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MODELING THE EFFECTS OF PRESCRIBED BURNING ON OZONE PRECURSORS AT FORT BRAGG, NC

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MODELING THE EFFECTS OF PRESCRIBED BURNING ON OZONE PRECURSORS AT FORT BRAGG, NC

1. Purpose.

a. The purpose of this Public Works Technical Bulletin (PWTB) is to transmit the results of an air pollution modeling study performed for Fort Bragg, NC. That study determined the effects of prescribed burning on the concentration of ozone precursors in the Fort Bragg area.

b. All PWTBs are available electronically (in Adobe® Acrobat® portable document format [PDF]) through the World Wide Web (WWW) at the U.S. Army Engineering and Support Center's Technical Information – Facility Design ("TechInfo") web page, which is accessible through URL:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability.

This PWTB applies to all U.S. Army Directorate of Public Works (DPW) activities that use prescribed burning to control vegetation or maintain habitat. While the Appendix to this PWTB contains general information regarding the use of models to predict ozone generation from prescribed burns, much of the information in the appendix is intended to be used by personnel that have a least a rudimentary understanding of modeling pollutants generated by open burning of vegetation.

3. References.

a. Army Regulation AR 200-1

b. Clean Air Act

c. 2004 Waste Minimization and Pollution Prevention program.

4. Discussion.

a. AR 200-1 requires that Army installations comply with Federal environmental regulations, including air emission restrictions established by the Clean Air Act.

b. The Clean Air Act authorizes the U. S. Environmental Protection Agency (USEPA) to establish emission standards for ozone precursors, to delineate ozone non-attainment zones, and to limit certain activities within those zones.

c. The Waste Minimization and Pollution Prevention (WMPP) program was established by Congress to demonstrate promising off-the-shelf environmental technologies at Army installations. Funding for the WMPP program ended in FY 05. During the 12-year tenure of this program, many environmental technologies were evaluated and demonstrated on Army installations by the prime contractor for the WMPP program, MSE Inc. Unfortunately, the WMPP program did not include sufficient funds to tech transfer the results from many of the successful projects during this program. One such project was an evaluation of prescribed burn practices at Fort Bragg using air emission modeling.

d. Prescribed burns are required at Fort Bragg for the maintenance of their longleaf pine-grassland ecosystem, which is a habitat for the red-cockaded woodpecker. Environmental personnel at Fort Bragg were concerned that emissions of ozone precursors during prescribed burns would affect regional air quality and threaten their maintenance program. A study was performed to model ozone precursor production from prescribed burns occurring within the Fort Bragg military reservation. Emission of ozone (O_3) precursors (i.e., carbon monoxide, volatile organic compounds, and oxides of nitrogen) was estimated from hypothetical 50-acre, 250-acre, and 1,250-acre burns located near the center of the Post by using the Fire Emission Production Simulator (FEPS) FEPS is a user-friendly computer program designed to predict emissions and heat release characteristics from prescribed burns or from wildfires. It was chosen by MSE for this study and is available from the Forest Service at https://www.fs.fed.us/pnw/fera/feps.

e. Output from FEPS was sent to the Environmental Policy Modeling Group (University of North Carolina-Chapel Hill) for incorporation into the state-approved Air Quality Modeling System (AQMS). The AQMS is comprised of the MM5-SMOKE-MAQSIP software packages. The meteorological parameters were based on the 19-30 June 1996, ozone episode. Thus, the AQMS results were conservative.

f. Localized air quality impacts were modeled for three sizes of fires for various days within the given ozone episode. While the results were specific to the particular inputs into FEPS and AQMS, they supported the current prohibition of prescribed burns during ozone (nonattainment) episodes. The results also showed that the effect of prescribed burning on regional 8-hour average ozone levels is probably trivial (≤3 parts per billion by volume [ppbv] over background). Therefore, the benefits attained by prescribed burns for restoration/maintenance of the longleaf pine-grassland ecosystem at Fort Bragg far outweigh the detriments of ozone production arising from such activities. It was concluded that there was no ozone-related basis for modifying the existing prescribed burning program at Fort Bragg. Essentially, the emission of ozone precursors and subsequent ozone formation from growing season burns has minimal effect on regional air quality.

g. The two significant recommendations are: (1) limit burns to days where the forecasted Air Quality Index is ≤75, and (2) evaluate the effect that prescribed burns at Fort Bragg have on regional PM2.5 levels.

h. See Appendix A, “Modeling the Effects of Prescribed Burning on Air Quality at Fort Bragg, NC”, for further information regarding the Fort Bragg study. Appendix A is the final report submitted by MSE to ERDC–CERL, edited for format and clarity.

i. A list of the acronyms and abbreviations used is in Appendix C.

5. Points of Contact.

HQUSACE is the proponent for this document. The point of contact (POC) at HQUSACE is Mr. Malcolm E. McLeod, CEMP-CEP, 202-761-5696, or e-mail: Malcolm.E.Mcleod@usace.army.mil .

