Determination of the Emission Factor for Cattle Feedyards by Applied Dispersion Modeling

by
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Introduction

Environmental quality is a major public concern, whether it be water or air quality or contaminated soil. Upon implementation of the amended Federal Clean Air Act (FCAA) and the anticipated increase in the resources of state air pollution regulatory agencies, regulation of air quality will expand to segments of the agricultural production and processing industries. In the 1970's, the California Cattle Feeders Association wanted more specific information on the dust emitted from a cattle feedyard to address the environmental issues of impact, urban encroachment, inspection fees, and possible human and animal health implications. Inspection fees were beginning to be assessed for cattle feedyards with the potential for particulate emissions, however, the cattle industry did not have sufficient technical information on dust emissions. These questions and concerns led the California Cattle Feeders Association to fund research on controlling feedyard pollution (Algeo et al., 1972). This research founded a data base for which Peters and Blackwood (1977) developed extrapolations under "worst case scenarios" which lead to the adoption by the EPA of a particulate emission factor of 280 pounds per 1000 head per day for cattle feedyards (U.S.EPA, 1986). This data, however, has limitations which render this emission factor suspect (Parnell et al., 1993). An emission factor needs to be developed that provides an accurate prediction of the particulate emissions from a feedyard. This new emission factor would permit the estimation of downwind particulate concentrations around a feedyard under various climatological conditions.

It has been found that many factors affect the amount of particulate emissions from a feedyard. The California research found that particulate emissions from a feedyard is generated primarily by the cattle movement within the holding pens and by wind acting on the dried feedyard surface. Road dust is also generated by vehicles on the alleyways, which contributes to the emission factor of a feedyard (U.S.EPA, 1986). Additional factors include the effect of manure on soil moisture which is a function of cattle density, and the influence of weather conditions such as wind speed, precipitation, and evaporation of soil moisture which are functions of geographic location. Consequently, the feedyard area,

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weather conditions, and cattle density in pens are primary influences on particulate generation (Sweeten et al., 1988). Due to the variety of climatological conditions which impact the emission factor, the emission factor changes seasonally. A method needs to be developed for predicting the emission factor throughout the year.

Literature Review

Emission Factors

Research performed during the summer of 1971 (Algeo et al., 1972) at twenty-five feedyards in California resulted in the current emission factor of 280 pounds per 1000 head per day. Data collected by Sweeten et al. (1988) at three different Texas feedyards was used with a modeling protocol to determine a daily emission factor intervals (Table 1) (Parnell et al., 1993). The emission factor varied with time of year. The mean emission factor found for the cattle feedyards in Texas was determined to be 9.2 pounds per 1000 head per day (Parnell et al., 1993).

Emission Standards

Currently, fugitive emissions are not regulated by the U.S.EPA. However, if the procedure was altered and fugitive emissions were regulated, the total suspended particulate (TSP) and the particulate matter less than ten microns (PM_{10}) regulations would affect the cattle feedyards.

The particulate standards for TSP and for PM_{10} are listed in Table 2. The particulate standards for TSP are 400 $\mu g/m^3$ for the one hour standard and 200 $\mu g/m^3$ for the three hour standard. PM_{10} standards are 150 $\mu g/m^3$ for twenty four hours and 50 $\mu g/m^3$ for the annual standard (Red, 1994).

Red (1994) stated that overall the three hour TSP standard and the twenty-four hour PM_{10} standards are the most stringent and the most difficult to meet. The three hour, the twenty-four hour, and the annual standard are generally proportional to the distance away from the source. The facility should be place a sufficient distance away from the fence line in order to comply with these standards. When permitting a facility, the Texas Natural Resource Conservation Commission (TNRCC) considers the maximum concentration measured on the adjoining property to occur at 50% and 40% of the distance between the affected neighbor and the fence line.

Hourly and Annual Emission Concentrations

To generate the hourly concentrations, Red (1994) suggested that worst case weather data from the ISC-SCREEN model should be utilized. The annual standard was developed by using the STAR weather data. The STAR weather data is a stochastic weather model which contains a set of probabilities of occurrence for stability class, wind speed, and wind direction. STAR weather data was recommended for yearly concentrations only (Ruggeri, 1994).

