MEMORANDUM

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SUBJECT: RECOMMENDATIONS FOR METHYL BROMIDE BUFFER ZONES FOR FIELD FUMIGATIONS

BACKGROUND

Methyl bromide (other names: bromomethane, monobromomethane, CAS 74-83-9) is a natural product, as well as manufactured synthetically. With a vapor pressure of approximately 2000 torr at 25 degrees Celsius, methyl bromide is a gas at normal pressure and temperature and a liquid under high pressure or at low temperature. It is colorless (a dye is sometimes added) and odorless except at high concentrations. Methyl bromide is primarily used as a pesticide.

The preliminary and final risk characterization by the Department of Pesticide Regulation (DPR) for methyl bromide indicated toxic effects at doses lower than those previously documented (Nelson 1992; Lim 1999). The risk characterization estimated that acute exposure to 0.21 parts per million (ppm, 24-hour time-weighted average) provides a I00-fold margin of exposure (100 times less than the no observed effect level in animal tests). Subsequently, DPR and others conducted off-site and worker air monitoring for methyl bromide field fumigations. Several methyl bromide applications exceeded 0.21 ppm outside the field (Attachment 1). Air concentrations are highly variable, with measured concentrations 30 feet from the field ranging from 0.042-1.1 ppm, plus 1.7 ppm detected 330 feet from the field for one application. Air concentrations vary with numerous factors such as distance from the field, wind speed, wind direction, application rate, field size and dimensions, and method of application.

In 1993, DPR issued recommendations (including buffer zones) to mitigate unacceptable methyl bromide exposure, based on initial monitoring data. DPR has updated its buffer zone and other mitigation recommendations as additional monitoring data was collected. Current buffer zones are set so that air concentrations measured at the specified distance are not likely to exceed 0.21 ppm.

This document explains the general method used by DPR to calculate buffer zones for methyl bromide field applications to mitigate acute (24-hour) exposure. This document also provides the basis for development of the criteria for spatially independent fields and buffer zone duration.

METHYL BROMIDE APPLICATION METHODS

There are a number of methods of applying methyl bromide to agricultural fields, depending on the crop and target pest. Most involve injection beneath the soil surface with tractor-mounted chisels. Several different types of chisels are used and injection depth varies from 6 to 30 inches. Many, but not all, of these application methods also cover the field with a plastic tarpaulin during the injection process. Methyl bromide can be applied to flat fields (broadcast) or to fields with preformed beds. Tarpaulins used for broadcast applications are normally removed several days after fumigation. Tarpaulins used for bed applications normally stay in place throughout the growing season.

GENERAL PROCEDURE FOR DETERMINING BUFFER ZONES

To gain an understanding of how different application techniques affected volatilization rates, DPR and others undertook a series of field monitoring projects to measure offsite air concentrations associated with a variety of different application types (Attachment I). Using the maximum offsite air concentration, DPR employed a "back-calculation" technique to determine the emission (flux) rates for various application types. These flux rates were in turn used to establish buffer zones for various application rates and number of acres, under a set of standardized meteorological conditions.

BACK-CALCULATION OF FLUX RATES

One of the major drawbacks to field monitoring is that it can only determine air concentrations at specific locations at specific times. Extrapolating these data to other locations and times is usually very difficult due to variability in field size, amount of methyl bromide applied, weather, and other factors. To overcome this drawback, DPR uses methyl bromide monitoring data in conjunction with a computer model, the Industrial Source Complex (ISC) model to estimate the flux rate (U.S. EPA 1995). The ISC model simulates air concentrations based on three main factors: 1) characteristics of the pollution source, such as flux rate and dimensions of the field; 2) weather conditions at the time of emission, such as wind speed and wind direction; and 3) terrain over the downwind area, such as urban or rural geography.

It employs the standard Gaussian equation for estimating downwind air concentration:

$$C(x,y,z) = \frac{Qf(uy(x),u_{,}(x))}{3.14u\ u\ y(x)\ u_{,}(x)}$$

where C(x,y,z) is the air concentration in micrograms per cubic meter (μg/m^3) at downwind distance x in meters (m), centerline offset y (m) and height z (m); Q is the emission rate for the field in micrograms per second (μg/s, when normalized by area, the units are μg/m^2s and the term flux is used); fis an empirical adjustment factor, a function ofx,y,z and the standard deviation oflateral (oy, meters, a function ofx) and vertical plume concentration spatial distribution (oz, meters, a function ofx); andμ is the wind speed (mis). An important feature in the Gaussian equation is the proportional relationship between flux and air concentration. Assuming the ISC model provides estimates of offsite air concentrations that are correlated to measured offsite air concentrations, regression or "back-calculation" can be used to adjust an assumed flux rate in order to estimate the actual flux rate. This procedure is described in detail in Johnson et al. (1999). In a test of this procedure, measured flux rates were compared to back-calculated flux values and found to be within a factor of two (Ross et al. 1996).

This back-calculation may not estimate the true flux rate under all conditions. The ISC model does not account for all factors that influence air concentrations, such as diffusion. If the unaccounted factors have little influence on air concentrations, then the back-calculated flux rate is assumed to be close to the true flux rate. But if the unaccounted factors play a major role in air concentrations, then the back-calculated flux rate accounts for the true flux rate plus the other factors. To compare fumigations, DPR expresses the flux rate over the peak 24-hour period as a proportion of the application rate, or "emission ratio."

FLUX RATES AND DESCRIPTIONS OF SPECIFIC APPLICATION METHODS

The back-calculated flux rate for 43 monitored applications is given in Attachment **I,** and summarized in Table 1. The relative flux rates are expressed as the proportion of applied methyl bromide volatilized during the peak 24-hour period, or emission ratio. For example, an emission ratio of0.20 indicates that 20 percent of the applied methyl bromide volatilizes during the 24 hours showing the highest air concentrations. The data show different emission ratios with different application methods. Based on these data, each application method is assigned an emission ratio to determine in part the size of the buffer zone.

