Paper No. 99-4192
An ASAE Meeting Presentation

Effect of Stocking Density on Fugitive PM_{10} Emissions From a Cattle Feedyard

Arturo Romanillos, EIT
Graduate Research Assistant
Texas A&M University System
6500 Amarillo Blvd. West
Amarillo, TX 79106
arturo@tamu.edu

Brent W. Auvermann, Ph.D.
Assistant Professor of Agricultural Engineering
Texas A&M University System
6500 Amarillo Blvd. West
Amarillo, 79106
b-auvermann@tamu.edu

Written for presentation at the
1999 ASAE Annual International Meeting
Sheraton Centre Hotel
Toronto, Ontario Canada
July 18-21, 1999

Summary: The objective of this study was to determine whether increasing the stocking density in cattle feedyards significantly reduces the emission of fugitive PM_{10} from the feedyard surface. Increasing the stocking density reduces the space allocated to each animal and concentrates the livestock excreta within a smaller surface area. We suppose that the resulting increase in moisture applied to the feedyard surface decreases the overall dustiness of the pens.

We conducted 16 ambient sampling events between August 1998 and March 1999 at a commercial feedyard in the Texas Panhandle. We operated Federal Reference Method PM_{10} samplers upwind and downwind of a 12-corral test area of which 6 pens were stocked at a typical cattle spacing (13.9 m^2 hd^{-1}) and 6 pens were stocked at 50% of that spacing (7.0 m^2 hd^{-1}). Sampler locations were selected to minimize the likelihood of cross-contamination. Sampling events spanned 6- and 24-hour time intervals in order to capture diurnal effects and shorter-duration effects. The net contribution of fugitive PM_{10} from each treatment was determined by subtracting background concentrations from downwind concentrations.

The data collected thus far only weakly support the hypothesis that increasing the stocking density during dry periods significantly reduces fugitive dust emissions. After ranking the quality of the data from all 16 events according to a set of objective wind-direction criteria, and then focusing our interpretive effort on the highest-quality and most reliable data, we found that doubling the stocking density resulted in only an 5-12% reduction in net PM_{10} concentrations. Because only 13% of the data collected were considered highly reliable, we cannot yet conclude that the 5-12% reductions are real and significant. It does not appear likely that using stocking density alone in a dust-management program is sufficient to reduce dust emissions, especially in semi-arid climates with a high annual rainfall deficit. In addition, we suspect that reducing the cattle spacing induces behavioral stresses that may reduce feed-to-gain performance and overall profitability. Both of these preliminary conclusions warrant further investigation.

Introduction

Title V of the Clean Air Act Amendments of 1990 provides for the designation of major air pollution sources and the assessment of emissions fees. Major sources (those emitting 91 metric tons or more of any regulated pollutant, except toxics) are assessed emissions fees by the State Air Pollution Regulatory Agencies (SAPRAs) for all emissions from the facility. Currently, cattle feedyards are not typically classified as major sources because fugitive sources are not included in the emissions inventory. Due to ever-increasing pressure for a cleaner environment, however, it is not hard to imagine that fugitive emissions will eventually be included. In fact, as of 1998, the State of Washington SAPRA has already begun the transition; major source classification may now be determined on the basis of point *and* fugitive sources (Washington Department of Ecology, 1998). Whether cattle feedyards and other agricultural sources will immediately feel the impact of this change is unknown.

For many years the agricultural community did not scrutinize the emission factors of agricultural operations. Because of increased pressure resulting from suburban encroachment on agricultural land, SAPRAs are looking more closely at agricultural operations, including cattle feedyards. Unfortunately, the cattle feedyard emission factor used by regulators and published by the U.S. Environmental Protection Agency (EPA) appears to overestimate total suspended particulate (TSP) emissions (Parnell, 1994). The AP-42 emission factor for cattle feedyards is 127 kg d^{-1} per 1,000 head of capacity (EPA, 1986). This emission factor has been challenged in recent years (Parnell, 1995; McGee, 1997). However, TSP has not been a regulated pollutant since 1987, when it was replaced as a regulated pollutant by PM_{10}, that fraction of TSP having an aerodynamic equivalent diameter (AED) of 10 micrometers and smaller. The accepted emission factor for fugitive PM_{10} from cattle feedyards, 32 kg d^{-1} per 1,000 head, is based on the PM_{10}/TSP ratio of 25% published by Sweeten et al. (1988).

