bryson City monitoring station during the first calendar quarter in the form of boxplots for the individual *monthly* distributions with reference lines showing the historical levels of the 75th and 95th percentile levels as well as the level of the National Ambient 98th-percentile Standard (12.8 µg/m^3, 20.7 µg/m^3, and 35.0 µg/m^3, respectively).

EPA has discussed the possible use of the historical 75th and 95th percentiles as objective thresholds for favorable concurrence decisions { [Federal Register: March 10, 2006 (Volume 71, Number 47)] The Treatment of Data Influenced by Exceptional Events: Proposed Rules, p. 12592} The historical 95th percentile level for this event is 20.7 µg/m^3. The 22 Mar 2007 exceedance exceeds the historical 95th percentile level by 110 percent.

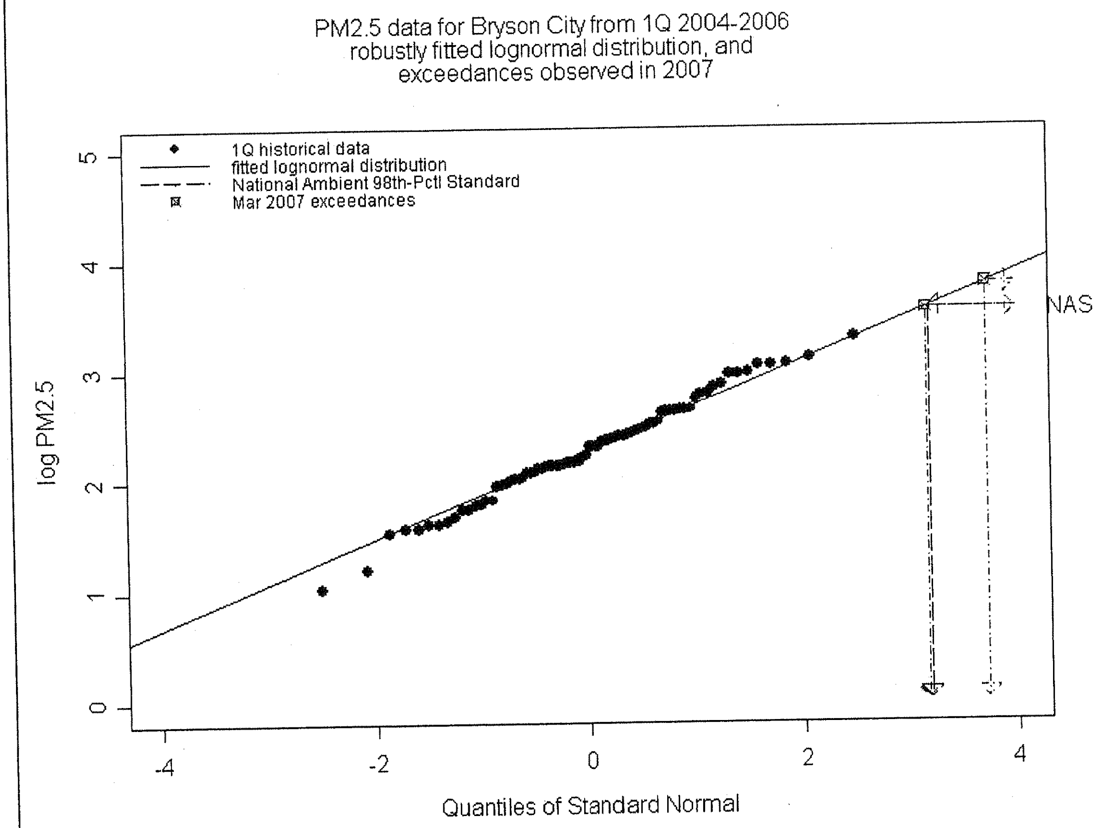


Figure 3.2 - shows "normal historical fluctuations" of PM2.5 data for the Bryson City monitoring station during the first calendar quarter in the form of a lognormal distribution quantile plot.

Particulate pollution data are often well approximated by lognormal distributions. This graph shows the natural logarithms of the historical data (in log-μg/m^3 units) sorted from smallest concentration to largest concentration, plotted against the corresponding quantiles of a standard normal distribution. An *exact* lognormal distribution closely matching these data is shown as a diagonal straight line in the graph. The level of the National Ambient 98th-percentile Standard (y=3.56) and the 22 Mar 2007 exceedance (y=3.77) are shown as points on the lognormal distribution line, illustrating that expected probability of exceeding the level of the National Ambient 98th-percentile Standard in the absence of exceptional events is about 0.07 percent (3.18 standard deviations greater than the lognormal mean value), and the expected probability of "unexceptional data" exceeding the level observed on 22 Mar 2007 is less than 0.01 percent (more than 3.72 standard deviations greater than the lognormal mean value).

The estimated parameters of the lognormal approximation are:

- median PM2.5 = 9.8
- mean PM2.5 = 10.6
- 98th pctl PM2.5 = 22.3

"But For" Test: There would have been no exceedance or violation "but for" the event at Bryson City on March 22, 2007.

Executive summary

To demonstrate that the Shortoff prescribed fire caused an exceedance of the daily fine particle standard of 35 micrograms per cubic meter at the Bryson City monitor on March 22, 2007, we need to find a way to either estimate (1) what the fine particle concentration value would have been on March 22, 2007, if the prescribed fire had not been present or (2) how many fine particles the prescribed fire contributed to the fine particle concentration measured at the Bryson City monitor on March 22, 2007. Either approach should be sufficient to demonstrate that the prescribed fire caused this exceedance. There are several possible ways to approach either question. For the impact of the Shortoff prescribed fire at Bryson City on March 22, 2007, we opted to develop a model using meteorological measurements to estimate what the fine particle concentration value would have been on March 22, 2007 at Bryson City if the prescribed fire had not occurred. A more detailed description of the model is provided below.

The model developed explains less than half of the observed variation in the fine particle concentrations in the dataset. As a result there is a large amount of uncertainty in the estimation of the fine particle concentration at Bryson City on March 22, 2007. However, we can use the value calculated by the model and the uncertainty calculated by the model for that value to calculate the maximum value that we would expect to see at Bryson City on March 22, 2007, with a certain probability. **If we calculate the maximum expected value using a 99 percent probability and it is less than 35 micrograms per cubic meter, then there is at most a 1 percent probability that a value above the standard would have occurred at Bryson City on March 22, 2007, if there had not been a prescribed fire in the area.**

Using the developed model and calculating the maximum expected value using a 99 percent probability indicates that there is a 1 percent probability that a value exceeding 24.96 micrograms per cubic meter would have occurred at Bryson City on March 22, 2007. Thus, without the prescribed fire, there is less than 1 percent probability that the National Ambient Air Quality Standard would have been exceeded on that day. As a result, we believe that the value of 43.4 micrograms per cubic meter, which exceeded the daily fine particle standard, would not have occurred at Bryson City if there had not been the Shortoff prescribed fire on the days of March 21 and 22, 2007.

Data Description

For each day in the 2nd quarter of 2004, 2005, 2006 and 2007 on which there was a valid PM2.5 concentration I acquired the following met data to model the PM2.5 concentrations:

- AT daily mean ambient temperature at the PM2.5 monitoring station
- RH daily mean relative humidity at the PM2.5 monitoring station
- SR daily mean solar radiation at the PM2.5 monitoring station
- PR daily total precipation at the PM2.5 monitoring station
- PR.lag1 previous-day daily total precipitation at the PM2.5 monitoring station
- WS24 daily arith mean wind speed at WAYN, the ECONET automated met station operated by the State Climate Office and NC Agricultural Research Service at the Mountain Research Station in Waynesville, NC.
- WD24 daily average wind direction at WAYN
- WG24 daily mean wind gust speeds at WAYN
- RN24 daily total precipitation at WAYN
- RN24.lag1 previous-day daily total precipitation at WAYN

Linear Models

Note that PR and RN24 are essentially the same variable measured at two different locations. I did not include them in the same model, but instead ran two different linear models, one using PR and PR.lag1, and the other using RN24 and RN24.lag1.

Method of analysis

1. Define a covariate for each exceptional event, setting its value at +1 on the the days of the event and 0 on all other dates. PM.e1 is the covariate for 03/22/2007 (actual concentration 43.4).
2. Define the response variable PM2.5 as follows:

   Response Variable "PM2.5" = actual PM2.5 concentration, if there is not an exceptional event

   = 0.0 on the days of this exceptional event

3. Fit linear model as defined in the models below. The coefficient associated with PM.e1 provides estimates of the expected concentrations that would have occurred if there had not been an exceptional event. (The coefficient value is to be subtracted from the surrogate 0.0 value, so it is actually the *negative* of the estimated concentration.

Results

Based on precipitation totals at the Bryson City met tower

Call: aov(formula = PM2.5 ~ AT + RH + SR + WS24 + WD24 + PR + PR.lag1 + PM.e1, data = BYtest001.df, na.action = na.exclude)

Residuals:				
Min	1Q	Median	3Q	Max
-7.424	-2.623	-0.2717	2.002	14.06

Coefficients:				
	Value	Std. Error	t value	Pr(>|t|)
(Intercept)	-68.5752	80.0237	-0.8569	0.3937
AT	0.2510	0.0916	2.7394	0.0074
RH	0.1117	0.1112	1.0050	0.3175
SR	-0.0152	0.0074	-2.0513	0.0431
WS24	-0.0368	0.2697	-0.1366	0.8916
WD24	0.0059	0.0045	1.3269	0.1878
PR	-0.1586	0.0564	-2.8101	0.0061
PR.lag1	-0.1804	0.1006	-1.7941	0.0761
PM.e1	-14.4956	4.5224	-3.2053	0.0019
Residual standard error: 4.343 on 92 degrees of freedom				
Multiple R-Squared: 0.3018				
F-statistic: 4.419 on 9 and 92 degrees of freedom, the p-value is 0.00008045				
11 observations deleted due to missing values				

Based on precipitation totals at the Mountain Research Station

Call: aov(formula = PM2.5 ~ AT + RH + SR + WS24 + WD24 + RN24 + RN24.lag1 + PM.e1, data = BYtest001.df, na.action = na.exclude)

Residuals:				
Min	1Q	Median	3Q	Max
-7.304	-2.632	-0.2384	2.122	12.76

Coefficients:				
	Value	Std. Error	t value	Pr(>|t|)
(Intercept)	-22.4483	76.2007	-0.2946	0.7690
AT	0.3104	0.0850	3.6504	0.0004
RH	0.0480	0.1059	0.4530	0.6516
SR	-0.0158	0.0067	-2.3379	0.0215
WS24	-0.0401	0.2458	-0.1631	0.8708
WD24	0.0045	0.0042	1.0779	0.2839
RN24	-6.4728	1.5721	-4.1173	0.0001
RN24.lag1	-9.6522	2.8816	-3.3496	0.0012

PM.e1	-14.8931	4.2555	-3.4997	0.0007
Residual standard error: 4.092 on 94 degrees of freedom				
Multiple R-Squared: 0.3916				
F-statistic: 6.723 on 9 and 94 degrees of freedom, the p-value is 2.181e-007				
9 observations deleted due to missing values				

Discussion

The model using PR (daily total precipitation at the fine particle monitoring station) had more missing days and a smaller R^2 than the model using RN24 (daily total precipitation at the Mountain Research Station meteorological tower in Waynesville, North Carolina). The linear model explains less than one-half of the observed variation in PM2.5 concentrations in the dataset, and there is accordingly a large amount of uncertainty in the estimation of the two concentrations that were affected by exceptional events.

Let's report the estimates using the assumptions that commonly justify regression analysis and analysis of variance. The expected values are as shown in the Coefficients tables, 2.3676× Std. Error defines a 99-percent upper bound under the observed uncertainty in the model using PR precipitation data, and 2.3667× Std. Error defines a 99-percent upper bound under the observed uncertainty in the model using RN24 precipitation data.

This means that "but for the exceptional event" we have concentrations as shown in Table 5. The column labeled "expectation" is the model's estimate of what concentration would have most likely been observed were the exceptional event not present. The column labeled "99% probability upper limit" takes the standard error into account and shows a threshold that there is less than 1 percent probability of exceeding. With this exceptional event, for the RN24 model, the expected concentrations were 14.9 $\mu g/m^3$ on 22 March 2007, and the 99-percent upper probability limits were approximately 25 $\mu g/m^3$ for each day.

This suggests a less than one percent probability that the concentrations on the exceptional event day would have exceeded the threshold of the annual standard under observed conditions that are independent of the event.

Table 5. Bryson City Exceptional Event Concentration Statistics on 22 Mar 2007 (PR model).