Questions and/or comments regarding this subject should be directed to the technical POC:

U.S. Army Engineer Research and Development Center
Construction Engineering Research Laboratory
ATTN: CEERD-CN-E (Gary L. Gerdes)
2902 Newmark Drive
Champaign, IL 61822-1076
Tel. (217) 373-5831
FAX: (217) 373-3430
E-mail: Gary.L.Gerdes@usace.army.mil

FOR THE COMMANDER:

JAMES C. DALTON, P.E
Chief, Engineering and Construction
Directorate of Civil Works

Appendix A

Modeling the Effects of Prescribed Burning on Air Quality at Fort Bragg, NC

Disclaimer

This report was prepared as an account of work sponsored by an agency of the U.S. Government. Neither that government, nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

Acknowledgement

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Background

Vegetation at Fort Bragg is a mosaic of southern pine and hardwood communities. Of particular interest are the forested stands dominated by longleaf pine (*Pinus palustris Mill.*) and Carolina wiregrass (*Aristida stricta Michx.*) because they are habitat for the endangered Red-Cockaded Woodpecker. Historically, these stands occupied much of the coastal plains and spread into the Piedmont uplands of the southeastern United States. Longleaf pine (LL) is capable of occupying moisture gradients ranging from flat, poorly drained sites to droughty ridgelines. Although at opposite ends of the moisture continuum, these communities are similar in appearance, share many of the same plant and animal species, and have similar fire regimes.

The longleaf pine-wiregrass ecosystem is dependent upon frequent (from 1- to 5-year intervals), low-intensity surface fires to maintain open, parklike conditions characterized by unevenly aged stands of pines with few other woody plants. The brushy understory is sparse, while groundcover is continuous and is comprised of a wide diversity of grass and forb (non-grass) plants. If fire occurrence is lowered, then scrub oaks (*Quercus spp.*) and other pines (e.g., loblolly (LB), *P.taeda*; shortleaf (SLP), *P.echinata*) encroach on the longleaf pine forests.

Such a disruption of the forest's structure would be very detrimental to the Red-Cockaded Woodpecker (*Picoides borealis*). The Red-Cockaded Woodpecker prefers open, frequently burned, mature and over-mature LL stands having sparse midstory layers; such forests provide food source(s) plus roosting and nesting habitat necessary to sustain this species (Ref. 2). Home range areas for Red-Cockaded Woodpecker social groups vary from 174–268 acres within and adjacent to the Fort Bragg military reservation (Ref. 3).

Prescribed burns for habitat maintenance focus on maintenance and improvement of the LL-wiregrass ecosystem and seek to control wildfire spread via lowered fuel accumulations throughout the reservation. While maintenance of the ecosystem is usually conducted during the growing season (i.e., April-June), wildfire control usually occurs during the winter months (December-February).

Fort Bragg and other similar military and federally managed lands use prescribed burning to recreate the natural fire regimes needed to maintain the health of its native longleaf pine forest. However, biomass burning can contribute to local and regional air pollutant loads and threatens an area’s ability to meet state and federal ambient air quality standards (Ref. 22).

Fort Bragg is required to conduct prescribed burning annually in the cantonment, range, and training areas for management of the longleaf pine-wiregrass ecosystem (Refs. 16-17). This burning is conducted in accordance with an agreement with the U.S. Fish and Wildlife Service to help recover the Red-Cockaded Woodpecker, an endangered species found on Post. Restoration of the Red-Cockaded Woodpecker population will lift restrictions on much-needed training areas. Prescribed burning also helps prevent damaging wildfires and makes fire containment more manageable.

Fort Bragg has been divided geographically into 106 habitat management areas (HMA) with each HMA being approximately 1,000 acres in size. Prescriptions for burning are written for each HMA based on input from natural resource experts from Fort

Bragg, U.S. Army Corps of Engineers, and the U.S. Fish and Wildlife Service (Ref. 4). The principal goal is to restore and maintain the longleaf pine-wiregrass ecosystem, including all of its associated plant community/animal habitat types.

Fort Bragg, including Camp Mackall, is also divided into 20 Smoke Management Blocks which are subdivided into over 1,400 Fire Management Blocks (FMB). The annual "burn plan" describes the location, size, and season of burning within the relevant FMBs. Growing season burns (April-June) stimulate seed production and growth in the forb/grass layer and inflict greater mortality ("top kill") of the hardwoods with negligible adverse effects on the longleaf pine seedlings. The dormant season (December-February) burns are for fuel management purposes (i.e., to lower the frequency and/or severity of spring/summer wildfires). The Post also recognizes and complies with the North Carolina Voluntary Smoke Management Program, which is accomplished via design and scheduling of prescribed burns in accordance with the North Carolina Division of Forest Resources' Smoke Management Guidelines (Ref. 21).

On April 15, 2004, the U.S. Environmental Protection Agency (USEPA) designated "nonattainment" areas throughout the country that exceeded the health-based National Ambient Air Quality Standard (NAAQS) for 8 hr ozone. Cumberland County, NC, which includes part of Fort Bragg, is one such area (Ref. 18). Because Fort Bragg is partially located in a nonattainment area for ozone, it must evaluate potential sources of ozone and plan for mitigation. Fort Bragg is also situated within an "Unclassifiable/Attainment" area for fine particulate matter (PM2.5[1]); this area includes both Cumberland and Hoke Counties (Ref. 20).

Given the above, environmental management personnel at Fort Bragg must balance ecological/forestry management requirements against their potential impacts on regional air quality, particularly on ambient ozone and fine particulate matter (PM2.5). Specifically, the following issues need to be better understood:

- How different environmental conditions and burning practices affect the emissions rates of ozone precursors and PM2.5.

[1] PM2.5 refers to particulate matter that is 2.5 micrometers or smaller in size.

- How these air pollutants are chemically transformed and/or transported in the atmosphere downwind of the Fort Bragg.
- How various burn conditions/practices can be managed to lower their impact on both local and regional air quality.

Objective

The objective of this project was to develop credible emission rates for ozone precursors generated during a growing season burn, followed by regional modeling of ozone formation.

Project Approach

Ozone formation is dependent on the presence of ozone precursors, compounds that are transformed into ozone in the presence of sunlight. Ozone precursors are generated by the combustion of live and dead vegetation, such as occurs during prescribed burning activities at Fort Bragg. A review of studies that examined the correlation between ozone precursor formation and prescribed burning activity was conducted. It was determined that several factors are involved in determining precursor concentrations, including volume of combustible material, moisture content, etc.