The California Cattle Feeders Association (CCFA) first examined the control of dust from cattle feedyards in the early 1970s. The four bulletins produced by this work were the first concerning ambient dust concentrations and control techniques for cattle feedyards (Algeo et al., 1972). In 1977, Peters and Blackwood produced a report to the EPA on the sources of pollution from cattle feedyards. Using the data from the California study, a TSP emission factor of 0.0361g/s-m was developed using a line-source dispersion model (Peters and Blackwood, 1977). In 1979, the EPA published the current emission factor for cattle feedyards based on the report by Peters and Blackwood, calling it a "crude estimate" (EPA,1986).

The research performed by the CCFA also provided much-needed information on control techniques for suppressing cattle feedyard dust. Current control measures include the following:

1. Solid-set sprinklers appear to be the most effective method of dust control, but they require large capital investments and quantities of water that can be prohibitive in some cattle feeding regions.

2. Chemical agents can be used to form crusts on manure packs but are ineffective because of the continuous deposition of fresh manure on the feedyard surface.

3. Frequent manure harvesting helps to reduce the quantity of excess manure and loose material that can be entrained in the air. However, this technique is labor-intensive and may add to cattle stress.

The manipulation of stocking density to reduce particulate emissions is another alternative. Stocking density refers to the number of cattle per unit area in a corral. The stocking density is increased during dry periods of the year while maintaining bunk space per animal. This can be accomplished by cross-fencing the corrals. Confining the cattle to a smaller area increases the moisture per unit area excreted by the cattle, increasing the cohesion of the manure pack. Increasing the stocking density, or reducing the cattle spacing, appears to reduce dust emissions (Simpson, 1970; Elam et al., 1971). Elam et al. (1971) also reported that a manure moisture content of 20 to 30 percent (wet basis) was the minimum to achieve dust control. However, the effect of stocking density on emissions of particulate matter` has been studied only qualitatively. This research was an attempt to quantify the anticipated reductions.

Objective

The goal of this research was to quantify the reduction of PM_{10} emissions from the feedyard surface through the manipulation of stocking density.

Procedure

Cooperation from a Texas Cattle Feeders Association member feedyard in the Texas Panhandle was obtained for this study. This particular feedyard was selected because of the orientation of its corrals. One row of corrals having an E-W orientation of the feedbunk was selected for the study. Since the prevailing winds in the region are from the south, the E-W orientation allowed for treatment-segregated upwind and downwind sampling of the corrals. Six of the corrals were chosen for the control group (nominal cattle spacing 13.9 m^2 hd^{-1}) and six more for the treatment group (7.0 m^2 hd^{-1}). The treatment group of corrals was modified to obtain the desired stocking density by building a gated fence diagonally across each corral (see Figure 1).

For better precision in accounting for the excretion component of the corral moisture balance, actual stocking densities in the control and treatment corrals were based on *liveweight* per unit area instead of the more traditional *livestock number* per unit area. Cattle selected at random for this study were distributed to the study corrals by forming sets of paired corrals upon arrival. Cattle were assigned to each pair of corrals until the desired stocking density of 2.51×10^5 (+/- 571) kg ha^{-1} was reached. Once the study corrals were filled, the cattle remained in them throughout the normal 130-day feeding cycle. The results reported herein represent data collected through two full turns of cattle. We made no attempt to maintain equivalent stocking densities beyond the initial allocation so that the feedyard owners would be more easily able to detect differences in feed-to-gain performance, which would indicate an effect of the dust-control practice on feedyard profitability.