The stability classes and mixing heights for the annual and hourly standards are listed in Table 3. The mixing height is the height above the ground where the inversion layer is located. This inversion layer prevents any mixing above this point (Cooper and Alley, 1986). However, it has been shown that predicted fugitive dust concentrations are generally insensitive to values used for mixing height due to the lack of vertical mixing within the inversion layer (Winges, 1990a).

Objectives

The goal of this research was to develop the method for the prediction of dust being emitted and transported downwind of a cattle feedyard. The objectives for the study were as follows:

1) the determination of a representative emission factor,
2) the prediction of downwind particulate concentrations for three feedyard capacities using worst case climatological data, and
3) the formulation of an emission factor representing the seasonality of dust emissions.

Methods

Representative Emission Factor

Due to the variation of the emission factor throughout the year, a cumulative frequency distribution, a weighted seasonal average and an arithmetic mean was applied to the daily emission factor data.

Predicting Downwind Concentrations

FDM was used to predict the average particulate concentrations around three model feedyards located on the High Plains, Southern High Plains and South Texas.
The model feedyards we assumed to have 10,000, 20,000, and 40,000 head of cattle. Each head was allotted 150 square feet and an emission rate of 10 pounds per 1000 head per day was used.
The particulate concentrations were plotted using Surfer 4.0 to obtain a visual estimate of particulate concentrations around the feedyard (Trinity Consulting INC, 1992). The isoplanes, or plots of concentration, were developed in relation with the hourly and annual standard.

To estimate the one hour standard, a hypothetical weather file was developed using the worst case weather data available from the ISC-SCREEN2 model (Table 3) (Red, 1994). The wind speed varied from 2 to 40 knots and the ceiling height ranged from 1600 to 10,000 feet for stability classes A through F. The weather data was set at a temperature at 70 degrees fahrenheit, the wind at a 20 degree angle across the feedyard (20 degrees east-northeast), the total sky cover at 30 percent and the total opaque sky cover of 30 percent. These factors were consistent throughout each hour of weather data. Each wind speed and ceiling height was set as one hour of weather data. A one hour concentration estimate was calculated using the worst case weather data available in the ISC-SCREEN2 model (Table 3). Isoplanes were developed using the minimum, average, and maximum concentrations for each stability class for each size feedyard. The average concentration isoplane is the average of all the concentrations for each stability class.

The annual standard was developed by using the STAR weather data and the method utilized by TNRCC (Red, 1994). The source was modeled with five different years of STAR weather data (1985-1989) and the year with the maximum concentration of particulate was chosen. Annual concentrations were developed for 40,000 head, 20,000 head and 10,000 head feedyards located at Amarillo, Brownsville, Lubbock, and San Angelo, Texas.

The PM_{10} standard was used for the annual concentrations. The particle size distribution required by the model was changed to include only the PM_{10}. fraction of feedyard dust (Table 4). The PM_{10} dust fraction accounted for 52.72% of the total dust collected. Therefore, the emission factor for PM_{10} dust was reduced to 5.27 pounds per 1000 head per day, compared to an emission factor of 10 pounds per 1000 head per day for TSP dust.

Emission Factor Equation

The emission factor equation was developed by applying a quadratic regression curve to the emission factors predicted with the modeling protocol. The curve was developed with the use of the SAS statistical package (Freeman et al., 1990).

Seasonal Emission Factor

The seasonal distribution for the emission factor was developed by plotting the daily predicted emission factors (Table 1) described by Parnell et al., (1993) according to the seasons: winter, spring, summer, and fall. The winter months included December, January, and February, the spring months included March, April and May, the summer months included June, July and August and the fall months included September, October and November. After separating the daily predicted emission factor data into seasons, the highest emission factor that occurred during the season was used to represent that season.

