Department of Pesticide Regulation

Brian R. Leahy
Director

Edmund G. Brown Jr.
Governor

M E M O R A N D U M
APPENDIX 4

TO: Randy Segawa
Environmental Program Manager I
Environmental Monitoring Branch

Original signed by Randy Segawa
for

FROM: Terrell Barry, Ph.D.
Research Scientist III
Environmental Monitoring Branch
916-324-4140

DATE: March 26, 2013

SUBJECT: DEVELOPMENT OF CHLOROPICRIN BUFFER ZONES

I. Background

The Department of Pesticide Regulation (DPR) completed a Risk Characterization Document (RCD) for chloropicrin as a toxic air contaminant (TAC) in February 2010. Focusing on residents and bystander exposure, the RCD assessed the health risk of chloropicrin based on evaluations of toxicology studies, and exposure estimates from air monitoring, computer modeling, and other data. In December 2010, DPR issued a Risk Management Directive that identified some unacceptable exposures in the RCD, and directing staff to develop use restrictions. DPR's Risk Management Directive determined that the primary effect observed with acute exposure to chloropicrin is sensory irritation, and the appropriate regulatory target level to restrict acute exposure to chloropicrin is 73 ppb or 0.073 ppm averaged over an eight-hour period. As with other fumigants, a key element in mitigating exposure is establishing a buffer zone between a fumigated area and residents and bystanders.

Label revisions for chloropicrin products developed by the U.S. Environmental Protection Agency (U.S. EPA) went into effect in December 2012 (Phase 2 labels). One of the main mitigation measures employed on the new labels is buffer zones. On the Phase 2 labels, U.S. EPA presents for each particular use scenario a main buffer zone table containing buffer zones of maximum length, then gives buffer zone credits of up to 80% to reduce the size of a buffer zone. Those credits are applied directly to the buffer zone distance, not to the flux used to generate the buffer zone. U.S. EPA allows the credits for the following factors: tarp type, organic matter, clay content, soil temperature, Symmetry System, potassium thiosulfate (KTS), and water seal applied over the tarp. The DPR mitigation measures may differ from the U.S. EPA approach. For example, the credits for organic matter, clay content, and soil temperature may be difficult to enforce. Thus, those factors may not be allowed in California at this time unless an enforcement strategy is developed. Flux reduction from the Symmetry System should be reflected in its lower application rate, so additional credit is not warranted and this fumigation rig is not currently used in California.

This memorandum presents chloropicrin field data analysis performed to provide a basis for California buffer zone development. In addition, preliminary buffer zones are presented. Supporting information for the approach used to develop the chloropicrin buffer zones is also presented. The supporting information is drawn from analysis and modeling performed to develop other fumigant mitigation measures. These fumigants include methyl bromide, metam sodium, and methyl iodide. The supporting topics included in this memorandum are an analysis of the protection level of whole field versus maximum direction buffer zones and analysis supporting the choice of weather data used to develop the chloropicrin buffer zones.

II. Field Data Analysis and Results

A. Database and Analysis

An EXCEL (Microsoft EXCEL, 2010) database of 47 chloropicrin applications as shown in Appendix 1. These are the same studies submitted to U.S. EPA, with the addition of two newer studies. One study with 2 applications submitted to U.S. EPA was rejected at DPR (Gillis and Smith, 2002). One study containing one application was submitted to U.S. EPA but not to DPR (Coloma, WA bed/untarp, MIRD 48011601). The four Arizona applications in Beard et al. (1996) were removed from the analysis at the direction of DPR management (Reardon, 2013). This left 40 chloropicrin applications in the initial analysis. MINITAB (2010) statistical software was used for all the data summaries, statistical analysis. Graphs were composed in MINITAB (2010), Sigmaplot (SPSS, 2001) or TableCurve2D (AISN software, 2000).

