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Smoke Management in the Willamette Valley

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Western Region

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NATIONAL WEATHER SERVICE

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SMOKE MANAGEMENT IN THE WILLAMETTE VALLEY

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WESTERN REGION
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TABLE OF CONTENTS

I. PRINCIPLES OF SMOKE MANAGEMENT

The cultural practice of open-field burning can produce significant contaminants with particulates from smoke generally accepted as the most important. Air quality associated with open-field burning can probably be managed, for a prescribed acreage, well enough to maintain acceptable standards of air quality. The definition of air quality is usually based on the needs and uses within an air basin. Also, the term, "air quality management", has been used to list current efforts for the abatement of existing pollution and the prevention of future pollution. The objective of a management approach is to provide an atmosphere of acceptable air quality. Air quality is usually fixed by law and stated as a given maximum value. Because the standard is a fixed value, it can be treated as a constant, and a model for management of this quality can be expressed as:

$$\text{Air Quality} = \frac{\text{Pollution Source Strength}}{\text{F(Meteorological Conditions)}}$$

Source strength is the acreage to be burned, and it can be managed or varied from day to day. Meteorological conditions cannot be managed, but they can be measured and they can be predicted for a future period of several hours with a reasonable degree of success.

Meteorological conditions can be said to define the "size of the container" into which smoke is dispersed. As meteorological conditions become "good", i.e., buoyancy and air transport increase, the container gets larger. Or, as source strength increases, meteorological conditions being constant, air quality must become smaller (poorer). It can thus be seen that air quality is a function of meteorological conditions. (Air loading by particulate, if a source exists, is inversely proportional to the function of meteorological conditions.) The management problem is to predict each day of the agricultural field burning season the source strength (i.e., acreage) which can be tolerated under prevailing meteorological conditions, maintaining air quality above the legally prescribed standards.

A useful measure of air quality is visibility. It is a long-standing practice in the National Weather Service to report obstructions to visibility when the visibility is 6 miles or less. Air which is so transparent that visibility is 7 miles or more is such that obstructions to these large visibility values are of no significance.

II. CLIMATOLOGICAL CONSIDERATIONS

Certain knowledge of the late summer climate in the Willamette Valley helps in deciding what meteorological factors to use in a management decision and how to apply the method derived. Two important meteorological variables necessary to make estimates of transport and dispersion are wind and thermal stability of the atmosphere. The mean wind serves as the horizontal transport of the pollutant from the source to the receptor, and deviations from the mean wind account for the horizontal or cross-wind spread of the air-borne material. The importance of the vertical distribution of temperature is its effect on vertical motion and mixing as indicated by the vertical mixing potential of each type of thermal stability. The mixing depth, determined by the thickness of a layer of unstable air, will determine the volume of the atmosphere available for dispersion and dilution.

The effective depth of the valley is equal to a height to which smoke can be lifted and dispersed by atmospheric dynamics. The mixing depth as meteorologically defined can be determined routinely from an adiabatic diagram, and it might be expected that this represents the effective depth of the valley. This evidently is not always the case since studies have not always shown significant correlation between mixing depth and atmospheric visibility. On nine mornings out of ten an inversion near 3000 feet or lower occurs in the July-August-September period and over half of these persist into the afternoon. Study of pollution (smoke) management by Bates and Chilcote (1970) indicates that large-scale field burning as practiced today is overloading the air on a number of days. This research also reveals that poor visibility, due to smoke, runs in periods of three to five days. For example, if visibility is reduced to one mile by smoke on one day, it is likely to remain low--no more than 6 miles--for the next two days. It appears from the study that burning 5000 acres of field residue could overburden the air on certain days with poor dispersal characteristics. The climatology of the Willamette Valley indicates that, at optimum ventilation conditions, burning should be held to no more than 10,000 acres on nearly all days.

Bates and Chilcote (1970) developed a method for predicting maximum acreage to be burned consistent with good air quality in the southern Willamette Valley, based upon meteorological conditions of the day. Research shows that there is a direct relationship between atmospheric instability near 3000 feet and visibility in the southern Willamette Valley. A temperature decrease of $4^{o}C$. ($7^{o}F$.) or more is required in the region between 3000 feet to 6000 feet over the valley to get sufficient vertical motion to disperse the smoke from the lower atmosphere of the valley when more than 6000 or 7000 acres are burned in one day. The air in the lowest 3000 feet is brought to a dry adiabatic lapse condition (approximately $3^{o}C$ or $5.4^{o}F$ per 1000 feet) on nearly all days of the field burning season by solar heating. It appears from this study that the condition of instability (temperature decrease of $4^{o}C$ or more between 3000 to 6000 feet aloft) occurs less than half of the time in the field burning season.

Field burning usually begins near July 15. Rainfall climatology shows that there is 55% probability of getting at least .06 inches of rain in the week beginning September 20. This high probability of rain indicates a time when field burning probably should end. Therefore, a 60- to 65-day period is a normal period to expect suitable weather for open field burning in the Willamette Valley. At the same time, sufficient instability aloft for good smoke dispersal can only be expected a little less than half of this time or about 25 to 30 days. On this basis, and assuming that burning would be restricted to 4000 acres, it would be possible to burn around 100,000 acres in a normal year in the Willamette Valley. This is well below the 7000 acres per day, which have been burned without noticeable problems when near optimum atmospheric conditions of wind and instability were present.