The assigned emission ratio is the average emission ratio for the method, rounded to the nearest multiple of 0.05. The assigned emission ratio and standard meteorological conditions are input into the ISC model to determine the size of the buffer zones. The average emission ratio was selected rather than some higher percentile because the average provides the appropriate level of protection (see COMPARISON OF BUFFER ZONE DISTANCE TO MONITORING DATA). In addition, meteorological conditions have an offsetting effect on the flux rate. Meteorological conditions that have higher methyl bromide air concentrations (i.e., low wind speed, stable atmosphere) have lower flux rates (Majewski et al. 1995). Using a "worst-case" emission ratio together with "worst-case" meteorological conditions could cause misleading buffer zone sizes since the two worst-case conditions do not occur simultaneously.

Most of the application methods are described by the depth of injection, type of tarpaulin, and whether the application is to a flat field (broadcast) or preformed beds. Five application methods have adequate data to determine the emission ratio.

The **nontarpaulin/shallow/bed method** consists of rearward-curved or swept-back chisels. The tractor implements include closing shoes and a bed-shaper to seal the channels created by the chisels. This method has an injection depth of 10 to 15 inches, and a chisel spacing of 40 inches. The highest application rate monitored was 200 pounds per acre. Based on the results from three applications, the emission ratio assigned for this method should be 0.40.

The **nontarpaulin/deep/broadcast method** consists of forward-curved chisels. Tractor implements to seal the channels created by the chisels appear to have little effect on flux rates for this method. This method has an injection depth of20 inches, and a chisel spacing of 68 inches. The soil was not disturbed for at least 4 days (96 hours) following completion of the application. The highest application rate monitored was 400 pounds per acre. Based on the results from five applications, the emission ratio assigned for this method should be 0.40.

The **tarpaulin/deep/broadcast method** is similar to the nontarpaulin/deep/broadcast method. The only difference is the use of a tarpaulin. With only one application monitored for this method, the flux rate cannot be determined conclusively. However, it is unlikely that the flux rate exceeds the flux rate for the nontarpaulin method. Therefore, based on the results from one application and its similarity to the nontarpaulin method, the emission ratio assigned for this method should be 0.40.

The **tarpaulin/shallow/broadcast method** includes a Nobel Plow. This plow consists of horizontal v-shaped blades mounted by a vertical arm to the tool bar that inject methyl bromide laterally at a depth of 10 to 15 inches beneath the soil surface. Shovels used to open and close the soil over the leading edge of the tarpaulin are equipped with two conventional vertical chisels on each end of the tool bar. The tarpaulin is laid down simultaneously (with fumigant injection) by tarpaulin-laying equipment mounted on the application tractor. For the monitored fields, the tarpaulin remained in place for at least 5 days. The highest application rate monitored was 400 pounds per acre.

Various types of tarpaulins were monitored with the tarpaulin/shallow/broadcast method. Most were "high barrier" tarpaulins with permeabilities between 5 and 8 milliliters of methyl bromide per hour per square meter per 1000 ppm at 30 degrees Celsius. The most consistent results were obtained with these tarpaulins. Inexplicably, applications monitored with other tarpaulins having lower permeabilities had flux rates equal or exceeding the less permeable tarpaulins. The lower permeability tarpaulins should not be used until these results can be explained. Based on the results from 13 applications using "high barrier" tarpaulins, the emission ratio assigned for this method should be 0.25.

There are several types of **tarpaulin/shallow/bed application methods.** All methods utilize rearward-curved chisels, with an injection depth of 6 to 15 inches. The methods vary with the type of implements used to close the channels created by the chisels. Some use closing shoes and compaction rollers, others use various types of bed shapers. The highest application rate monitored was 250 pounds per acre. Most of these methods appear to have very similar flux rates. Based on the results from nine applications, the emission ratio assigned for this method should be 0.80.

The **drip system-hot gas method** applies methyl bromide through a subsurface drip irrigation system to tarpaulin-covered beds. The flux rates for this system approach I00 percent of the applied methyl bromide. This method should only be used if precautions are taken to avoid leaks in the system. For example, all fittings and emitters should be buried in the soil. All drip tubing and irrigation system connections should be checked for blockage. The tarpaulin should be inspected for tears, holes, or improperly secured edges prior to fumigating. All fittings above ground and outside of the tarpaulin should be pressure tested. All apparent leaks should be eliminated prior to the fumigation. Prior to disconnecting any line containing methyl bromide, the system should be purged of methyl bromide. All disconnected lines leading into the treated field should be secured to prevent gas from escaping. Based on the results from three applications and high potential for leaks, the emission ratio assigned for this method should be 1.0.

STANDARD METEOROLOGICAL CONDITIONS

Based on analysis of two initial methyl bromide studies, DPR chose "standard" weather conditions consisting of C stability, 1.4 mis, 24-hour constant wind speed and 24-hour constant wind direction were used. With these conditions the 24-hour average air concentrations were adequately characterized in two studies. An alternative to using a standard set of weather condition is to use historical weather data from various locations throughout the state of California. The Air Resources Board recommends that Air Pollution Control Districts use this method for permitting stationary sources. This method is arguably a more scientifically sound approach than the current methods. However, developing buffer zone tables using this method will require a substantial investment of staff time and departmental computer resources. In addition, there are several decision points that will require clear, consistent policy determinations before analysis and development of buffer zone tables can be completed.

For this type of analysis, a minimum of five years of weather data from each site is required. A minimum of one site from each area or region in the state where methyl bromide is used is required, in order for the analysis to be considered complete. We would need to determine the boundaries each site represents. The product of this analysis is a table containing required buffer zone lengths for a range of applications rates to fields of various sizes. To obtain these required buffer zone lengths, the ISC model must first be run for combinations of acreage and application rates using the five years of historical weather from each location. Twenty-four hour time weighted average air concentrations surrounding the field on each day are produced. These 24-hour time-weighted average air concentrations can be either a static midnight to midnight time-weighted average (the usual practice), or a running 24-hour time-weighted average. Obtaining a running 24-hour time-weighted average is more difficult and may require additional processing of model output before a buffer zone can be determined. Ultimately, the length of buffer zones required for the same acreage and application rate for each 24-hour period during the five years must be obtained and stored. A distribution of all buffer zone lengths for the five years of data is then assembled. From this distribution of buffer zone lengths, any percentile can be chosen. For example, the 95th percentile buffer zone length is that buffer zone length beyond which air concentrations would not exceed the target level during 95% of all future application events, provided the five years of weather data adequately represents the universe of weather conditions at the site. Choice of the absolute worst-case (longest buffer) versus some percentile (e.g., 95th percentile) is a policy decision that must be made before the table can be developed. Buffer zone tables can be developed for individual regions. It is likely that some counties would have more than one region and buffer zone table, making the regulatory program complex. Alternatively, a statewide, uniform buffer zone table can be developed. Merging of buffer zone distributions from multiple locations can aid in developing a statewide table.