In order to quantify the PM_{10} emitted from the corral surfaces, we installed ambient samplers upwind and downwind from both the control and treatment corrals. We used five to eight EPA Federal Reference Method PM_{10} samplers manufactured by Wedding & Associates, Inc. Gasoline-powered electric generators ranging from 4 to 5.5kW powered the PM_{10} samplers. The filters used were EPA approved 203 mm x 254 mm microquartz filters (Whatman QM-A). During the last sampling event, we also used borosilicate filters having nearly identical penetration characteristics. The filters were conditioned before weighing by placing them in a drying oven at 90°C for 24 hours to ensure that differences in moisture found on the filters would not create weighing errors. The filters were each weighed three times before and after exposure using an analytical balance (Mettler-Toledo Model AG245) with a resolution of 0.1 mg. Filters were exposed for 6- or 24-hour nominal durations. Filter blanks were collected during each sampling event to determine error associated with filter handling. The PM_{10} samplers were calibrated *in-situ* using a slack tube manometer to determine actual flow rates. Meteorological data was recorded on-site by an automatic weather station (Campbell Scientific, Inc. WeatherWatch 2000) during all sampling events. Meteorological data included one-hour averages of temperature, barometric pressure, relative humidity, wind speed and wind direction, as well as the one-hour standard deviation of wind direction. Using timers located on the samplers in conjunction with recorded meteorological data, the PM_{10} concentrations ($\mu g\ m^{-3}$) were calculated and corrected to micrograms per dry standard cubic meter ($\mu g\ dscm^{-3}$).

Sampling events began in August 1998 and continued sporadically until March 1999, producing 16 sampling intervals (Table 1). Sampling events occurred roughly every two to three months in order to sample during different seasons and different stages of cattle feeding. The arrangement of the samplers during each sampling event varied according to the availability of samplers, generators, and favorable winds. Figures 1, 2, 3 and 4 show the sampler deployment for the August 1998, October 1998, December 1998 and March 1999 sampling events. Careful attention was given to wind direction in order to ensure that upwind and downwind samplers were labeled correctly. Sampling events are labeled by starting date and, for the 6-hour samples, the letters A, B, C and D representing the portion of the day in which it occurred (A = 2400 to 0600 hrs; B = 0600 to 1200 hrs; C = 1200 to 1800 hrs; D = 1800 to 2400 hrs).

Results and Discussion

PM_{10} concentrations from the four sampling trips are presented in Table 2. The concentrations are presented as average upwind and average downwind for the control and treatment corrals. Table 3 shows (a) the net PM_{10} increases (decreases) for the control and treatment corrals, (b) the results of the wind direction test and (c) the reduction of net PM_{10} resulting from the increased stocking density. Out of the 16 data sets, only five sets (2, 3, 4, 10, and 15) show the expected reduction of PM_{10} attributed to the increased stocking density. These events produced reductions ranging from 5% to 52%. Data sets 4, 10 and 15, which produced the highest reductions, all failed the wind test. (The test for wind variability is discussed under *Sources of Error* below.) Upon closer inspection, data sets 10 and 15 only failed the wind test slightly. However, data set 4 failed the wind test over half of the sample duration. An opposing trend was found in data set 1, which shows a 53% increase in net PM_{10} resulting from the increased stocking density.

The remaining data sets showed an unexpected trend. These sets (5-9, 11-14, and 16) show that either the control, treatment, or both sets of corrals acted as net sinks of PM_{10} instead of net sources. Set 7 shows that the control group had a net reduction of PM_{10} across the corral surface. Sets 5, 11, 12, 14, and 16 show that the treatment group had a net reduction across the corrals. Sets 6, 8, 9, and 13 show that both the control and treatment groups acted as sinks. Sets 6 and 9 show that the treatment corrals had a greater reduction than the control group. Sets 8 and 13 showed the opposite. Set 10 produced a negative upwind concentration, so net PM_{10} increase was calculated assuming a background concentration of zero.

Sources of Error

Upon initial examination of the results, it was apparent that we needed to look closely at sources of error. Data sets that produced net decreases of PM_{10} across the corral surfaces were of particular interest, and we identified several possible sources of error. In commercial feedyards, multiple feedings occur during the course of a day, during which large feed trucks travel down the unpaved feeding alley. Samplers inside the feeding alley were set up in the middle of the alley, leaving enough space on each side for the trucks to pass. To suppress the resulting road dust, a water truck was used to irrigate the feed alley twice a day before the feedings during the August and October sampling events. The fact that the water truck was not used during the first August event and all of the December and March sampling events may have contributed to the errors. During one event, fill dirt was being excavated near the upwind samplers, and this dust may have settled out prior to reaching the downwind samplers.