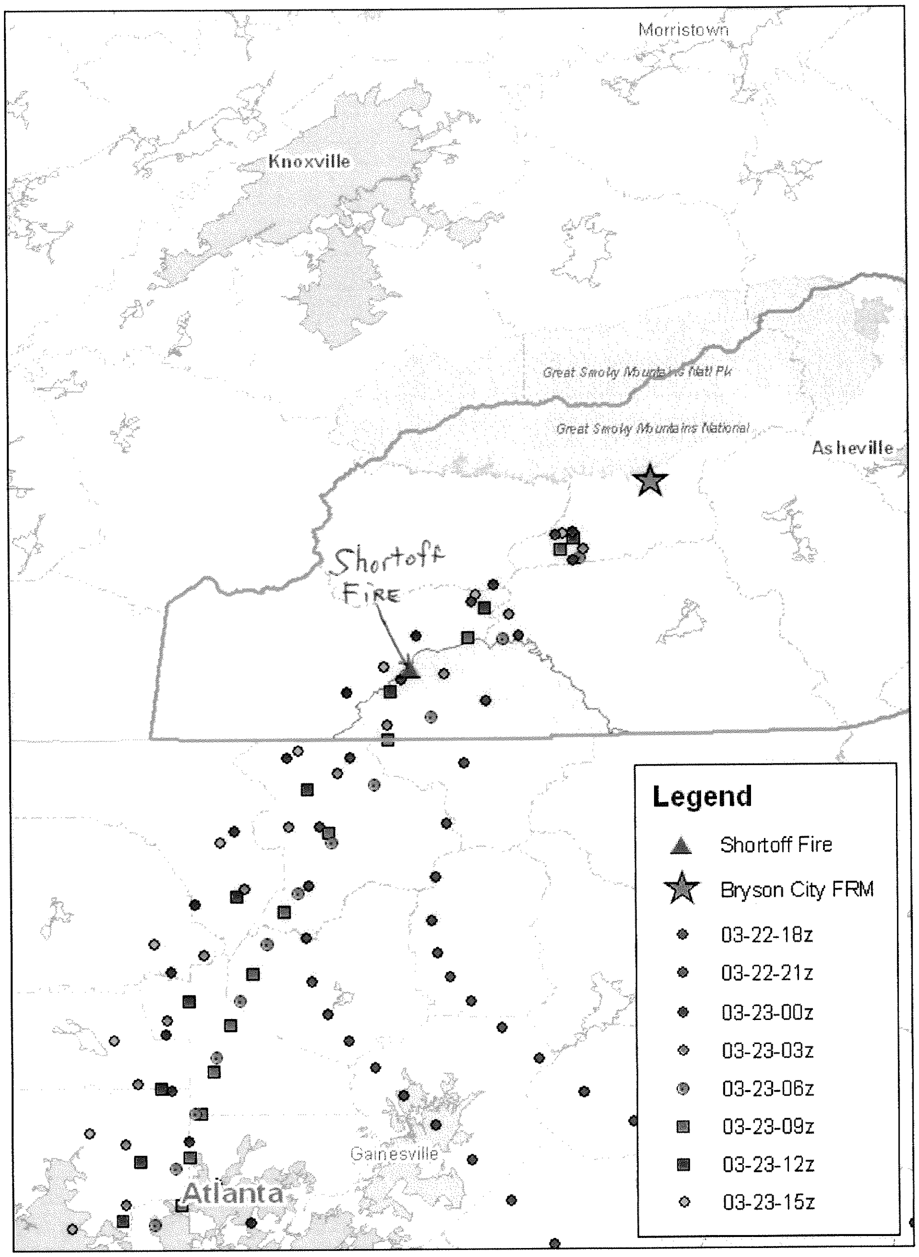
Date	actual	expectation	99% probability upper limit
22 Mar 2007	43.4	14.50	25.20

Table 6. Bryson City Exceptional Event Concentration Statistics on 22 Mar 2007 (RN24 model).

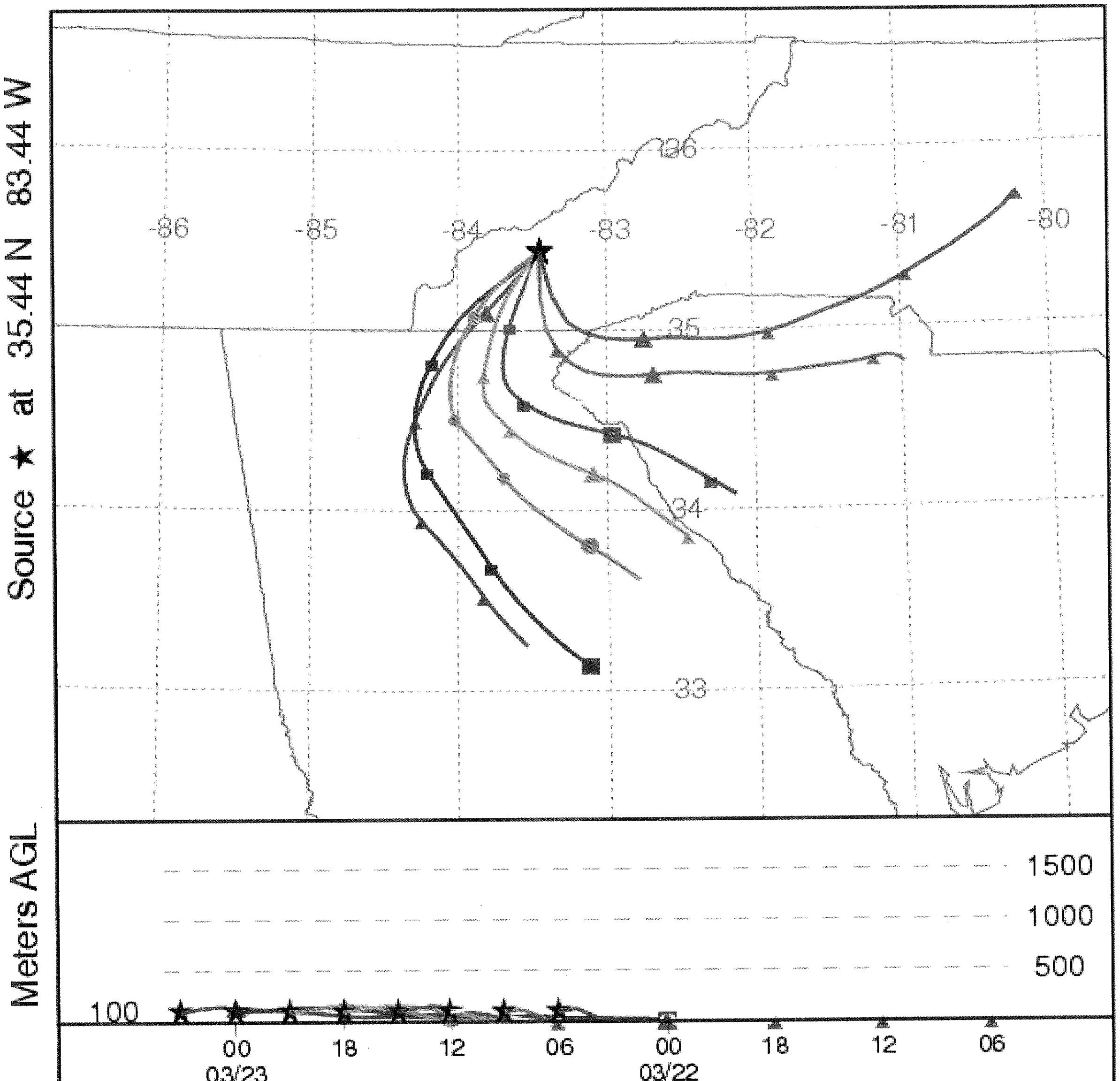
Date	actual	expectation	99% probability upper limit
22 Mar 2007	43.4	14.89	24.96

HYSPLIT Back Trajectories at Bryson City at various times at 100m on 03/22/07

Legend: date I time(zulu). HYSPLIT trajectories use Zulu Time or Coordinated Universal Time (UTC) as their time reference. The trajectory images that appear below are stamped in Zulu time. [To make the conversion to Eastern Daylight time(EDT)(Mar to Nov 2007) use this formula: Zulu - 4, e.g. 18z - 4 = 14z = 2 P.M. Local EDT]



NOAA HYSPLIT MODEL
Backward trajectories ending at 03 UTC 23 Mar 07
EDAS Meteorological Data

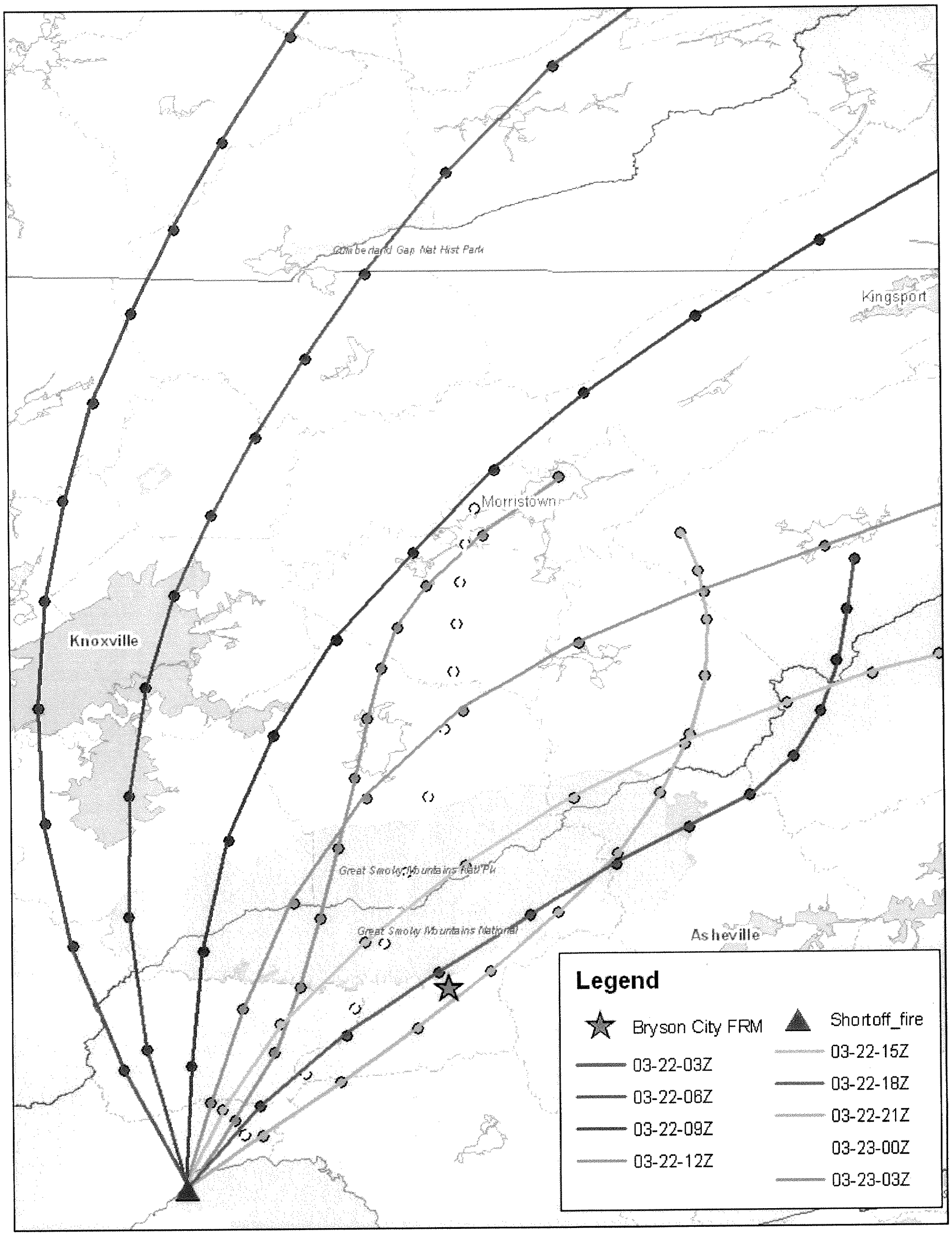


Job ID: 348936 Job Start: Tue Oct 30 14:35:59 GMT 2007
Source 1 lat.: 35.43551 lon.: -83.4437 height: 100 m AGL

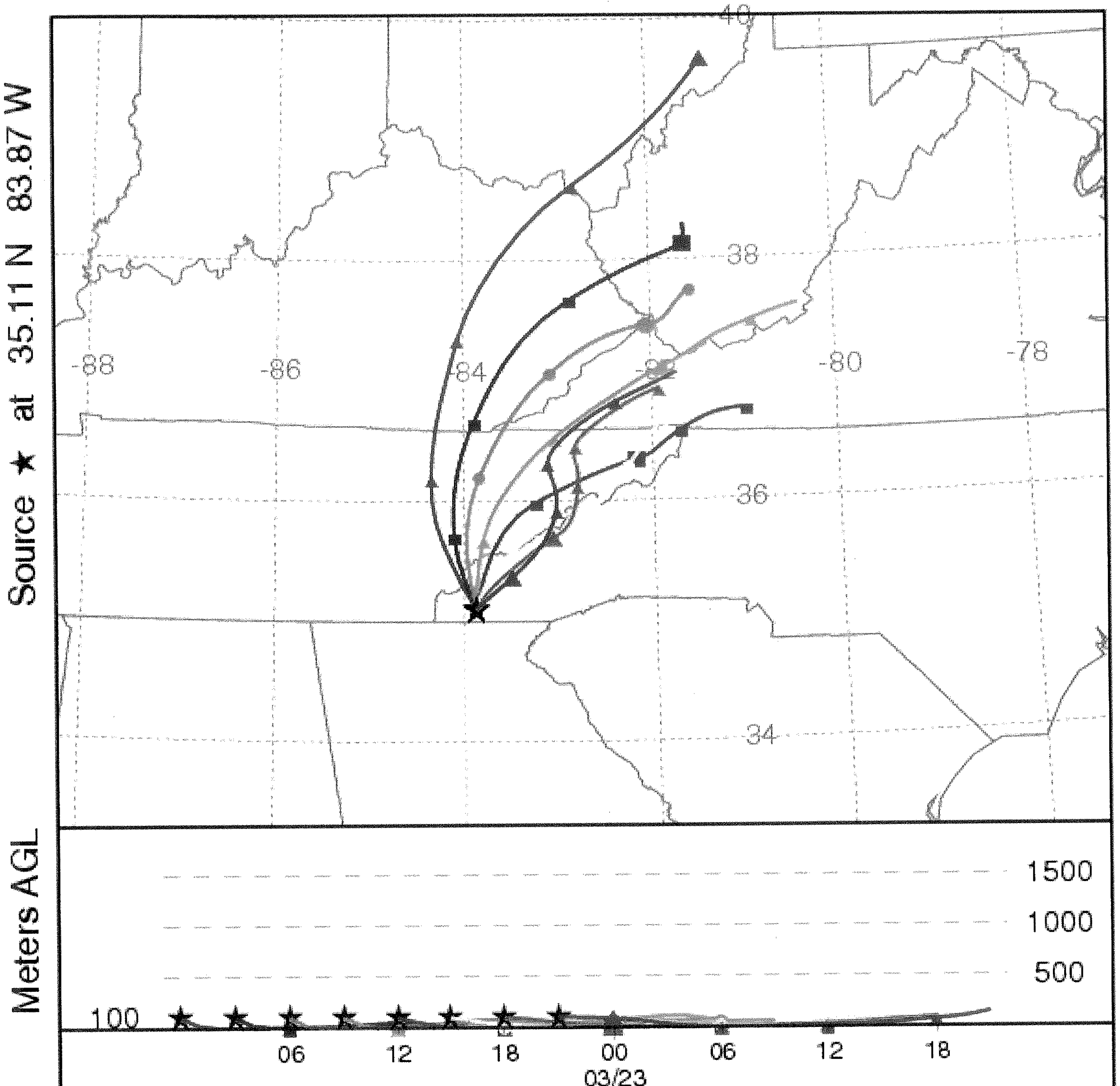
Trajectory Direction: Backward Duration: 24 hrs Meteo Data: EDAS40
Vertical Motion Calculation Method: Model Vertical Velocity
Produced with HYSPLIT from the NOAA ARL Website (http://www.arl.noaa.gov/ready/)

