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A comparison of smoke emissions from prescribed burns and wildfires

David Frisbey

San Jose State University

A COMPARISON OF SMOKE EMISSIONS FROM PRESCRIBED BURNS AND WILDFIRES

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David Frisbey

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APPROVED FOR THE DEPARTMENT OF GEOGRAPHY

Dr. Richard Taketa

Dr. Gary Pereira

Ms. Amy Taketomo, Hartnell College

APPROVED FOR THE UNIVERSITY

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ABSTRACT

A COMPARISON OF SMOKE EMISSIONS FROM PRESCRIBED BURNS AND WILDFIRES

by David Frisbey

This thesis describes a means of comparing the potential smoke impacts from prescribed burning versus the possible smoke impacts of a wildfire as if it had occurred in the same given area. The methodology of evaluating these impacts is based on the results of available computer models designed for determining smoke production and pollutant dispersion. The results of a test case comparing prescribed burn and wildfire conditions verified that there could be significant downwind impacts from both types of burning. A method is then examined by using the models to size a prescribed burn based on fuel load/acre to limit downwind smoke particulate concentration, thereby providing land managers with a possible means to further limit the risk of adverse smoke impacts on adjacent communities.

ACKNOWLEDGEMENTS

Undoubtedly, this thesis would not exist without the assistance of my colleagues at the Monterey Bay Unified Air Pollution Control District, especially Amy Taketomo whose encouragement and wise counsel is valued so much by myself and many others, Bob Nunes whose perspective and enthusiasm contributed to the best aspects of this thesis, and Ed Kendig who is ever supportive of self improvement and for going to bat for me when things were looking bleak. Special thanks are in order for Dr. Richard Taketa not only for his guidance and mentoring through the process of writing this thesis, but also for his willingness to work with each student personally as a partner in their success. Thanks also to Dr. Gary Pereira for his interest in this project and for his encouraging comments, which lead to its completion. The successful conclusion to this project is mostly a reflection of the sacrifices made by Linda, Ben, and Garrett. Thanks for their tolerance and understanding throughout this journey.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The disruption in natural fire return frequency by many years of aggressive fire protection has led to excessive vegetation growth on public and private wildlands. This growth has ironically led to an increase in fire hazard risk and a reduction in species diversity. In many cases the fire risk is heightened by the proximity of these wildlands to adjacent urbanized areas (described as the urban wildland interface). In order to control excessive vegetation (also called fuel) managers of wildlands deliberately introduce fire under select conditions (e.g., temperature, fuel moisture, humidity) in a practice known as prescribed burning.

Before conducting a prescribed burn a land manager must consider the risks of smoke impacts on the local populations and the potential for these fires to escape. Conversely, it has been argued that prescribed burning actually reduces the risk of smoke impacts that might potentially come from wildfires that would otherwise occur in those areas. Wildfires can and often do occur under conditions that direct smoke into a local community, whereas, a prescribed burn can be ignited under meteorological conditions that are more favorable to moving smoke away from the local urban areas.

While this may be intuitively true, in practice there have been many instances of prescribed burns that have sent smoke into the adjacent communities. So then do prescribed burns actually reduce smoke impacts on the adjacent communities that would be experienced if the same area burns under uncontrolled wildfire conditions? In an attempt to better understand this problem the research described here explores a means by which to examine whether the use of prescribed burning benefits local communities by reducing the potential impact of smoke from wildfires.

As a point of departure to compare wildfire and prescribed fire conditions this research begins with a discussion of the pollutants that are generated by fire and identifies the ones that can be measured effectively for this comparison. Several computer models (fuel consumption models) that are freely available for measuring pollutant generation from open burning are also surveyed here. These models are then compared and evaluated to determine which ones will work best for this project. But smoke impacts also need to be assessed based on the dispersion of the emissions away from the source. To address this aspect several dispersion models are surveyed and evaluated as well.

A methodology is proposed by which the models can be used to make a comparison of smoke impacts on local communities between wildfires and prescribed burns. Based on the surveys of the fuel consumption and dispersion models the ones that will work best with this methodology are selected. To confirm that the models will function for this project they are validated based on data collected during an actual prescribed burn. A wildfire event is then compared with a prescribed burn using the methodology. Finally, a means of using the methodology to help land managers reduce adverse smoke impacts from prescribed burns on adjacent communities is discussed.

Background

The examination of smoke impacts from prescribed fire can be better understood by examining the context of the risks of prescribed burning and wildfire. The starting point for this review was an exploration of the current state of research into fire ecology. Bowman and Franklin (2005) provide a survey of research that considers examining the broad implications of fire on a regional basis. They stress the importance of the evaluation of urbanization near wildlands due to various complex issues.

Fire risks cannot be understood outside of the human perception of those risks. At times people are willing to trade what some might consider more hazardous risks for risks to their resources. Carroll, Cohn, and Blatner (2004) found that landowners could be more concerned with regulations that might cause them to lose access to harvesting their lands than they are with concerns over fire, insects and disease. Other discussions of risk due to fire find that knowledge of the benefits of an activity might allow people to tolerate higher risk environments. Toman, Shindler, and Reed (2004) examine how perceptions change when citizens visit areas where land managers need to conduct prescribed fires. Their research suggests that smoke levels are more acceptable to the public if it means a healthier forest.

Visibility can also be included as a risk of prescribed burning and wildfires. Regional haze has become an important issue in National Monuments and other viewsheds. Tombach and Brewer (2005) indicate that there are wide ranging effects of wildfires on viewsheds. In some cases pollutants generated from wildfires in Northwestern Canada have impacted Tennessee.

Much research has been done on developing tools for assessing the risk of smoke from wildfires by using dispersion models. In 2005, the Bureau of Land Management (BLM) issued a report evaluating the air quality impacts of various vegetation treatment methods using dispersion modeling. One of these models is CalPuff, developed for the California Air Resources Board. This model has also been used to identify the sources for regional impacts of particulate and visibility in the Colombia Gorge by running the CalPuff model in reverse mode (Avise, Xie, Chen, & Lamb, 1998). Breyfogle and Ferguson (1996) indicate the need for an expansion of the use of dispersion models because regulators do not use models to authorize prescribed burns to proceed. While this may or may not be true now, significant refinement has been done on fuel consumption and emission calculators and dispersion models to this end. The Fire Consortia for the Advanced Modeling of Meteorology and Smoke provide an overview of the current state of modeling used by regulatory agencies, fire professionals and land managers.

Effects of Smoke on Human Populations

While smoke impacts from wildfires and prescribed burns tend to be focused on the local populations, the impacts can be regional as well as global, acute as well as chronic, and health as well as aesthetic. Smoke from wildland fires can cause acute episodic impacts on local human populations, which can cause respiratory distress in compromised individuals, children, the elderly and those with respiratory disease. Ambient air quality standards (AAQS) set by the Federal and in some instances state governments can be violated. Fires occurring in other states and in some cases in other nations can compromise regional haze goals set by statute for some viewsheds. For example, in some documented instances fires from northwestern Canada have affected air quality in Tennessee (Brewer and Tombach, 2005).

The burning of vegetation in a largely uncontrolled environment causes incomplete combustion. This inefficient combustion causes smoke emissions that include a soup of particulate matter (PM), sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), various hydrocarbon compounds (HC), and a multitude of toxic compounds. Some of these components of smoke are precursors to other compounds such as Ozone (O_3). The generation of these pollutants differs from fire to fire depending on many variables. The primary factor in determining the generation of smoke is the amount of consumption of vegetation. Consumption is dependent upon the type of vegetation (fuel), amount of dead fuel, fuel moisture content, size of fuel, slope, duration, air temperature, relative humidity, etc.

Once the smoke has been released it has to go somewhere, potentially causing impacts on the local residents. Smoke dispersion is dependent upon many factors including the temperature of the fire which can cause the plume to rise or fall, phase of the fire (e.g. flaming, smoldering, glowing), duration of the burn, elevation of the burn, and various meteorological factors including height of the inversion layer, regional subsidence, wind direction and air temperature.

Many Environmental Protection Agency (EPA) and state air quality regulations are based on the concentration of pollutants called criteria pollutants. These include compounds such as O3, SOx, NOx, CO, PM10 and PM2.5 (there are separate standards for particulate matter < 10 and < 2.5 microns in size). If these pollutants exceed standards in a particular region, further regulation on existing industry and future development in those regions may be initiated. There are also visibility standards for smoke in many wilderness areas and national parks. Wildland fires generate these criteria pollutants as well as the pollutants discussed above. For this paper the collective pollutants from prescribed burns and wildfires will be termed "smoke."

Differences in acute and chronic impacts of these pollutants on human populations are a result of frequency and duration of exposure. Acute impacts are of short duration, generally on the local communities closer to a burn. Population centers near a particular burn area are likely to be impacted directly by low intensity burns as well as catastrophic wildfires. A higher concentration of smoke can potentially be seen in these areas than those further downwind. Chronic impacts can be seen in areas where fires burn frequently, are left to burn for a longer duration or when weather patterns don't allow for the smoke to clear from the area. Impacts on visibility are especially sensitive in those areas that are visited by the public for their aesthetically pleasing views such as Grand Canyon or Yosemite National Parks.

While this discussion will not delve entirely into the risks associated with all aspects of fire management, varying perceptions of risk or impact from the smoke from fires on wildlands are important to discuss. When discussing this risk other hazards must be considered as well. When people fear the hazards of a wildfire, they may be more willing to accept more risk of smoke impacts from a prescribed burn. However, for those who have severe asthma and are much more vulnerable to serious health problems from exposure to a minor amount of smoke, any impact of smoke from a prescribed fire may be deemed intolerable. Unfortunately, for these individuals the fact remains that wildlands will burn with or without human intervention. The significance of smoke impact is on some level a perception of what is acceptable by the individual being impacted.

Increasing encroachment upon wildlands has caused the need for more education about the realities of living in the urban-wildland interface. In one study (Toman, Shindler and Reed, 2004) groups of people were taken to areas that were to be treated with prescribed burns to see if this would have any influence on whether it would change their perception of the purposes of burning. Although, the researchers could verify no change in the group's attitude about prescribed burning after the visit to burn sites, there was an accepted view by the researchers that more education and awareness would increase tolerance of smoke from these fires. Community Wildfire Protection Plans developed by the Society of American Foresters, the Western Governors Association and others, encourage communities to be involved in understanding nearby fire risks and for the community to be part of the solution.

CHAPTER 2

COMPUTER MODELING OF SMOKE EMISSIONS

Two types of models are available for evaluating emissions from prescribed burning and wildfires: fuel consumption models (emissions calculators) and dispersion models. Several fuel consumption and dispersion models are currently used for determining potential smoke impacts from prescribed fire. Federal and State agencies have developed these models specifically for use in planning prescribed fires and in understanding weather patterns that might contribute to regional smoke impacts. Air quality models for prescribed burns can range from simple emissions calculators based on vegetation type, air temperature and other variables to complex dispersion models, which are coupled with complex meteorological models.