Results and Discussion

Representative Emission Factor

The emission factor varies though the year, however, it stays predominantly under the 10 pounds per 1000 head per day (Table 1). A cumulative frequency distribution of the emission factors shows that the emission is less than 10 lbs./1000 hd./day 86% of the time (Table 5). Therefore, an emission factor of 10 lbs./1000 hd./day would represent the emissions 86% of the year. An emission factor of 10 lbs/ 1000 hd./day agrees with the average emission factor of 9.2 lbs./1000 hd./day presented by Parnell et al., (1993) and is significantly less than the current AP-42 emission factor of 280 lbs./1000 hd./day.

Prediction of Downwind Particulate Concentration

The isoplane shown (Figure 1) is the minimum concentrations for the 10,000 head feedyard in stability class A. The PM_{10} dust concentration around a 10,000 head feedyard exceeds the annual standard for a west-east distance of 2642.86 meters (8670.8 feet) and a north-south distance of 2985.5 meters (6842.2 feet) (Figure 2).

Minimum concentration isoplanes were identical for each differing stability class. This similarity was attributed to two factors:

1) the TSP and PM_{10} particles are non-buoyant and
2) the feedyard is a low level source.

Therefore, TSP and PM_{10} were not influenced by the inversion layer.

The maximum concentration for each stability class occurred at the highest wind speed for that class. The wind speeds range from six to forty knots (Table 3). These isoplanes can be utilized to show how the concentration can vary with varying wind speeds.

The TNRCC analyzes the concentration at the 24 hour average and the annual maximum rate of pollutant and compares the standards to measured concentration at a distance of 50% and 40% from the fenceline (Red, 1994). Therefore, the placement of the fenceline is critical and the isoplanes were developed to aid in the fenceline placement.

Emission Factor Equation

In the development of the emission factor equation, the April 14th daily emission factor was eliminated (Table 1). After qualitative evaluation of the data, it was determined that the sampler was affected by heavy road traffic. It has been shown that as few as five vehicles per day traveling on a dirt road can contribute 7 $\mu g/m^3$ to the overall TSP concentration (King, 1980). A sampler in the April 14th collection was placed in a high traffic area. Because there were only 4 samplers available during this day, and with one placed in the high traffic area, the resulting emission factor was unreasonably high. The goal of this study was to determine the amount of TSP and PM_{10} dust emitted from the feedyard surface. Therefore, the April 14th daily emission factor was removed.

The emission factor equation was developed by applying a quadratic regression equation to the daily emission factors. The equation representing the emission factor as a function of Julian day is as follows:

$$\text{Emission Factor} = 3.227+0.0673*(\text{Julian Day})+0.0002*(\text{Julian Day})^2.$$

The predicted emission factor varies throughout the year which corresponds with qualitative evaluations by the authors (Figure 3). However, this equation should only be used to predict the general trend of the emission factor and not predict an emission factor at a certain day. This limitation is addressed because the experiment was not designed for the purpose of developing an equation and further work is warranted for the validation of this equation. Although the data to validate this equation is not available, the trends represented by this equation follow the results of qualitative field evaluations and should be considered when determining the AP-42 factor.

Seasonal Emission Factor

The seasonality of the emission factor is represented by a bar chart (Figure 4). The emission factor for the winter, spring, summer and fall are 6.4, 25.6, 3.2 and 6.4 pounds per 1000 head per day, respectively. Utilizing a weighted average, the emission factor was found to be 10.2 pounds per 1000 head per day. The winter, summer, and fall emission factors are all lower than the average emission factor of 9.2 pounds per 1000 head per day (Parnell et al., 1993). The seasonality of the emission factor is evident and should be considered when developing an overall emission factor. Again, this seasonal emission factor was developed with a limited data set and should be used to show trends in the emission factor.

EPA and Regulating the Feedyard Industry

The selection of an accurate emission factor is vital to both the regulatory agencies and the beef cattle feeding industries. If the emission factor is unreasonably high, the fee that the cattlemen would pay to the regulatory agencies would also be unreasonably high. However, if the emission factor is too low, the feedyard could be out of compliance with their permit and a fine could be levied for being out of compliance. Thus, if the emission factor was an equation or set seasonally, the feedyard would always be in compliance, and the fees should not be unreasonable.