A key factor in determining the size of a buffer zone is the magnitude of the fumigant flux (emissions) to air. Table 1 shows a summary of the maximum 6-hour chloropicrin flux for the 40 applications. Statistical analysis of the full database (40 applications) is problematic due to empty cells. So, only a summary table (Table 1) was produced initially for informational purposes. Most chloropicrin fumigation applications in the monitoring studies show peak air concentrations and peak fluxes occurring sometime during the first two days following the start of application. During the first two days, air concentrations and flux were generally measured in 6-hour intervals, with 12-hour intervals after the first two days. To determine buffer zones, DPR used the 6-hour flux values as a surrogate for 8-hour values (time period of target concentration) with no adjustment.

U.S. EPA primarily relied on computer modeling with a modified version of CHAIN 2D to identify and quantify most of the label buffer zone credits. In contrast, this analysis relies on flux estimated using field monitoring data to evaluate the buffer zone credits. Consequently, DPR's conclusions about the buffer zone credits differ from U.S. EPA. DPR is also evaluating the buffer zone credits using a modification of HYDRUS, a state of the art computer model based on the original CHAIN 2D model. However, this work is not complete and was not used for this

analysis. After the HYDRUS analysis is completed, DPR may revisit U.S. EPA factors to determine if buffer zone credits are supported.

In order to proceed with the analysis the Symmetry Method, metallized (20% Credit tarp), VIF (40% Credit), strip and deep injection applications were removed from the data base. Symmetry Method is not practiced in California and use of metallized tarps is discouraged in California due to disposal issues. The VIF (40% Credit) tarp, strip, and deep injection applications were not conducted in enough combinations of application type and tarp type to allow inclusion in the statistical analysis. Grouping those applications with the other methods in the initial analysis is inappropriate due to differences in application type. A separate evaluation for strip and deep injection applications may determine if partial (strip) tarping or injection depth influences maximum flux (ug/m^2sec). Finally, two outliers were also removed: 1) the Ventura drip application from data volume 0199-0142 (Sullivan and Ajwa, 2010) because that application was significantly affected by a large drip application nearby, and 2) the Wasco broadcast/TIF Tarp + KTS application from data volume 0123-0220 (Ajwa and Sullivan, 2010a) because the maximum flux estimate was not acceptable due to estimation difficulties.

The reduced dataset includes 28 applications and does not have any empty cells. An unbalanced two way analysis of variance (ANOVA) was performed. Both original scale and log scale analysis was examined. Residual patterns were acceptable for both the log and original scale maximum 6-hour flux. Results are presented on the original scale. There is no significant interaction effect between application type and tarp type ($p = 0.12$). Table 2 and Figure 1 illustrate this finding of no significant interaction effect between application type and tarp type on the maximum flux. There is a lack of a substantial difference between the mean maximum flux values for the application types within each tarp type (the blue circle with the cross in the middle indicates the mean). There is a marginally significant difference in maximum 6-hour flux between application types ($p = 0.04$). When comparisons between application types are examined it is clear this marginally significant difference between application types is due solely due to a high flux value for the single untarp drip application (111.0 ug/m^2sec) present in the database. Bed and broadcast application types are not different. Drip and bed application types are not different. Broadcast and drip application types are marginally different. Thus, separating application types for buffer zone development is not recommended. There is a highly significant difference in maximum 6-hour flux between tarp types with all three tarp types being distinct ($p = 0.000$). Therefore, separating untarped, Poly Tarp and TIF Tarp into independent groups for developing buffer zones is supported. The marginal average maximum 6-hour flux values for the three tarp types are shown in Table 2.

Table 1. Summary of the maximum flux (ug/m^{2}sec) in the chloropicrin database. Flux values are normalized to a 200lb/ac broadcast application rate. Most averaging times are 6 hours. See Appendix 1 for full details. (n = sample size)