Consumption Models

When calculating emissions from a wildland fire many variables need to be considered. The topography (slope), vegetation type, fuel moisture content, dead fuel content, air temperature, humidity, season, how the fire is ignited (e.g., backing fire vs. heading fire), temperature of fire, and flame length, which when considered comprehensively can provide a basis for the determination of smoke emissions and total consumption of fuel in mass/acre. Several fuel consumption and emissions calculators have been developed to allow land managers and air quality planners to evaluate the potential emissions of broadcast and pile burning. The primary calculators being used now are the First Order Fire Effects Model (FOFEM), the Fire Emission Production

Simulator (FEPS), Consume and UC Berkeley's Fire Emission Estimation System (EES). All of these models have a graphical user interface (GUI) that allows for the input of several variables and provides output of the fuel consumption and generated emissions. They differ primarily in the ease of user input, the amount of knowledge the user must have, and the complexity of the output. These models do not provide any information about the dispersion of the pollutants, but can be a foundation for dispersion models so that downwind concentrations of pollutants can be estimated.

The US Forest Service (USFS) developed the Consume model. It evaluates data that has been manually input by the user although the input for daily weather can be imported from other sources. The GUI allows the user flexibility and control for input of the various fuel types and meteorological conditions, but requires more specialized knowledge by the user. It also provides input and output specifically for pile burning. This model is lacking in providing the user the ability to generalize the model to varying habitats. An advantage to this calculator is that it can calculate specifically for pile burning as well as for broadcast burns. Fuel consumption and emissions can be addressed for several piles at a time. An example of the Consume GUI can be seen below in Figure 1.

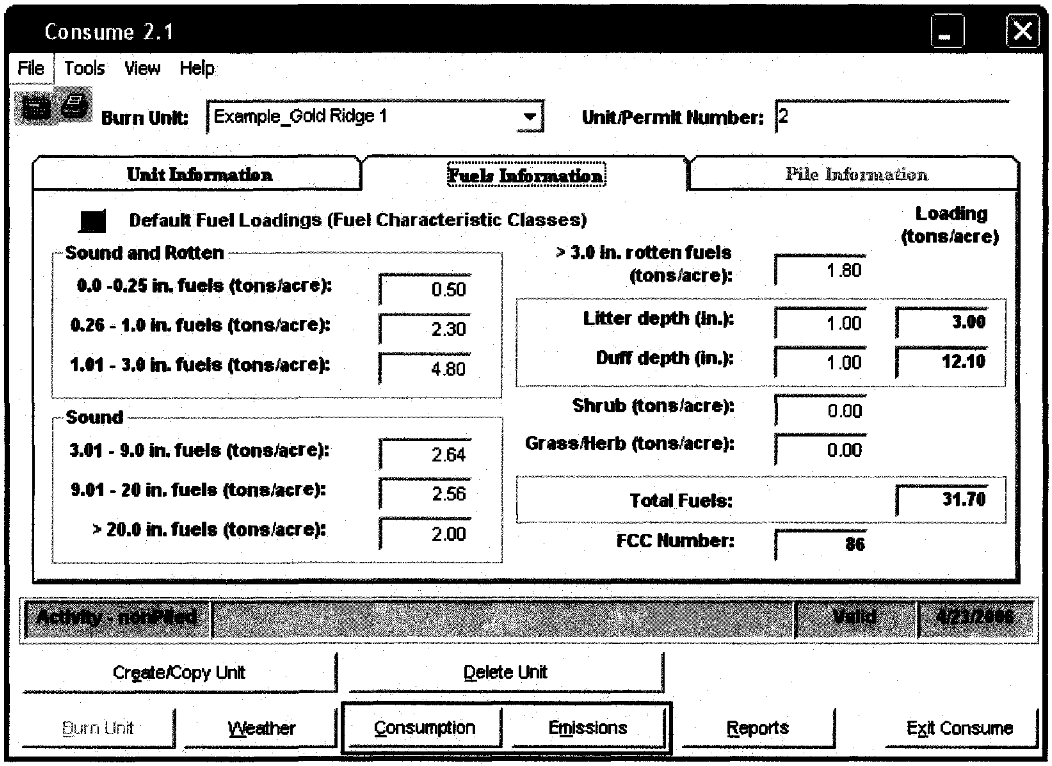

Figure 1. The Consume graphical user interface.

FEPS is another consumption and emissions calculator that was recently developed from the Emissions Production Model produced by the USFS. It operates similar to the Consume model, however, it provides for more complex data input for fuel type, moisture content, and meteorological variables. It also provides hourly output of consumption and emissions. An example of the calculations from FEPS can be seen below in Figure 2.

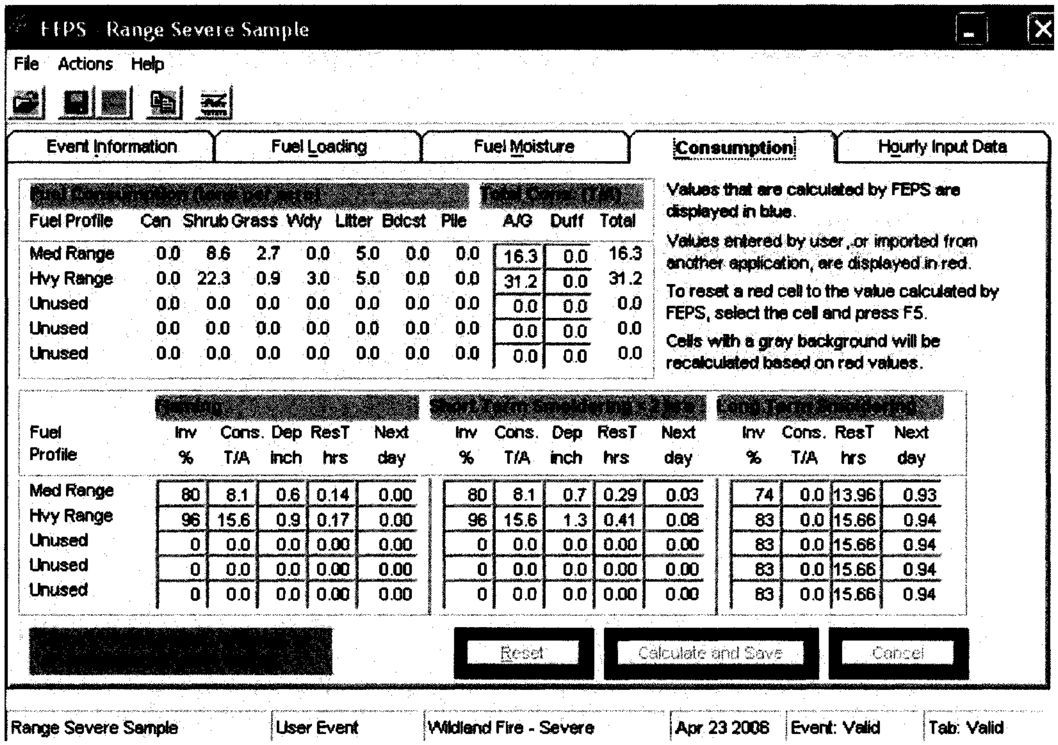

Figure 2. The Fire Emissions Production Simulator graphical user interface.

The FOFEM model allows the user to input factors such as species type, region, and time of year. It calculates fuel consumption and emissions based on the default values for each of these different generalized variables. This generalized method of data entry provides a user with a rudimentary knowledge of fire and forestry science to use the product without much difficulty. However, it also gives the user the flexibility to change the values for each of the factors to make it more explicit to the area to be burned. The results can be displayed in a table or as a graph for each of the pollutants. See example of the output for a sample run of FOFEM in Figure 3.

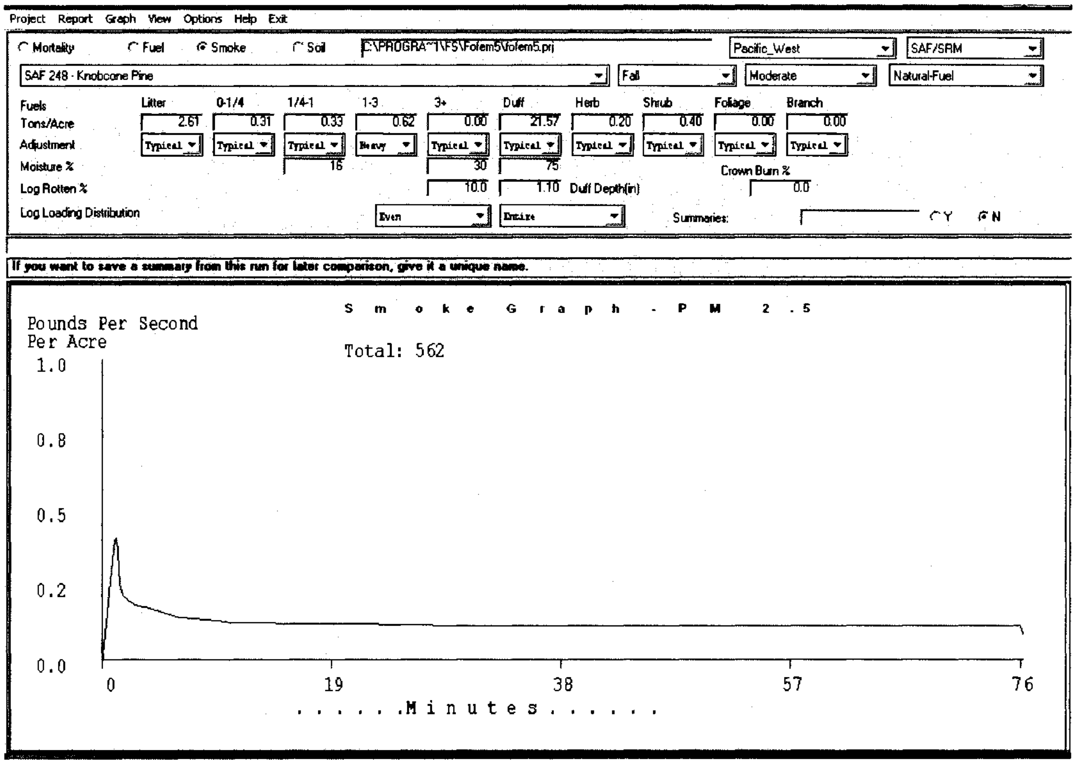

Figure 3. The First Order Fire Effects Model graphical output.

The EES model is the easiest to use and the most applicable to this project because it has a seamless interface combining the FOFEM emissions calculator with the Environmental Systems Research Institute, Inc. (ESRI) mapping software ArcMap. The user simply enters the parameters for the fuel conditions as described above for the FOFEM model. The fuel type and size of the burn is determined by defining the perimeter of the burn area in ArcMap by drawing a polygon around the area. The vegetation cover is already included as a data layer in this model so the total mass/acre of vegetation is automatically entered based on the defined area to be burned. EES compares the parameters entered earlier with the fuel loading in the selected area and calculates the fuel consumption and emissions. See Figure 4 below for an example of a defined burn area. The results of this simulated fire located northwest of Santa Cruz, CA can be seen below in Table 1. The advantage that this model has over the other models reviewed is that the selection for vegetation can be more exemplary of the area to be burned and can be updated with higher resolution vegetation layers.