Two more possible sources of error were found in the sampling procedure. First, careless handling of filters can introduce large errors when the edges of the brittle microquartz filters fray against the filter cartridges or the protective envelopes. We also believe that placing filters into sampler cartridges and inserting and retracting the cartridges from the samplers may introduce extraneous filter loading. Filter blanks collected during sampling trips reported an average error and standard deviation of 0.011 ± 0.0446 g., which translates into potential errors of 34.0 to 136.6 $\mu g\ m^{-3}$ for 6- and 24-hour samples, respectively. Second, we suspect that one or more of the electric generators may not have been running properly, perhaps due to poor generator performance.

One more source of error lies unquestionably in the uncontrollable direction of the wind. Examining the weather logs, we found that the wind direction varied by as much as 115° during one 6-hour sample. The change in wind direction means that while samplers were set up to measure dust from the study corrals, they may have been sampling dust from the feed alleys, surrounding corrals, and open fields. To measure the quality of the sampling data, the average wind direction during each sampling event was tested against the optimal wind directions (for an E-W feedbunk orientation, wind directions of 180° or 0° were optimal). Results from this test are presented in Table 3. Further studies should record data in smaller time intervals in order to evaluate sampling data more precisely. We conducted another sampling event in late June 1999 using 2-minute weather data, but the sampling data were not yet available as of this writing.

Conclusions

It has long been accepted that increased stocking density in cattle feedyards reduces the emission of fugitive PM_{10}. However, this study has not produced enough reliable data to support this hypothesis. From the five data sets that produce the expected results, the average reduction of PM_{10} was 28.6%, while the one contradicting data set produced a net increase of 53.0%. If we take into account only the two data sets that passed the wind direction test, the average PM_{10} reduction was 8.5%. First, it is important to take the variability of wind direction into account and rank the data quality according to the orthogonality of the wind directions to the feedbunk orientation. Second, extraneous upwind sources and moist corral surfaces can give rise to apparent “sink” behavior, which complicates data interpretation. Third, tight control of errors in filter handling is essential to measuring ambient PM_{10} accurately in a feedyard environment. Finally, background concentrations must be reduced as much as possible. Even ideal orthogonality of wind direction to feedbunk orientation cannot ensure reliable data if upwind concentrations are excessively high. Continued research into stocking density manipulation under more tightly controlled conditions is needed in order to assign to the technique any reliable estimate of its effectiveness.

Acknowledgments

The authors wish to express their appreciation to the Texas Cattle Feeders Association and its member feedyard for their financial support and continued working relationship.

References

Algeo, J.W., C.J. Elam, A. Martinez, and T. Westing. 1972. Feedlot Air, Water, and Soil Analysis: Bulletin D, How to Control Feedlot Pollution, California Cattle Feeders Association, Bakersville, California.

Elam, C.J., J.W. Algeo, T. Westing and L. Hokit. 1971. Measurement and Control of Feedlot Particulate Matter: Bulletin C, How to Control Feedlot Pollution, California Cattle Feeders Association, Bakersville, California.

McGee, R.O. 1997. A Critical Analysis of the AP-42 Emission Factor for Cattle Feedyards. M.S. Thesis, Texas A&M University, College Station, Texas.

Parnell, S.E. 1994. Dispersion Modeling for Prediction of Emission Factors for Cattle Feedyards. M.S. Thesis, Texas A&M University, College Station, Texas.

Peters, J.A. and T.R. Blackwood. 1977. Source Assessment: Beef Cattle Feedlots. EPA-600/2-77-107, U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina.

Simpson, F.M. 1970. The CCFA Control of Feedlot Pollution Plan: Bulletin A, How to Control Feedlot Pollution, California Cattle Feeders Association, Bakersville, California.

Sweeten, J.M., C.B. Parnell, R.S. Etheredge, and Dana Osborne. 1988. Dust Emissions in Cattle Feedlot. In: Stress and Disease in Cattle, Veterinary Clinics of North America: *Food Animal Practice*, Vol. 4, No. 3, 557-578.