Summary and Conclusions

The implementation of the Federal Clean Air Act and the anticipated expansion of state air pollution regulatory agencies will require accurate EPA AP-42 emission factors for the cattle feedyards to be regulated justly. These factors can be developed with accurate source sampling and application of an appropriate EPA approved model.

An emission factor of 10 lbs./1000 hd./day is recommended for the cattle feeding industry. This emission factor agrees with the average and seasonally weighted emission factor of 9.2 and 10.2 pounds per 1000 head per day, respectively. This was much lower than the worst case scenario (Peters and Blackwood,1977) which lead to the current EPA AP-42 emission factor of 280 pounds per day per 1000 head.

Isoplanes describing the PM_{10} and TSP concentrations around feedyards using an emission factor of 10 pounds per 1000 head per day were developed. These isoplanes can provide guidance to members of the cattle feeding industry when siting feedyards with respect to the downwind particulate concentrations.

The seasonal variation in the emission factor was presented as a quadratic regression equation and a bar chart. Both representations illustrate that the rate of particulate emissions was greatest during the spring months and was fairly constant but at a lower rate for the summer, fall, and winter months. When these trends are taken into consideration, the feedyard should continually be in compliance without having fees that are unreasonably high.

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Table 1. Emission Factors Predicted with Modelling Protocol (Parnell et al., 1993)

Date	Sampling Period	Feedyard	No. of Samplers	Emission Factor*
Jan 12-13	27	A	6	1.6
Jan 14-15	24	B	6	0.1
Apr 14-15	24	C	4	51.2
Apr 15-16	24	C	6	25.6
May 18-19	24	B	6	6.4
May 20-21	24	A	5	12.8
May 21-22	24	A	6	3.2
Aug 17-18	29	C	6	1.6
Aug 18-19	24	C	6	3.2
Oct 6-7	24	A	6	6.4
Oct 7-8	24	A	6	3.2
Oct 14-15	24	C	6	6.4
Oct 15-16	24	C	6	6.4
Dec 7-8	24	B	6	6.4
Dec 8-9	25	B	6	3.2

* emission factor is in pounds/1000 head/day

Table 2. TSP and PM_{10} Standards (Red, 1994)

Standards	TSP ($\mu g/m^3$)	PM10 ($\mu g/m^3$)
one hour	400	N/A
three hour	200	N/A
twenty four hour	N/A	150
annual	N/A	50

Table 3. Worst Case Weather Data from ISC-SCREEN2 (Red, 1994)

Stability Class	Mixing Height (feet)	Wind Speed (knots)
A	1600	2,3,4,5,6
B	1200	2,3,4,5,6,7,8,9,10
C	800	2,3,4,5,6,7,8,9,10,16,20
D	400	2,3,4,5,6,7,8,9,10,16,20,30,40
E	10,000	2,3,4,5,6,7,8,9,10
F	10,000	2,3,4,5,6,7,8

Table 4. PM10 Particle Size Distribution (Sweeten and Parnell, 1989)

Size Range (microns)	Aerodynamic Diameter (microns)	Particle Fraction
1.26-1.59	1.65-2.08	.0137
1.59-2.00	2.08-2.62	.0456
2.00-2.52	2.62-3.29	.0574
2.52-3.17	3.29-4.14	.0747
3.17-4.00	4.14-5.23	.0998
4.00-5.04	5.23-6.59	.01352
5.04-6.35	6.59-8.30	.1618
6.25-8.00	8.30-10.46	.1936
8.00-10.08	10.46-13.18	.2182

Table 5. Cumulative Frequency Distribution

Emission Factor *	Occurrences	Cumulative Occurrences	Percent of Total Occurrences(%)
0-5	7	7	50
5-10	5	12	85.7
10-15	1	13	92.9
15-20	0	13	92.9
20-25	1	14	100