HYSPLIT forward trajectories at Bryson City at various times at 100m on 03/22/07

Legend: date I time(zulu). HYSPLIT trajectories use Zulu Time or Coordinated Universal Time (UTC) as their time reference. The trajectory images that appear below are stamped in Zulu time. [To make the conversion to Eastern Daylight time (EDT)(Mar to Nov 2007) use this formula: Zulu - 4, e.g. 03z - 4 = 23z = 11 P.M. Local EDT]



NOAA HYSPLIT MODEL
Forward trajectories starting at 00 UTC 22 Mar 07
EDAS Meteorological Data



Job ID: 348907 Job Start: Tue Oct 30 14:33:24 GMT 2007
Source 1 lat.: 35.109 lon.: -83.868 height: 100 m AGL

Trajectory Direction: Forward Duration: 24 hrs Meteo Data: EDAS40
Vertical Motion Calculation Method: Model Vertical Velocity
Produced with HYSPLIT from the NOAA ARL Website (http://www.arl.noaa.gov/ready/)

USDA United States Department of Agriculture | Forest Service | National Forests in North Carolina Supervisor's Office | 160 ZILLICOA ST STE A ASHEVILLE NC 28801-1082 828-257-4200

File Code: 5140
Date: September 25, 2007

J.P. Chauhan
North Carolina Division of Air Quality
Ambient Monitoring Section
1641 Mail Service Center
Raleigh, NC 27699-1641

Dear Mr. Chauhan:

With regards to your letter dated August 14, 2007 to Forest Supervisor Hilliard, requesting for information on the Shortoff Prescribed Fire which was conducted in Clay County on March 21-22, 2007, please find the enclosed information. The document entitled; A technical Evaluation of Smoke Dispersion from the Hogback and Shortoff Prescribed Fire and Possible Impacts on Air Quality in Bryson City, NC, can be used to address items 1, 3 and 4 in your August 14th letter. A second document is also being provided which will address item number 2 in your letter.

We hope the information contained in the two enclosed documents will provide the basis for flagging the monitoring data in Bryson City, NC.

If my office can be of any further help in this matter please feel free to contact either myself or members of my staff.

Sincerely,

Dale Remington

DALE R. REMINGTON
Acting Ecosystems, Fire, & Forest Staff
Officer

Enclosures

Item 2: **Document why prescribed burning was selected over other land management alternatives**:

The Shortoff Mountain area is found in the mountainous terrain of the Southern Appalachians in western North Carolina. High fuel loading existed in portions of the Shortoff Mountain area because no fire activity (prescribed or wildfires), nor any other fuel reduction techniques occurred prior to the year 2000. The last treatment in the area was a prescribed fire conducted in 2000, which did reduce the fuel loadings but also caused some mortality of the larger trees. Further heavy tree mortality occurred in 2001 and 2002 along the ridges and in the lower slopes as a result of a native insect called the southern pine beetle (*Dendroctonus frontalis* Zimmermann). The dead trees increased the fuel loading.

Natural resource specialist have developed a classification called the Fire Regime Condition Classes (FRCC) [1/] to describe the amount of departure from natural fire regimes (Hann and Bunnell 2001). The higher the FRCC category, the greater the vegetation fuel loading will be. Higher fuel loadings can be the result of past fire suppression causing a departure from the natural fire return interval, and/or excessive vegetation mortality from insect, disease or storm damage. The Shortoff Mountain area included lands classified in three different FRCC categories. The majority of acres were in FRCC 3 (which had the highest fuel loading) prior to the prescribed fire on March 22, 2007 (Table 1). During the prescribed fire planning stages the burn unit area was viewed as two sections: 1) the lower elevation section encompassing approximately 950 acres and 2) the upper elevation section encompassing approximately 694 acres. The lower section had been treated with prescribed fire in 2000, while the upper section has never received any prescribed fire treatment.

Table 1. Fire Regime Condition Classes* before (prior) and after (post) the Shortoff Mountain prescribed fire on March 22, 2007.

	Fire Regime Condition Class	Prior Conditions	Post Treatment Conditions
Lower Section (950 acres)	1	5%	10%
	2	30%	50%
	3	65%	40%
Upper Section (694 acres)	1	0%	5%
	2	15%	35%
	3	85%	60%

The primary reason for implementing a land management treatment in the Shortoff Mountain area was to reduce the available fuel loading to prevent catastrophic fires from occurring which could result in: 1) the loss of personal property, 2) severe resource

1/ see http://www.nwcg.gov/teams/wfewt/message/FrccDefinitions.pdf for a brief description of the Fire Regime Condition Classes.

damage, and 3) extremely unhealthy air quality for communities impacted by the smoke. In order to accomplish this objective it is important to return the area to the natural fire return interval by reducing the fuel loading. An additional resource management objective was to enhance wildlife habitat by creating and restoring numerous canopy openings that would allow sunlight to reach the forest floor.

Mechanical treatments were considered as one method to reduce fuel loadings at Shortoff Mountain. One technique is to crush or chop the larger woody material into smaller sizes that could decay more rapidly. In forested areas, mechanical treatments can also include reducing the density of trees in an area through thinning (cutting down some of the trees). The resulting fuels from thinning are often piled and burned using prescribed fire, or may provide an opportunity for biomass utilization. However, mechanical treatments were not chosen due to the extremely steep and rugged topography, which could have resulted in resource damage if heavy equipment was used on the steep slopes. Furthermore, the area did not have the potential to generate any revenue from the woody material being thinned commercially. Therefore the potential resource impacts and the lack of any commercial operation made utilizing mechanical treatments prohibitive. Also, it should be kept in mind that any mechanical fuel treatments that left woody material on the site would have resulted in a short term increase in fuel loading until the woody material decayed. For these reasons it was determined that prescribed fire was the only management option available to reduce fuel loading and move the area closer to a natural fire regime.

Item 3: **Document the role of fire in restoring ecological processes and how prescribed fire is being used to mimic natural fire regimes.**

The long-term goal for Shortoff Mountain is to return the area to a FRCC 1, which will reduce the chances of a catastrophic fire that could cause damage to personal property and cause unhealthy air pollution concentrations in communities impacted by the smoke. By moving the FRCC closer to the historical norm, it will be possible to return the Shortoff Mountain area to a natural fire regime.

According to the Forest Ecologist for the National Forests in North Carolina, the natural fire regimes for Shortoff Mountain are as follows:

- For dry (xeric) and more moist (mesic) upland hardwood sites the fire return interval is 10-15 years.
- For dry (xeric) pine sites found along the ridges the fire return interval is less than 10 years.
- For the lower elevation sites with the greatest moisture (cove hardwoods) the fire return interval is 35 to 100 years, or longer.

Most of the acreage in this burn unit would have a natural fire return interval of 10-15 years, meaning fire could be expected to occur naturally somewhere on Shortoff

Mountain about every 10 years. However, the current plan is to use prescribed fire again in the next 4 to 6 years. It is believed that the next prescribed fire will move the majority of the acreage to FRCC 1, and some smaller percentage in FRCC 2. After the next prescribed fire, it is hoped future prescribed fires will match the natural fire regime for the different vegetation types within the Shortoff Mountain area.

Item 4: **Document the Smoke Management Practices that were followed for the prescribed fire.**

Basic smoke management practices used for this burn included:

A. Smoke sensitive sites were identified during the planning phase and weather conditions and parameters were selected to minimize smoke impacts at the sensitive sites. The sensitive sites identified for this burn were the Andrews/Murphy airport located 5 miles north; Highway 19/129 located 5 miles west and north; U.S. Highway 64 located 4 miles south; the town of Andrews located 6 miles north; and Murphy Medical Center located 3.5 miles west of the burn area. Bryson City is located approximately 40 miles northeast of the burn area and was considered in the initial identification of smoke sensitive areas, but based on anticipated weather and fuel conditions a judgment was made that the smoke should lift and disperse beyond Bryson City or at least would have dispersed enough so no impacts would occur.
B. All meteorological conditions at the time of the burn met all Region 8 and Forest guidelines in regard to wind direction, wind speed, mixing height, transport wind speed and direction, temperature, and relative humidity. (See the smoke dispersion report for actual recorded weather data for the day of the burn).
C. Emission reduction techniques used included: aerial ignition to reduce the active burning time period, cut off of ignition prior to the evening hours, and aggressive mop-up of heavy fuels that could be reached near all the control lines. Mop-up is a term used in fire management that means after the flaming phase of the fire has passed, personnel go into the burn area to extinguish heavy smoldering fuels, fell any snags that would pose a threat to personnel or to control lines, and/or scatter smoldering fuels so that they will consume more quickly. Due to the size of the area, limited personnel, and the rough topography, mop up operations were done only on critical areas near control lines that could be reached safely by ground personnel.
D. Fuel moisture conditions were planned to be high enough that only the forest floor herbaceous layer, duff, and woody material less than 3 inches in diameter would be ignited and consumed. However, the long-term cumulative drought reduced the fuel moisture so woody fuels classified in the 2 to 20 inch, and 20 inches or larger also ignited and a significant portion of these fuels were consumed on March 22, 2007, especially in areas impacted by the Southern Pine Beetle.
E. The public was notified prior to the burn through newspaper articles in both Cherokee and Clay County newspapers, notification through the local radio

stations, as well as posting information around the perimeter of the burn area. Bryson City is located in Swain County.

F. Actions to be taken to protect the public if smoke did not disperse as planned or if the smoke began to move into sensitive areas included plans to notify and request assistance through the Sheriff's department, Highway Patrol, and local EMS in regard to impacts to highways, airport, or medical centers.

G. Smoke monitoring was done by having Forest Service employees stationed at vantage points providing a good view of the smoke as well as employees patrolling Highway 19/129 toward the town of Andrews and the Andrews/Murphy Airport. In addition we were kept updated on dispersion and movement of the smoke by the helicopter assigned to the burn as well as the North Carolina Forest Service spotter plane. Late in the afternoon of March 22 we had reports from the aircraft that the smoke column was rising to approximately 10,000 feet and dispersing to the northeast as planned and reports from our field monitors indicated no smoke problems in the identified sensitive areas.

H. The North Carolina Forest Service was notified prior to igniting the burn and no permit is required in our area from the State Forestry agency prior to burning.

Reference:

Hann, W.J., Bunnell, D.L. 2001. Fire and land management planning and implementation across multiple scales. Int. J. Wildland Fire. 10:389-403.

A Technical Evaluation of Smoke Dispersion from the Hogback and Shortoff Prescribed Fires and Possible Impacts on Air Quality in Bryson City, NC

Prepared by Air Specialists, Cindy Huber and Bill Jackson
Finalized August 8, 2007
Revised August 29, 2007

On March 22, 2007 the fine particulate monitor in Bryson City, NC registered concentrations above normal from about 1700 until 0900 the following day, March 23, 2007. The concentrations were high enough to cause the 24-hour average for March 22, 2007 to exceed the new 24-hour fine particulate National Ambient Air Quality threshold of 35 micrograms per cubic meter.

Satellite imagery (Figure 1) reveals two fires burning on March 22, one in southwestern NC and another in southeastern Tennessee. These are prescribed fires that were being conducted by the US Forest Service (Figure 2). The focus of this evaluation is to determine the likelihood that smoke from one or both of these prescribed fires affected the air quality in Bryson City and contributed to higher than normal nighttime fine particulate measurements.