U.S. EPA. 1986. AP-42 Compilation of Air Pollution Emission Factors Volume I: Stationary Point and Area Sources. Research Triangle Park, North Carolina.

Washington Department of Ecology. 1998. Air Pollution: General Guidance. WAC 173-400-105.

Table 1. Feedyard Sampling Event Descriptors.

Data Set	**Event**	**Date**	**Sampling Time**	**Nominal Duration (hr)**	**Wind Direction (deg.) x±σ**
1	081798	8/17/98 - 8/18/98	12 p.m. - 1 p.m.	24	190±20
2	081898	8/18/98 - 8/19/98	1 p.m. – 1 p.m.	24	173±14
3	081998	8/19/98 - 8/20/98	1 p.m. – 2 p.m.	24	184±24
4	082098	8/20/98 - 8/21/98	2 p.m. – 3 p.m.	24	261±55
5	101798-C	10/17/98	12 p.m. - 6 p.m.	6	317±66
6	101798-D	10/17/98	6 p.m. – 12 a.m.	6	22±13
7	101898-A	10/18/98	12 a.m. - 6 a.m.	6	336±30
8	101898-B	10/18/98	6 a.m. – 12 p.m.	6	280±18
9	120598-C	12/5/98	12 p.m. - 6 p.m.	6	245±5
10	120598-D	12/5/98	6 p.m. – 12 a.m.	6	240±19
11	031599-D	3/15/99	5 p.m. – 11 p.m.	6	194±19
12	031699-A	3/16/99	1 a.m. – 7 a.m.	6	213±18
13	031699-B	3/16/99	8 a.m. – 2 p.m.	6	226±18
14	031699-C	3/16/99	3 p.m. – 9 p.m.	6	200±23
15	031699-D	3/16/99 - 3/17/99	10 p.m. – 4 a.m.	6	223±40
16	031799-B	3/17/99	6 a.m. – 12 p.m.	6	39±10

Table 2. PM_{10} Concentrations.

Data Set	**Event**	**PM_{10} Concentration (μg/dscm)** Upwind	Control	Treatment
1	081798	14.57	131.69	193.70
2	081898	28.16	138.78	133.42
3	081998	38.28	189.92	171.61
4	082098	125.06	269.37	234.06
5	101798-C	175.07	511.62	159.35
6	101798-D	1541.57	1287.36	780.33
7	101898-A	340.42	237.45	708.22
8	101898-B	460.14	321.42	378.34
9	120598-C	234.47	148.32	97.46
10	120598-D	0.00†	440.78	212.52
11	031599-D	9.38	14.34	2.93
12	031699-A	43.51	69.34	11.26
13	031699-B	226.93	4.31	59.00
14	031699-C	48.93	88.53	15.65
15	031699-D	62.37	103.66	83.18
16	031799-B	200.92	265.12	49.39

†Upwind concentration was negative, replaced assuming zero background.

Table 3. Effect of Stocking Density on PM_{10} Concentrations.

Data Set	**Event**	**Net Increase (μg/dscm)** Control	Treatment	**% Reduction**	**Wind Test†**
1	081798	117.12	179.14	-52.95	Pass‡
2	081898	110.63	105.26	4.85	Pass‡
3	081998	151.64	133.32	12.08	Pass‡
4	082098	144.31	109.00	24.47	Fail
5	101798-C	336.56	-15.71	104.67	Fail
6	101798-D	-254.21	-761.24	-199.46	Pass‡
7	101898-A	-102.96	367.81	457.22	Pass
8	101898-B	-138.71	-81.79	41.03	Fail
9	120598-C	-86.15	-137.01	-59.04	Pass
10	120598-D	440.78	212.52	51.79	Fail
11	031599-D	4.96	-6.45	230.16	Pass‡
12	031699-A	25.82	-32.25	224.89	Pass‡
13	031699-B	-222.62	-167.93	24.57	Pass
14	031699-C	39.60	-33.29	184.05	Pass‡
15	031699-D	41.29	20.80	49.61	Fail
16	031799-B	64.20	-151.53	336.02	Pass‡

†Test wind direction within ±90° of 0° or 180°.