* emission factor is in pounds/1000 head/day

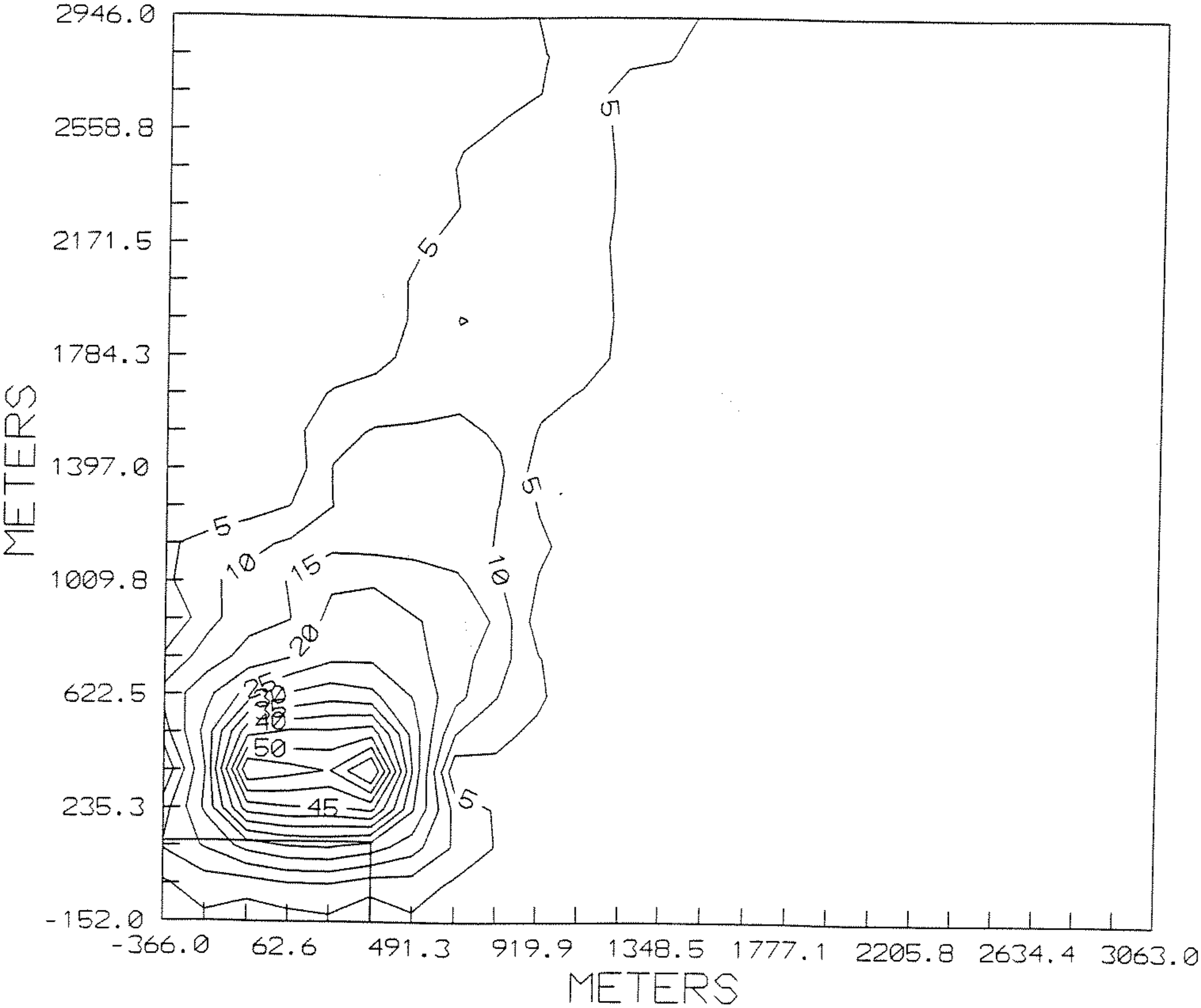

Figure 1. Hourly Minimum Concentrations of TSP around a 10,000 head feedyard $\mu g/m^3$