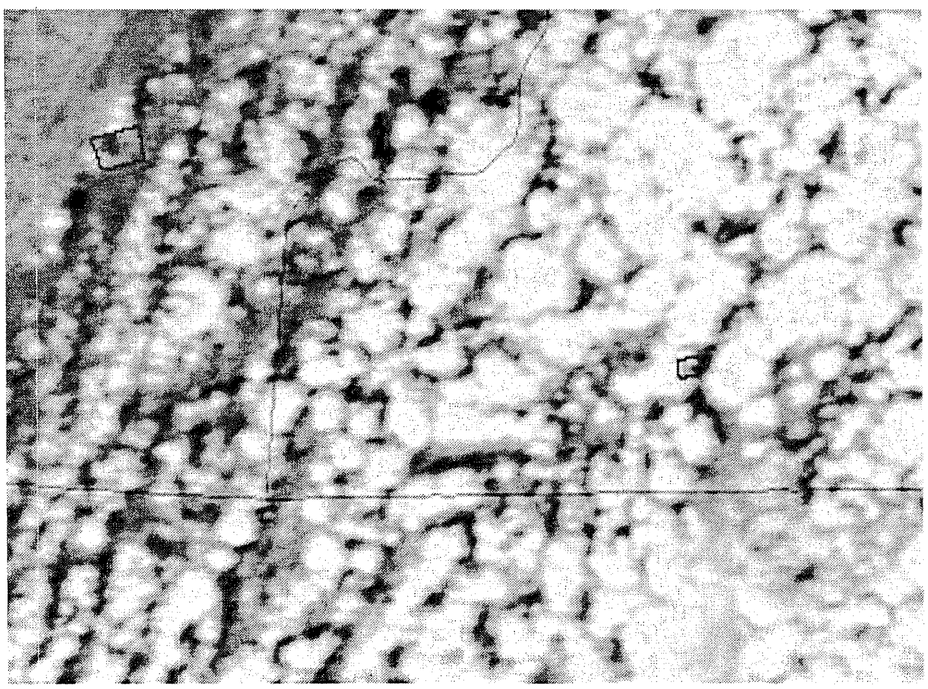


Figure 1. MODIS image from March 22, 2007 showing fires (red outline) in southwestern NC and southeastern TN.

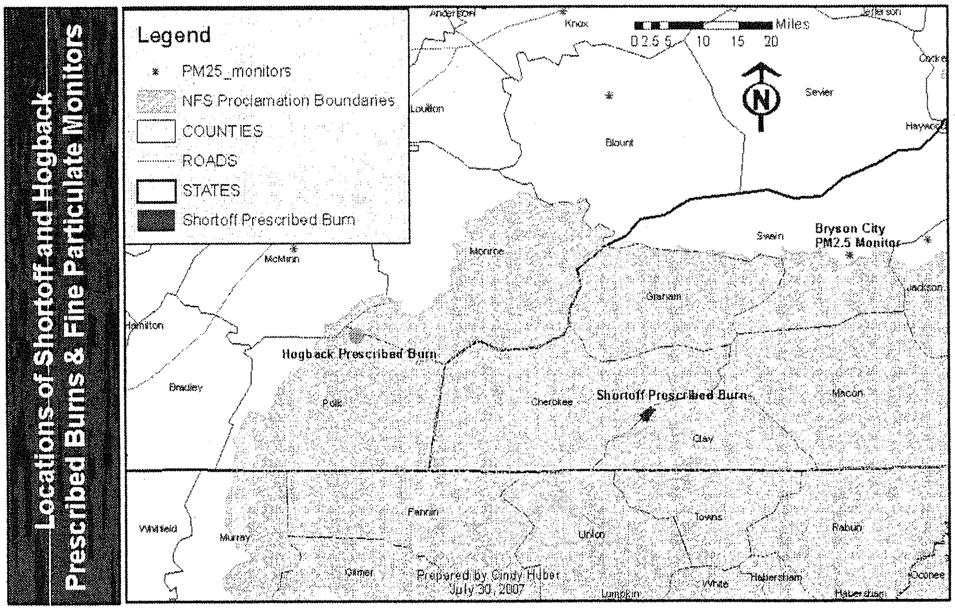


Figure 2. Locations of prescribed burns and fine particulate monitors used for this evaluation.

Air Quality at Bryson City, NC

Smoke from wildland fire contains particulate matter, primarily fine particulate less than 2.5 microns in diameter ($PM_{2.5}$). High concentrations of $PM_{2.5}$ can have a negative impact on people's health and reduce visibility along roadways and scenic views. To help people understand the relationship between pollutant concentration and human health, the Environmental Protection Agency has developed a system that color codes air quality data based on human health effects (Appendix A) and it is called the Air Quality Index (AQI). The index is color-coded from green (no effect) to maroon (hazardous for all people). When the AQI value for any pollutant is color-code green or yellow it carries no cautionary health statement. But at the next level, AQI equals orange, people who are sensitive to air pollutants or have other health problems, may experience health effects. This means they are likely to be affected at lower levels than the general public. Sensitive groups of people include the elderly, children, and people with either lung disease or heart disease. The general public is not likely to be adversely affected when the AQI equals orange. Everyone may begin to experience health effects when AQI equals red, and those sensitive to air pollutants may experience more serious health effects. Purple and maroon, the next two levels in the AQI, represent increasingly hazardous conditions for human health.

Elevated fine particulate concentrations were measured at the continuous $PM_{2.5}$ monitor (AIRS Site ID: 371730002) in Bryson City on March 22-23, 2007. The continuous monitoring conducted by North Carolina Division of Air Quality meets Federal Reference methods criteria established by the Environmental Protection Agency. The highest hourly average concentrations were measured between 1700 March 22 and 0900 March 23, and reached a maximum of 170 micrograms per cubic meter at 1700 March 22 (Figure 3). This value is equivalent to a 1-hour AQI value of code red which has an associated "unhealthy" level of health concern. The average $PM_{2.5}$ concentrations returned to normal levels for the monitoring site at about 1000, March 23.

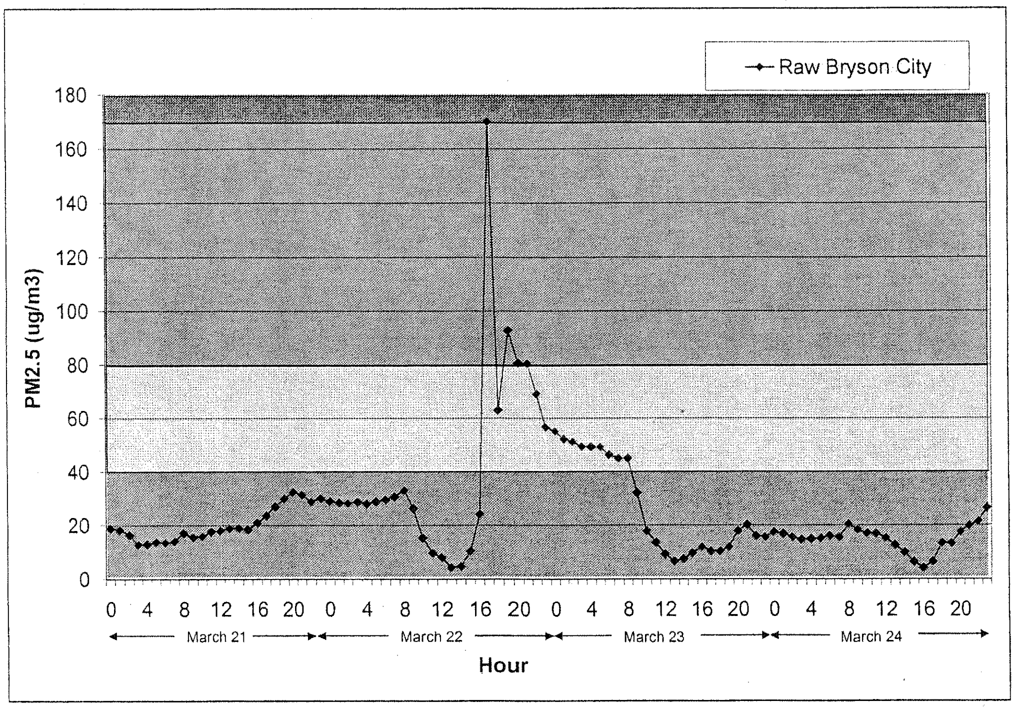


Figure 3. Fine particulate measurements from the Bryson City, NC Federal Reference Monitor for March 21-24, 2007.

Figure 4 shows how the inclusion of higher hourly concentrations on March 22 contributed to increases in the daily average $PM_{2.5}$ concentrations. Daily averages are important because there is a National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$ which states must attain. The red line in Figure 3 shows the new 24-hour standard for $PM_{2.5}$, which is 35 micrograms per cubic meter. (The standard was lowered from 65 to 35 micrograms per cubic meter in September 2006, based on current health effects research.)

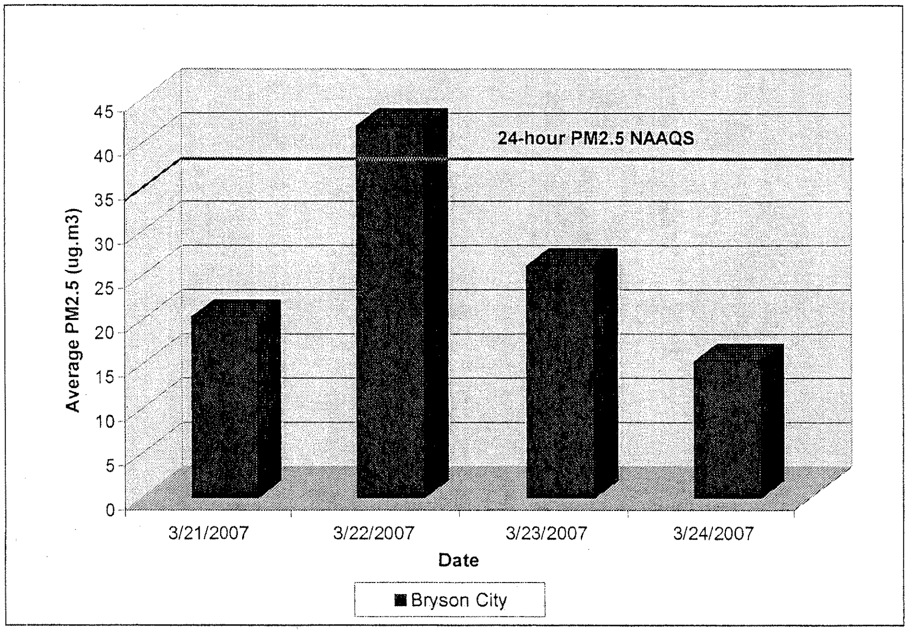


Figure 4. Comparison of daily average concentrations to the 24-hour National Ambient Air Quality Standard for fine particulate ($PM_{2.5}$).

What happened to the smoke dispersed from the Hogback and Shortoff prescribed fires on March 22, 2007?

Fire Activity: On March 22, 2007 prescribed burning was taking place at two sites, the Hogback prescribed fire on the Ocoee District of the Cherokee National Forest in TN and the Shortoff prescribed fire on the Tusquitee District of the Nanatahala National Forest in NC. The areas are approximately 35 miles apart (Figure 2).

Hogback Prescribed Fire: The Cherokee National Forest (TN) implemented the Hogback prescribed fire using a combination of hand ignition and aerial ignition from a helicopter. The burn unit covers 1875 acres and elevation varies from 1000-2100 feet. Ignition began around noon on March 22 and was completed by 1700 the same day. It is estimated that fuels were consumed on about 1700 acres of the burn unit. The active fire phase continued into the night until about midnight. The Fire Emissions Production Simulator (FEPS) was used to estimate hourly fine particulate emissions (Figure 5) and heat release rate from the burn unit. Maximum emissions from the prescribed fire probably occurred between 1400 and 1700 the afternoon of March 22.

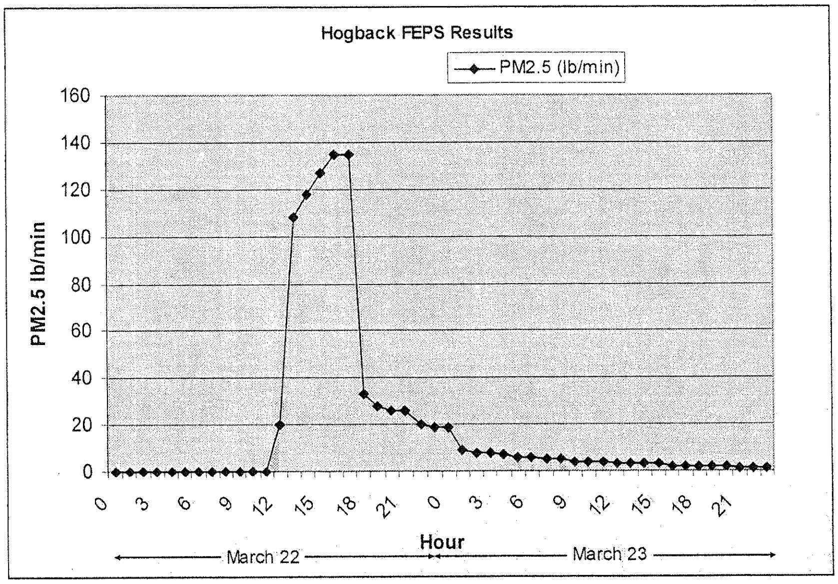


Figure 5. Hourly fine particulate emissions estimates from the Hogback prescribed fire using FEPS.

The Morristown, TN National Weather Service (NWS) office provides daily fire weather forecasts for both areas (east Tennessee and southwestern NC) where prescribed burning was planned. The NWS also provides spot weather forecasts for specific burn units at the request of the Forest. The following chart summarizes the weather parameters reported in both the fire weather and spot weather forecasts for the Hogback prescribed fire.

March 22, 2007	Fire Weather Forecast (0515)	Spot Weather Forecast (0721)
Mixing Height (above mean sea level)	6100	5500
Transport Winds (miles per hour)	From SW at 17 mph	from SW at 20 mph
Dispersion	93	97
Sky/Weather	Partly Cloudy*	Partly Cloudy*
Surface Temperature (°F)	72-77	Max 76
Relative Humidity (%)	35-40	Min 38
Windspeed at 20 ft above ground (miles per hour)	From SW at 7 mph	From SW at 7-12 mph, with occasional higher winds

*According to the Georgia Forestry Commission website a Partly Cloudy day is interpreted to have 30% to 50% cloud cover (http://weather.gfc.state.ga.us/Info/WXexp.aspx).

The NWS forecasts predicted transport winds from the SW at speeds of 17-20 mph on March 22, which would have moved smoke from the Hogback prescribed fire toward Knoxville, TN which is located NE of the burn unit.