‡Passed for wind direction within ±60° of 0° or 180°.

Figure 1. August ’98 Sampler Configuration.

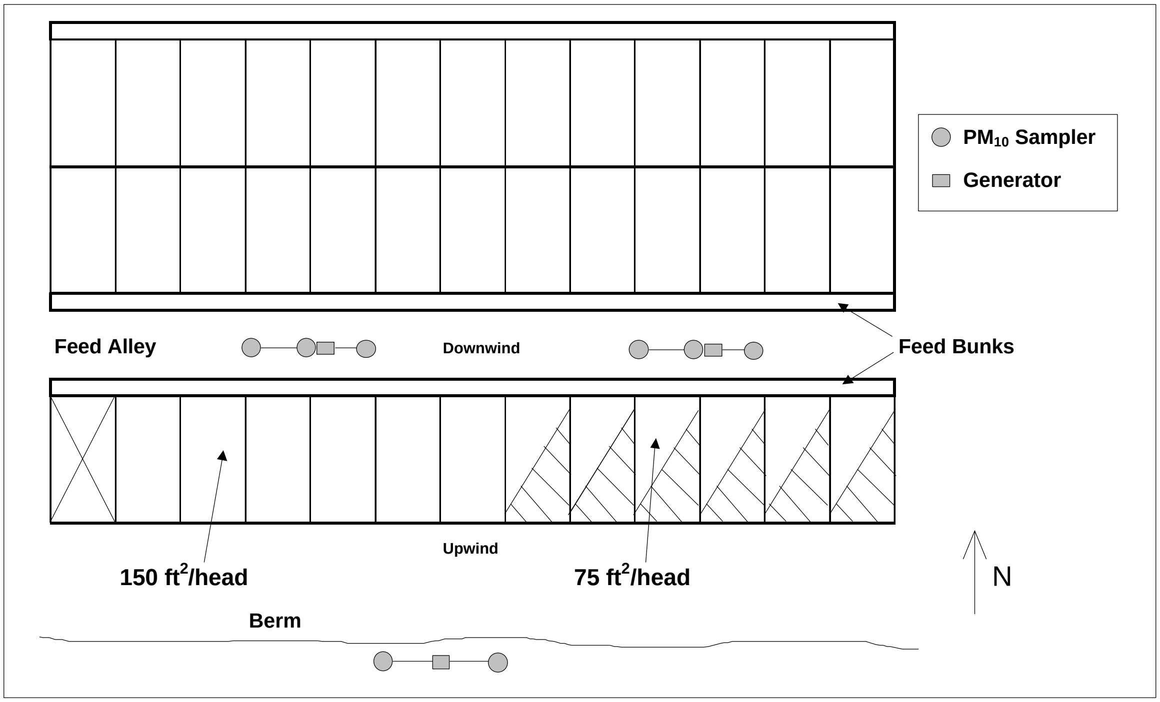

Figure 2. October ’98 Sampler Configuration.