Based upon the current format of the buffer zone tables, the buffer zone table to be developed using these methods has potentially 1600 cells - 1 to 40 acres in one-acre steps and 30 pounds/acre-day to 225 pounds/acre-day flux. Obviously, producing 1600 buffer zone length distributions to fill each cell of a table, potentially for each air basin, represents a substantial effort. Alternatively, a smaller number of cells in this table (or tables) would be filled with modeling results and the remainder of the required buffer zones could be estimated by numerical interpolation. This will be a reasonable solution as long as the changes in buffer zone length with flux rate and acreage can be represented by smooth functions. It is likely that tables for individual air basins would satisfy this requirement. However, it is not clear whether a statewide table could be filled using this method.

EMPIRICAL EQUATIONS

Assuming standard weather conditions, buffer zone size varies with field size and flux rate. As discussed previously, there are 1600 possible buffer zones, based on combinations of field size and flux rate. Rather than modeling all 1600 combinations, the downwind centerline concentrations were fitted with an empirical equation. Buffer zones were calculated utilizing standard weather conditions (constant wind direction for 24 hours, C stability, 1.4 meters/second wind speed) and simulating maximum flux rates for eight selected acreages. The simulations utilized ISC and estimated concentrations at a downwind centerline transect. The resulting concentrations/distance table for each acreage was fit with an empirical function. The function was incorporated into a FORTRAN program, which utilized the function to interpolate values into a table of buffer zones covering I to 40 acres and 30 to 400 pounds/acre-day emissions. These calculations assume that flux rate is proportional to application rate (i.e., doubling the application rate doubles theflux rate).

The ISC (98356) model was utilized to calculate downwind air concentrations for eight different field sizes: 0.8, 3.2, 7.2, 12.8, 20.1, 28.9, 39.3 and 51.4 acres. The resulting downwind distance and concentration functions were fit with function #1498 from TableCurve (Jandel Scientific 1989). This function is

$$y^{1} = a+bx21n(x)+cx^{0\ 5}1n(x)$$

where x = distance (m); y = concentration (µg/m3); a, b, care coefficients that vary with acreage.

This particular function adequately characterized the downwind decline in air concentrations over the range of distances and acreages. For each acreage, the particular coefficients, a,b,c were determined with least squares analysis.

After determining the eight sets of coefficients, a FORTRAN program (Attachment 2) was written that utilized the eight empirical functions in combination with a cubic spline interpolation routine to determine the buffer zone distance for each tabulated flux rate. A series of 24 values covering the table were compared to simulated values and found to be within 2%. The determination of the empirical equations is explained in detail in Attachment 2.

CREATION OF BUFFER ZONE TABLE

The empirical equation derived above was used to calculate the distance to 0.21 ppm for field sizes of 1 to 40 acres, and flux rates of 30 to 400 pounds per acre-day (Table 1). The 40-acre and 400 pounds per acre limits were chosen because these were the largest field and application rates monitored (Attachment 1). As discussed previously, each application method is assigned an emission ratio, or proportion of applied methyl bromide volatilized in 24 hours. The relationship between the absolute flux rate and emission ratios is shown by the following equation:

application rate x emission ratio = absolute flux rate

Buffer zone tables can be created **in** two ways. One way is to use Table 1 (which lists the absolute flux rates) and look up the appropriate buffer zone by multiplying the application rate by the emission ratio assigned to the method. A second way is to create separate buffer zone tables for each application method by dividing the emission ratio into the absolute flux rates listed **in** Table 1. The buffer zone is then determined by looking up the application rate. The first method handles multiple application methods more efficiently. The second method is simpler to use since no calculations are necessary. The buffer zones described here are the distance at which 0.21 ppm for 24 hours is unlikely to occur. These buffer zones are appropriate for residents and other people who may be near fumigations for 24 hours.

People who are near fumigations for a shorter period of time, such as workers can have equivalent safety with shorter buffer zones. The 0.21 ppm target level is a 24-hour time-weighted average. If exposure is limited to 12 hours, the equivalent target level is 0.42 ppm. Buffer zones for a 12-hour exposure are shown in Table 2.

COMPARISON OF BUFFER ZONE DISTANCE TO MONITORING DATA

To evaluate the safety provided by the buffer zones, the buffer zone table distance was compared to the distance to 0.21 ppm for each monitored field. The furthest distance to 0.21 ppm for each field was determined by using the measured air concentrations and onsite meteorological data specific to each field, and the ISC model. The back-calculated flux rate, specific field dimensions, and onsite weather data were input into the ISC model. Details of this procedure are described in Johnson, et al. (1999). For the 43 applications for which the back-calculation can be done, 34 used recommended application methods (9 applications used very high barrier or virtually impermeable tarpaulins that are not recommended). The buffer zone table distance was greater than the distance to 0.21 ppm estimated by the ISC model for 33 of the 34 applications. On average, the buffer zone table distance exceeded the distance to 0.21 ppm by 520%, with a median of 400% (Table 3). We made these calculations when the monitoring data were originally analyzed, using unadjusted air concentrations and the first version of the ISC model. DPR is updating these calculations using the adjusted air concentrations and version 3 of the ISC model.

CRITERIA FOR INDEPENDENT FIELDS

Determining the criteria for independent fields is important to develop requirements for nearby, same-day treatments. The basis for these criteria is composed of two components: 1) a computer simulation analysis of two 40 acre fields at a distance of 1300 feet apart (1/4 mile), chosen because that distance was familiar to county agricultural commissioners; and 2) an analysis of wind direction data from seven counties where methyl bromide principally was used. DPR used the wind direction data to quantify the probability of interaction between two fields.