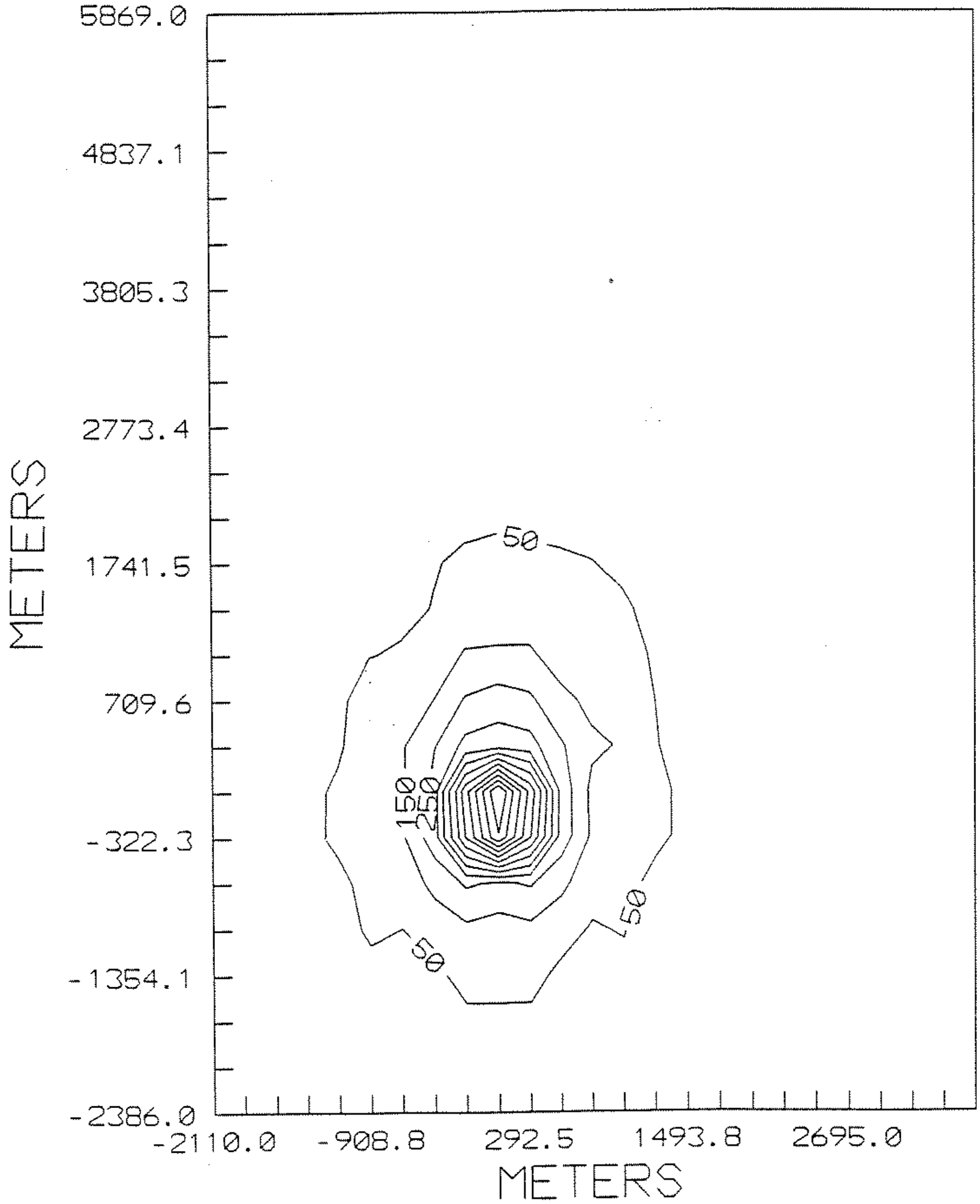

Figure 2. Average Yearly Concentrations of PM_{10} around 10,000 head feedyard $\mu g/m^3$