MSE worked with the U.S. Department of Agriculture/U.S. Forest Service (USFS) Fire Science Laboratory (FSL) in Missoula, Montana, to address fuel moistures as they affect ozone and particulate formation. MSE was interested in the moisture content in relation to combustion efficiency/intensity and subsequent smoke production. The primary objective of FSL was to address local knowledge gaps in characterizing soil and live fuel moisture trends in North Carolina vegetation complexes that are of significant concern to a fire management plan's development and implementation.

There has been very little research done on the live fuels that are consumed during a burn. These fuels have higher moisture content than the dry dead fuels, and the greater moisture content contributes to an increase in smoke. Smoke lingering in sensitive areas, such as highways, airports, hospitals, and developments has created safety concerns, and (in some cases) resulted in accidents. It is imperative that the smoke from prescribed burns be as well managed as the fire itself. (see succeeding sections of this report)

Literature on emissions from fires similar to the prescribed burns at Fort Bragg was used to develop ozone precursor-specific emission rates. These emission rates were entered into an approved Air Quality Modeling System (AQMS) by personnel at the Environmental Modeling for Policy Development (EMPD) Group, which is part of the Carolina Environmental Program (CEP) at the University of North Carolina at Chapel Hill.

The CEP/EMPD groups have been studying 8-hr ozone nonattainment issues in North Carolina for the past several years. More recently, under modeling support provided for the North Carolina Division of Air Quality (DAQ), they have performed extensive modeling using the MM5-SMOKE-MAQSIP modeling system for the Early Action Compact Process for 8-hr ozone nonattainment areas, including the Fayetteville region.

The USDA/USFS FSL have monitored seasonal changes in the moisture contents of the understory ("fine fuel") and shrub layers in forested stands at Fort Bragg. MSE incorporated the Spring 2005 data into implementation of the Fire Emissions Production Simulator (FEPS) modeling work.

Estimating Ozone Precursor Emissions

Selection of Fire Emission Production Simulator (FEPS)

At project onset, MSE evaluated various fire behavior/pollutant emissions simulation models available in the public domain: BehavePlus, BlueSky/RAINS, FARSITE, FEPS, and First Order Fire Effects Model (FOFEM) (Ref. 26).

The criteria for selecting the model for this study are that:

- it did not require input of digitized environmental databases (e.g., for topography, meteorology, forest characteristics);
- it produced hourly PM2.5 and ozone precursor emission rates, as well as heat release/plume rise data for a given burn event, and the output is readily integrated into the AQMS; and
- it was judged to be technically sound, very intuitive, and easy to implement.

It was determined that the FEPS Version 1.0 (Ref. 27) best met the above criteria.

Prior to use of the FEPS model, a literature review was performed to determine the underlying assumptions and algorithms used in the model. Key references discussing fire behavior include those by Rothermel (Ref. 28), Pyne et al. (Ref. 29), and

National Wildfire Coordinating Group (Ref. 30). An excellent update of Rothermel's work has been prepared by Scott and Burgan (Ref. 31). MSE suggests this reference be consulted prior to performance of any follow-up on emissions modeling at Fort Bragg. The references by Mobley et al. (Ref. 32) plus Wade and Lunsford (Ref. 33) provide good introduction to prescribed burning practices in the southeastern Unites States. State-of-the-art approaches to estimation of pollutant emissions and subsequent assessment of air quality effects resulting from various types of biomass combustion are presented in proceedings of the May 2004 National Fire Emissions Technical Workshop (Ref. 34).

MSE used FEPS (Ref. 27) to derive hourly pollutant emissions plus smoke plume buoyancy parameters (i.e., hourly plume heat release and buoyancy efficiencies) based on burn-specific biomass combustion rates and meteorological conditions.

Model Description

FEPS version 1.0 is a PC-based Visual Basic software program available at https://www.fs.fed.us/pnw/fera/feps. FEPS is a user-friendly computer program designed to predict emissions and heat release characteristics from prescribed burns or from wildfires by using system defaults, user templates, specific event information, or conjectural input at any spatial scale or level of specificity. Algorithms are included to predict fuel consumption that partitions outputs among flaming, smoldering, and residual combustion stages, based on fuel moisture inputs. Approximate plume rise is also predicted by FEPS (Ref. 27).

FEPS can be used for most forest, shrub, and grassland types in North America and even around the world. The program allows users to produce reasonable results with very little information, by providing default values and calculations. Advanced users can customize the data they provide to produce very refined results. FEPS Version 1.0 produces emission and heat release data for both prescribed and wild fires. Total burn consumption values are distributed over the life of the burn to generate hourly emission and release information. Data managed includes the amount and fuel moisture of various fuel strata, hourly weather, and a number of other factors (Ref. 27).

The basic steps for using the model are as follows (Ref. 27):
1. Describe an event, including the name, location, start date, end date, and other miscellaneous properties.
2. Specify up to five unique fuel profiles. Each profile includes fuel loading and moisture information.

3. FEPS then calculates total fuel consumption for each profile.
4. FEPS determines flaming, short-term smoldering, and long-term smoldering involvement and consumption (Figure A-1).
5. FEPS indicates how the event behaves over time.
6. FEPS calculates PM2.5 emissions and heat release parameters on an hourly basis. Fuel characteristics for each hour are managed by distributing the fire across the user-specified fuel profiles (Figure A-2).