In the computer simulations, two 40-acre fields were placed 1300 feet apart (396m) from edge to edge, aligned on a north-south line. Each field consisted of sixteen, I 00 m x 100 m subsources. The wind direction was set successively at 360, 350, 340, 330, 320, 310 degrees. Meteorological conditions were C stability and wind speed at 1.4 *mis*. The flux rate was set at I00 $\mu g/m^2s$. At 330 degrees, the buffer zone for the northern field ceased to be influenced by the emissions from the southern field. Therefore, wind blowing either north or south in ±30 degree sector from a north-south alignment would cause the buffer zones based on an isolated field to be inadequate because plume additivity would lengthen the needed buffer zone from the downwind edge of the downwind field. For two 40-acre fields on a north-south alignment and 1300 feet apart, wind blowing towards 210 to 330 degrees or towards 30 to 150 degrees would cause no interaction between the downwind plumes originating from the two fields.

Wind direction probabilities. The 1990 pesticide use report was used to determine counties with the largest methyl bromide use.. The seven largest counties were San Joaquin, Monterey, Santa Barbara, Tulare, Fresno, Ventura and Kem. Within each of these counties, one-year period of meteorological data was obtained from California Irrigation Management Information System (CIMIS) stations. Not all stations were able to provide a full year. The data obtained was as follows:

CIMIS Station	County	Dates of data
042	San Joaquin	11/91-10/92 (missing most of 8/92)
037	Monterey	10/91-7/92 (missing 8,9/92 -2 mos)
064	Santa Barbara	11/91-10/92 (missing 4 days 10/92)
086	Tulare	11/91-10/92 (missing 2 days 10/92)
002	Fresno	10/91-9/92
101	Ventura	10/91-9/92
093	Kem	10/91-9/92

A computer program was written which analyzed each day of wind direction and determined what the maximum angular difference was between those directions. A histogram was created in increments of 10 degrees, from O to 360 degrees and a cumulative histogram was produced for each station which indicated the fraction of days which had less than or equal to a given wind direction variation during the day. Of the seven stations, the maximum value for 60 degrees was Ventura, with a figure of37 days ourof366, since this included a leap year.

Calculation. The final calculation brings together these data to estimate the probability that two 40-acre fields at a 1300-foot separation would interact. Amongst the seven counties studied, for 1991-92 the probability that the wind direction for an entire day varies by less than 60 degrees is no more than 37/366=0.10. The probability with reference to a given wind direction, that two fields are located within a 60 degree sector of each other is 60/360=0.17. The probability that the two fields will interact is then (0.10)(0.17)(2)=0.034. The factor "two" in the equation arises from the two possible ways of arranging the fields within the 60 degree sector *(i.e.* wind could blow north or south). Therefore, given two 40 acre fields separated by 1300 feet and using the standard conditions, the probability that the buffer zone would be inadequate is 3.4% in Ventura, the worst case county.

BUFFER ZONE DURATION

Peak concentrations and flux rates ge_nerally occurred during the first 36-hour period from start of application (Table 4). Buffer zones based on that peak must remain in place some period of time following application as volatilization diminishes. Using the decrease in flux rates over time and the standard weather conditions described above, no buffer zone is necessary two to three days following fumigation, depending on the method of application. In other words, air concentrations are less than 0.21 ppm at the edge of the treated area, as;mming standard weather conditions, and the flux rate two or three days following fumigation. Flux rates are higher during tarpaulin removal in comparison to the day before tarpaulin removal, generally five to six days following fumigation. However, air concentrations are less than 0.21 ppm at the edge of the treated area, assuming standard weather conditions and the flux rate during tarpaulin removal. Based on this analysis, the recommended buffer zone duration is three days following the start of fumigation, or approximately 60 hours following the end of fumigation.

BUFFER ZONE DEFINITION AND DISCUSSION

The proposed buffer zone sizes, measurement, and duration are described in detail and very rigid. The specificity and precision of the buffer zone requirements are necessary for enforcement (i.e., to determine compliance). However, air concentrations vary with numerous factors. Some of these factors may provide the opportunity to adjust the buffer zones for local conditions. The buffer zone size is a fixed distance for any given application rate, number of acres, and application method. The fixed buffer zone sizes are used to set a standard for enforcement. The fixed buffer zone sizes do not imply fixed or constant air concentration. There is a general relationship between distance and concentration, with lower concentrations at farther distances. However, air concentrations at the buffer zone distance are variable. The buffer zone distance cannot be used as a surrogate for estimating air concentrations. For example, if the buffer zone distance is 200 feet, this does not mean that the air concentration is always 0.21 ppm at 200 feet. In fact, air concentrations should be less than 0.21 ppm almost all of the time at the buffer zone distance. Similarly, if someone is 190 feet away from the application, this does not mean that he/she will be exposed to a harmful amount of methyl bromide.

The buffer zone depends on two main factors, the flux rate and weather conditions. The flux rate was determined from 43 monitored fumigations. Most if not all of the monitored fumigations appeared to be high quality applications, with the tarpaulins remaining intact, few methyl bromide leaks, correct calibration, etc. Methods of application that are different from those monitored, may have a higher or lower flux rate than anticipated.

DPR chose "conservative" weather conditions to determine the size of the buffer zones. These weather conditions may not be appropriate for all regions of California at all times. Monitoring was conducted in several areas during several seasons, so that most regional and seasonal differences should be accounted for. However, detailed evaluation of historical weather data may show regional or seasonal differences that would lead to higher or lower air concentrations than currently estimated. Height of inversion layers was not measured for any of the studies. The ISC model indicates that an inversion of 100 feet or less will cause higher methyl bromide air concentrations.

The buffer zone is not an exclusion zone meant to prohibit entry throughout the buffer zone duration. People may spend short periods of time inside the buffer zone and not exceed an exposure of0.21 ppm, as a 24-hour average. Since 0.21 ppm is a time-weighted average, the equivalent concentration increases linearly as the duration of exposure decreases. For example, 0.21 ppm for 24 hours is equivalent to 0.42 ppm for 12 hours, or 5 ppm for 1 hour. The buffer zone is measured to the property line to provide a common benchmark for enforcement. In reality, people rarely spend 24 hours near property lines. Similarly, if the adjoining property is another agricultural field, pasture, or other area where people spend little time, the property line may be an inappropriate benchmark for the buffer zone distance.