Weather observations and measurements are taken on-site the day of the burn, for all prescribed fires conducted by the US Forest Service. Observed surface winds were of variable low speeds and from the SW throughout the day. Weather measurements are also taken automatically at remote stations located across the National Forest System.

This network of weather stations is called RAWS (Remote Automated Weather Stations) and the closest site to the burn unit is Coker Creek (CCKT1, elevation 1700 feet). Data from this site shows that surface winds on March 22 were from the S and SW. Surface wind speeds were 6-7 mph during the afternoon hours. Winds became more variable on March 23 shifting from S to SSW throughout the day. Based on the combination of predicted and observed weather information, it is unlikely that smoke from the Hogback prescribed fire would have affected the Bryson City monitor.

Shortoff prescribed fire: The Shortoff prescribed fire was accomplished using a combination of hand ignition and aerial ignition from a helicopter. The burn unit covers 1644 acres and elevation varies from 2000-3900 feet. The burn actually began on March 21, 2007 when the Forest used hand ignition of fuels on the perimeter of the burn to prepare control lines used to contain the fire. This began at approximately 1200 hours and continued until about 1800. The fire was allowed to burn (in what is called a "backing" fire) through the night and into the next day. Hand ignition resumed on March 22 at 1000 to complete preparation of the control lines. It is estimated that 300 acres had burned before aerial ignition began.

Aerial ignition was used on March 22 to treat the interior of the burn unit, and began at approximately 1345-1400. All ignitions were completed by 1600 and the active/flaming fire phase ceased in the burn unit about 1700. It is estimated that fuels were consumed on 95 percent of the area, or 1561 acres. FEPS was used to estimate hourly fine particulate emissions (Figure 6) and heat release rate from the burn unit. Maximum emissions from the prescribed fire probably occurred between 1500 and 1700 the afternoon of March 22.

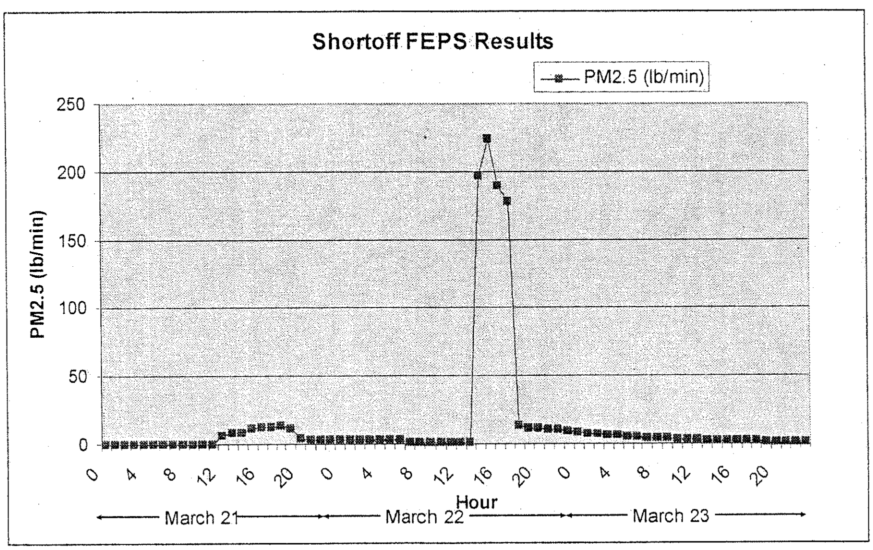


Figure 6. Hourly fine particulate emissions estimates from the Shortoff prescribed fire using the Fire Emissions Production Simulator.

National Weather Service forecasts were obtained for the Shortoff project and the following chart summarizes the parameters from both the fire weather and spot weather forecasts for the Shortoff prescribed fire on March 21 and 22.

March 21, 2007	Fire Weather Forecast (0515)	Spot Weather Forecast (1456 on March 20, 2007)
Mixing Height (above mean sea level)	6600	6400
Transport Winds (miles per hour)	From S at 17 mph	from S at 18 mph
Dispersion	98	102
Sky/Weather	Partly Cloudy*	Partly Cloudy*
Surface Temperature (°F)	64-69	Max 68
Relative Humidity (%)	43-48	Min 50
Windspeed at 20 ft above ground (miles per hour)	From S at 7 mph	From S at 6-9 mph
Nightime dispersion conditions		Decreasing to near zero (reflects light transport winds and mixing height decreasing near surface)

*According to the Georgia Forestry Commission website a Partly Cloudy day is interpreted to have 30% to 50% cloud cover (http://weather.gfc.state.ga.us/Info/WXexp.aspx).

March 22, 2007	Fire Weather Forecast (0515)	Spot Weather Forecast (0641)
Mixing Height (above mean sea level)	6000	5500
Transport Winds (miles per hour)	From SW at 16 mph	from SW at 20 mph
Dispersion	81	84
Sky/Weather	Partly Cloudy*	Partly Cloudy*
Surface Temperature (°F)	71-75	Max 75
Relative Humidity (%)	33-38	Min 37
Windspeed at 20 ft above ground (miles per hour)	From SW at 6 mph	From SW at 7-12 mph

*According to the Georgia Forestry Commission website a Partly Cloudy day is interpreted to have 30% to 50% cloud cover (http://weather.gfc.state.ga.us/Info/WXexp.aspx).

Weather forecasts for March 22 predicted transport winds from the SW at speeds of 16-20 mph, which would have moved smoke from the Shortoff prescribed fire unit toward Bryson City. Considering that the Shortoff prescribed fire unit is only 33 miles from Bryson City, smoke could have traveled to Bryson City in about 2 hours.

Field measurements taken near the burn at Barlow High Top (elevation 2280 feet) on March 22 showed ground level wind speeds of 3-5 mph in the morning increasing to 8 by afternoon. Surface winds were from the SE when burning began on March 22, and became variable form SSE, S or SSW during the afternoon, and shifted to the S by the evening. Perhaps most important for smoke dispersion is the observation that cloud-cover increased from about 30% in the morning to 80% at 1600; affecting stability of the atmosphere. This will be important in the smoke dispersion modeling discussion that follows.

The nearest representative RAWS station for the Shortoff prescribed fire unit would be Wayah, (TOPN7, elevation 2160 feet) but data is not available for March 21 and 22. The next closest station is Tusquitee (TSQN7, elevation 1000 feet), which is considerably lower than the burn unit. However, for the record, data from the Tusquitee site is comparable to the field observations taken at Barlow High Top. Another nearby site in Jackson County (315902) located at 2800 feet elevation also matched the field observations at Barlow High Top (Appendix B).

Smoke Dispersion Modeling: Atmospheric dispersion models have many uses. Two that are of particular interest to fire managers are predictive modeling of smoke dispersion to help inform the decision for the burn, and retrospective modeling to help understand where and how smoke actually dispersed. Provided with information about the Hogback and Shortoff prescribed fires and the weather, it is possible to conduct dispersion modeling to estimate the direction and ground-level particulate concentrations within the smoke plumes on March 22, and in doing so consider the likelihood that smoke from these fires affected Bryson City air quality monitor.

The VSMOKE-GIS model was run using as much measured or observed meteorological data as possible, to get post-burn estimates of smoke dispersion. VSMOKE allows modeling of only one burn at a time, and assumes that smoke is dispersed to the mixing height, but not above it. More advanced models will be needed to assess the possibility that: 1) smoke moved through the mixing height and was dispersed by different wind conditions, and/or 2) the plumes merged and affected Bryson City and other downwind communities.

VSMOKE predictions of daytime smoke dispersion from the Hogback and Shortoff prescribed fires are shown in Figure 7. The colors in the "plumes" represent different fine particulate concentrations (Appendix A, EPA Air Quality Index) at ground level for the hour with highest estimated emissions. For Hogback this occurred at 1600, for Shortoff at 1500. VSMOKE results are most reliable at distances less than 30 miles downwind; and therefore the plume plots are truncated at 30 miles. Details of the modeling can be found in the VSMOKE reports for each burn located in Appendix C.

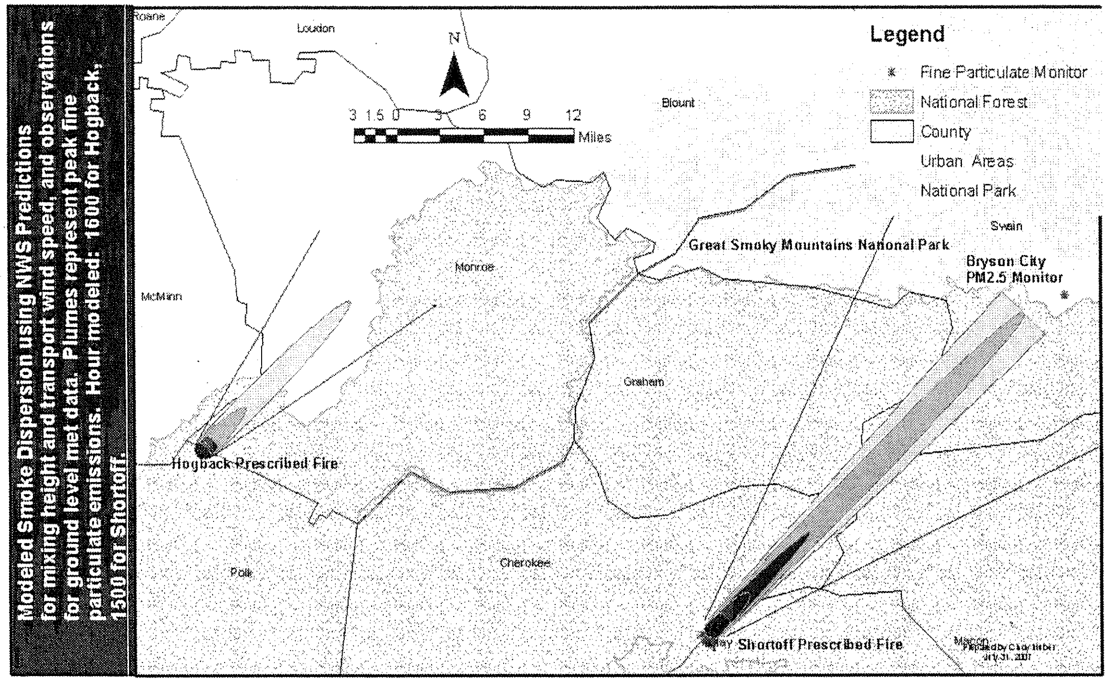


Figure 7. VSMOKE-GIS results showing ground-level fine particulate concentrations for time of peak emissions from the Shortoff and Hogback prescribed fires.

The plume plots show that smoke from the Hogback prescribed fire was not traveling toward Bryson City; the NWS forecast predicted transport winds from the SW; and observations taken on-site also showed surface winds from the SW. All indications are that the smoke from the Hogback prescribed fire probably did not affect Bryson City (located to the east of the Hogback fire) and no additional analysis is warranted.

On the other hand, the plume plots show that smoke from the Shortoff prescribed fire was traveling toward Bryson City. VSMOKE shows that ground level concentrations were elevated for a considerable distance downwind. The presence of ground-level smoke downwind from the burn was confirmed by Forest personnel observations (at about 1700) of noticeable smoke near Topton, NC which is located at the head of the Nantahala River gorge. Aerial observations of smoke dispersion also indicate that smoke was moving toward Bryson City from the Shortoff prescribed fire. During the peak active burning period from about 1430 to 1600, the NC Division of Forestry spotter plane reported that the smoke was rising to about 10,000 feet and the plume was going toward Sylva, NC (Jackson County). However, it should be kept in mind that this is a view of the plume from above and that a portion of the smoke remains below the mixing height (research has demonstrated that about 25 percent of the smoke is dispersed at ground level). At 1630 the helicopter pilot who was conducting the aerial ignition reported that the smoke column was rising and dispersing well to the northeast (consistent with predicted transport winds from the southwest). At 1700 the helicopter pilot reported that smoke seemed to be dropping down in the Nantahala River Gorge areas of Cherokee, Macon and Swain Counties (directly in the modeled plume path shown in Figure 7).

It seems likely that some emissions from the Shortoff prescribed fire could have been transported to Bryson City. Maximum emissions occurred at 1500, and predicted transport winds would have moved the plume toward Bryson City at 16-20 miles per hour. This would put whatever smoke remained in the "plume" over Bryson City at 1700, the same time that the air quality monitors registered an increase in fine particulate. Aerial observers could see a visible plume during the afternoon and early evening and reported that it was moving in the direction of Bryson City. They also reported the plume "dropping down" at 1700. About an hour before sunset (approximately 1700 in March) it is typical for a surface-based inversion to begin. This inversion tends to trap smoke closer to the ground and results in the plume appearing to drop or be pushed toward the earth. Furthermore, emissions/smoke that were below 6000 feet elevation when they reached the Great Smoky Mountains (a Federally mandated Class 1 area) would have become trapped on the east side of the mountains and dispersed down slope during the night, which would include Bryson City.

VSMOKE predicted the maximum ground-level fine particulate concentrations of 92 micrograms per cubic meter, 25 miles from the Shortoff prescribed fire (see Appendix C, Shortoff VSMOKE report). This pattern of dispersion is probably due to the relatively low mixing height of 1800 feet above ground level (even though this is above US Forest Service, Region 8 minimum standards) and near neutral stability at the time when maximum emissions were released. (Weather observations taken on-site at Barlow High Top showed that cloud cover increased about 10 % each hour from 0900 (30%) to 1600 (80%), changing conditions from moderately unstable to near neutral between early morning and early afternoon.) It appears that the mixing height was not adequate to overcome the near neutral stability conditions and the large amount of smoke entering the atmosphere over a relatively short period of time.