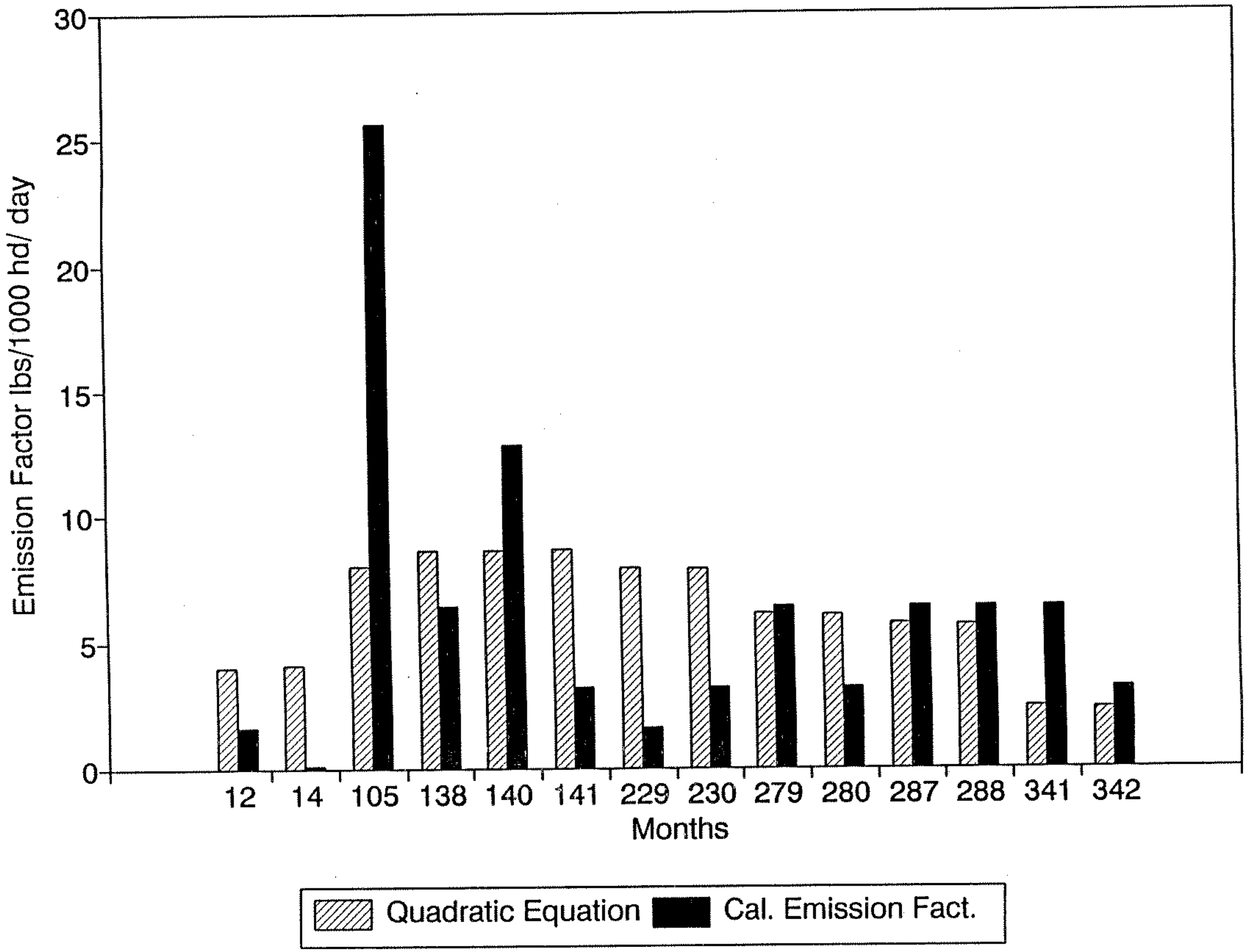

Figure 3. Quadratic Regression Equation of Daily Emission Factors

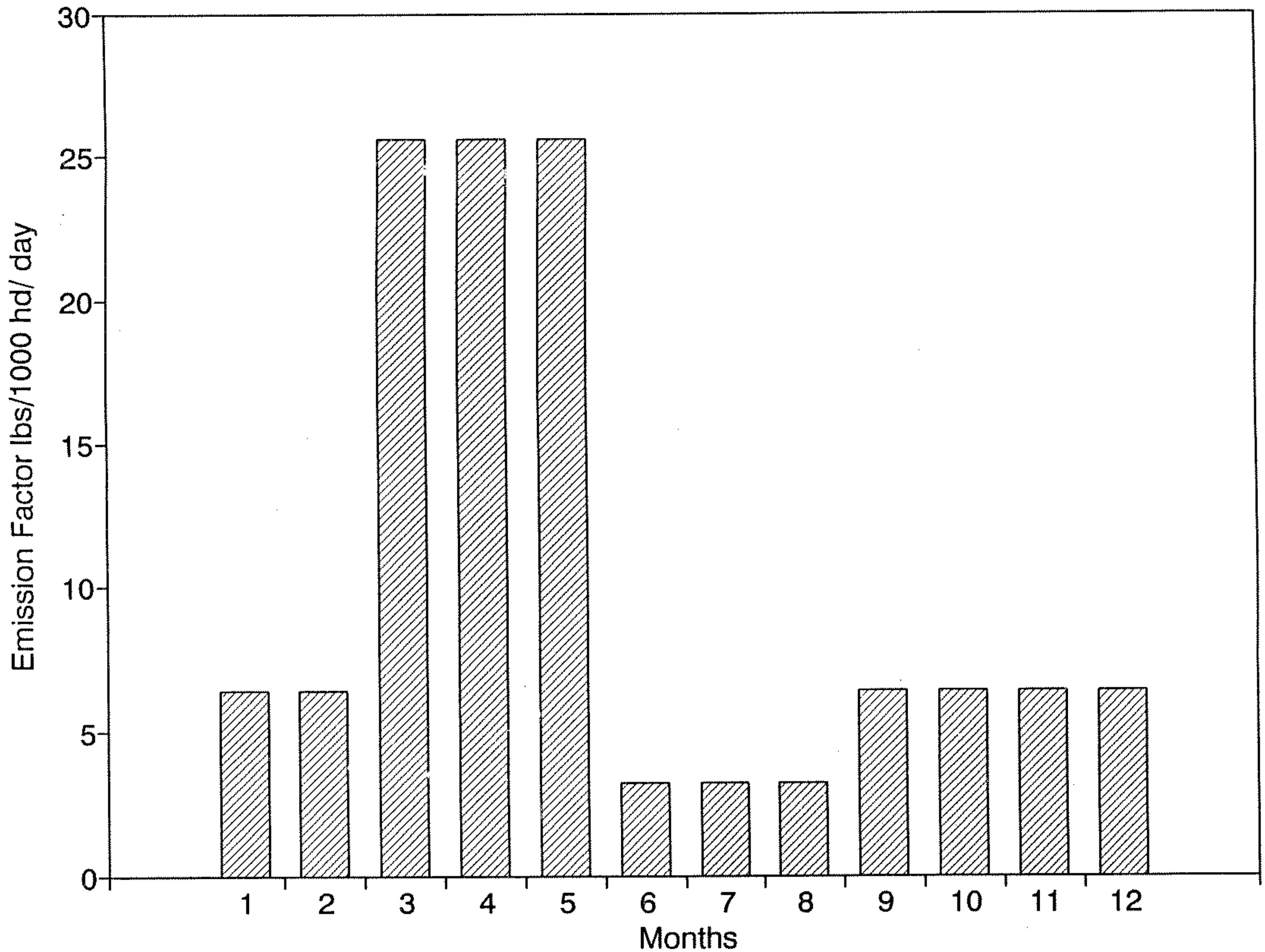

Figure 4. Seasonal Emission Factors

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DETERMINATION OF AN EMISSION FACTOR FOR CATTLE FEEDYARDS BY APPLYING DISPERSION MODELING

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Summary:

As emission factor of 10 lbs./1000 hd./day was established for particulate emissions from cattle feedyards. The emission factor was used in a dispersion model to predict particle concentrations around a model feedyard. This information can assist cattlemen when siting feedyards.

Keywords:

Dispersion modeling, Cattle feedyards, Air pollution, Emission Rates, FCAA, Emission Factor