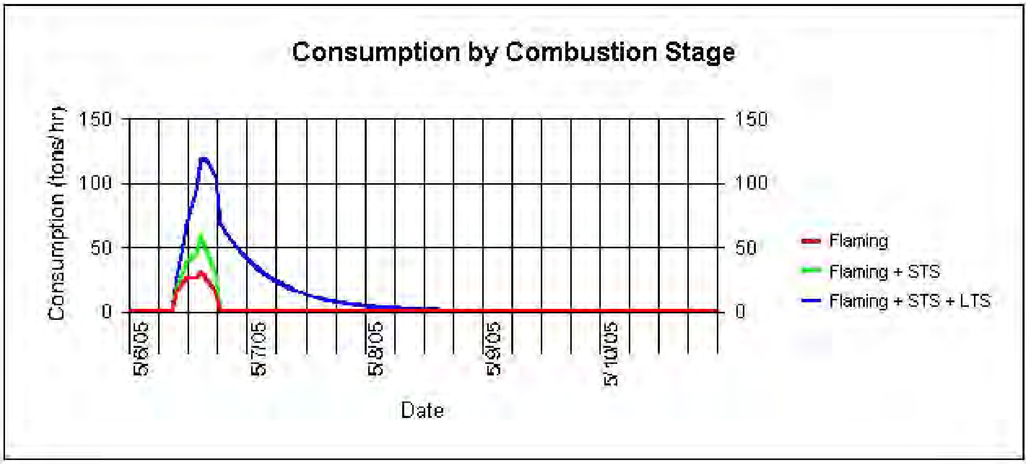

Figure A-1. Typical FEPS model total fuel consumption plot output.

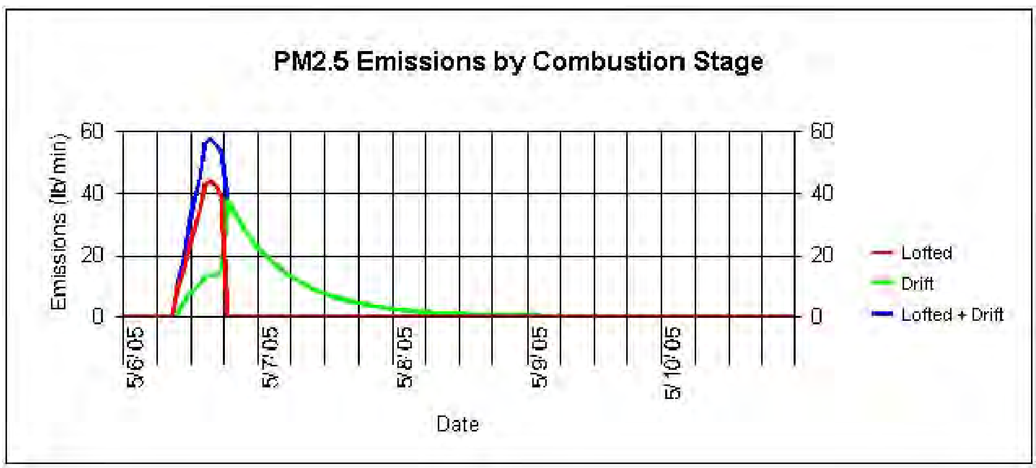

Figure A-2. Typical FEPS predicted PM2.5 emissions by smoke dispersion type.

Fuel Loading

Abundant data exists for species-specific timber production as well as layer-by-layer plant species listings for the various forest types at Fort Bragg. However, MSE could not identify biomass production (dry weight/unit area) data for the understory and shrub layers in these forests, but initial literature review identified some biomass data (Table A-1). While this data was not specific to Fort Bragg, it was used as best available.

Table A-1. Understory biomass inventory for longleaf pine sites subject to prescribed burning (dry lb/acre).

Forest Layer					
Location	**Grass/Forb**	**Scrub**	**Litter**	**Total**	**Information Source***
Escambia Experimental Forest, southwestern Alabama	346	568	8,264	9,178	Ref. 41
Escambia Experimental Forest, Escambia County, Alabama	318	515	11,888	12,721	Ref. 42
Catahoula and Calcasieu RDs of the Kisatchie NF, Alexandria and Leesville, Louisiana	402-1,460	—	—	—	Ref. 43
Alapaha Experimental Range of the Coastal Plain Experiment Station, Berrien County, southcentral Georgia	616	—	—	—	Ref. 44
Rapides Parish and southwest of Alexandria, Louisiana	664	—	3,603	—	Ref. 45
Tiger Corner study site, app. 2.5 mi southeast of Jamestown, South Carolina in the Francis Marion NF	890	3,449	—	—	Ref. 46
Sites in the Osceola NF (Baker and Columbia Cos.) Georgia-Pacific/ITT-Rayonier lands (Bradford and Union Cos.) and Florida Division of Forestry site (Putnam and Volusia Cos.)	623	6,675	8,633	15,931	Ref. 47

NF = National Forest
RD = Ranger District
* = see Reference List

A follow-on attempt was made to quantify fuel loadings for each of the vegetation types as shown in Table A-2. This approach was based on hypothesized response of overstory biomass production to on-site soil moisture and fertility gradients (Refs. 35, 36). Layer-specific biomass data from particular forest stands were taken from published and unpublished photo series (Refs. 37–40) and then assigned to the vegetation mapping units (Table A-2) where they were judged to fit best.

The values used in the FEPS modeling effort are shown in Table A-2. (The model accepts only one significant figure to the right of the decimal point.)

Table A-2. Central tendency estimates of potential fuel loading at Fort Bragg (tons/acre).