The HYSPLIT (http://www.arl.noaa.gov/ready/hysplit4.html) model was the second tool used to examine what direction smoke released from the Shortoff Mountain would travel. HYSPLIT is a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. The model forecast was operated in the forecast mode with the smoke released from the burn site at 1500. The HYSPLIT results predict the smoke released from the burn unit at 1500 would have reached Bryson City between 1700 and 1800 on March 22, 2007 (Figure 8).

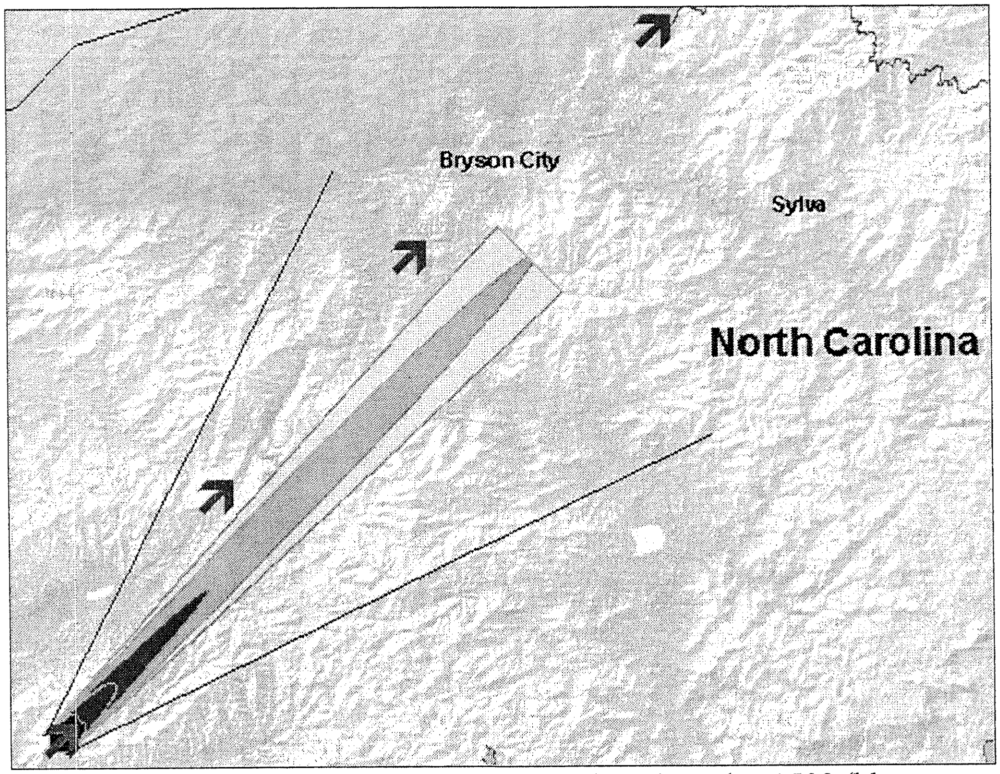


Figure 8. HYSPLIT predicted trajectory of the smoke released at 1500 (blue arrow on lower left) from the Shortoff Mountain prescribed fire. Each arrow shows the approximate location of the smoke dispersion for each hour to 1800 (upper right blue arrow).

What can we learn from this evaluation?

Good smoke dispersion requires a balance between adequate atmospheric conditions and the amount of fuel consumed (and emissions released) over each hour. If large amounts of fuel are consumed over a short period of time, the ventilation index must be high (high mixing height and transport wind speed) and stability class unstable (fewer clouds and moderate surface winds) in order to achieve maximum dilution and dispersion.

To demonstrate the effects of mixing height and atmospheric stability on smoke dispersion we used VSMOKE and the Shortoff prescribed fire inputs for all parameters; changing only mixing height and/or stability class. VSMOKE modeling results in the table below show that a change in either mixing height or stability class results in similar substantial reductions of particulate matter downwind. Of course the greatest reductions occur when mixing height increases considerably and the atmosphere is more unstable. Had the stability class of the atmosphere been more unstable and mixing height greater on the day of the Shortoff prescribed fire, then ground level concentrations would have been lower and the potential impacts to Bryson City decreased or eliminated.

		Downwind Fine Particulate Concentrations in micrograms per cubic meter		
Mixing Height in feet	Stability Class	At 10 miles	At 30 miles	At 50 miles
1800	Near Neutral	170	80	60
5000	Near Neutral	105	45	35
1800	Mod Unstable	95	50	40
5000	Mod Unstable	47	30	27

One additional analysis was conducted for this evaluation. The NC Division of Forestry currently posts Voluntary Smoke Management Guidelines for prescribed burning on their website (http://www.dfr.state.nc.us/fire_control/fire_menu.htm). We used these guidelines and found that for the fuel loading (and estimated consumption) on the Shortoff prescribed fire unit and the weather conditions on March 22, a mixing height of 5600 feet above ground level was needed. VSMOKE was run again for the Shortoff prescribed fire unit, changing only the mixing height from 1800 to 5600 feet above ground level. Figure 9 shows that higher fine particulate concentrations would not have extended as far downwind, if the mixing height had been higher on the day of the burn.

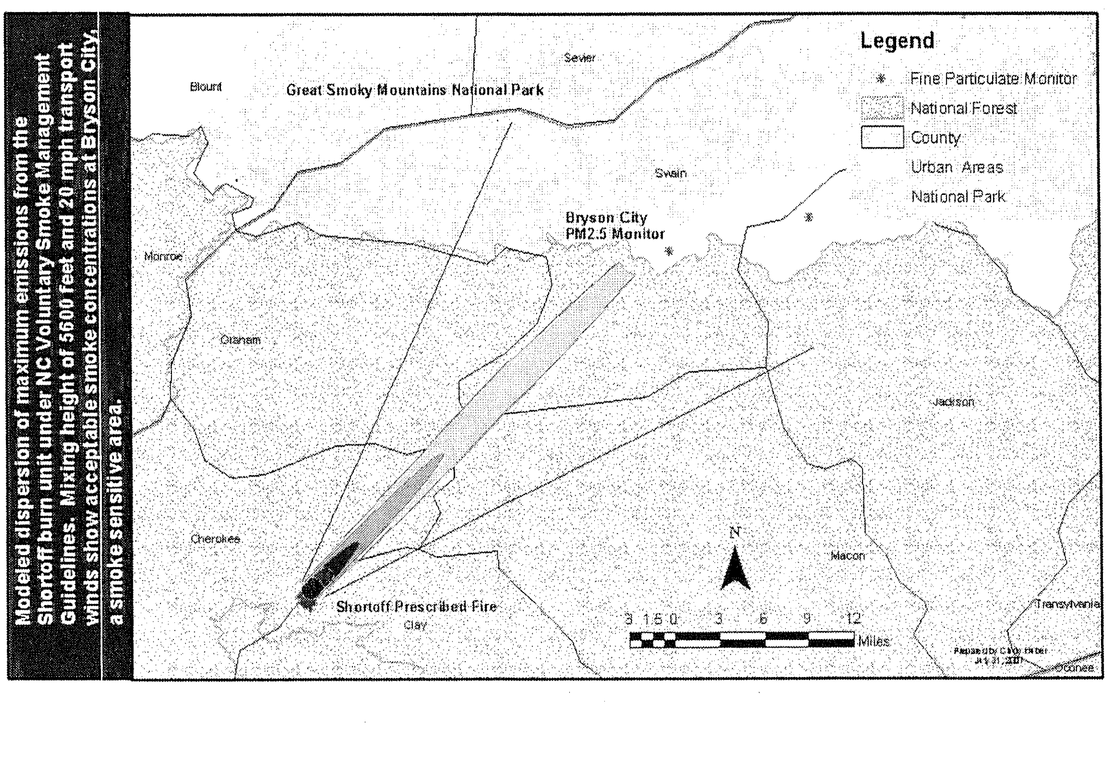


Figure 9. VSMOKE-GIS modeling results for the Shortoff prescribed fire with mixing height increased to 5600 feet above ground level.

APPENDIX A

EPA's Air Quality Index (AQI) for Particulate Matter 2.5 ($PM_{2.5}$) including the breakpoints of PM 2.5 concentrations for the Air Quality Index rankings

$PM_{2.5}$ 24-hr Avg. Concentration (ug/m^3)	$PM_{2.5}$ 1-hr Avg. Concentration (ug/m^3)	Index Values	Visibility (Miles)	Level of Health Concern	Cautionary Statements
0.0 – 15.4	0.0 – 40.0	0-50	> 10	**Good**	None
15.5 – 40.4	40.1 – 80.0	51 – 100**	5.1 – 10.0	**Moderate**	None
40.5 – 65.4	80.1 – 175.0	101 - 150	3.1 – 5.0	**Unhealthy for Sensitive Groups**	People with respiratory or heart disease, the elderly, and children should limit prolonged exertion.
65.5 – 150.4	175.1 – 300.0	151 – 200	1.6 – 3.0	**Unhealthy**	People with respiratory or heart disease, the elderly and children should avoid prolonged exertion, everyone else should limit prolonged exertion.
150.5 – 250.4	300.1 – 500	201 – 300	1.0 – 1.5	**Very Unhealthy**	People with respiratory or heart disease, the elderly and children should avoid any outdoor activity, everyone else should avoid prolonged exertion.
250.5 +	500.0 +	301 - 500	**< 1.0**	**Hazardous**	Everyone should avoid any outdoor exertion; people with respiratory or heart disease, the elderly and children should remain indoors.

Health index rankings are based on 1-hour and 24-hour concentration averages. EPA developed the health indices based on 24-hour averages. Idaho State's Department of Environmental Quality developed health indices based on 1-hour averages.

** An AQI of 100 for $PM_{2.5}$ corresponds to a $PM_{2.5}$ level of 40 micrograms per cubic meter (24-hr avg.).

APPENDIX B

Jackson County Weather Station (315902)
Elevation: 2800 feet

Obs Date	*Ob Tm*	*Dry Tmp*	*RH*	*Wind*		*Temp*		*RH%*		*Precip Dur*	*Precip Amt*
				Dir	*SP*	*Max*	*Min*	*Max*	*Min*		
22-Mar-07	0	54	79	112	4	66	49	100	52	0	0
22-Mar-07	1	54	78	90	5	66	49	100	52	0	0
22-Mar-07	2	53	79	107	4	66	49	100	52	0	0
22-Mar-07	3	54	82	83	4	66	49	100	52	0	0
22-Mar-07	4	51	86	40	2	66	49	100	52	0	0
22-Mar-07	5	53	77	224	3	66	49	99	52	0	0
22-Mar-07	6	53	82	76	1	66	50	99	52	0	0
22-Mar-07	7	52	85	220	1	66	51	97	52	0	0
22-Mar-07	8	54	80	322	1	66	51	88	52	0	0
22-Mar-07	9	57	75	15	3	66	51	86	52	0	0
22-Mar-07	10	61	62	8	3	66	51	86	52	0	0
22-Mar-07	11	64	58	12	3	66	51	86	52	0	0
22-Mar-07	12	69	45	242	5	69	51	86	45	0	0
22-Mar-07	13	66	46	198	10	69	51	86	45	0	0
22-Mar-07	14	69	42	233	7	69	51	86	42	0	0
22-Mar-07	15	68	41	217	7	69	51	86	41	0	0
22-Mar-07	16	70	41	222	8	70	51	86	41	0	0
22-Mar-07	17	66	44	199	8	70	51	86	41	0	0
22-Mar-07	18	63	49	218	7	70	51	86	41	0	0
22-Mar-07	19	61	52	216	9	70	51	86	41	0	0
22-Mar-07	20	59	56	202	4	70	51	86	41	0	0
22-Mar-07	21	59	59	33	2	70	51	86	41	0	0
22-Mar-07	22	57	64	165	3	70	51	86	41	0	0
22-Mar-07	23	52	72	101	3	70	51	86	41	0	0

APPENDIX C

Hogback Prescribed Fire (Polk/Monroe County, TN) on the Ocoee District of the Cherokee National Forest (Assumes 1700 acres of 1875 were blackened)
VSMOKE-GIS results appear in Figure 7 of the main paper.
Prepared by: Cindy Huber
Date: 8/8/2007

The smoke dispersion modeling analysis (using VSmoke and/or VSmoke-GIS) for this project was performed for 1130.0 acres to be burned on 03/22/2007 at the time period of 1600 hours. This time period has daytime dispersion characteristics to disperse the pollutants from the fire. The location of the fire is at approximately 35.285 degrees latitude and -84.473 degrees longitude (356653.011 meters east and 1250873.42 meters north using US Albers projection). The emission rate of PM2.5 (fine particles) this hour was 1022.0 grams/second, and carbon monoxide was 12605.3 grams/second. The heat release rate was 388911.4 megawatts. Both emission rates and the heat release rates were calculated using the Fire Emission Production Simulator (FEPS) model. The estimated background concentration of fine particles and carbon monoxide of the air carried with the winds into the fire are 20 micrograms/cubic meter and 5 parts per million, respectively. The proportion of the smoke subject to plume rise was -0.75 percent, which means 75 percent of the smoke is being dispersed gradually as it rises to the mixing height, and 25 percent is dispersed at ground level.

The meteorological conditions used in this model run were:

1.) Mixing height was 4000 feet above ground level (AGL).
2.) Transport wind speed, and surface wind speed were 20 and 7 miles per hour, respectively.
3.) The sky had 30 percent cloud cover, and the clouds were located 5000 feet above the ground.
4.) Surface temperature was 78 degrees Fahrenheit, and the relative humidity was 38 percent.
5.) The calculated stability class from VSmoke was slightly unstable.

The VSmoke model produces three types of outputs that estimate: a.) The ability of the atmosphere to disperse smoke and the likelihood the smoke will contribute to fog formation, b.) Downwind concentrations of particulate matter and carbon monoxide, and c.) Visibility conditions downwind of the fire.