Application Type		Tarp Type					
		Untarp	Poly[1] (No Credit Tarp)	Metallized (20% Credit Tarp)	VIF (40% Credit Tarp)	TIF (60% Credit Tarp)	All
Bed	Mean	56.8	40.7	45.0	7.7	13.3	35.5
	Median	56.8	40.7	45.0	7.7	13.3	38.6
	n	2	2	2	1	2	9
Broadcast	Mean	61.4	29.6	-	-	15.7	25.3
	Median	61.4	33.4	-	-	5.9	17.5
	n	1	7	-	-	7	15
Broadcast/Deep	Mean	46.6	-	-	-	6.6	26.6
	Median	46.6	-	-	-	6.6	26.6
	n	1	-	-	-	1	2
Strip	Mean	-	46.2	-	-	-	46.2
	Median	-	46.2	-	-	-	46.2
	n	-	1	-	-	-	1
Strip/Deep	Mean	-	-	-	-	5.6	5.6
	Median	-	-	-	-	5.6	5.6
	n	-	-	-	-	1	1
Symmetry	Mean	-	-	46.7	2.9	1.1	17.9
	Median	-	-	49.7	2.9	1.1	2.9
	n	-	-	1	1	1	3
Drip	Mean	111.0	49.1	-	-	10.2	47.4
	Median	111.0	46.4	-	-	10.2	42.3
	n	1	6	-	-	2	9
All	Mean	66.5	39.3	46.6	5.3	12.2	32.1
	Median	61.4	40.1	49.7	5.3	5.7	33.1
	n	5	16	3	2	14	40

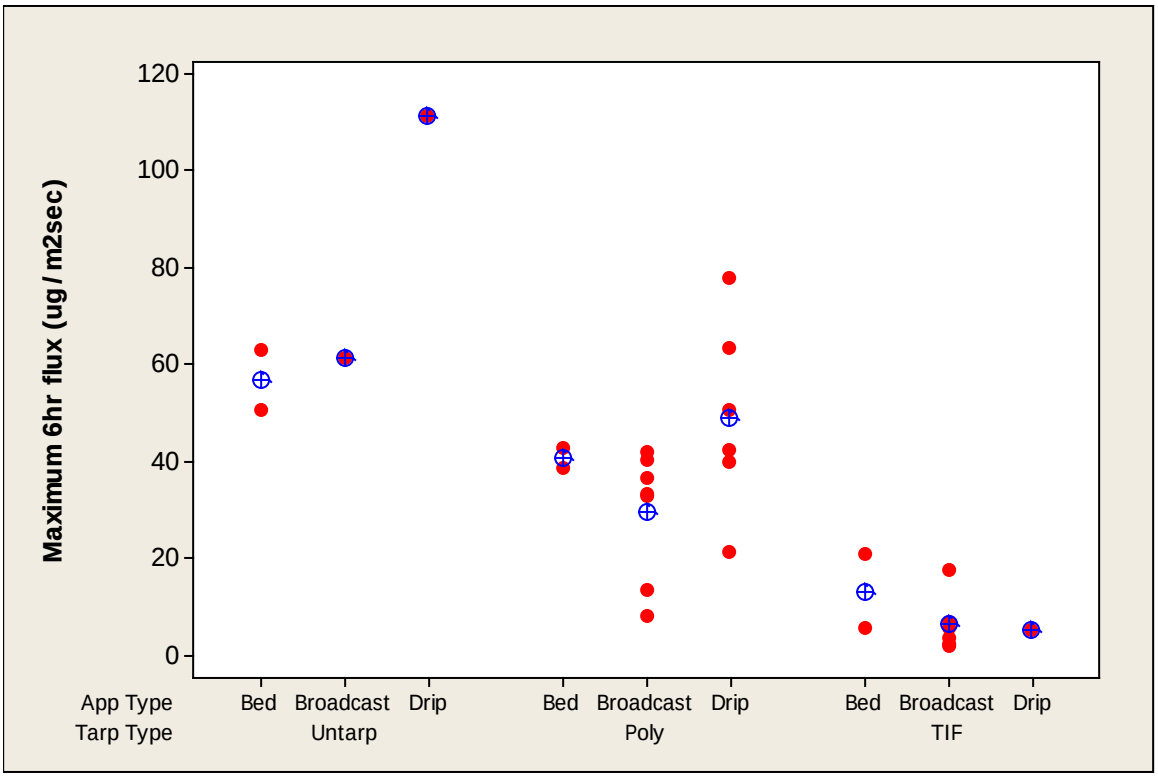
[1] The Poly tarp group includes both Low Density Polyethylene (LDPE) and High Density Polyethylene (HDPE) tarps that receive no buffer zone reduction credit on the current labels. See Appendix 1 for details.