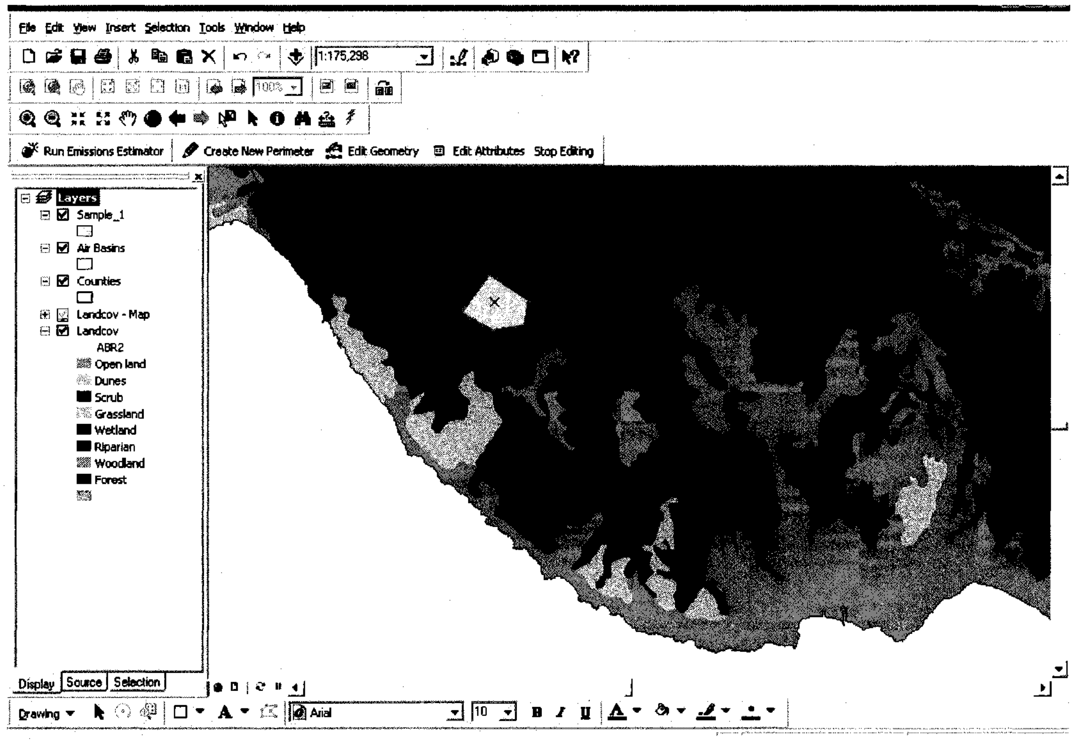

Figure 4. The Emissions Estimation System vegetation layer in ArcMap.

Table 1

Tabular output of the First Order Fire Effects Model

Modeling Domain: Sample_1
Year: All Years

Total CO:	376.7877 (tons)
Total PM 10:	42.4712 (tons)
Total PM 2.5:	36.0539 (tons)
Total CH4:	15.0715 (tons)
Total NMHC:	26.3753 (tons)
Total NH3:	3.7679 (tons)
Total N2O:	1.1044 (tons)
Total NOx:	18.7196 (tons)
Total SO2:	5.7678 (tons)

FOFEM settings:

Fuel Category:	Natural
Dead Fuel adjustment factor:	Typical
Moisture Conditions:	Very dry
Fire intensity:	Extreme
Will this fire burn tree crown:	Yes
Tree crown biomass burning:	Typical
Herbaceous density:	Typical
Shrub density:	Typical
Tree regeneration density:	Typical
NFDR-TH moisture percent:	20

Performed special GAP processing? No

Dispersion Models

A dispersion model attempts to provide an understanding of how a pollutant disperses through the atmosphere once released. Generally, these models consider meteorological data input and geographic location of the release of a pollutant to determine where a pollutant might be headed. Some of these models are three-dimensional, displaying elevation distribution of a pollutant as well. Their primary function is to display where a pollutant might end up once it has been released. These models can also be used in reverse to identify the potential origin of a detected pollutant (Avise et al., 1998). The models discussed here are those that are under development or are currently used by land managers and air quality planners to gain an understanding of the behavior of the potential smoke plumes from prescribed burning or wildfires. Some of these models can be run on PCs or are web based. The models that are reviewed here are Hysplit, CalPuff, Bluesky/BlueskyRAINS, and CMAQ.

The National Oceanic and Atmospheric Administration (NOAA) and Australia's Bureau of Meteorology developed the HYbrid Single-Particle Lagrangian Integrated Trajectory (Hysplit) model. This model is a web-based and PC application, which allows for the input of basic parameters such as coordinates and date. It can then generate a terrain following horizontal and vertical trajectory based on various meteorological models. Hysplit combines a puff and particle model to determine both vertical and horizontal dispersion. An advantage to this model is that the output can be exported to an ESRI shapefile or a .kmz file for use as a layer in Google Earth. See Figure 5 below for the dispersion output and Figure 6 for the trajectory output of this model.

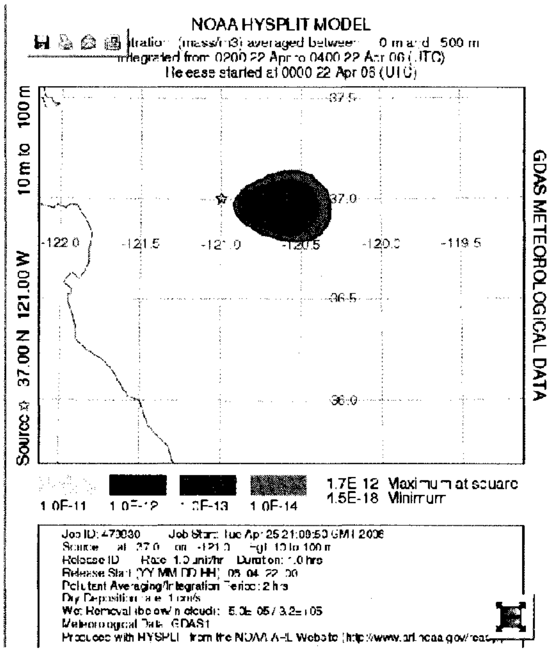

Figure 5. Dispersion output using the HySplit model.

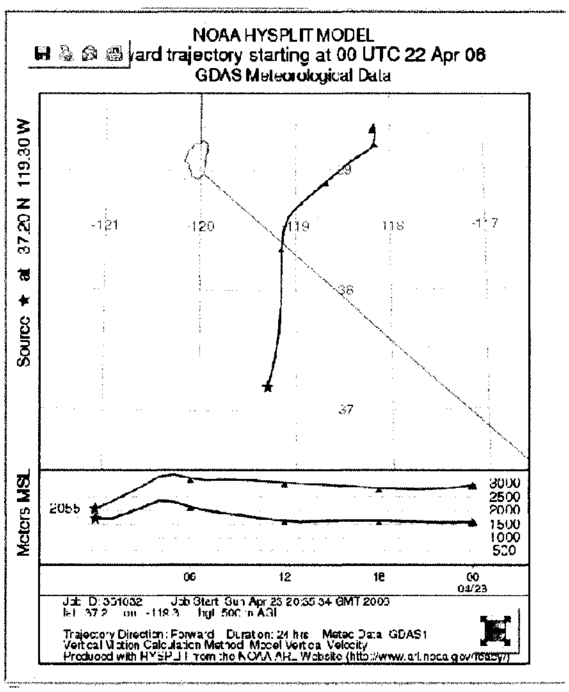

Figure 6. Trajectory output using the Hysplit model.

The CalPuff dispersion model provides the user with a wide range of control over the input of variables. Unfortunately, this makes the program complicated to use. A user would need significant training and experience before becoming proficient with this model. The benefit of CalPuff is that it uses meteorological input from models such as MM5, a mesoscale meteorological model that forecasts conditions in three dimensions. CalPuff can analyze input from several different emissions points (e.g., factories) as well as emissions generated over a broad area (e.g., wildfires). A user can select different map datum and coordinate systems. The output can be generated over a particular time frame in an animation based on historical or forecasted meteorological conditions. An example of this model can be found in the Naval Postgraduate School's MM5 website which has a daily forecast of meteorological data on California's Central Coast. They have plugged-in the CalPuff model for a simulated prescribed burn on the former Ft. Ord military reservation (See Figure 7 below).

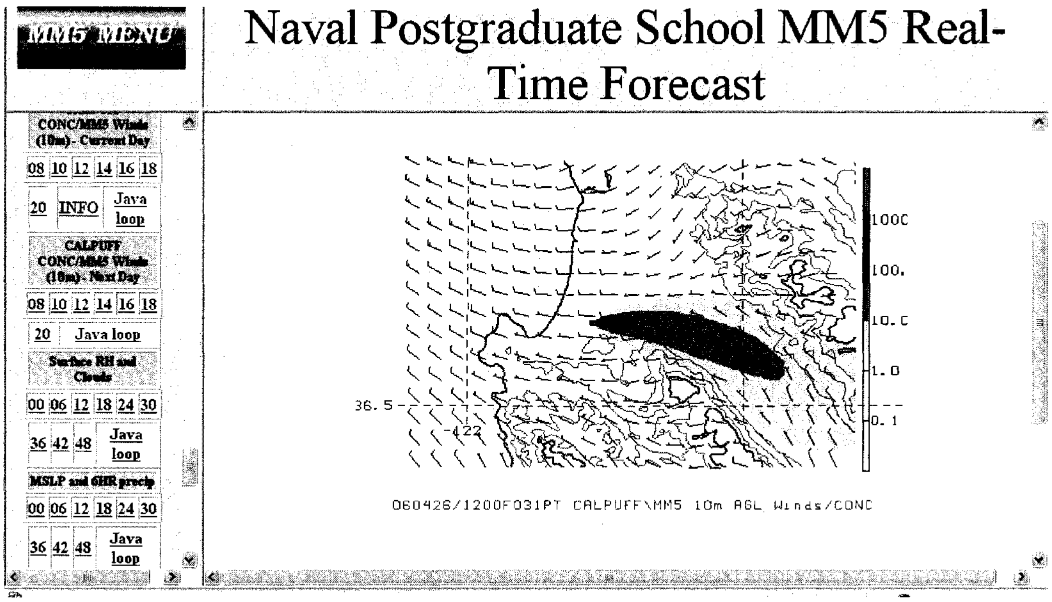

Figure 7. The Naval Postgraduate School output of CalPuff for a simulated fire at the former Ft. Ord Military Reservation.

The Community Multiscale Air Quality Model (CMAQ) produced by the EPA and NOAA is designed to look at a more holistic view of the atmosphere and the fate of pollutants within it. The model considers various issues including tropospheric ozone, toxics, and visibility. It is a multiple scale model that uses a generalized coordinate system and can accommodate varying map projections. This model's application to prescribed burning is still being evaluated but can potentially provide understanding of a wider range of pollutant distribution from wildland fires.

BlueSky and BlueSkyRAINS is a modeling system currently under development by the California and Nevada Smoke and Air Committee (CANSAC). There has been some effort recently to combine fuel consumption models with dispersion models to generate estimates of downwind pollution concentrations. For example, BlueSky uses the Consume and FEPS fuel consumption models discussed above and the CalPuff and

Hysplit models in conjunction with the MM5 meteorological data to forecast impacts from prescribed burns. BlueSkyRAINS is an operational web based application of BlueSky for the Pacific Northwest. See Figure 8 below for an example of BlueSky and Figure 9 for an example of BlueSkyRAINS.