Live Biomass		**Woody Dead (Sound and Rotten)**				**Other**		
Grass/Forb	**Shrub**	**1-hr**	**10-hr**	**100-hr**	**1,000-hr**	**Litter**	**Duff**	**Total**
0.50	0.20	0.30	0.20	0.10	0.10	0.90	0.20	2.50

Fuel Moisture

Central tendency estimates for strata-specific moisture contents (percentage, dry weight basis) are shown in Table A-3. Key references include the National Wildlife Coordinating Group (Ref. 30), Mobley et al. (Ref. 32) and Burgan (Ref. 48). The entries reflect (1) information obtained during a March 30 site visit, and (2) follow-on data received from, and discussions with, USDA/USFS and North Carolina Forestry Division personnel (Ref. 49).

Table A-3. Central tendency estimates of strata-specific moisture contents (%, dry weight basis).

Live Biomass		**Woody Dead (Sound and Rotten)**				**Other**	
Grass/Forb	**Shrub**	**1-hr**	**10-hr**	**100-hr**	**1,000-hr**	**Litter**	**Duff**
100	75	8	12	16	22	10	40
a = (wet weight-dry weight)/dry weight) (100)							
b = average of leaves and woody material							

Hourly Meteorological Data

Central tendency estimates for a "typical" prescribed burn event during the April–June time period were based on recent meteorological data from Fayetteville (2002–2004), Simmons Army Airfield (2002–2004), Pope Air Force Base (2002–2004), and Moore County Airport (2002–2004). Meteorological conditions for burn events were derived from the USDA/USFS Southern Region Guidance for Prescribed Burns (Ref. 33) plus prescribed burn/smoke management guidelines for Virginia (Ref. 50) and Tennessee (Ref. 51).

The resulting "typical" burn day weather conditions are shown in Table A-4. However, the FEPS model takes only the respective minimum-maximum temperature and relative humidity values to create its own cyclic patterns using algorithms found in the User's Manual (Appendix C in Ref. 27). Nevertheless, the MSE and FEPS plots are very similar.

Table A-4. "Typical" weather for prescribed burn during April-June at Fort Bragg.

Clock Time	**Transport Wind (mph)[a]**	**Wind at Flame Ht (mph)[b]**	**Temp. (°F)**	**RH (%)**	**Pasquill Stability Class**
0000-0100	4.5	0.9	64	79	E
0101-0200	4.5	0.9	63	81	F
0201-0300	4.5	0.9	62	84	F
0301-0400	4.5	0.9	60	92	F
0401-0500	4.5	0.9	60	92	E
0501-0600	4.5	0.9	60	85	E
0601-0700	4.5	0.9	60	82	E
0701-0800	5.0	1.0	61	74	D
0801-0900	7.0	2.1	64	70	C
0901-1000	8.0	2.4	68	63	C
1001-1100	9.0	2.7	70	48	C
1101-1200	11.0	3.3	74	44	C
1201-1300	12.0	3.6	76	42	C
1301-1400	12.0	3.6	78	42	C
1401-1500	14.0	4.2	80	42	C
1501-1600	13.0	3.9	81	42	C
1601-1700	11.0	3.3	82	43	C

Clock Time	Transport Wind (mph)[a]	Wind at Flame Ht (mph)[b]	Temp. (°F)	RH (%)	Pasquill Stability Class
1701-1800	10.0	3.0	81	47	C
1801-1900	8.0	2.0	81	50	C
1901-2000	7.0	1.8	80	66	D
2001-2100	5.0	1.2	77	72	E
2101-2200	4.5	1.1	72	76	E
2201-2300	4.5	1.0	68	77	E
2301-2400	4.5	1.0	65	78	E
a = As measured 20 ft above ground surface b = For backing fire in 3-yr rough, average 2-2.5 ft above ground surface					

Estimated Burn Rates

The baseline burn rates shown in Table A-5 are based on the following assumptions:

- habitat restoration burn event sites are typically small (50 acre), medium (250 acre) or large (1,250 acre);
- all burns start at 0901 [i.e., after mixing height is ≥ 1,650 feet (ft)], and flaming combustion is complete by 1800;
- fire behavior responds to the given meteorological conditions (Table A-4) in a scalable manner; while
- potential fuel loads (Table A-2) and strata-specific moisture contents (Table A-3) are the same for all burn sizes.

The burn rates, adjusted for burn size, are shown in Table A-6. Per discussions during the March 30 site visit, it was agreed that: (1) the different burn sizes would be “nested” around a point situated west of the geographic center of Fort Bragg, and (2) the coordinates of this point are N35O 07' 00" (latitude) and W79O 10' 00" (longitude). The center of the burns is located near the northeastern tip of FMB 805, as well as being situated approximately 0.8 mi west of the southwestern corner of the Sicily Drop Zone.

Table A-5. "Baseline" hourly burn rates for 200acre fire.

Clock Time	Burn Rate (acre/hr)	Cumulative Burn (acres)
0901-1000	15	15
1001-1100	20	35
1101-1200	25	60
1201-1300	25	85
1301-1400	25	110
1401-1500	30	140
1501-1600	25	165
1601-1700	20	185
1701-1800	15	200

Table A-6. Cumulative areal progression of burn events.