Table 2. Mean maximum 6-hr flux (ug/m^{2}sec) for the reduced set of chloropicrin applications. Flux values are normalized to a 200lb/ac broadcast application rate. See text for description of records removed. Most averaging times are 6 hours. (n = sample size).

Application Type		Tarp Type			
		Untarp	Poly[1] (No Credit Tarp)	TIF (60% Credit Tarp)	All
Bed	Mean	56.8	40.7	13.3	36.9
	Median	56.8	40.7	13.3	40.7
	N	2	2	2	6
Broadcast	Mean	61.4	29.6	6.4	21.9
	Median	61.4	33.4	4.8	15.6
	N	1	7	6	14
Drip	Mean	111.0	49.1	5.5	51.4
	Median	111.0	46.4	5.5	46.4
	N	1	6	1	8
All	Mean	71.5	38.9	7.8	33.6
	Median	62.2	39.8	5.5	35.1
	n	4	15	9	28

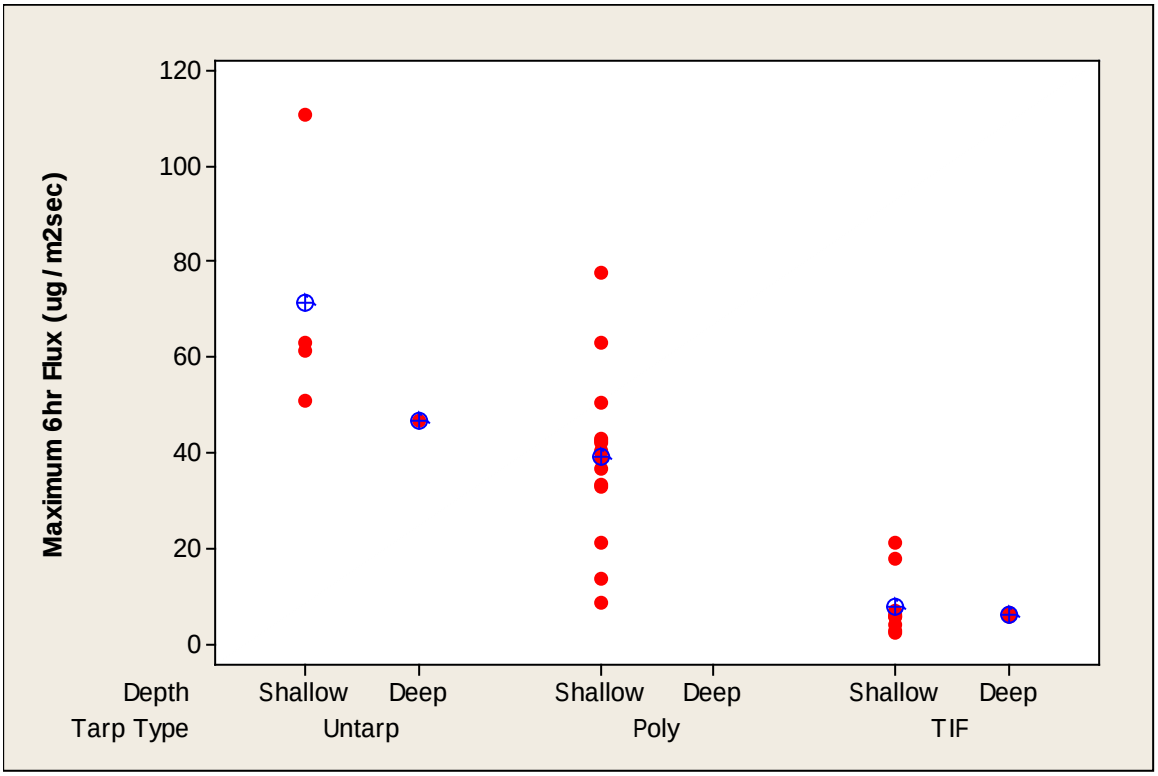
[1] The Poly tarp group includes both Low Density Polyethylene (LDPE) and High Density Polyethylene (HDPE) tarps that receive no buffer zone reduction credit on the current labels. See Appendix 1 for details.