Monitoring data shows that the peak air concentrations for methyl bromide occur within 24 - 36 hours of the start of application, and decline over several days. Buffer zones distances are established for 60 hours, based on the peak 24-hour air concentration. The buffer zone distance is fixed for 60 hours primarily for ease of enforcement. A shorter buffer distance would provide equivalent protection during the latter parts of the time period.

Buffer zone distances are based on the highest downwind air concentrations. Air concentrations in the upwind direction are much lower than the downwind direction. However, since methyl bromide continues to volatilize for several days, it is problematic to establish different buffer zone distances in different directions. Once methyl bromide is applied, volatilization cannot be stopped. If the wind direction changes because of diurnal variation or other changes in weather conditions, the upwind direction during fumigation may be the downwind direction several hours or days after fumigation.

MINIMUM BUFFER ZONES AND SENSITIVE AREAS

The data show that 0.21 ppm is not exceeded even with no buffer zone in some cases, using both empirical data and computer modeling. While the data may support no buffer in some cases, a minimum buffer or a larger buffer for "sensitive areas" should be required for several reasons. 1) *Flux Variability Within Field:* We assume that flux rate is the same across the entire field. It is likely that variation in soil type, tarpaulin permeability, leaks in the tarpaulin, application method, etc. cause variation in the flux within a field; some areas have lower flux, some areas have higher flux. We have no estimate as to the variation of the flux magnitude within a field, or the size of the areas that may have a higher flux rate. If there are significantly large areas with higher flux rates within a field, a larger buffer zone may be necessary. It is likely that the flux variability has greater impact on smaller fields in comparison to larger fields. For example, if a two-acre field has an area 100 x 100 feet with twice the normal flux rate this comprises 11 percent of the field. A 20-acre field with an area I 00 x 100 feet with high flux only comprises only one percent of the field; 2) *Diffusion and Other Unaccounted Factors:* The ISC model calculates the methyl bromide.air concentration based solely on air movement. If wind speed is zero, the ISC model cannot predict air concentrations. For a few monitored fields, wind speed was zero for long periods of time and the ISC model did not match the monitoring data, and a flux rate could not be determined (Attachment 1). If wind speed is near zero, diffusion may have a significant role in determining air concentrations and could cause higher than expected air concentrations near the edge of the field. Other factors unaccounted for by the ISC model may also effect air concentrations, such as swirling winds. The effect of flux variability and diffusion on air concentrations cannot be quantified with the available data; 3) *Receptor Height:* Monitoring data and the ISC model indicate that air concentrations vary with height or vertical distance above the field; the air concentration decreases with increasing height. This effect is more pronounced if the horizontal distance from the field is small. All monitoring and modeling is conducted at a height of four feet. Exposure may be higher than indicated by the data for small children or kneeling workers, especially if they are close to the field.

The buffer zones can be minimized by limiting the application rate and number of acres fumigated. In addition, the monitoring data indicate that the lowest air concentrations are associated with broadcast applications and a normal high barrier tarpaulin (method 5 in the permit conditions) conducted during non-winter months in coastal areas. This specific type of application can be used where sensitive areas are nearby. The permit conditions include a separate table for these types of fumigations. Since the data indicate that no buffer zone is necessary, whether this table should lie retained or not is a policy decision.

CHANGES FROM PERMIT CONDITIONS

DPR issued suggested permit conditions for methyl bromide field fumigations to county agricultural commissioners in 1993. The county agricultural commissioners use the suggested permit conditions as a guide to modify the restricted materials permits within their jurisdiction.

The suggested permit conditions have been updated several times to incorporate data from additional monitoring. The permit conditions form the foundation of these recommendations for statewide regulations. However, there are some significant differences between the permit conditions and these recommendations. Table 5 summarizes the changes for buffer zones.

Application Method Changes. The recommended application methods have been reorganized. Some methods have been dropped and others have been combined. Some methods have been combined for buffer zone purposes. However, they may remain separate because of worker safety requirements.

As shown in Table 4, the following methods should no longer be used: 1.1, 7, 8, 8.1, and 11.1. Methods 1.1, 7, and 8 employ a "winged chisel" and may be significantly different from other application methods. No monitoring data is available for methods using a winged chisel. Methods 8.1 and 11.1 use a "very high barrier" tarpaulin. There is conflicting monitoring data for these methods, some show lower air concentrations and others show higher air concentrations in comparison with the standard "high barrier" tarpaulin. These methods should not be used until the monitoring data are more conclusive.

In terms of buffer zone requirements, the monitoring indicates little if any difference between some methods. These methods have been combined for buffer zone purposes. All non-tarpaulin and deep injection methods (Methods 1, 2, 3, 11, 11.2) have been combined for buffer zone purposes. Monitoring data for the non-tarpaulin methods (Methods 1, 2 and 3) are very similar. There is little or no data for the deep injection methods with tarpaulins (Methods 11 and 11.2). However, it is likely that air concentrations for tarpaulin methods are no higher than methods without a tarpaulin. This is a change from the permit conditions when it was assumed that air concentrations from deep injections with a tarpaulin (Methods 11 and 11.2) were the same as shallow injections with a tarpaulin (Methods 4 and 5). Reevaluation of the method descriptions shows that Methods 11 and 11.2 are more similar to Methods 2 and 3, rather than Methods 4 and 5.

The only difference between Methods 4 and 5 was worker safety requirements. These methods have been combined for buffer zone purposes.

The monitoring data for tarpaulin/shallow/bed methods (9, 9.1, 10) are very difficult to interpret. Recent monitoring data shows that most, if not all, tarpaulin/shallow/bed fumigation methods have higher flux rates than broadcast methods. The data comparing different bed fumigation methods is much less conclusive. There are significant differences in the injection methods and fumigation equipment. However, these method differences may or may not make a difference in air concentrations. Until more conclusive data can be collected, these methods should be combined.

Recovery Adjustment. As discussed in Attachment I, the flux rates have been adjusted for the sampling and analytical recovery documented in Biermann and Barry (1999). The suggested permit conditions employed a partial·recovery adjustment based on standard laboratory quality control analyses. In general, the suggested permit conditions are based on a recovery of 70 - 80 percent, the regulations are based on a recovery of 50 percent.