Cumulative Burn (Acres)			
Clock Time	50-Acre Event	250-Acre Event a	1,250-Acre Event b
0901-1000	15	19	94
1001-1100	35	44	219
1101-1200	50	75	375
1201-1300	—	106	531
1301-1400	—	138	688
1401-1500	—	175	875
1501-1600	—	206	1,031
1601-1700	—	231	1,156
1701-1800	—	250	1,250

a = (250/200)-fold above hourly baseline estimates
b = (1,250/200)-fold above hourly baseline estimates

Ozone Emissions Model

Precursor Emissions

The CEP/EMPD Group has modeled surface ozone levels arising from mobile and stationary sources of ozone precursors during four separate ozone noncompliance episodes that occurred in the summers of 1995, 1996, and 1997. The modeling domain was a nested system of 36 /12 /4 km^2 grids centered over North Carolina. Gridded meteorological inputs to the Multiscale Air Quality Simulation Platform (MAQSIP) were generated using MM5 and were readily available for all three grid resolutions. The present application used the 19–30 June 1996, meteorological database, as this period exhibits sinusoidal changes in ozone levels over time. Pollutant levels initially build up, are then diluted by a cold front (i.e., cooler, stormy conditions), and are then followed by ozone "rampup" due to development of another high-pressure weather system. Therefore, the MM5 data set used during the Fort Bragg prescribed burn study is the same as that developed for the Fayetteville Early Action Plan (EAP) process.

The calendar year 2000 ozone precursor emission inventory for the Fayetteville metropolitan statistical area (MSA) was processed using the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system. SMOKE is the emissions modeling system used to process inventory data and perform chemical speciation, and temporal and spatial allocation to the resolution needed by the air quality modeling system. The CEP then merged the fire emissions file with the existing model-ready emissions file that contained the anthropogenic and biogenic emissions for the episode period. Emissions estimates from other sources thus remained unchanged. Biogenic emissions were estimated using the BEIS-3 implementation within SMOKE.

The hourly, precursor-specific emission rates for each burn scenario were processed through SMOKE; typical summer day background emission rates (i.e., from non-burn sources) were processed in the same manner. Output from SMOKE was allocated throughout a typical burn day, distributed throughout a three-dimensional volume of air (as defined by the particular horizontal grid size and height intervals within the atmospheric boundary layer), and chemically speciated for use in the photochemical modeling routines. The prescribed burns were treated as pseudo-point sources. The plume-rise algorithm in SMOKE was adjusted to allow use of the same meteorological database (from MM5) for both background and burn-related ozone precursor emissions.

Air Quality Modeling Methods

The MAQSIP is a comprehensive urban- to intercontinental-scale atmospheric chemistry-transport model developed in collaboration with the USEPA. MAQSIP has been applied to simulation of tropospheric ozone distributions and trends over the eastern United States on a seasonal scale for 1995; model predictions have been rigorously evaluated against surface and aircraft measurements contained in the Southern Oxidant Study databases (Refs. 55, 56). MAQSIP is being applied in North Carolina to assess attainment of the 8-hr NAAQS for ozone (Refs. 19, 57).

MAQSIP simulations were run for the "no-burn", "small burn" (50 acre), "medium burn" (250 acre), and "large burn" (1,250 acre) scenarios. The predicted 1 hr and 8 hr ozone concentrations at the Wade and Hope Mills air quality monitoring stations were compared graphically against observations made at these sites during the June 1996 ozone episode. Predicted ozone levels (at these monitoring sites) for the no-burn vs. defined burn scenarios were also compared graphically. Finally, the EMPD Group evaluated ozone pollution persistence and severity; such metrics provide insight into the spatial extent as well as the intensity of the exceedances of ozone levels above a regulatory threshold value (e.g., 8 hour NAAQS for ozone).

Ozone Modeling Results

The MM5-SMOKE-MAQSIP modeling system was employed to assess air quality impacts from three burn sizes (50, 250, and 1,250 acres) in the Fort Bragg region for the 19–30 June 1996 ozone episode in North Carolina. CEP/EMPD personnel acquired the ozone precursor emissions information (generated by MSE using the FEPS modeling system) and successfully processed emissions through two different approaches (Western Regional Air Partnership Fire Emissions Joint Forum [WRAP-FEJF] and BlueSky/SMOKE) for subsequent use in the air quality modeling system. The emissions from the other anthropogenic sources and biogenic sources were kept constant in all modeled scenarios. Although the magnitude of emissions was identical between the two approaches for processing emissions from these burns, the maximum plume height (and hence the emissions allocation in the vertical layers of the model) was very different between the two approaches for all three burn sizes.

The WRAP-FEJF approach allocates considerably more emissions to the lowest layer than the BlueSky/SMOKE approach for all fire sizes and for all hours. While WRAP-FEJF uses precomputed plume rise, the BlueSky/SMOKE approach uses a form of the Brigg’s algorithm with episode-specific meteorology to compute the plume rise. The latter approach thus makes the emissions allocation from the prescribed burns inherently consistent with the rest of the emissions processing in the modeling system. It should be noted that the magnitude of emissions that are estimated for burns on Fort Bragg is very small compared to the total emissions generated in Cumberland and Hoke counties, and compared to the total emissions in North Carolina.

Due to the contrasting results from the processing of the emissions from these burns, CEP/EMPD extended the scope of this work to model emissions developed from both these approaches (i.e., WRAP-FEJF vs. BlueSky/SMOKE) within MAQSIP to evaluate changes in ambient ozone. Various metrics including daily maximum 8 hr ozone, AQI-based counts, persistence, severity, and time-series analyses at monitored locations were used to evaluate the impacts of these burns. The domain-wide daily maxima did not change due to the burn scenarios on all episode days; however, differences of up to 1–3 parts per billion (ppb) downwind of the burns were observed on some episode days. The persistence and severity counts based upon hourly 8 hr ozone showed a significant increase (38%) only on 22 June. Based on the AQI counts, 1–3 grid-cells did transition from nonexceedance to exceedance of the 8 hr form of the NAAQS for ozone in the 1,250 acre BlueSky/SMOKE scenario on a few days. The model predictions at all observed locations were almost insensitive to the emissions from these burns, indicating that these burns will have no impacts on current model performance. However, given the changes in persistence for the 1,250 acre scenario seen on 22 June in the Fayetteville MSA, a potential new monitor location in central Cumberland County, or even a relocation of the Wade monitor slightly southwest of its current location, may affect model performance.