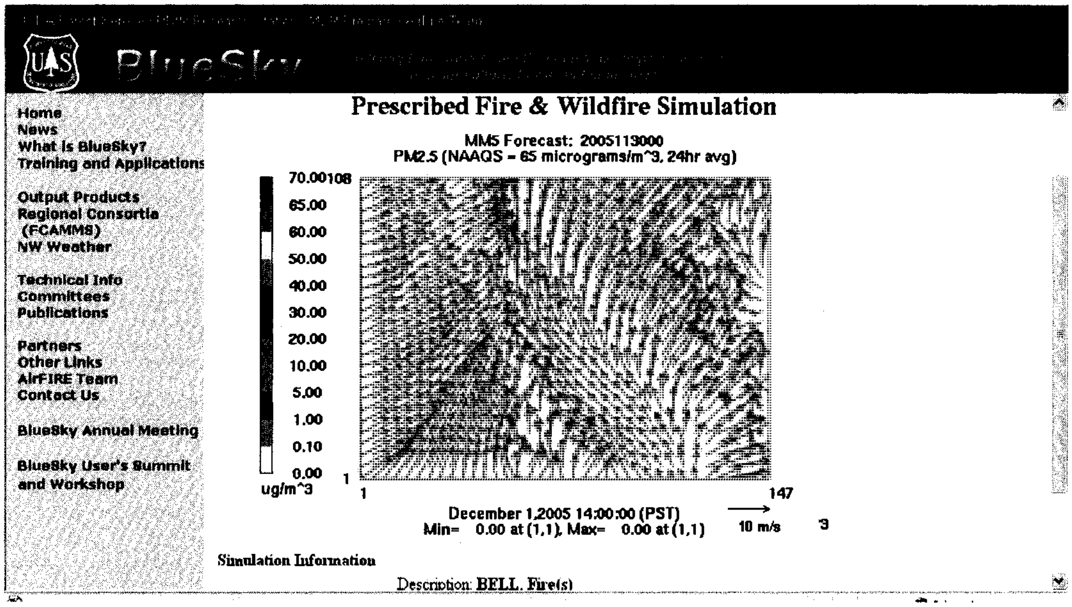

Figure 8. The BlueSky output for a simulated fire in California.

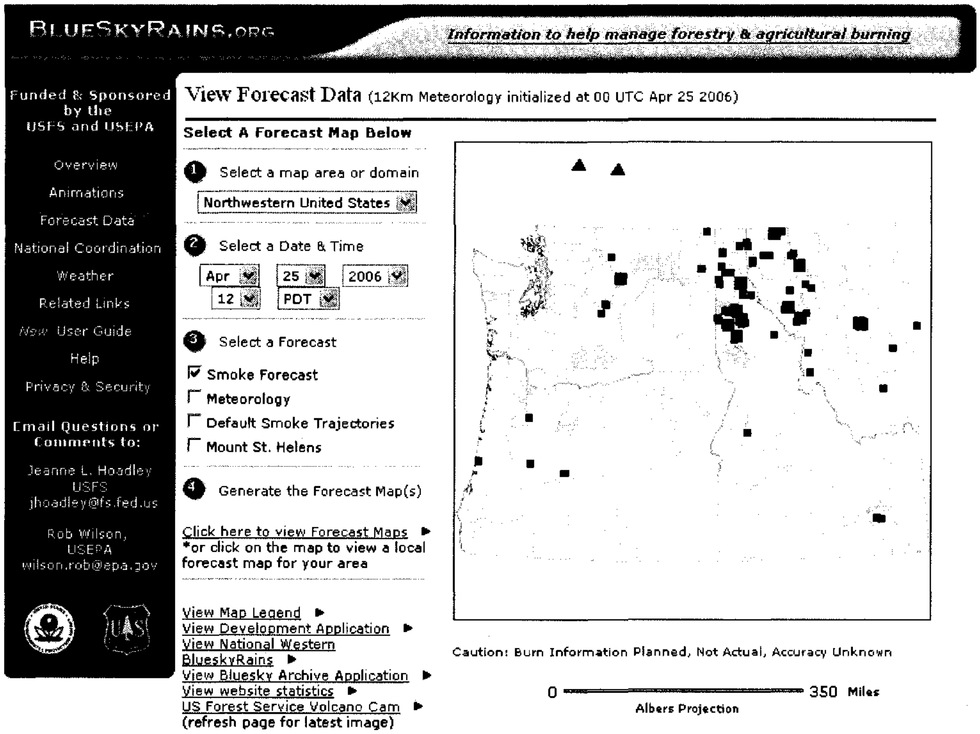

Figure 9. The BlueSkyRains.org graphical user interface.

CHAPTER 3

METHODOLOGY

In order to compare and display the differences of smoke dispersion between prescribed burning and wildfires there must be a means to measure impacts. The difficulty of understanding plume dispersion is due to the combination of variables in burning. In an attempt to understand the differing smoke impacts between wildfire and prescribed burning this research assumes that if all conditions (e.g., fuel moisture content, air temperature, relative humidity) are the same when a particular area is burned the consumption of fuel would be the same whether it's a wildfire or a prescribed burn. This provides a baseline rate of emissions related to the consumption of fuel under specific conditions. Therefore, for the purposes of this research the net emissions will also be equivalent between a wildfire and a prescribed burn if the acreage is the same for each. These assumptions help to limit the variables to the more pertinent concerns of frequency and atmospheric conditions when comparing the differences between wildfire and prescribed burning. The frequency is significant in that the total consumption of fuel from a single wildfire can be considered equivalent to several prescribed burns when burning the same area under the same fuel conditions. For the sake of this comparison, prescribed burning frequency can be based simply on the interval of fuel re-growth, with the understanding that this may not be entirely representative for all habitats. This baseline rate of consumption and emissions over time may be determined using a fuel consumption calculator like those described above. Once the baseline emission rate and frequency have been established the general atmospheric conditions can then be evaluated for each type of burn to determine potential smoke impacts using one of the dispersion models described above.

All of the fuel consumption models discussed here could be used with this methodology to study the impacts of smoke from prescribed burning and wildfires. The Emission Estimation System (EES) appears to be the most adequate fuel consumption model to estimate emissions from a test burn area. To understand these smoke impacts its necessary to determine the natural wildfire interval for the area to be studied and to establish a frequency for prescribed burning. When the frequency of emissions has been established the projected fuel load and the emissions data can be applied to a dispersion model to evaluate how the smoke will impact people in a prescribed burn condition and a wildfire scenario. The Hysplit model would be appropriate for this purpose as it is has been used for evaluating smoke dispersion in other applications, for example the oil well fires in Kuwait after the first Gulf War (Draxler 1994). Hysplit provides a means of evaluating downwind concentrations of a pollutant once the total mass of a released pollutant has been determined.

Model Use and Validation

While there are many individuals justifiably sensitive to the potential results of a fire, such as fear of wildfire, adverse health effects, or visibility reduction, for the purposes of this thesis the impact of emissions on humans will be viewed as elevated emissions above California's AAQS for PM10 (0.050 mg/m^3) projected by the dispersion model. This is appropriate because PM10 can be used as a surrogate for other pollutants that are released in a fire. PM10 is measurable and can be validated empirically by using a monitoring network. Once a total PM10 mass has been determined for a particular burn, the numbers can be evaluated with the Hysplit output of concentration factors over time to evaluate downwind concentrations.

The goal of this research is not to take the best and worst case scenarios for wildfire and prescribed burning (this would provide the obvious answer that a prescribed burn will have little impact on local populations when burning under ideal conditions that cause the smoke to rise above and leave an area vs. a wildfire that may have a low plume temperature and low lofting which would cause excessive smoke impacts on the local populace) but to evaluate whether the use of a combination of models can provide an understanding of the pollutant concentration differences between a prescribed burn condition and a wildfire condition by illustrating the relationship of atmospheric conditions, fuel consumption and the frequency of burning. To accomplish this the simulations were based on atmospheric conditions from actual prescribed fire and wildfire events in the study area.

In order to verify that the research question can be answered by using these models they must first be validated. To do this validation the model results were evaluated against data collected during a prescribed burn, which was conducted on October 24, 2003 at the former Ft. Ord Military Reservation located near Monterey, CA. The purpose of this prescribed burn was to remove vegetation from artillery ranges 43-48 (see Figure 10) in order to provide safe access to ordnance removal crews to remove unexploded ordnance from prior years of military training exercises. After these lands have been cleared of ordnance they will be handed over to local jurisdictions for development.

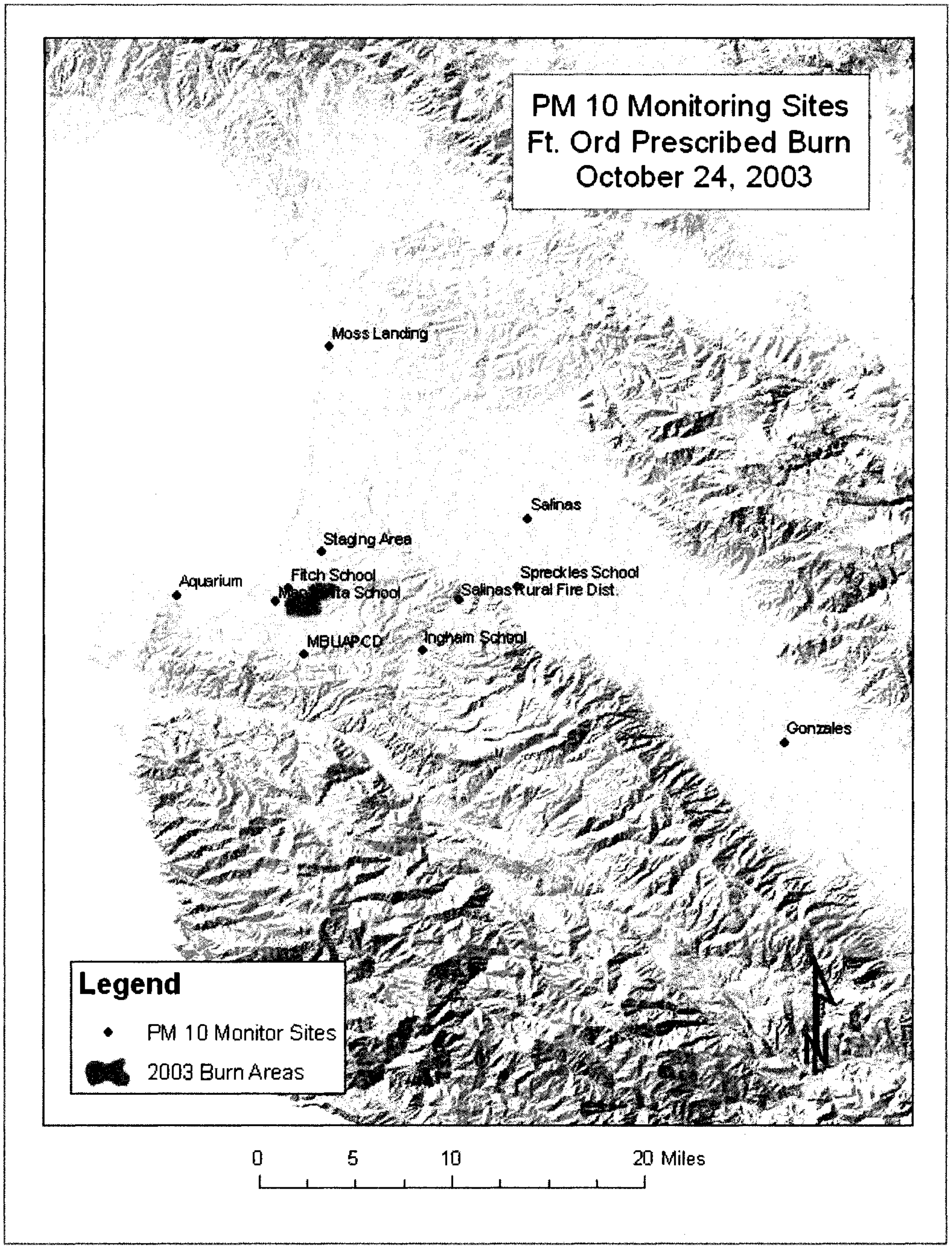

Figure 10. Ft. Ord Ranges 43-48 and PM10 sampling sites.