Figure 1. Plot of maximum 6 hr flux (ug/m^{2}sec) versus application type grouped by tarp type. Flux values are normalized to a 200lb/ac broadcast application rate.



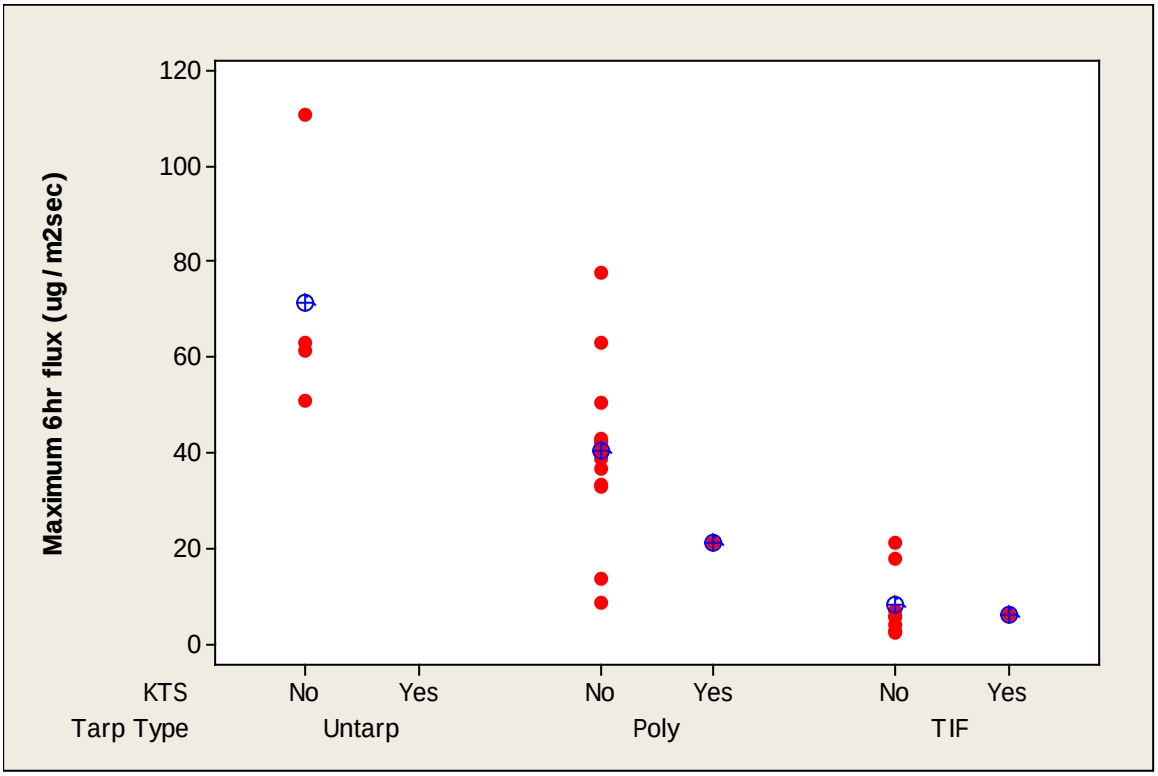
Injection depth has been presented as a potential mitigation measure. However, there are only three deep injection applications in the chloropicrin data base, one application is untarp and two are 60% Credit Tarps. Figure 2 shows that the deep application maximum 6-hour flux values in this database are similar to the shallow application maximum 6-hour flux values. The untarp deep injection is on the low end of the shallow injections. However, this is only one application and the variability of deep untarp maximum 6-hour flux is unknown. In the case of 60% Credit Tarp, it is more likely that the 60% Credit Tarp is the factor leading to the low maximum 6-hour flux than the injection depth. The deep untarp application is from the Wasco study conducted in 2008 (Ajwa and Sullivan, 2008; 0199-0130). The two deep 60% Credit Tarp applications are from the 2010 MBIP study (Ajwa and Sullivan, 2010a; 0123-0220). No statistical analysis can be performed on these data due to the small sample size of the deep applications relative to the shallow applications. Thus, at this time it is impossible to make a distinction between maximum 6-hour flux for shallow and deep applications. As stated above, a separate evaluation for deep injection applications using the Hydrus model may determine if injection depth influences flux.