While CEP included a representative set of days from the June 1996 episode for this project, a different meteorological regime for the region could potentially show different air quality impacts from such fires. Hence, the results presented here are specific only to the episode considered. Detailed discussion of the CEP's modeling methods is posted on their website (Ref. 58).

Comparison to Other Burns

It has been suggested that 38% of the annual global production of ozone arises from biomass burning (Ref. 59). Source categories for generation of the ozone precursors include prescribed wildland/range fires, burning of agricultural and logging/land clearing wastes, and wildfire.

Large wildfires occurring in boreal forests and tropical savannas can have significant effects on "baseline," ground level ozone levels. An example of the former case is the lightning-caused fire that burned approximately 330,000 acres in northeastern Alberta, Canada between late May and early June 1995. Median ozone levels in Edmonton, located approximately 185 mi south of the fire, increased from 26 ppbv (the seasonal median) to 43 ppbv in early June; the 1 hr average Provincial Guideline for ozone (82 ppbv) was exceeded a number of times and at a number of monitoring stations during this time (Ref. 60). Carbon monoxide and nonmethane volatile organic compound (VOC) emissions from Canadian wildfires in 1995 may have contributed substantially to these pollutant levels in the southeastern and eastern United States during this time; the resulting "excess" ozone concentrations may have been in the tens of ppbv (Ref. 61). Similarly, the tens of millions of acres of tropical savanna/brushland that are burned in West Africa each year (Ref. 62) may have contributing effects. Ground-level ozone concentrations can increase from background concentrations of ≤ 45 ppbv to ≥ 120 ppbv during periods of intense burning and at distances up to 1,600 mi downwind of such activities (Ref. 63).

The Alberta wildfire just mentioned probably consumed up to 15 tons/acre biomass (NFDRS Timber Fuel Models G and H) and burned at rates of 5–10,000 acres/day. MSE also estimates that the tropical savanna fires probably consumed about 1.5 tons/acre (i.e., NFDRS Grass Fuel Models L and T) and burn at a cumulative rate of 100,000 acres/day. In both cases, regional increases in ozone above background levels can be ≥ 20 ppbv at distances > 100 miles downwind of such burns. The hypothesized 1,250 acre prescribed burn at Fort Bragg consumed approximately 0.9 ton dry biomass/acre throughout the burn area within a 24 hr period. The predicted incremental increase in 8 hr average ozone levels is ≤ 3 ppbv, and it would occur approximately 20 mi downwind of the burn (see “Estimated Burn Rates” from Section 2). However, as the hypothesized burn(s) occurred during an ozone episode, this increment resulted in localized noncompliance with the 8 hr ozone NAAQS.

Regarding the Fayetteville MSA, the increment was sufficient to:

- cause one 4 km^2 grid-cell to transition from AQI Code Yellow (≤ 84.9 ppbv ozone) to Code Orange (85 ppbv ozone) for both 50- and 250-acre scenarios;

- cause three such transitions for the 1,250-acre scenario

    Note: minor air quality inputs were also observed in the Triangle MSA, which is located approximately 60 air miles north of the hypothetical burn site(s).

- transition two grid-cells from Code Yellow to Code Orange on 24 June in the 250-acre BlueSky/SMOKE scenario; and

- transition one grid-cell from Code Yellow to Code Orange on 30 June, in both the 50-acre and 250-acre WRAP FEJF scenarios.

The modeling results are limited to the particular ozone episode considered; other episodes (e.g., for 12-15 July 1995) may produce outcomes that differ from the one reported here.

Furthermore, ground-level ozone concentrations observed at a particular point are dependent upon the following:

- fuel type, moisture, and combustion intensity effects on the composition and relative concentrations of the reactive hydrocarbons (RHC) (Ref. 53);

- the mass ratios of nitrogen dioxide; that is, nitrogen oxide and NOx: RHCs (Ref. 64);

- the relative proportion of biogenic compared to other sources of emissions of ozone precursors (Ref. 65); and

- effects of prevailing weather conditions on precursor-related regional transport and photochemical processes (Ref. 66).

Nevertheless, the study demonstrated the inadvisability of implementing controlled burns (of any size) during regional ozone exceedance episodes. However, the results also indicated that prescribed burns set during AQI Code Green (≤ 64.9 ppbv ozone), or even transitions to Code Yellow, will have negligible effect(s) on regional ozone levels. Given regional background levels of ≤ 25 ppbv (Appendix C and Figures A-26 and A-27in Ref. 67), local biogenic increment of about 10 ppbv (Ref. 67), and total anthropogenic contributions of ≤ 30 ppbv (i.e., during non-ozone episodes; Appendix C in Ref.67), the Fayetteville MSA would be often on the Code Green-Yellow "margin" for ozone. In such cases, prescribed burns within the Fort Bragg reservation could "push" the regional AQI into the lower end of Code Yellow (i.e., from 65 to 68 ppbv, as measured at the Wade and/or Hope Mills air quality monitoring stations).

Furthermore, the NC DENR's DAQ applies standard methods (e.g., Ref. 68) for prediction of ozone and PM2.5 concentrations within different geographic regions of the state. Information from the DAQ's Ozone Forecast Center (Ref. 69) is included in the "fire weather"/prescribed burn planning process at Fort Bragg. Uncertainties exist regarding accuracy of output from the FEPS and AQMS modeling, as well as from ozone forecasting efforts. Nevertheless, MSE suggests that ozone-related AQIs of ≤ 75 (i.e., ≤ 75 ppbv ozone) during burn events can be performed without transitioning into AQI Code Orange (> 85 ppbv ozone, nonattainment) situations. Such an approach may provide a 20 ppbv "buffer" (i.e., 85 ppbv regulatory threshold minus the 65 ppbv predicted by the present study).