This prescribed burn was monitored extensively with PM10 monitoring equipment set up by the Monterey Bay Unified Air Pollution Control District (MBUAPCD) and the U.S. Army (see Figure 10 above for sampling locations). The monitors were set up to run for 24 hours at a time because the AAQS for PM10 is based on an average concentration over a 24-hour duration. The PM10 results for the sites are outlined below in Table 2 and displayed on the map in Figure 11.

Table 2

PM10 Results by monitoring site

Site_Number	Site_Desc	Latitude	Longitude	Elevation	PM10	PM2.5
PS-9	Aquarium	36.61793	-121.90187	10	70	
PS-1	Staging Area	36.64974	-121.79295	264	42	
PS-7	Spreckles School	36.62429	-121.64586	59	77.8	
PS-6	Salinas Rural Fire Dist.	36.61491	-121.68983	88	82.2	
PS-8	Ingham School	36.57610	-121.71723	328	92.8	61.2
PS-3	Manzanita School	36.61316	-121.82765	239	248	
PS-2	Fitch School	36.62254	-121.81818	321	100.6	80.8
PS-5	MBUAPCD	36.57276	-121.80537	247	68.3	
AMS	Moss Landing	36.80415	-121.78743	7	77.3	
AMS	Salinas	36.67534	-121.63915	48	56	
	Gonzales	36.50675	-121.44527	279	63.9	

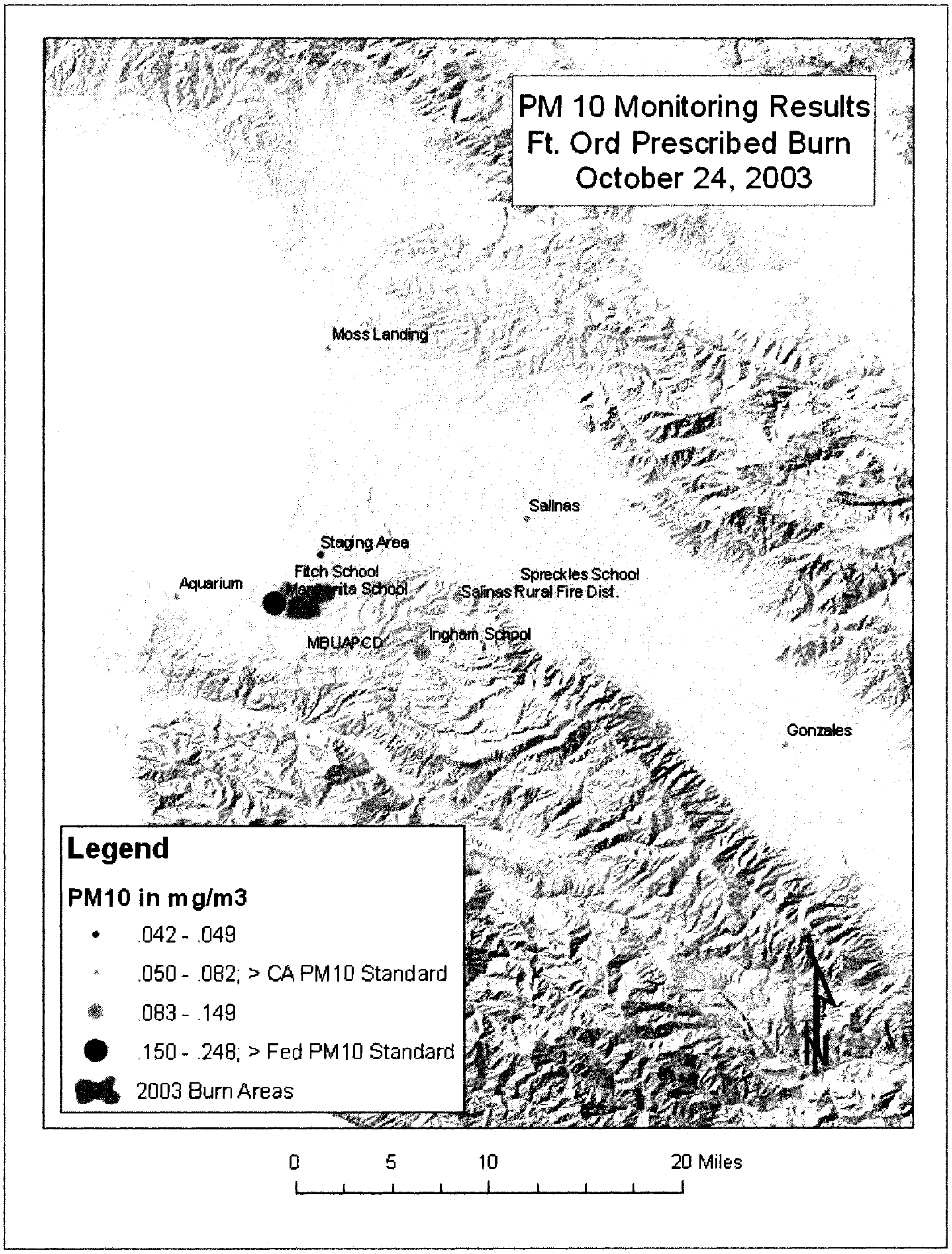

Figure 11. Map of PM10 results by site.

As discussed earlier in the methodology section the EES consumption model was used for the polygon identified as the burn area for Ranges 43-48. When running the model it became clear that the vegetation data layer was inadequate for this project as there was no fuel loading data for the portion of California around the former Ft. Ord (i.e. the model output zero fuel load and zero emissions). So, instead the next best alternative model that would suffice for this project was used: The First Order Fire Effects Model (see Figure 3 above). The former Ft. Ord ranges 43-48 consist of a combination of maritime chaparral and oak woodland. The closest vegetation type listed in FOFEM is ceanothus chaparral. The default settings were used for the fuel moisture content and flame temperature, etc. Results for the model can be found below in Table 3.

Table 3

FOFEM results for ceanothus chaparral

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TITLE: Results of FOFEM model execution on date: 3/8/2007

FUEL CONSUMPTION CALCULATIONS

Region: Pacific_West
Cover Type: SAF/SRM - SRM 208 - Ceanothus Mixed Chaparral
Fuel Type: Piles
Fuel Reference: PMS-833