Attachments

REFERENCES

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Table1. Methylbromidebufferzonetablefor24-hourexposure

	Flux Rate(pounds/acre-day)														
Acres	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
1	100	100	100	JOO	100	JOO	100	100	110	110	110	120	130	140	150
2	JOO	JOO	100	JOO	100	JOO	110	120	130	150	160	170	190	210	230
3	JOO	JOO	JOO	JOO	100	100	120	140	160	180	200	230	250	270	290
4	JOO	100	100	100	JOO	110	140	160	190	220	240	270	300	330	350
5	JOO	JOO	100	100	110	120	150	180	210	250	280	310	340	370	400
6	100	JOO	JOO	100	120	140	170	210	240	270	310	340	370	410	440
7	JOO	JOO	JOO	100	130	160	190	230	260	300	330	370	410	440	480
8	JOO	JOO	JOO	110	140	180	210	250	280	320	360	400	440	480	510
9	100	100	100	120	150	190	230	270	300	340	380	420	470	510	550
JO	JOO	100	JOO	120	160	200	240	280	320	370	410	450	500	540	580
11	100	JOO	100	130	170	210	260	300	340	390	430	480	520	570	620
12	JOO	100	110	140	180	220	270	310	360	410	450	500	550	600	650
13	100	JOO	110	150	190	230	280	330	380	430	480	530	580	630	680
14	100	100	IJO	160	200	240	290	340	390	440	500	550	600	660	710
15	100	100	120	160	210	250	300	350	410	460	520	570	630	680	740
16	100	100	120	170	210	260	310	370	420	480	540	590	650	710	770
17	JOO	100	130	180	220	270	330	380	440	500	550	610	670	730	790
18	JOO	100	130	180	230	280	340	390	450	510	570	630	700	760	820
19	100	100	140	190	240	290	350	410	470	530	590	650	720	780	840
20	JOO	JOO	140	190	240	300	360	420	480	540	610	670	740	800	870
21	JOO	100	150	200	250	310	370	430	490	560	620	690	760	820	890
22	JOO	100	150	200	260	320	380	440	510	570	640	710	780	850	920
23	100	110	160	210	270	330	390	450	520	590	660	730	800	870	940
24	JOO	110	160	210	270	330	400	470	530	600	670	750	820	890	960
25	JOO	110	170	220	280	340	410	480	550	620	690	760	840	910	980
26	100	120	170	220	290	350	420	490	560	630	710	780	860	930	1000
27	JOO	120	170	230	290	360	430	500	570	650	720	800	870	950	1000
28	JOO	120	180	240	300	370	440	510	580	660	740	810	890	970	1100
29	JOO	130	180	240	310	370	450	520	600	670	750	830	910	990	llOO
30	JOO	130	180	250	310	380	450	530	610	690	770	850	930	1000	1100
31	100	130	190	250	320	390	460	540	620	700	780	860	950	I000	1100
32	JOO	140	190	260	320	400	470	550	630	710	800	880	960	1000	1100
33	JOO	140	200	260	330	400	480	560	640	730	810	900	980	1100	1200
34	JOO	140	200	270	340	410	490	570	650	740	820	910	1000	1100	1200
35	JOO	140	200	270	340	420	500	580	660	750	840	930	1000	1100	1200
36	100	150	210	270	350	420	510	590	680	760	850	940	1000	llOO	1200
37	JOO	150	210	280	350	430	510	600	690	770	870	960	1000	1l00	1200
38	JOO	150	210	280	360	440	520	610	700	790	880	970	1100	1200	1300
39	100	150	220	290	360	440	530	620	710	800	890	990	1100	1200	1300
40	JOO	150	220	290	370	450	540	630	720	810	900	1000	1100	1200	1300

Table 1. continued

Acres	Flux Rate (pounds/acre-day) 105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
1	170	180	190	200	210	220	240	250	260	270	280	290	300	3 JO	320
2	240	260	280	290	310	330	350	360	380	390	410	430	440	460	470
3	320	340	360	380	410	430	450	470	490	510	530	550	570	590	610
4	380	410	430	460	490	510	540	560	590	610	640	660	690	710	730
5	430	460	490	520	550	580	610	640	670	700	720	750	780	810	830
6	480	510	540	580	610	640	670	700	740	770	800	830	860	890	920
7	520	550	590	620	660	690	730	760	800	830	860	900	930	960	990
8	550	590	630	670	710	750	780	820	860	890	930	960	1000	1000	1100
9	590	630	670	710	760	800	840	870	910	950	990	1000	1100	1100	1100
10	630	670	720	760	800	840	890	930	970	1000	1000	1100	1100	1200	1200
11	660	710	760	800	850	890	940	980	1000	1100	1100	1200	1200	1200	1300
12	700	750	800	840	890	940	990	1000	1100	1100	1200	1200	1300	1300	1300
13	730	780	830	880	930	980	1000	1100	1100	1200	1200	1300	1300	1400	1400
14	760	820	870	920	970	1000	1100	1100	1200	1200	1300	1300	1400	1400	1500
15	790	850	900	960	1000	1100	1100	1200	1200	1300	1300	1400	1400	1500	1500
16	820	880	940	990	1000	1100	1200	1200	1300	1300	1400	1400	1500	1500	1600
17	850	910	970	1000	1100	1100	1200	1300	1300	1400	1400	1500	1500	1600	1600
18	880	940	1000	1100	1100	1200	1200	1300	1400	1400	1500	1500	1600	1600	1700
19	910	970	1000	1100	1200	1200	1300	1300	1400	1400	1500	1600	1600	1700	1700
20	930	1000	1100	1100	1200	1200	1300	1400	1400	1500	1500	1600	1700	1700	1800
21	960	1000	1100	1200	1200	1300	1300	1400	1500	1500	1600	1700	1700	1800	1800
22	980	1100	1100	1200	1300	1300	1400	1400	1500	1600	1600	1700	1800	1800	1900
23	1000	1100	1100	1200	1300	1400	1400	1500	1500	1600	1700	1700	1800	1900	1900
24	1000	1100	1200	1200	1300	1400	1500	1500	1600	1700	1700	1800	1800	1900	2000
25	1100	1100	1200	1300	1300	1400	1500	1600	1600	1700	1800	1800	1900	1900	2000
26	1100	1200	1200	1300	1400	1400	1500	1600	1700	1700	1800	1900	1900	2000	2100
27	1100	1200	1300	1300	1400	1500	1600	1600	1700	1800	1800	1900	2000	2000	2100
28	1100	1200	1300	1400	1400	1500	1600	1700	1700	1800	1900	1900	2000	2100	2100
29	1200	1200	1300	1400	1500	1500	1600	1700	1800	1800	1900	2000	2100	2100	2200
30	1200	1300	1300	1400	1500	1600	1600	1700	1800	1900	1900	2000	2100	2200	2200
31	1200	1300	1400	1400	1500	1600	1700	1800	1800	1900	2000	2100	2100	2200	2300
32	1200	1300	1400	1500	1500	1600	1700	1800	1900	1900	2000	2100	2200	2200	2300
33	1200	1300	1400	1500	1600	1700	1700	1800	1900	2000	2100	2100	2200	2300	2400
34	1300	1300	1400	1500	1600	1700	1800	1900	1900	2000	2100	2200	2200	2300	2400
35	1300	1400	1500	1500	1600	1700	1800	1900	2000	2000	2100	2200	2300	2400	2400
36	1300	1400	1500	1600	1700	1700	1800	1900	2000	2100	2200	2200	2300	2400	2500
37	1300	1400	1500	1600	1700	1800	1900	1900	2000	2100	2200	2300	2400	2400	2500
38	1300	1400	1500	1600	1700	1800	1900	2000	2100	2100	2200	2300	2400	2500	2500
39	1400	1500	1500	1600	1700	1800	1900	2000	2100	2200	2300	2300	2400	2500	2600
40	1400	1500	1600	1700	1800	1800	1900	2000	2100	2200	2300	2400	2500	2500	2600