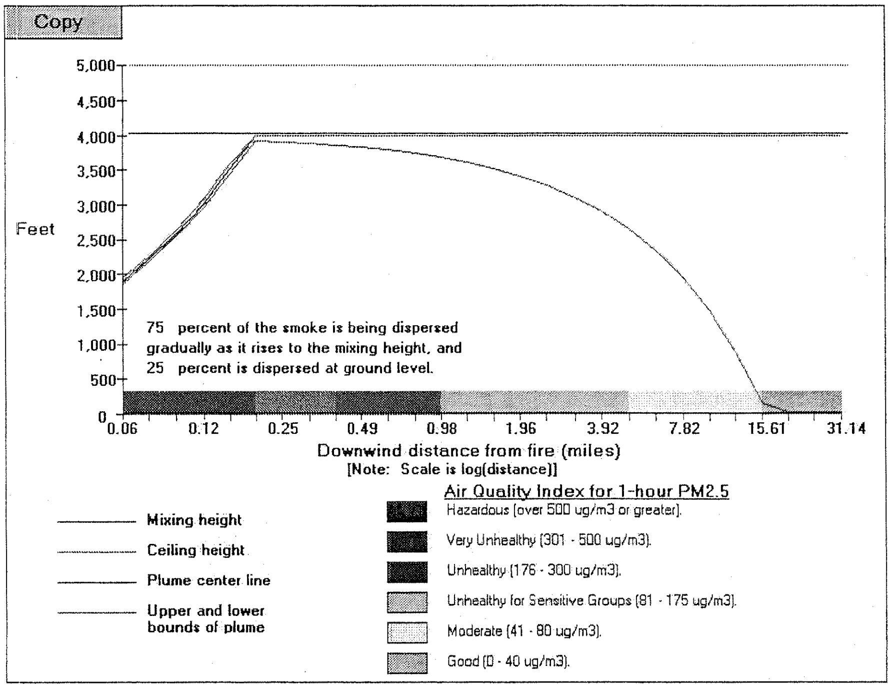
The Dispersion Index (DI) is an estimate of the ability of the atmosphere to disperse smoke to acceptably low average concentrations downwind of one or more fires. This value could represent an area of approximately 1000 square miles under uniform weather conditions. Typically, the Dispersion Index value should be greater than 30 when igniting a large number of acres within an area. The calculated Dispersion Index value was 75, which predicts the atmosphere has a good capacity to disperse smoke.

Combining the Dispersion Index and relative humidity values provide an estimate (like is used in insurance actuary tables) of the likelihood of the smoke contributing to fog formation. The Low Visibility Occurrence Risk Index (LVORI) ranges from 1 (lowest risk) to 10 (greatest risk) and usually you want the value to be less than 4. The base line risk of having low visibility as a result of smoke contributing to fog formation is about 1 in 1000 accidents. The Low Visibility Occurrence Risk Index value for this VSmoke analysis was 1 and this is equal to the base line.

High concentrations of particulate matter, especially fine particles (PM2.5), and carbon monoxide can have a negative impact on people's health. The Environmental Protection Agency has developed a color coding system called the Air Quality Index (AQI) to help people understand what concentrations of air pollution may impact their health. When the AQI value is color code orange then people who are sensitive to air pollutants, or have other health problems, may experience health effects. This means they are likely to be affected at lower levels than the general public. Sensitive groups of people include the elderly, children, and people with either lung disease or heart disease. The general public is not likely to be affected when the AQI is code orange. Everyone may begin to experience health effects when AQI values are color coded as red. People who are sensitive to air pollutants may experience more serious health effects when concentrations reach code red levels.

This analysis shows the air quality at downwind distances less than 0.98 miles from the edge of the fire may have a 1-hour particulate matter concentrations predicted to be code red or worse, while distances less than 4.94 miles are predicted to be code orange or worse. At distances less than 656 feet from the edge of the fire the one-hour carbon monoxide concentrations are predicted to be code red or worse, and distances less than 0.25 miles from the fire are predicted to be code orange or worse.

Distance from fire	PM2.5 (ug/m3)	CO (ppb)	Distance from fire	PM2.5 (ug/m3)	CO (ppb)
328 ft	996.64	16.16	2.47 mi	101.19	5.93
413 ft	873.38	[illegible]	3.11 mi	91.16	5.81
518 ft	758.19	[illegible]	3.92 mi	81.65	5.70
656 ft	652.64	12.23	4.94 mi	72.36	5.60
823 ft	557.68	11.15	6.21 mi	63.53	5.50
1037 ft	474.49	10.19	7.82 mi	55.55	5.41
0.25 mi	405.73	9.41	9.85 mi	48.77	5.33
0.31 mi	346.45	8.73	12.40 mi	43.38	5.27
0.39 mi	[illegible]	8.15	15.61 mi	39.22	5.22
0.49 mi	[illegible]	7.67	19.65 mi	35.92	5.18
0.62 mi	[illegible]	7.26	24.74 mi	33.18	5.15
0.78 mi	[illegible]	6.92	31.14 mi	30.86	5.12
0.98 mi	163.22	6.64	39.21 mi	28.96	5.10
1.24 mi	142.94	6.41	49.36 mi	27.38	5.08
1.56 mi	126.27	6.21	62.14 mi	26.08	5.07



Smoke can also have an impact on how far and how clearly we can see on a highway or in viewing scenery. The fine particles in the smoke are known to be able to scatter and absorb light, which can reduce visibility conditions. The visibility estimates from VSmoke are valid only when the relative humidity is less than 70 percent. Also, the visibility estimates assume the smoke is passing in front of a person who is looking through the plume of smoke. The visibility thresholds used for this modeling analysis were to maintain a contrast ratio of greater than 0.05 and a visibility distance of 0.25 miles. Visibility conditions may exceed the threshold less than 328 feet from the edge of the fire.

Distance from fire	Crossplume Visibility (miles)	Contrast Ratio (miles)	Distance from fire	Crossplume Visibility (miles)	Contrast Ratio (miles)
317 ft	0.56	0.26	2.47 mi	18.38	0.87
422 ft	0.64	0.31	3.11 mi	18.87	0.88
528 ft	0.73	0.36	3.92 mi	19.27	0.89
634 ft	0.85	0.41	4.94 mi	19.60	0.90
845 ft	0.99	0.47	6.21 mi	19.87	0.91
1056 ft	1.17	0.53	7.82 mi	20.08	0.92
0.25 mi	1.87	0.58	9.85 mi	20.25	0.93
0.31 mi	5.09	0.62	12.40 mi	20.35	0.94
0.39 mi	7.83	0.67	15.61 mi	20.40	0.94
0.49 mi	10.14	0.71	19.65 mi	20.41	0.95
0.62 mi	12.08	0.74	24.74 mi	20.42	0.95
0.78 mi	13.69	0.77	31.14 mi	20.42	0.95
0.98 mi	15.03	0.80	39.21 mi	20.42	0.96
1.24 mi	16.13	0.82	49.36 mi	20.42	0.96

The VSMOKE-GIS model estimates the distance downwind of the fire that pre-selected fine particulate matter concentrations (41, 81, 176, 301, and 501 micrograms per cubic meter) are predicted to occur. The map of results can be viewed in Figure 7 of the main report. The VSmoke-GIS analysis had daytime dispersion characteristics to disperse the pollutants from the fire and this is the same as the VSmoke analysis. The downwind spacing interval was set at 0.025 kilometers, and the model ceased making downwind estimates at 30 miles from the edge of the fire. The stability class used for the VSmoke-GIS analysis was slightly unstable and this is the same as the calculated stability from VSmoke.

Shortoff Prescribed Fire (Clay County, NC) on the Tusquitee District of the Nantahala National Forest (Assumes 95% of the acres in the burn unit were blackened; 1561 acres)
VSMOKE-GIS results appear in Figure 7 of the main paper.
Prepared by: Cindy Huber
Date: 8/6/2007

The smoke dispersion modeling analysis (using VSMOKE and/or VSMOKE-GIS) for this project was performed for 931 acres to be burned on 3/22/2007 at the time period of 1500 hours. This time period has daytime dispersion characteristics to disperse the pollutants from the fire. The location of the fire is at approximately 35.109 degrees latitude and -83.868 degrees longitude (412096.048 meters east and 1231394.321 meters north using US Albers projection). The emission rate of PM2.5 (fine particles) this hour was 1695.1 grams/second, and carbon monoxide was 20788.5 grams/second. The heat release rate was 708123.5 megawatts. Both emission rates and the heat release rates were calculated using the Fire Emission Production Simulator (FEPS) model. The estimated background concentration of fine particles and carbon monoxide of the air carried with the winds into the fire are 20 micrograms/cubic meter and 5 parts per million, respectively. The proportion of the smoke subject to plume rise was -0.75 percent, which means 75 percent of the smoke is being dispersed gradually as it rises to the mixing height, and 25 percent is dispersed at ground level.

The meteorological conditions used in this model run were:

1.) Mixing height was 1800 feet above ground level (AGL), for the upper elevations of the burn unit (from the spot weather forecast).
2.) Transport wind speed (from the spot weather forecast) and surface wind speed (from field observations) were 20 and 8 miles per hour, respectively.
3.) The sky had 70 percent cloud cover (based on field observations and the satellite image in Figure 1 of the main report), and the clouds were located 5000 feet above the ground.
4.) Surface temperature was 74 degrees Fahrenheit, and the relative humidity was 45 percent (both from on-site measurements).
5.) The calculated stability class from VSMOKE was near neutral.

The VSMOKE model produces three types of outputs that estimate: a.) The ability of the atmosphere to disperse smoke and the likelihood the smoke will contribute to fog formation, b.) Downwind concentrations of particulate matter and carbon monoxide, and c.) Visibility conditions downwind of the fire.

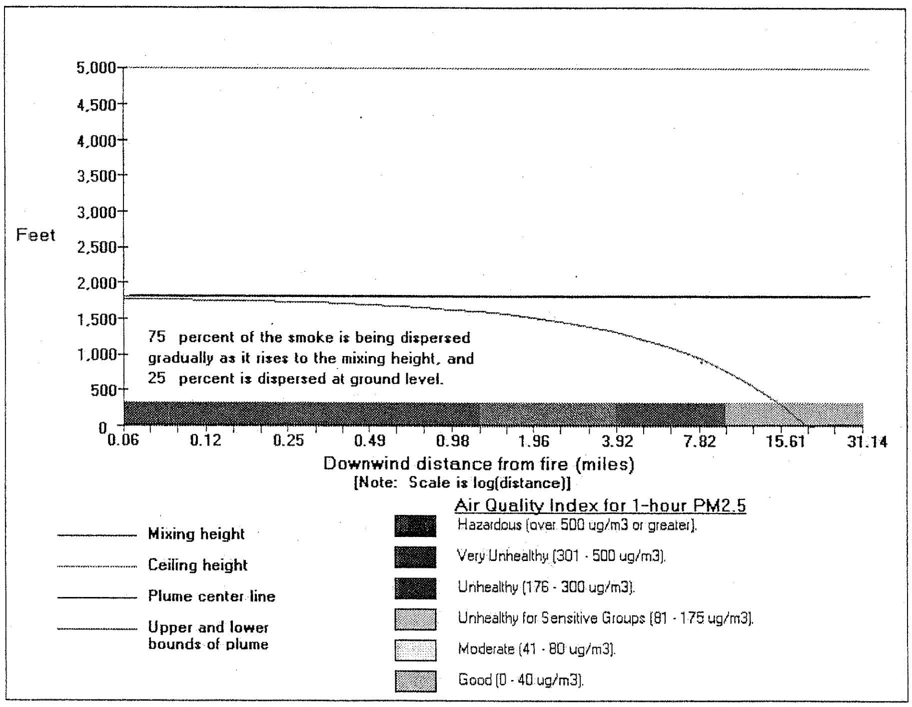
The Dispersion Index (DI) is an estimate of the ability of the atmosphere to disperse smoke to acceptably low average concentrations downwind of one or more fires. This value could represent an area of approximately 1000 square miles under uniform weather conditions. Typically, the Dispersion Index value should be greater than 30 when igniting a large number of acres within an area. The calculated Dispersion Index value was 38, which predicts the atmosphere has a fair to good capacity to disperse smoke.

Combining the Dispersion Index and relative humidity values provide an estimate (like is used in insurance actuary tables) of the likelihood of the smoke contributing to fog formation. The Low Visibility Occurrence Risk Index (LVORI) ranges from 1 (lowest risk) to 10 (greatest risk) and usually you want the value to be less than 4. The base line risk of having low visibility as a result of smoke contributing to fog formation is about 1 in 1000 accidents. The Low Visibility Occurrence Risk Index value for this VSMOKE analysis was 1 and this is equal to the base line.

High concentrations of particulate matter, especially fine particles (PM2.5), and carbon monoxide can have a negative impact on people's health. The Environmental Protection Agency has developed a color coding system called the Air Quality Index (AQI) to help people understand what concentrations of air pollution may impact their health. When the AQI value is color code orange then people who are sensitive to air pollutants, or have other health problems, may experience health effects. This means they are likely to be affected at lower levels than the general public. Sensitive groups of people include the elderly, children, and people with either lung disease or heart disease. The general public is not likely to be affected when the AQI is code orange. Everyone may begin to experience health effects when AQI values are color coded as red. People who are sensitive to air pollutants may experience more serious health effects when concentrations reach code red levels.

This analysis shows the air quality at downwind distances less than 9.85 miles from the edge of the fire may have a 1-hour particulate matter concentrations predicted to be code red or worse, while distances less than 31.14 miles are predicted to be code orange or worse. At distances less than 0.78 miles from the edge of the fire the one-hour carbon monoxide concentrations are predicted to be code red or worse, and distances less than 1.96 miles from the fire are predicted to be code orange or worse.