FUEL CONSUMPTION TABLE

Fuel Component Name	Preburn Load (t/acre)	Consumed Load (t/acre)	Postburn Load (t/acre)	Percent Reduced (%)	Equation Reference Number	Moisture (%)
Litter	0.00	0.00	0.00	0.0	999	
Wood (0-1/4 inch)	0.00	0.00	0.00	0.0	999	
Wood (1/4-1 inch)	0.00	0.00	0.00	0.0	999	22.0
Wood (1-3 inch)	0.00	0.00	0.00	0.0	999	
Wood (3+ inch) Sound	0.00	0.00	0.00	0.0	999	40.0
3->6	0.00	0.00	0.00	0.0		
6->9	0.00	0.00	0.00	0.0		
9->20	0.00	0.00	0.00	0.0		
20->	0.00	0.00	0.00	0.0		
Wood (3+ inch) Rotten	0.00	0.00	0.00	0.0	999	40.0
3->6	0.00	0.00	0.00	0.0		
~~~~~~

6->9	0.00	0.00	0.00	0.0		
9->20	0.00	0.00	0.00	0.0		
20->	0.00	0.00	0.00	0.0		
Duff	0.00	0.00	0.00	0.0	17	130.0
Herbaceous	0.00	0.00	0.00	0.0	22	
Shrubs	38.70	30.96	7.74	80.0	231	
Crown foliage	0.00	0.00	0.00	0.0	37	
Crown branchwood	0.00	0.00	0.00	0.0	38	
Total Fuels	38.70	30.96	7.74	80.0		

FIRE EFFECTS ON FOREST FLOOR COMPONENTS

Duff Depth Consumed (in)	0.0	Equation: 0
Mineral Soil Exposed (%)	10.0	Equation: 18

Emissions -- lbs/acre

	flaming	smoldering	total
PM 10	190	0	190
PM 2.5	161	0	161
CH 4	49	0	49
CO	404	0	404
CO 2	110121	0	110121
NOX	198	0	198
SO2	62	0	62

	Consumption tons/acre	Duration hour:min:sec
Flaming:	30.96	00:01:00
Smoldering:	0.00	00:00:00
Total:	30.96	

After determining the fuel load the Hysplit dispersion model was run for October 24, 2003, the day of the prescribed burn. When using this model with archived meteorological data, there are several options for which meteorological model applies. Hysplit was run with the historical data using the Eta Data Assimilation System (EDAS) meteorological model, being that it was the most appropriate for this application. The EDAS data was downloaded from the NOAA Air Resources Laboratory (ARL) server and then the coordinates of a point within the burn polygon were applied. The resolution for the data stored on the ARL server for the EDAS meteorological data is 40 km every 3 hours beginning on January 1, 2004, however, prior to that date the resolution is 80 km. So the best resolution available for this simulation was 80 km. See the results of the model run below in Figure 12.

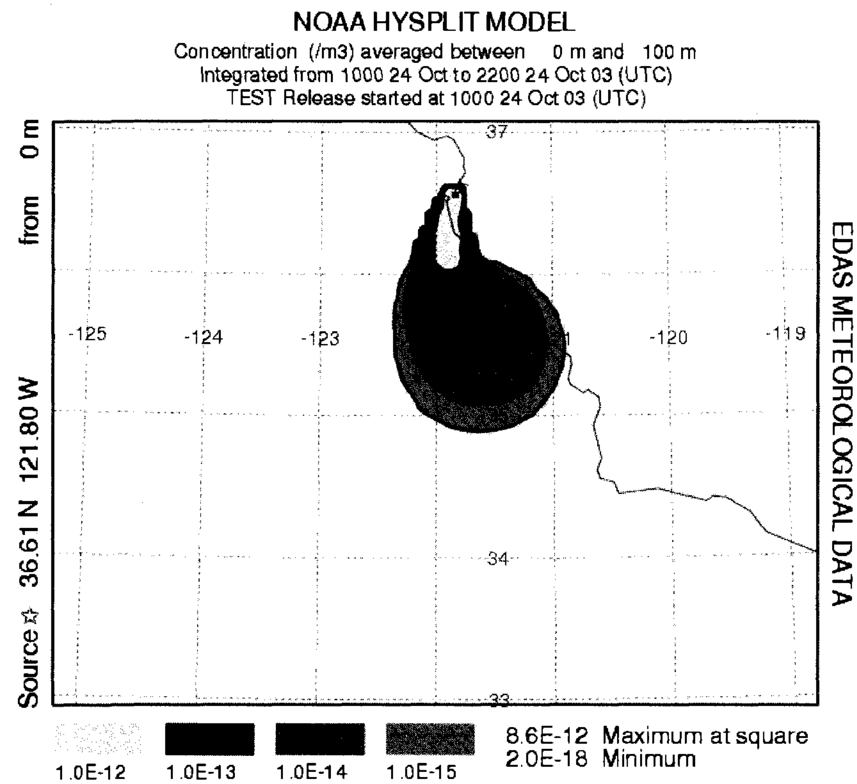

Figure 12. Results of Hysplit run for Ft. Ord for 10/24/03.

The model was run to cover a 24-hour period because the PM10 AAQS is averaged over 24 hours and because the PM10 monitors also ran for that duration. Note that the map heading in Figure 13 indicates that this was a 12-hour run between 1000-2400 hours when it was actually for a 24-hour duration. Running the model for 24 hours provides a different output than 12 hours, but the same header. The Hysplit model was also run as a trajectory in order to display the plume rise (see Figure 13 below). All models were run using the default settings unless where otherwise stated.

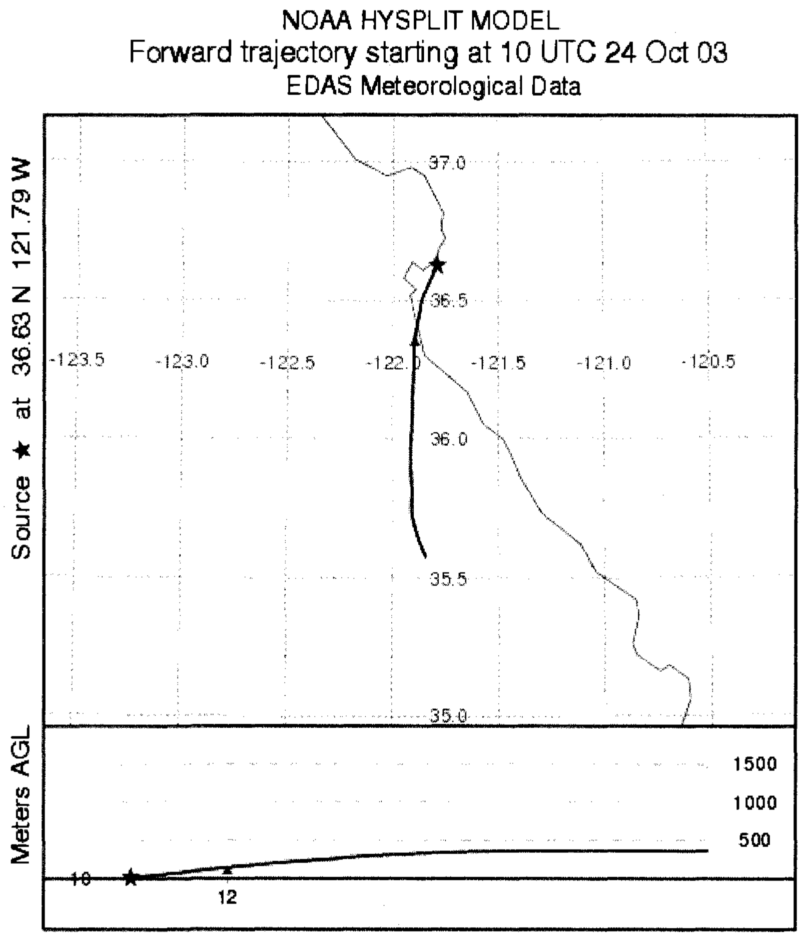

Figure 13. Horizontal and vertical trajectory of plume.

An advantage to using the Hysplit model is that the product polygon can be output as an ESRI shapefile and a Google Earth file. Applying the Google Earth file to this situation allows for an oblique perspective of the concentration isopleths. Figure 14 below displays the plume concentrations looking southwest.

Figure 14. Google Earth view of Hysplit output.

Exporting the Hysplit results as an ESRI shapefile is advantageous because the output can be added as a layer onto a map along with the monitoring sites and burn polygon. When this is done a perspective of the impact of the plume on the monitoring stations and the results of the monitoring can be displayed graphically (see Figure 15 below).

The next step in the methodology is to apply the output from the consumption model to the map display. The mass emission rate of 190 lbs./acre of PM10 released at the burn (results from FOFEM in Table 3 above) was applied to the total acreage from the burn polygon (1469.41 acres) and then the concentration from the model results was factored in using this simple formula:

$$A \times E \times Y \times F = C$$

Where:

A = Acreage of Burn Polygon
E = Emission Rate for PM10
Y = Conversion Factor
F = Concentration Factor
C = Concentration

The following are the calculation concentrations using the above formula:

1469.41 Acres **x** 190 lbs./acre **x** 453592.37mg/pound *(or 1.266E + 11)* **x**

2.0E – 18 = 0.0000002532 mg/m^3 (lowest of range at square)

8.6E – 12 = 1.08876 mg/m^3 (highest of range at square)

1.0E – 12 = 0.1266 mg/m^3

1.0E – 13 = 0.01266 mg/m^3

1.0E – 14 = 0.001266 mg/m^3

1.0E - 15 = 0.0001266 mg/m^3

The results of the combination of the monitoring sites, the Hysplit output isopleths and the projected concentrations are displayed in Figure 15.

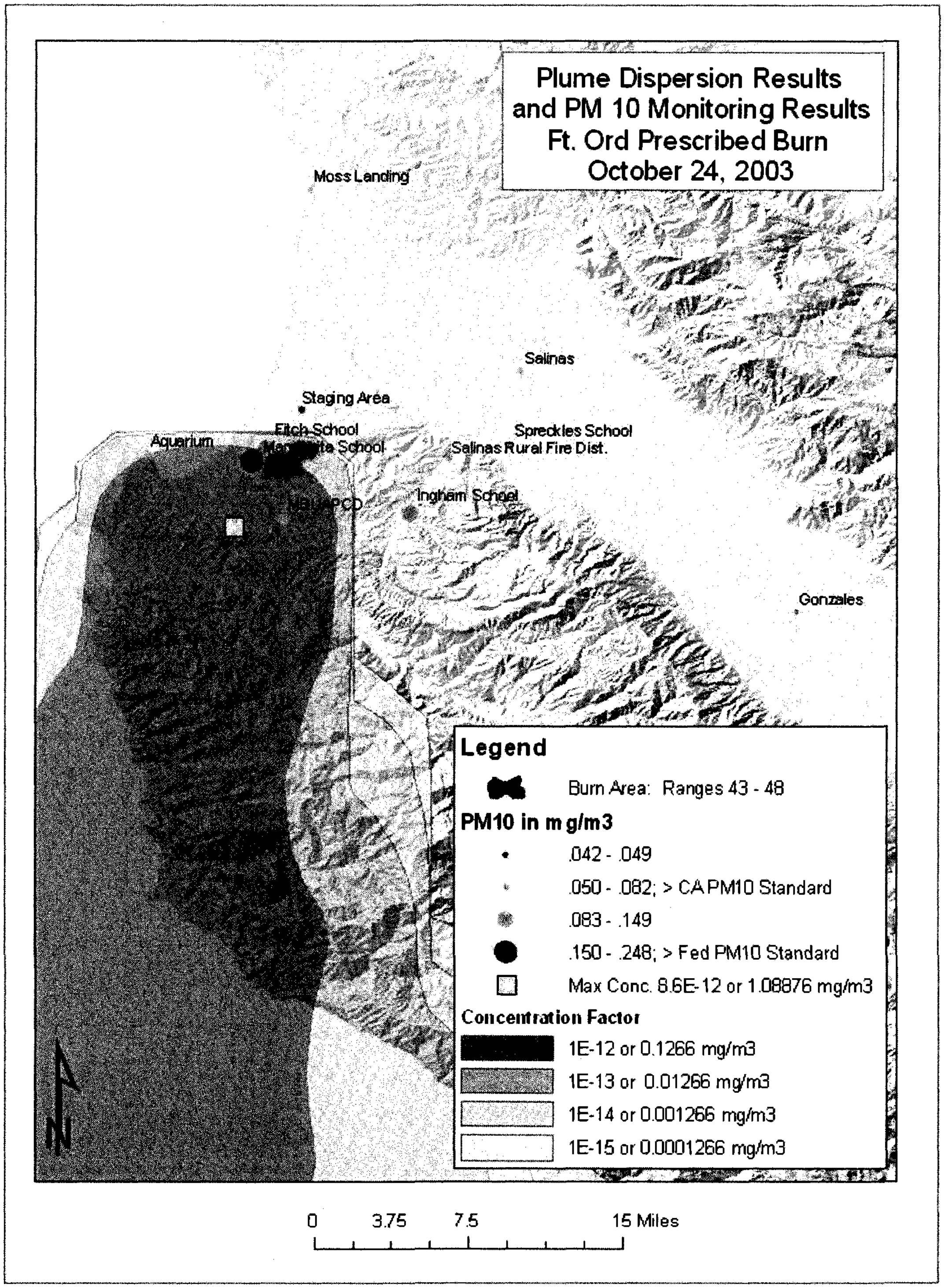

Figure 15. Burn polygon, monitoring sites, and plume shapefile.

When applying the consumption model to the dispersion model there appears to be only a rough correlation between the simulated output and the real world results from the monitoring stations. It's difficult to determine because the resolution of the Hysplit model results are low and the scale of the results is much smaller and almost too rough to compare to the relatively close proximity of the monitors to the burn. Of the eleven monitoring sites, seven lie outside of the simulated plume and four within. Of the four sites within the simulated plume concentrations, two are the highest of all of the readings and two are similar to those outside of the plume. The concentration suggested by the model at the maximum location (1.08876 mg/m^3) based on the fuel load from the consumption model is four times greater than the results of the highest PM10 monitor reading of 0.248 mg/m^3. The monitor site to the north and upwind of the burn polygon is the lowest reading. There also seems to be some limitation in the extent of the dispersal of smoke where there were some elevated readings outside of the simulated plume concentration distribution. Its important to make the distinction here that the displayed concentration isopleths do not show the entire distribution of the plume over 24 hours only the concentration distribution based on the atmospheric conditions for that 24 hour period. The isopleths indicate the concentration over 24 hours, not a snapshot of the plume at any given time. The sites outside of the plume were relatively low with the exception of the Ingham School site, which may be due to the 80 km resolution of the atmospheric model. According to the developers of this model, it is difficult to interpolate concentrations between the isopleths delineating concentration because the concentration change is not linear between them. The comparison of the model to real world results indicates that there are limitations in the validation of the model on the scale monitored. If more monitoring had been done at a wider range and/or if the meteorological data had a higher resolution there might be more of a correlation between the model output and the monitored concentrations.

As for the dispersion model's ability to simulate a plume's graphical dispersion characteristics, observe the comparison of the plume to a satellite image of California at the time of the burn (see Figure 16 below).

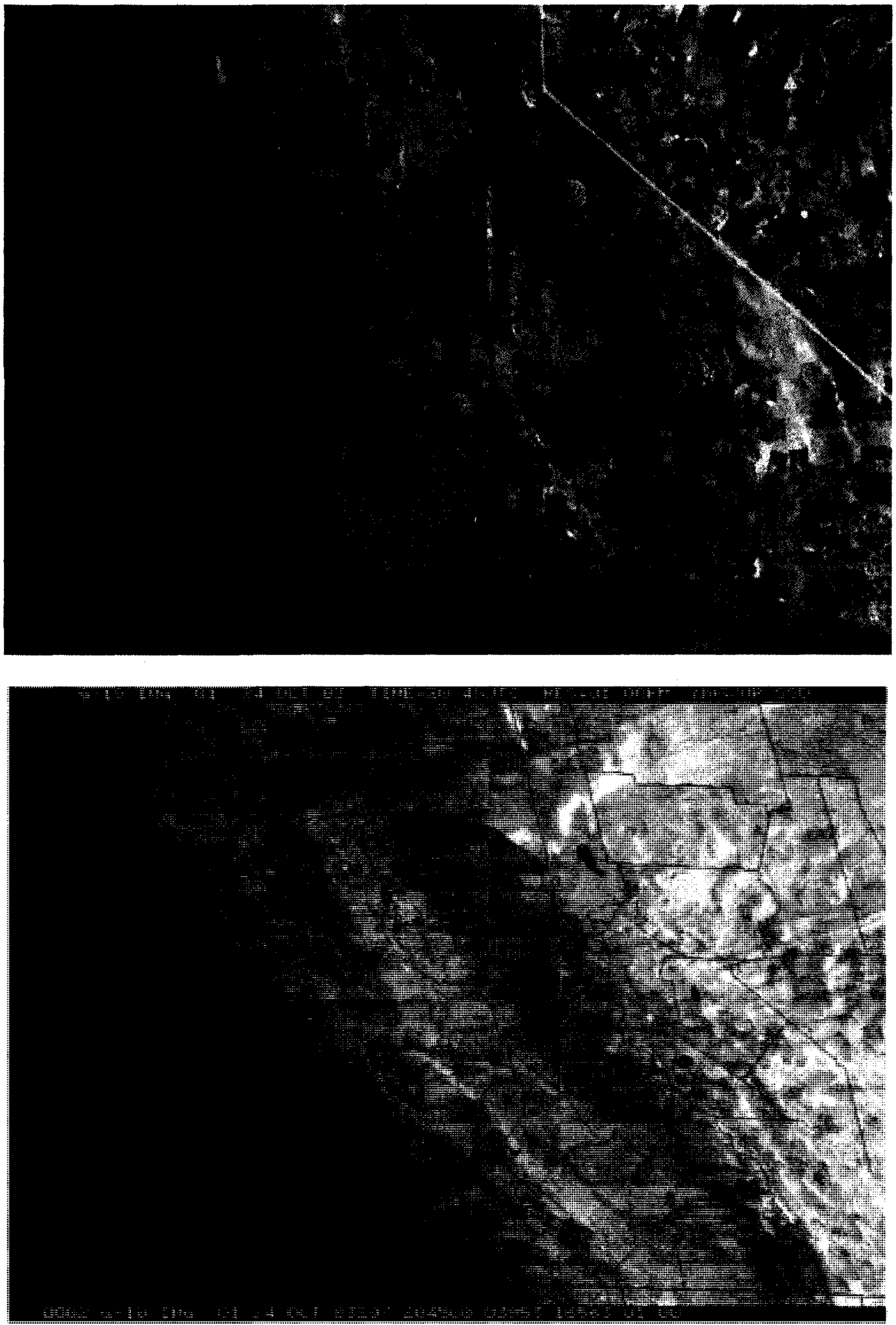

Figure 16. Hysplit plume dispersion characteristics represented on Google Earth compared to a satellite image of the actual burn.

This comparison is for illustrative purposes only because the plume dispersion representation is for the concentrations over a 24-hour period whereas the satellite image is only a snapshot at 1:00 p.m. on October 24, 2003.