Table 1. continued

	Flux Rate (pounds/acre-day)									
Acres	180	185	190	195	200	205	210	215	220	225
1	330	350	360	370	380	390	400	400	410	420
2	490	500	520	530	550	560	570	590	600	620
3	630	650	670	690	710	730	750	760	780	800
4	760	780	800	830	850	870	890	910	930	950
5	860	890	910	940	960	990	1000	1000	1100	1100
6	950	970	1000	1000	1100	1100	1100	1100	1200	1200
7	1000	1100	1100	1100	1100	1200	1200	1200	1300	1300
8	1100	1100	1200	1200	1200	1300	1300	1300	1400	1400
9	1200	1200	1200	1300	1300	1300	1400	1400	1400	1500
10	1200	1300	1300	1400	1400	1400	1500	1500	1500	1600
11	1300	1400	1400	1400	1500	1500	1500	1600	1600	1600
12	1400	1400	1500	1500	1500	1600	1600	1700	1700	1700
13	1400	1500	1500	1600	1600	1700	1700	1700	1800	1800
14	1500	1600	1600	1600	1700	1700	1800	1800	1800	1900
15	1600	1600	1700	1700	1700	1800	1800	1900	1900	2000
16	1600	1700	1700	1800	1800	1900	1900	1900	2000	2000
17	1700	1700	1800	1800	1900	1900	2000	2000	2100	2100
18	1700	1800	1800	1900	1900	2000	2000	2100	2100	2200
19	1800	1800	1900	1900	2000	2000	2100	2100	2200	2200
20	1800	1900	1900	2000	2000	2100	2100	2200	2200	2300
21	1900	1900	2000	2000	2100	2200	2200	2300	2300	2400
22	1900	2000	2000	2100	2200	2200	2300	2300	2400	2400
23	2000	2000	2100	2200	2200	2300	2300	2400	2400	2500
24	2000	2100	2100	2200	2300	2300	2400	2400	2500	2500
25	2100	2100	2200	2300	2300	2400	2400	2500	2500	2600
26	2100	2200	2200	2300	2400	2400	2500	2500	2600	2700
27	2200	2200	2300	2400	2400	2500	2500	2600	2700	2700
28	2200	2300	2300	2400	2500	2500	2600	2600	2700	2800
29	2300	2300	2400	2500	2500	2600	2600	2700	2800	2800
30	2300	2400	2400	2500	2600	2600	2700	2800	2800	2900
31	2300	2400	2500	2500	2600	2700	2700	2800	2900	2900
32	2400	2500	2500	2600	2700	2700	2800	2900	2900	3000
33	2400	2500	2600	2600	2700	2800	2800	2900	3000	3000
34	2500	2500	2600	2700	2800	2800	2900	3000	3000	3100
35	2500	2600	2700	2700	2$00	2900	2900	3000	3100	3100
36	2500	2600	2700	2800	2800	2900	3000	3100	3100	3200
37	2600	2700	2700	2800	2900	3000	3000	3100	3200	3200
38	2600	2700	2800	2900	2900	3000	3100	3100	3200	3300
39	2700	2700	2800	2900	3000	3000	3100	3200	3300	3300
40	2700	2800	2900	2900	3000	3100	3200	3200	3300	3400