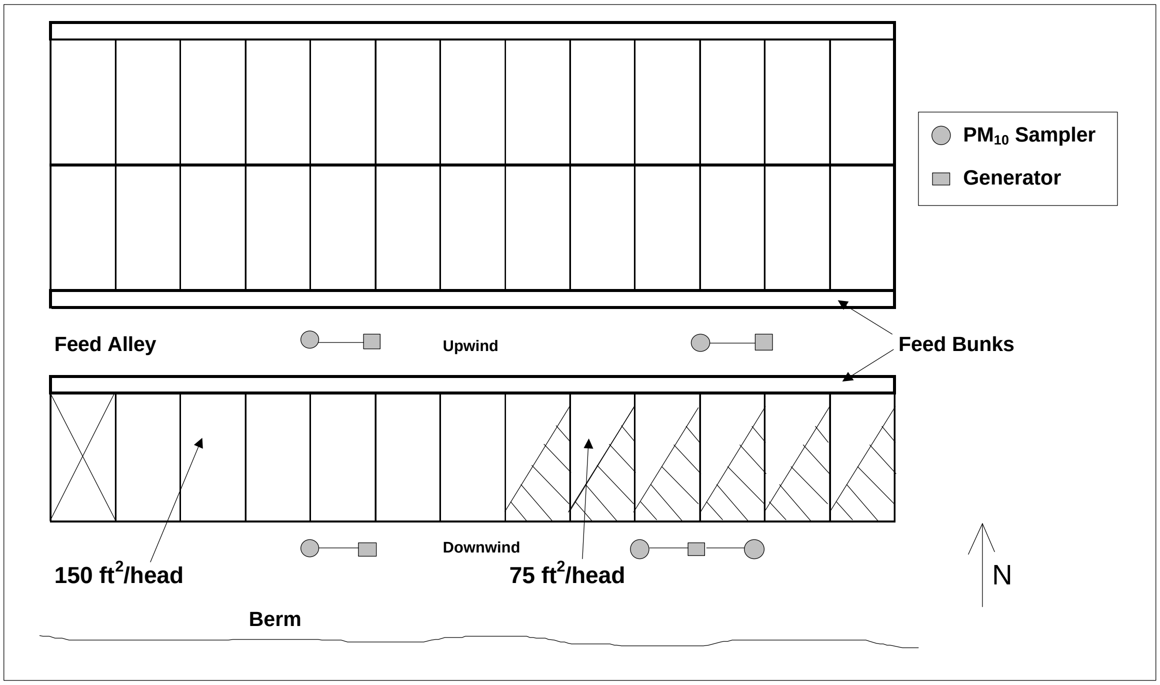

Figure 3. December ’98 Sampler Configuration.

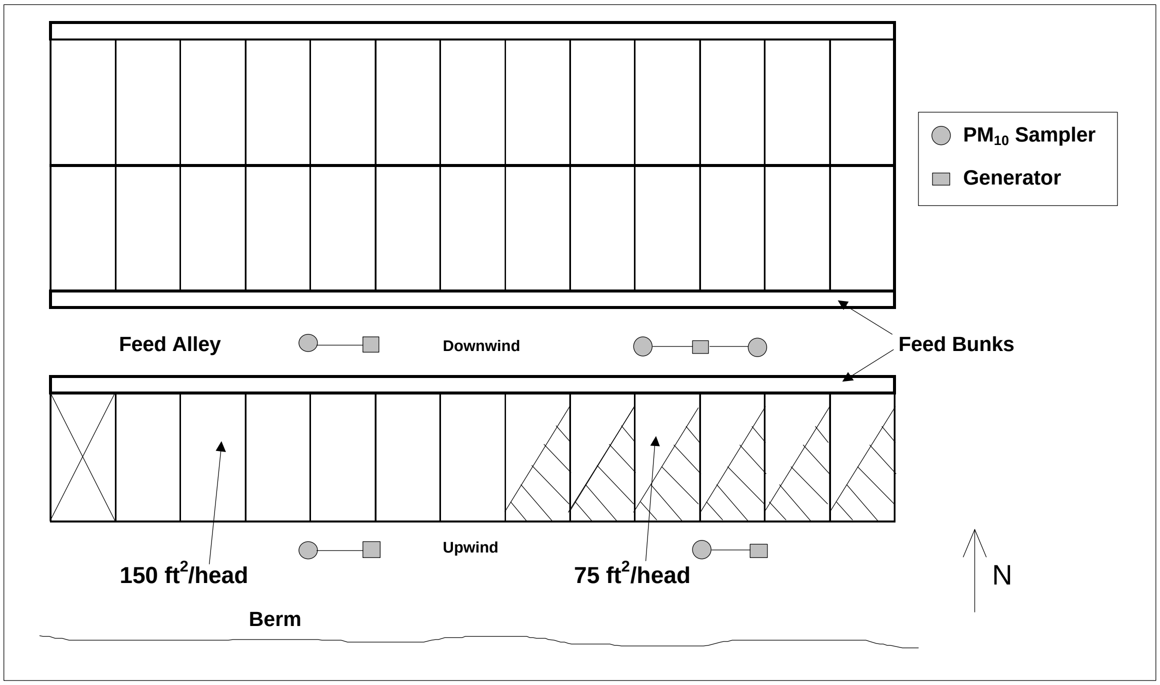

Figure 4. March ’99 Sampler Configuration.