The comparison of the modeled emission concentrations with the results of the monitoring combined with the physical observation of the satellite image suggests that this modeling method is only a rough tool for comparing wildfire vs. prescribed fire impacts both qualitatively and quantitatively because the model does not represent the full extent of the smoke distribution. There is still some value in continuing with the comparison of a prescribed burn to a wildfire condition because refinements on the emission rates for the specific fuels, a more sophisticated approach to running the Hysplit model, and a higher resolution meteorological model may improve the correlation of the monitoring results to the modeled concentration.

Applying the Methodology

So with the model roughly validated, the methodology can be applied to a hypothetical wildfire condition on the same ranges. For the atmospheric conditions representing a wildfire the same data was used for the day on which a wildfire occurred nearby that same year on July 17, 2003. Following the procedure in the methodology the same fuel conditions for the simulated wildfire were used as those used for the prescribed burn in the model validation so that the two could be compared with the same rate of PM10 release. It is necessary to assume a consistent emission rate for the purpose of comparison, although, its more likely that the emission rate would change during differing conditions, for example, there would be lower total emissions released during cooler conditions with higher moisture content than might be expected with a prescribed burn. Running Hysplit for a 24-hour period with the atmospheric conditions represented in the wildfire shows an extensive regional distribution. See graphical characteristics of the plume below in Figure 17.

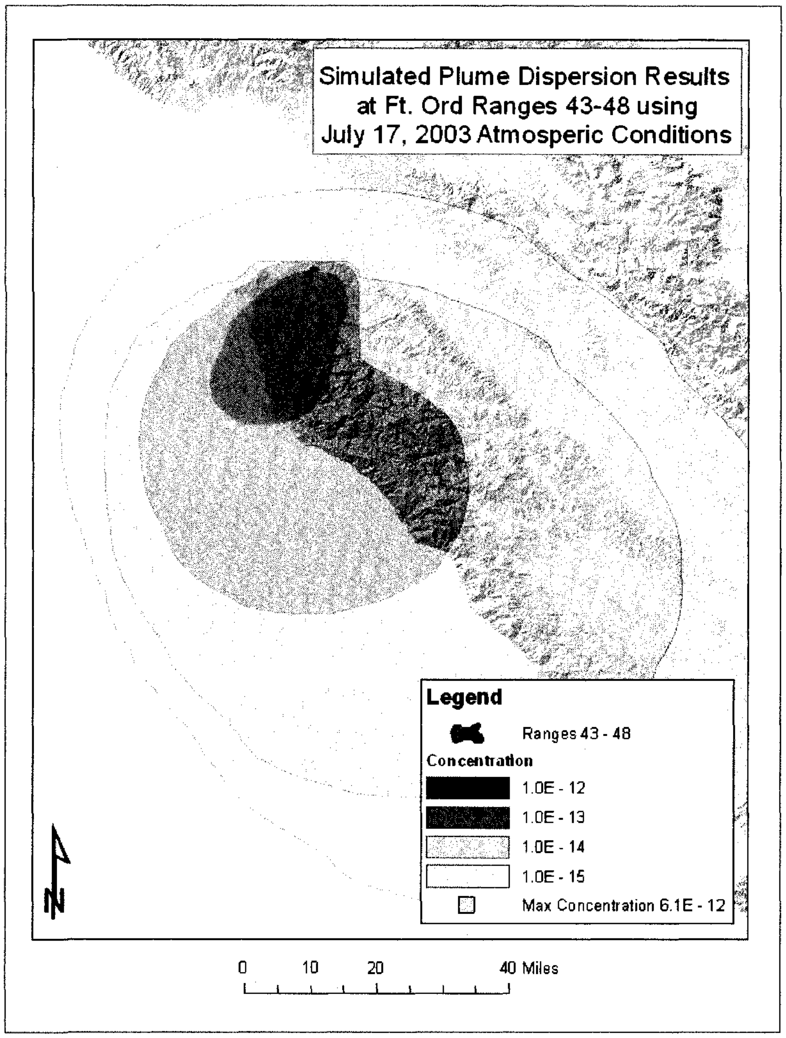

Figure 17. Representation of average plume concentrations for July 17, 2003.

The final piece to the methodology is to consider the fuel loading depending on fire return frequency. Frequency of fire return in maritime chaparral is anywhere between 10 to 100 years (Van Dyke, Holl & Griffin, 2001). Determining fuel loading based on the last time a fire rolled through a given area likely depends on many variables such as drought conditions, annual rainfall, etc. Its safe to assume, though, that the fuel loading will change due to vegetation growth every year since the last time the area burned. If a fire manager believes that an area needs to be burned every 30 years the impacts can be limited by selecting optimal forecasted atmospheric conditions. Considering that a wildfire may occur as rarely as once in every four generations, increasing the frequency will cause increased smoke impacts on more generations regardless of the atmospheric conditions. But will that concentration exceed the ambient PM10 standards with the expected lower fuel loading? Can the assumption be made that there are lower downwind concentrations of smoke in a prescribed burn with increased fire frequency?

Frequency of fire return is an important consideration for the land manager due to the aggressive suppression of fire over the past century. Especially when considering that a habitat may be defined by the frequency of fire return. If fire is removed from a shrub land for too long it can be taken over by other species, for example, transitioning from chaparral to oak woodland (Van Dyke, Holl & Griffin, 2001). Conversely, if fire is introduced too frequently, the seed bank may not be maintained (Odion & Tyler, 2002). One of the main goals of a prescribed burn is to simulate the natural rate of fire return in order to maintain the existing habitat; otherwise a different habitat may result. For the purpose of comparison the growth rate was considered to be linear, with the recognition that in reality the growth rate for the vegetation may change as it reaches maturity.

Unfortunately, the fuel models surveyed here are unable to provide an estimation of increased fuel loading over time since the last burn in a given area. In order to effectively compare emissions from prescribed burning vs. wildfire a fire return frequency of 90 years was considered for wildfires and split into thirds for a prescribed burn frequency of 30 years. The numbers were then plugged into the models for the differing burns. So, for the wildfire condition the same emission output results were used as in the validation and the prescribed burn condition was 1/3 of the concentration output. This comparison between wildfire vs. prescribed burn results using the methodology is best seen graphically (see Figure 18 below).

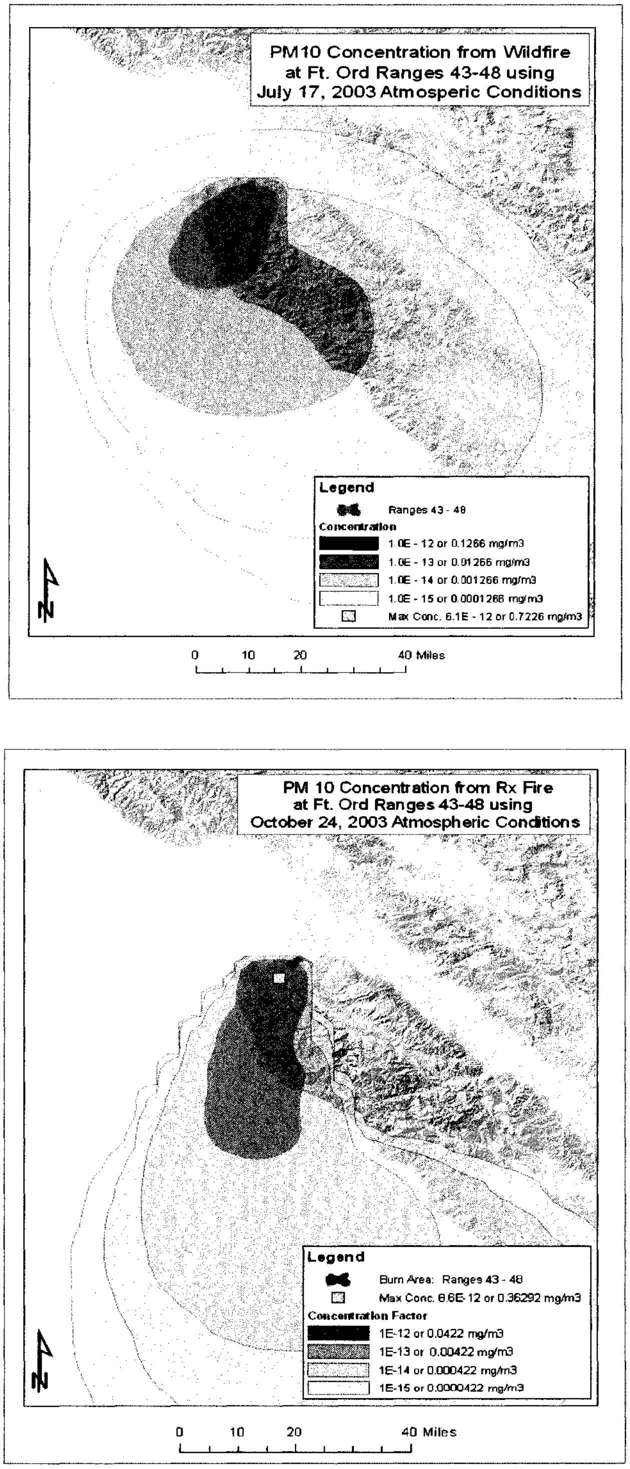

Figure 18. Comparison of PM10 concentrations between a wildfire and a prescribed burn.

The maximum concentration estimated by the model indicates 0.363 mg/m^3 for the prescribed burn and 0.723 mg/m^3 for the wildfire, which are both greater than 0.050 mg/m^3 indicating a significant downwind concentration for each. The isopleth closest to the burn site indicates expected concentrations to be higher than 0.050 mg/m^3 for the wildfire; however, we can expect to see the PM10 concentration drop below the standard for the prescribed burn (although only to 0.042 mg/m$^{3)}$ by the first isopleth. The wildfire concentrations can be expected to drop below the standard somewhere between the first and second isopleths. In the prescribed burn illustration the shape of the first isopleth extends to a far greater extent than for the wildfire. Even with 1/3 of the emission rate, the concentration above 0.050 mg/m^3 from a prescribed burn may extend to a greater distance than a wildfire. While this comparison illustrates that the downwind smoke from a wildfire may be experienced over a broader area than the prescribed burn, its not clear that the wildfire has a more extensive distribution of downwind PM10 concentration above 0.050 mg/m^3 than the prescribed burn.

The Methodology as a Tool

While the combination of models works by and large for illustrative purposes, this methodology may also be effective as a tool to help land managers reduce smoke impacts on local populations. The October 24, 2003 burn described above was initially planned as a prescribed burn. Unfortunately, this burn slopped over the control lines and became a wildfire. Once this occurred the smoke significantly affected the local community. As can be seen from the Range 43-48 fire (see Figure 19 below) the smaller size and fuel loading of the area meant to be a prescribed burn may have been adequate to reduce the concentrations to tolerable levels for people downwind of the burn. It was asserted by the land managers at the time that the smoke impact became significant only when the prescribed burn transitioned to a larger wildfire. But is this true?

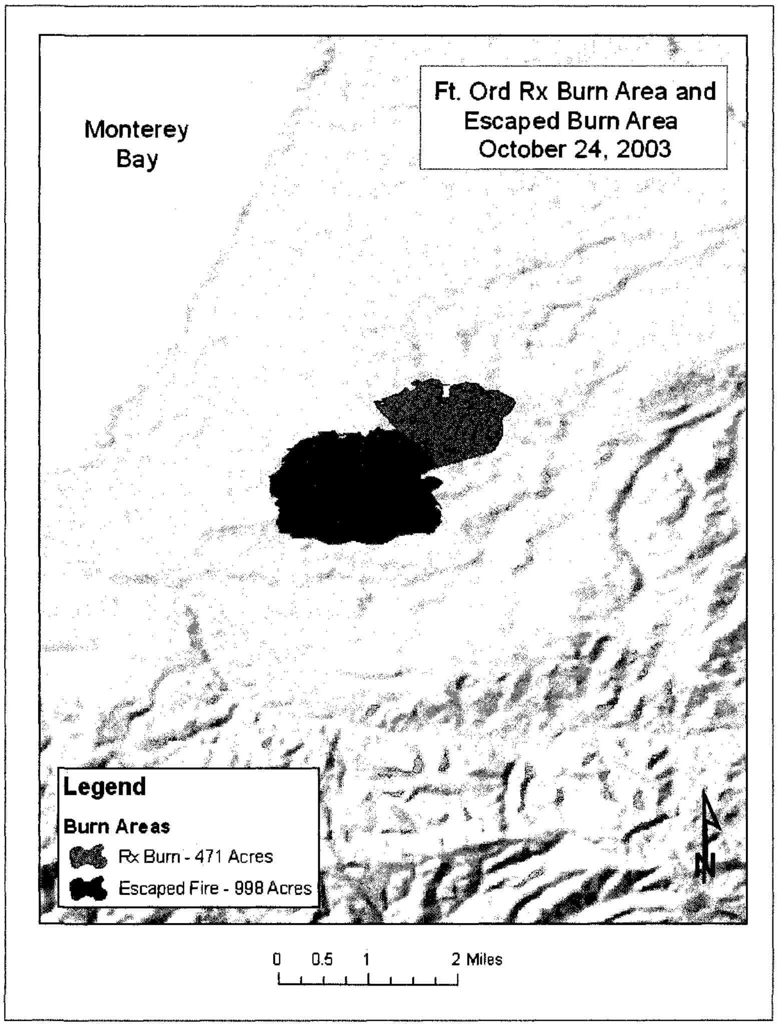

Figure 19. Area of intended burn vs. wildfire area.

Considering that an increase in an area being burned increases the amount of fuel consumed and emissions released, the downwind impacts can potentially be limited by planning for an optimal sized burn area based on the fuel load per acre by using forecasted wind data with the combination of the models. This can be done by using the factors in the Hysplit model to estimate the concentration of PM10 in the forecast data prior to a burn and then limiting the size of the burn relative to the modeled PM10 concentration based on the forecast data and the fuel loading of the habitat type where the burning is to be done.