Table 2. Methyl bromide buffer zone table for 12-hour exposure

	Flux Rate (pounds/acre-day)														
Acres	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
1	50	50	50	50	50	50	60	70	80	90	100	120	130	140	150
2	50	50	50	50	60	70	90	100	120	140	150	170	190	210	230
3	50	50	50	60	80	100	120	140	160	180	200	220	250	270	290
4	50	50	60	70	100	.120	140	170	190	220	240	270	300	320	350
5	50	50	60	90	110	130	160	190	220	250	280	310	340	370	400
6	50	50	70	100	120	150	180	210	240	270	310	340	370	410	440
7	50	50	80	100	130	160	200	230	260	300	330	370	400	440	480
8	50	60	80	110	140	180	210	250	280	320	360	400	430	470	510
9	50	60	90	120	150	190	230	260	300	340	380	420	460	510	550
10	50	70	100	130	160	200	240	280	320	360	410	450	490	540	580
11	50	70	100	140	170	210	250	300	340	380	430	480	520	570	620
12	50	70	110	140	180	220	270	310	360	400	450	500	550	600	650
13	50	80	110	150	190	230	280	330	370	420	470	520	580	630	680
14	50	80	120	160	200	240	290	340	390	440	490	550	600	650	710
15	50	80	120	160	210	250	300	350	410	460	510	570	630	680	740
16	50	90	130	170	210	260	310	370	420	480	530	590	650	710	760
17	60	90	130	170	220	270	320	380	440	490	550	610	670	730	790
18	60	90	130	180	230	280	340	390	450	510	570	630	690	750	820
19	60	100	140	190	240	290	350	400	460	530	590	650	710	780	840
20	60	100	140	190	240	300	360	420	480	540	600	670	740	800	870
21	60	100	150	200	250	310	370	430	490	560	620	690	760	820	890
22	70	110	150	200	260	310	380	440	500	570	640	710	780	850	910
23	70	110	160	210	260	320	390	450	520	590	650	730	800	870	940
24	70	llO	160	210	270	330	390	460	530	600	670	740	820	890	960
25	70	110	160	220	280	340	400	470	540	610	690	760	840	910	990
26	70	120	170	220	280	350	410	480	550	630	700	780	850	930	1000
27	80	120	170	230	290	350	420	490	570	640	720	800	870	950	1000
28	80	120	170	230	300	360	430	500	580	660	730	810	890	970	1100
29	80	130	180	240	300	370	440	520	590	670	750	830	910	990	llOO
30	80	130	180	240	310	380	450	530	600	680	760	850	930	1000	1100
31	80	130	190	250	310	390	460	540	620	700	780	860	950	1000	llOO
32	80	130	190	250	320	390	470	550	630	710	790	880	960	1000	1100
33	90	140	190	260	330	400	480	560	640	720	810	890	980	llOO	1200
34	90	140	200	260	330	410	490	570	650	740	820	910	1000	1100	1200
35	90	140	200	270	340	420	500	580	660	750	840	930	1000	1100	1200
36	90	140	210	270	350	420	500	590	680	760	850	940	1000	llOO	1200
37	90	150	210	280	350	430	510	600	690	780	870	960	1000	1100	1200
38	90	150	210	280	360	440	520	610	700	790	880	970	1100	1200	1200
39	90	150	220	290	360	440	530	620	710	800	890	980	1100	1200	1300
40	100	150	220	290	370	450	540	630	720	810	900	1000	1100	1200	1300

Table 3. Comparison of methyl bromide buffer zones to monitoring data

Application Monitored and Study ID'	Bed/ Broadcast	Tarpaulinb	Chisel Type'	Injection Depth	Applic Rate (lb/ac)	Acres	Distance to 0.21 ppm, Unadjusted Recovery (ft)	Buffer Zone, Unadjusted Recovery (ft)
1:SEI.I	Bed	None	Rearward	12	186	19	290	390
2: SEl.2	Bed	None	Rearward	12	180	15	190	330
3: SEl.3/EHI27-2	Bed	None	Rearward	12	180	15	240	330
4: SE2.2	Broadcast	None	Forward	20	396	15"	770	1170
5: EHl64-7	Broadcast	None	Forward	20	348	33	60	1540
6: Sl04.2-1	Broadcast	None	Forward	24	396	40	1710	2010
7: SIOOBl.l	Broadcast	None	Forward	24	400	20	190	940
8: SI JO.I	Broadcast	None	Forward	24	450	7	50	780
9: TCl99	Broadcast	HB	Nobel Plow	12	396	20	470	590
10: EHl27-l	Broadcast	HB	Nobel Plow	12	235	10	<10	100
11: EHl50-6	Broadcast	HB	Nobel Plow	12	200	10	<30	50
12: EHl63-2	Broadcast	HB	Nobel Plow	12	180	9	<20	90
13: EHl64-5	Broadcast	HB	Nobel Plow	12	205	12	<20	220
14: EHl64-IOA	Broadcast	HB	Nobel Plow	12	231	I	<IO	50
15: EHl64-IOC	Broadcast	HB	Nobel Plow	12	234	I	<10	50
16: EHl64-IOE	Broadcast	HB	Nobel Plow	12	231	I	<10	50
17: EHl64-IOG	Broadcast	HB	Nobel Plow	12	226	I	<10	50
18: TC324.l	Broadcast	HB	Nobel Plow	12	216	5	<10	50
19: EHl63-4	Broadcast	HB	Nobel Plow	12	214	2	<IO	50
20: BR787.IA	Broadcast	HB	Nobel Plow	12	186	I	<10	100
21: BR787.2A	Broadcast	HB	Nobel Plow	12	178	I	<10	100
22: SIIOFI	Bed	HB	Rearward	6	256	9	<10	110
23: EHl64-2	Bed	HB	Rearward	6	160	4	90	130
24: EH 164-11	Bed	HB	Rearward	6	206	9	310	430

Table 3.continued

Application Monitored and Study ID'	Bed/ Broadcast	Tarpaulinb	Chisel Type'	Injection Depth	Applic Rate (lb/ac)	Acres	Distance to 0.21 ppm, Unadjusted Recovery (ft)	**Buffer Zone,** Unadjusted Recovery (ft)
25: BR787.IB	Bed	HB	In	6	177		<IO	100
26: BR787.IC	Bed	HB	Ahead	6	176		<IO	100
27: BR787.2B	Bed	HB	Ahead	6	245		I IO	140
28: BR787.2C	Bed	HB	In	6	174		140	100
29: EH150-2	Bed	HB	Rearward	6	200	20	990	1430
30: EH164-6	Bed	HB	Rearward	6	196	16	620	1260
31: TC203	Broadcast	HB	Forward	20	405	7	30	810
32: EH150-1	Bed	HB	Drip Tubing		200	25	740-1020	2590
33: EHl50-3	Bed	HB	Drip Tubing		200	14	260	1870
34: EHl50-4	Bed	HB	Drip Tubing		200	14	730	1870

Table 4. Emission Ratios Over Time.

Hours After Start of Fumigation	Emission Ratio		
	No Tarpaulin	Broadcast Tarpaulin	Bed Tarpaulin
0-24	0.369	0.240	0.803
24-48	0.316	0.205	0.099
48-72	0.146	0.095	0.037
72-96	0.071	0.047	0.018
96-120	0.038	0.025	0.011
120-144	0.021	0.014	0.007
144- 168	0.013	0.008	0.005