III. FURTHER INVESTIGATION

During 1969 more data on fields burned was collected and studied. Bates, Chilcote and Hartmann (1972) made extensive investigations of the smoke management problem by making use of the principle as earlier stated:

$$\text{Air Quality} = \frac{\text{Pollution Source Strength}}{\text{F(Meteorological Conditions)}}$$

For a measure of air quality, visibility was used and with a value of visibility $\geq$ 10 miles, air quality was considered satisfactory; thus we could say:

$$V = \frac{A}{F(M)}$$

Where: V is visibility
A is acreage burned
F(M) is a combination of meteorological variables.

The preliminary work done by Bates and Chilcote (1970) considered only the southern Willamette Valley. The 1972 study considered the entire valley, and predictive equations for the two centers of population, Salem and Eugene, were developed.

Two Models

In the Willamette Valley wind speed and shear seem to be effective in plume rise and pollution transport problems. Panofsky and Prasad (1967) indicate the fluctuations in concentrations in pollution are fairly well explained by wind speed and vertical velocity. In their case, wind direction was only important on special occasions. This also seems to be generally true in the Willamette Valley.

Salem is centrally located in the valley and is surrounded by burning for many miles both up and down the valley. Wind speed at both surface and aloft are important for this community. Stability through the first 3000 feet shows a relationship to pollution concentration.

The wind direction appears to have some influence on the concentration of smoke in the Eugene vicinity. This is probably because nearly all agricultural burning at this season lies down valley from that city. Surface wind speed is an influencing factor; but aloft, at 5000 feet, the direction is of greatest importance. Stability between about 6000 and 10,000 feet has a relatively strong influence in this south valley location.

Bates, Chilcote and Hartmann (1972) stated: "Using a step-wise discriminant analysis for two groups, a model of the form $D(X)=F(m)+C$ was developed where $F(m)$ is the function of acreage burned plus eight meteorological variables. If $D(X) > 0$, we classify the day into the group of low visibility; that is, a day with visibility under 10 miles. If $D(X) \leq 0$, the day is classified into the group of high visibility--10 miles or greater. The discriminant is set equal to zero and the solution to the resulting equation, after substituting the meteorological variables, yields an acreage that can be burned in one day consistent with good air quality in the Willamette Valley.

"The general form of the equation for Eugene is:

$$\text{South Zone Acreage} = \{(+ .2583X_1 + .4248X_2 + .0130X_3 - .08756X_4 - .1687X_5 + .009952X_6 + 42563X_7 + .25436X_8) \times .00010508\}^{-1}\ 48.6$$

Where: X_1 = 1000 mb to 900 mb temperature change in degrees C.

X_2 = 800 mb to 700 mb temperature change in degrees C.

X_3 = expected Max. temperature "today" (in degrees C).

X_4 = surface wind speed (in knots).

X_5 = cosine 5000 ft wind direction.

X_6 = temperature advection.

X_7 = visibility at Eugene airport (in statute miles).

X_8 = previous day's lowest visibility (in statute miles).

"The X_6 advection term is the thermal wind, $\vec{V}th$, (5000 ft. wind minus 1000 ft. wind) multiplied by the magnitude of the component of the 5000 ft. wind normal to $\vec{V}th$. If the 5000 ft. wind component is normal to the left side of $\vec{V}th$, the term is negative; but if it is normal to the right side of $\vec{V}th$, the term is positive. This equation developed on 1969 data was tested on independent meteorological and acreage data for 1970. The test results show an ability to predict acreages in the South zone consistent with Eugene visibility of 10 miles or more 80% of the time.

The general form of the equation for Salem is:

$$\text{North Zone Acreage} = \{(- .31208X_1 + .02202X_2 - .03546X_3 + .06742X_4 - .13206X_5 - .0762X_6 + .18459X_7 + .01518X_8) \times .0005742^{-1}\} + 1.209$$

Where: X_1 = 1000 mb to 900 mb temperature change in degrees C.

X_2 = 800 mb to 700 mb temperature change in degrees C.

X_3 = low relative humidity.

X_4 = pressure gradient direction x 7 a.m. visibility.

X_5 = surface wind speed (in knots).

X_6 = lagged 5000 ft. winds (in knots).

X_7 = 7 a.m. visibility (in statute miles) at Salem airport.

X_8 = previous day's lowest visibility (in statute miles).

The X_3 term is the relative humidity at the next measured point in the radiosonde observation below the top of the inversion. The X_6 term is the 5000 ft. wind speed from the observation 12 hours previous. The equation developed on 1969 data was tested in independent 1970 data. Test results showed an ability to predict acreages in the North zone consistent with a visibility of 10 miles or greater at the Salem airport 88% of the time."

IV. SUMMARY

There seems to be evidence that the number of acres of field residue which can be burned in the Willamette Valley on a given day without overburdening the air can be predicted. Climatology of the valley indicates that by making proper use of the predictive equations, management of smoke from field burning is possible. One hundred thousand acres of burning seems to be a reasonable estimate of what can be well-managed in one season.

V. ACKNOWLEDGMENT

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