Distance from fire	PM2.5 (ug/m3)	CO (ppb)	Distance from fire	PM2.5 (ug/m3)	CO (ppb)
328 ft	2,363.03	31.43	2.47 mi	343.97	8.66
413 ft	2,149.31	29.02	3.11 mi	311.72	8.29
518 ft	1,935.76	26.61	3.92 mi	[illegible]	7.97
656 ft	1,729.69	24.29	4.94 mi	[illegible]	7.66
823 ft	1,542.16	22.17	6.21 mi	[illegible]	7.34
1037 ft	1,365.83	20.18	7.82 mi	[illegible]	7.01
0.25 mi	1,203.21	18.35	9.85 mi	169.82	6.69
0.31 mi	1,055.79	16.69	12.40 mi	144.41	6.40
0.39 mi	924.16	[illegible]	15.61 mi	123.20	6.16
0.49 mi	808.17	[illegible]	19.65 mi	105.96	5.97
0.62 mi	707.08	[illegible]	24.74 mi	91.64	5.81
0.78 mi	619.82	11.77	31.14 mi	79.51	5.67
0.98 mi	545.08	10.92	39.21 mi	69.25	5.56
1.24 mi	481.43	10.21	49.36 mi	60.67	5.46
1.56 mi	427.56	9.60	62.14 mi	53.55	5.38



Smoke can also have an impact on how far and how clearly we can see on a highway or in viewing scenery. The fine particles in the smoke are known to be able to scatter and absorb light, which can reduce visibility conditions. The visibility estimates from VSMOKE are valid only when the relative humidity is less than 70 percent. Also, the visibility estimates assume the smoke is passing in front of a person who is looking through the plume of smoke. The visibility thresholds used for this modeling analysis were to maintain a contrast ratio of greater than 0.05 and a visibility distance of 0.25 miles. Visibility conditions may exceed the threshold less than 413 feet from the edge of the fire.

Distance from fire	Crossplume Visibility (miles)	Contrast Ratio (miles)	Distance from fire	Crossplume Visibility (miles)	Contrast Ratio (miles)
317 ft	0.24	0.04	2.47 mi	6.84	0.63
422 ft	0.26	0.06	3.11 mi	8.42	0.65
528 ft	0.29	0.07	3.92 mi	9.73	0.68
634 ft	0.32	0.10	4.94 mi	10.83	0.71
845 ft	0.36	0.13	6.21 mi	11.74	0.73
1056 ft	0.41	0.16	7.82 mi	12.50	0.76
0.25 mi	0.46	0.20	9.85 mi	13.13	0.79
0.31 mi	0.53	0.24	12.40 mi	13.59	0.82
0.39 mi	0.60	0.29	15.61 mi	13.88	0.84
0.49 mi	0.69	0.34	19.65 mi	13.99	0.86
0.62 mi	0.78	0.39	24.74 mi	14.02	0.88
0.78 mi	0.89	0.43	31.14 mi	14.03	0.89
0.98 mi	1.02	0.48	39.21 mi	14.03	0.91
1.24 mi	1.22	0.52	49.36 mi	14.04	0.92

The VSMOKE-GIS model estimates the distance downwind of the fire that pre-selected fine particulate matter concentrations (41, 81, 176, 301, and 501 micrograms per cubic meter) are predicted to occur. The map of results can be viewed in Figure 7 of the main report. The VSMOKE-GIS analysis used daytime dispersion characteristics to disperse the pollutants from the fire and this is the same as the VSMOKE analysis. The downwind spacing interval was set at 0.025 kilometers, and the model ceased making downwind estimates at 30 miles from the edge of the fire. The stability class used for the VSMOKE-GIS analysis was near neutral and this is the same as the calculated stability from VSMOKE.

Shortoff Prescribed Fire (Clay County, NC) on the Tusquitee District of the Nantahala National Forest (Assumes 95% of the acres in the burn unit were blackened; 1561 acres) **Modeled to show dispersion under the NC Voluntary Smoke Management Guidelines, VSMOKE-GIS results appear in Figure 8 of the main paper.**
Prepared by: Cindy Huber
Date: 8/8/2007

The smoke dispersion modeling analysis (using VSmoke and/or VSmoke-GIS) for this project was performed for 931 acres to be burned on 3/22/2007 at the time period of 1500 hours. This time period has daytime dispersion characteristics to disperse the pollutants from the fire. The location of the fire is at approximately 35.109 degrees latitude and -83.868 degrees longitude (412096.048 meters east and 1231394.321 meters north using US Albers projection). The emission rate of PM2.5 (fine particles) this hour was 1695.1 grams/second, and carbon monoxide was 20788.5 grams/second. The heat release rate was 708123.5 megawatts. Both emission rates and the heat release rates were calculated using the Fire Emission Production Simulator (FEPS) model. The estimated background concentration of fine particles and carbon monoxide of the air carried with the winds into the fire are 20 micrograms/cubic meter and 5 parts per million, respectively. The proportion of the smoke subject to plume rise was -0.75 percent, which means 75 percent of the smoke is being dispersed gradually as it rises to the mixing height, and 25 percent is dispersed at ground level.

The meteorological conditions used in this model run were:

1.) Mixing height was 5600 feet above ground level (AGL). This is the mixing height that would be required under the current Voluntary Smoke Guidelines in North Carolina (This assumes consumption of 9000 tons of fuel on a day with fair to good smoke dispersion or a Burn Category 5 day. Burn Category 5 requires a ventilation rate of 112,000 or higher, and carries a warning of Burn with Caution, Good Smoke Dispersion, and Potential Severe Fire Behavior. Given the transport wind speed of 20 mph, a mixing height of 5600 would be needed to get a ventilation rate of 112,000.)
2.) Transport wind speed, and surface wind speed were 20 and 8 miles per hour, respectively.
3.) The sky had 70 percent cloud cover, and the clouds were located 5000 feet above the ground.
4.) Surface temperature was 74 degrees Fahrenheit, and the relative humidity was 45 percent.
5.) The calculated stability class from VSmoke was near neutral.

The VSmoke model produces three types of outputs that estimate: a.) The ability of the atmosphere to disperse smoke and the likelihood the smoke will contribute to fog formation, b.) Downwind concentrations of particulate matter and carbon monoxide, and c.) Visibility conditions downwind of the fire.

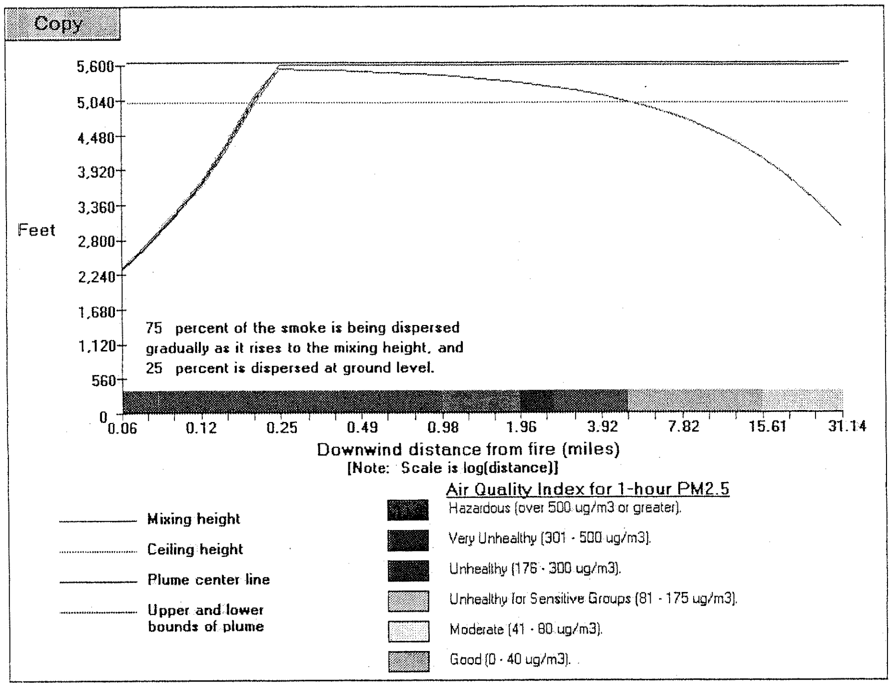
The Dispersion Index (DI) is an estimate of the ability of the atmosphere to disperse smoke to acceptably low average concentrations downwind of one or more fires. This value could represent an area of approximately 1000 square miles under uniform weather conditions. Typically, the Dispersion Index value should be greater than 30 when igniting a large number of acres within an area. The calculated Dispersion Index value was 58, which predicts the atmosphere has a good capacity to disperse smoke.

Combining the Dispersion Index and relative humidity values provide an estimate (like is used in insurance actuary tables) of the likelihood of the smoke contributing to fog formation. The Low Visibility Occurrence Risk Index (LVORI) ranges from 1 (lowest risk) to 10 (greatest risk) and usually you want the value to be less than 4. The base line risk of having low visibility as a result of smoke contributing to fog formation is about 1 in 1000 accidents. The Low Visibility Occurrence Risk Index value for this VSmoke analysis was 1 and this is equal to the base line.

High concentrations of particulate matter, especially fine particles (PM2.5), and carbon monoxide can have a negative impact on people's health. The Environmental Protection Agency has developed a color coding system called the Air Quality Index (AQI) to help people understand what concentrations of air pollution may impact their health. When the AQI value is color code orange then people who are sensitive to air pollutants, or have other health problems, may experience health effects. This means they are likely to be affected at lower levels than the general public. Sensitive groups of people include the elderly, children, and people with either lung disease or heart disease. The general public is not likely to be affected when the AQI is code orange. Everyone may begin to experience health effects when AQI values are color coded as red. People who are sensitive to air pollutants may experience more serious health effects when concentrations reach code red levels.

This analysis shows the air quality at downwind distances less than 4.94 miles from the edge of the fire may have a 1-hour particulate matter concentrations predicted to be code red or worse, while distances less than 15.61 miles are predicted to be code orange or worse. At distances less than 0.62 miles from the edge of the fire the one-hour carbon monoxide concentrations are predicted to be code red or worse, and distances less than 1.24 miles from the fire are predicted to be code orange or worse.

Distance from fire	PM2.5 (ug/m3)	CO (ppb)	Distance from fire	PM2.5 (ug/m3)	CO (ppb)
328 ft	2,332.74	31.09	2.47 mi	[illegible]	7.63
413 ft	2,104.33	28.52	3.11 mi	[illegible]	7.27
518 ft	1,878.17	25.96	3.92 mi	[illegible]	6.96
656 ft	1,661.30	23.52	4.94 mi	167.91	6.67
823 ft	1,464.50	21.30	6.21 mi	143.69	6.40
1037 ft	1,280.22	19.22	7.82 mi	120.92	6.14
0.25 mi	1,112.59	17.33	9.85 mi	100.50	5.91
0.31 mi	965.17	15.68	12.40 mi	83.13	5.71
0.39 mi	833.55	[illegible]	15.61 mi	68.98	5.55
0.49 mi	717.55	[illegible]	19.65 mi	57.81	5.43
0.62 mi	616.47	11.73	24.74 mi	49.16	5.33
0.78 mi	529.20	10.75	31.14 mi	42.54	5.25
0.98 mi	454.45	9.90	39.21 mi	37.51	5.20
1.24 mi	390.82	9.18	49.36 mi	33.75	5.16
1.56 mi	336.35	8.58	62.14 mi	30.98	5.12



Smoke can also have an impact on how far and how clearly we can see on a highway or in viewing scenery. The fine particles in the smoke are known to be able to scatter and absorb light, which can reduce visibility conditions. The visibility estimates from VSmoke are valid only when the relative humidity is less than 70 percent. Also, the visibility estimates assume the smoke is passing in front of a person who is looking through the plume of smoke. The visibility thresholds used for this modeling analysis were to maintain a contrast ratio of greater than 0.05 and a visibility distance of 0.25 miles. Visibility conditions may exceed the threshold less than 413 feet from the edge of the fire.

Distance from fire	Crossplume Visibility (miles)	Contrast Ratio (miles)	Distance from fire	Crossplume Visibility (miles)	Contrast Ratio (miles)
317 ft	0.24	0.04	2.47 mi	11.30	0.71
422 ft	0.26	0.06	3.11 mi	12.88	0.74
528 ft	0.30	0.08	3.92 mi	14.19	0.77
634 ft	0.34	0.11	4.94 mi	15.29	0.79
845 ft	0.38	0.14	6.21 mi	16.21	0.82
1056 ft	0.43	0.18	7.82 mi	16.97	0.85
0.25 mi	0.50	0.22	9.85 mi	17.60	0.87
0.31 mi	0.58	0.27	12.40 mi	18.12	0.89
0.39 mi	0.67	0.33	15.61 mi	18.56	0.91
0.49 mi	0.77	0.38	19.65 mi	18.92	0.92
0.62 mi	0.90	0.43	24.74 mi	19.22	0.93
0.78 mi	1.05	0.49	31.14 mi	19.47	0.94
0.98 mi	1.44	0.54	39.21 mi	19.68	0.95
1.24 mi	4.54	0.59	49.36 mi	19.83	0.95

The VSMOKE-GIS model estimates the distance downwind of the fire that pre-selected fine particulate matter concentrations (41, 81, 176, 301, and 501 micrograms per cubic meter) are predicted to occur. The map of results can be viewed in Figure 8 of the main report. The VSmoke-GIS analysis had daytime dispersion characteristics to disperse the pollutants from the fire and this is the same as the VSmoke analysis. The downwind spacing interval was set at 0.025 kilometers, and the model ceased making downwind estimates at 30 miles from the edge of the fire. The stability class used for the VSmoke-GIS analysis was near neutral and this is the same as the calculated stability from VSmoke.