The smoke impacts from a particular burn can be determined by the optimal acreage based on the highest acceptable downwind concentration of PM10 because it's possible to discern that downwind PM10 impacts correlate directly as a result of the fuel loading and acreage of a burn. In the October 24, 2003 prescribed fire the amount of acreage intended to burn was 471 acres. When the fire slopped over the prescribed area another 998 acres were burned or an additional 189,620 lbs. of PM10 were released. The original 471 acres to be burned would have emitted 89,490 lbs. (These numbers are based on the FOFEM fuel consumption model results of 190 lbs./acre of PM10 used in the validation above). To illustrate the differences in projected downwind PM10 impacts the same formula that was used above is solved for on optimal concentration of 0.050 mg/m^3:

$$\text{Acreage} \times \text{Emission Rate} \times \text{Conversion Factor} \times \text{Max Conc. Factor} = 0.050 \text{ mg/m}^3$$

For example by using the conditions of the prescribed burn noted above for October 24, 2003 the maximum acreage that could be burned to reduce downwind impacts to below the PM10 standard would be:

$$\text{Acreage} \times \text{lbs/Acre} \times 453592.37\text{mg/lbs} \times \text{Max Concentration} = 0.050\ \text{mg/m}^3$$
$$\text{Acreage} \times 190 \times 453592.37 \times 8.6\text{E-}12 = .050\ \text{mg/m}^3$$
$$\text{Acreage} = 0.050/0.00074116993258$$
$$\text{Acreage} = 67.5\ \text{Acres}$$

By this estimation even if only the intended amount of 471 acres had been burned there still would have been downwind concentrations exceeding 0.050 mg/m^3. The size of the burn based on the estimated fuel loading was about seven times larger than it should have been given the atmospheric conditions in which the burn was conducted. Regardless of the fire jumping the lines this prescribed burn would have caused downwind impacts greater than the California's ambient standard for PM10. The advantage of using this methodology for a land manager may be seen when applying the forecasted atmospheric conditions to the size of the burn. A prescribed burn may be allowable if the size of the burn could be adjusted to fit the potential downwind concentration to avoid excessive impacts on the local communities.

CHAPTER 4

CONCLUSION

The argument made by some land managers that wildfires could have much larger smoke impacts than prescribed burns is based on observations where it is difficult at best to compare. Wildfires can burn in poor conditions for smoke dispersal and tend to burn a great deal more vegetation than prescribed burns. Sometimes, wildfires burn for weeks while most prescribed burns are generally burned over one day. On the other hand there are many documented instances of prescribed burns that have caused smoke to impact populated areas. The results of this research suggests that while a prescribed burn releases less PM10 and the smoke dispersion may be more confined, the concentration of PM10 is affected by more than just attempting to burn on days when the atmospheric conditions are favorable. Planning a prescribed burn around smoke management issues must also take into consideration the fuel loading of the habitat and the acreage as well.

The overall assessment in this research was limited by several factors. Wildland burning is an extremely complex process that occurs within dynamic systems. For the sake of comparison and consistency the problem is not approached here with a more complex use of the Hysplit dispersion model such as adjusting the model for vertical plume rise based on temperature. For this variable the model was able to accomplish the task of simulating vertical dispersion using the vertical component of the meteorological model. Also, the fuel consumption model was not tweaked to display results that were closer to the reality of the fuel loading for the area evaluated. It's possible that the concentrations estimated by this modeling process can be made more precise for smoke dispersion by fine-tuning the models based on a more localized knowledge of the atmospheric conditions, the varying habitat and the terrain. The duration of the burn, the ignition process, the temperature of the fire, the phases of the burn, were also not addressed here. Consideration of these aspects would refine the data input quality of the models and may lead to better accuracy when evaluating the potential impacts of future burns using this methodology as a tool for estimating the size of a prescribed burn. It's likely that these models can work better as a tool if the evaluator knows the conditions well and has feedback on the results of a modeled burn. Increased air monitoring and a comparison of these results with the models will make the process more effective so that the models can be tuned to be more representative of the real conditions.

There were some problematic discrepancies that limit the functionality of both the consumption and dispersion models in this application. The fire consumption models need to be more representative of what is happening on the ground. For example the accuracy of the PM10 concentrations can be further increased by refinements of the vegetation type and seasonal fuel calculations. Another problem was encountered when the EES calculator failed to provide an accurate assessment of the vegetation for the area to be burned because the data did not exist. FOFEM had to be used instead to evaluate the potential emissions of PM10. FOFEM was limited in that the output was consistently one emission rate for all seasons and all conditions of weather and fuel (moisture content, dead fuel, etc.) and there was no input variable taking into consideration the age of the fuel. The Hysplit dispersion model worked well for this application however it was limited by the resolution of the meteorological model available for the fires evaluated here.

In spite of these limitations the distinctions between smoke impacts from wildfires and prescribed burns could be examined and illustrated using the methodology and available models. The results suggest that the smoke impacts of a wildfire may not be any greater than a prescribed burn when compared using the methodology. This research demonstrates how a combination of the fuel load and the size of the burn may be more significant in controlling downwind concentration of PM10 than the atmospheric conditions. Even when there is a planned burn under prescribed meteorological conditions there can be significant impacts if the size of the burn and fuel loading are not also considered.

Smoke management is only one of many issues to address when considering prescribed fire as an option for managing wildlands. But land managers, policy makers and affected communities must evaluate prescribed burning relative to the effects of smoke on the local population. An effective prescribed burn program should consider whether the risk of smoke impacts on local populations from prescribed burns is balanced by the rewards of managing wildlands with fire: habitat preservation, fire hazard reduction, ordnance removal, increased species diversity, increased grazing land, etc. Using the methodology described here may be useful in understanding the impacts of smoke on local populations in light of prescribed fire's benefits.

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