Conclusions and Recommendations

Based on the modeling of prescribed burning practices at Fort Bragg, MSE sees no ozone-related basis for modifying the existing program. Essentially, the emission of ozone precursors and subsequent ozone formation from growing season burns has minimal effect on regional air quality. Therefore, MSE concludes that the benefits attained by prescribed burns for restoration/maintenance of the longleaf pine-grassland ecosystem (Ref. 70) at Fort Bragg far outweigh the detriments of ozone production arising from such activities.

Time and funding limitations precluded similar evaluations of fine particulate (PM2.5) emissions arising from either spring/summer or winter (fuel reduction) burns. Given the present debate regarding causal associations between PM2.5 exposure and public health response (Ref. 71; Ref. 72), generation of such particulates from prescribed burns and its effects on regional air quality and public health, merits further attention. It would be useful to estimate the prescribed burning contribution (from Fort Bragg sources) to PM2.5 loading within the Fayetteville MSA. Much of the biological, meteorological, background emissions, and fire-related data needed to implement this task are either in-hand or their sources have been identified. The results would also contribute to a holistic view of air quality management in the Fort Bragg area.

Table A-7. Proposed fuel-loading mapping units for the Fort Bragg military reservation.

Geounit (Fm.)[a]	Soil Units[b]	Hydrology[c]	Vegetation Type(s) Present Cover[d]	Natural Community	Burn Characteristics
PEp (Pinehurst)	LaB, CaB, KuB	Xeric, excessively drained	LL, SP, B/G Open	Xeric Sandhill Scrub	Frequent, low-intensity surface fires occur naturally throughout the year, although most often in early summer. Species diversity and biomass of the grass/forb and shrub strata are greatly affected by the return interval of fire (in years) plus season of occurrence.
Km (Middendorf)	BaD GdB/GdD, VaB/VaD, VgE, AeB, NoB, Pa	Dry to xeric, with brief occurrences of perched water table	LL, LB	Pine/Scrub Oak Sandhill	Same as above.
	KaA, WaB, plus some of the above units	Dry	UHAR	Dry Oak-Hickory Forest	Such forests exist largely in areas that are sheltered from fire spread (i.e., within the above vegetation units) and have fire return intervals of 3 to 5 years.
	DhA, FuB, BnB, BaB, WaB, WfB	Mesic to dry-mesic	LL, LB, SP	Mesic Pine Flatwoods	Naturally experience low- to moderate-intensity fires, which maintains a somewhat open canopy plus sparse shrub layer and vigorous herb (grass/forb) layer.
	BaB/BaD, VaB/VaD	Seasonally to permanently saturated with oligothrophic waters	LL, LB, SP	Sandhill Seep	Subject to fires spreading from adjacent sandhill communities and thus burn more frequently than other similarly wet community types.
Kcf (Cape Fear)	GoA, Ly, Le,Wo, Co, Pg, Pa, Ra	Seasonally saturated by high or perched water tables	LL, LB, SLP	Wet Pine Flatwoods/Pine Savannah	Naturally experience frequent, low- to moderate-intensity surface fires, which maintains a somewhat open canopy plus open to sparse shrub layer and vigorous grass/forb layer. In the absence of fire, some of these sites can be invaded by loblolly pine and weedy facultative wetland hardwoods.
Qal (Alluvium)	Bb, JT, We, CT, Ro, Ch	Seasonally to semipermanently saturated soils	LHAR, SLP, LB	Streamhead Pocosin and Blackwater swamps	Although usually too wet to carry fire, these units can be disturbed along their edges by fires burning on the adjacent upland units.

a References 7-9 were used to roughly map surficial geology at 1:40,500-scale (map in project files at MSE).

b The soil series-slope phases are spelled out in (Appendix Table A-1 from Ref. 10), and were taken from the 1:40,500-scale soils map for the Reservation.

c References 11-12 were used to create the hydrology categories and to assign soils units to each category.

d The cover units include loblolly pine (LB), longleaf pine (LL), shortleaf pine (SLP), slashpine (SP), bush/grass (B/G), plus upland and lowland hardwoods (UHAR/LHAR) and were taken from the 1:40,500-scale vegetation cover map for the military reservation.

e Descriptions of the natural communities, including discussions on their burn characteristics, are presented in Schafale and Weakley (Ref. 13). References 14-15 were consulted during this mapping exercise.

Appendix B

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Appendix C

Acronyms and Abbreviations

Term	Spellout
AQMS	Air Quality Modeling System
AR	Army Regulation
CEP	Carolina Environmental Program
CERL	Construction Engineering Research Laboratory
DA	Department of the Army
DAQ	Department of Air Quality
DC	District of Columbia
EMPD	Environmental Modeling for Policy Development
ERDC	Engineer Research and Development Center
FEPS	Fire Emission Production Simulator
FMB	Fire Management Blocks
FSL	Fire Science Laboratory
FY	fiscal year
HMA	habitat management areas
HQUSACE	Headquarters, U.S. Army Corps of Engineers
NAAQS	National Ambient Air Quality Standard
PC	personal computer
PDF	Portable Document Format
POC	point of contact
PWTB	Public Works Technical Bulletin
URL	Universal Resource Locator
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
WMPP	Waste Minimization and Pollution Prevention
WWW	World Wide Web

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