Figure 2. Plot of maximum 6 hr flux (ug/m^{2}sec) versus depth grouped by tarp type. Blue circles with the cross are the mean of each group. Flux values are normalized to a 200lb/ac broadcast application rate.



Application of the chemical KTS has been presented as a mitigation measure. There are only two applications with KTS applied as a mitigation measure that are acceptable in the chloropicrin data base. One application used a Poly Tarp and one used a TIF Tarp. Figure 3 shows that the two KTS applications have maximum 6-hour flux values that are similar to other applications in the same tarp grouping. The fact that only one application in each tarp type used KTS results in the variability of maximum 6-hour flux associated with the use of KTS being completely unknown. The Poly Tarp application is from the Salinas drip study conducted in 2010 (Ajwa, 2010; 0199-0136). The 60% Credit Tarp application is from the Lost Hills study in 2012 (Ajwa and Sullivan, 2012; 50046-0198). The sample size of KTS application was too small to perform statistical analysis on these data. Thus, at this time it is impossible to make a distinction between maximum 6-hour flux for applications that employ KTS as a mitigation measure and applications without KTS.

Figure 3. Plot of maximum 6 hr flux (ug/m^{2}sec) versus KTS use grouped by tarp type. Blue circles with the cross are the mean of each group. Flux values are normalized to a 200lb/ac broadcast application rate.



Application of a "water seal" over the tarp has also been assigned a buffer zone reducing credit by U.S. EPA. Only one application in the chloropicrin database used a post application "water seal." This was a drip/Poly Tarp application in the Salinas study (Ajwa, 2010; 0199-0136). The maximum flux from this application was 50.4 ug/m^{2}sec. The mean maximum 6-hour flux for the Poly Tarp group is 38.9 ug/m^{2}sec. So, based on the data currently available a post application water seal cannot be justified as an additional mitigation measure beyond the tarp type.

DPR buffer zone development will use the maximum 6-hour flux from each application as a surrogate for an 8-hour flux matching the target concentration averaging time. It is not necessary to use the remainder of the flux profile because the maximum flux interval will determine the size of the buffer zone. Examination of the chloropicrin database shows that 20 of the 28 applications (71%) showed a maximum 6-hour flux during daylight hours and 8 of 28 applications (29%) showed a maximum 6-hour flux during night hours (Table 3). An unbalanced two-way ANOVA with interaction on the factors tarp type and Day/Night showed

that there was no interaction between tarp type and Day/Night (p = 0.39). This means that although there may be a difference between Tarp Type, the magnitude of the difference does not vary between day and night. This also means that the two factors, tarp type and Day/Night can be examined separately. The highly significant difference between tarp type was presented above. There was no significant difference between Day/Night flux (p = 0.88). On average, the maximum 6-hour flux does not differ whether it occurs during the day or at night (Figure 4). However, night meteorological conditions are more stable relative to day conditions. The same flux value will produce higher air concentrations at night. Thus, buffer zone development must take into account whether the maximum 6-hour flux occurred at night or day.

Table 3. Maximum 6-hr flux (ug/m^{2}sec) grouped by tarp type and whether the maximum flux occurred during the day or at night. Flux values are normalized to a 200lb/ac broadcast application rate.

Day/Night		Tarp Type			
		Untarp	Poly[1] (No Credit Tarp)	TIF (60% Credit Tarp)	All
Day Maximum Flux	Mean	74.9	34.7	8.5	31.6
	Median	62.9	36.6	5.9	27.0
	N	3	10	7	20
Night Maximum Flux	Mean	61.4	47.3	5.5	38.6
	Median	61.4	40.3	5.5	39.5
	N	1	5	1	8
All	Mean	71.5	38.9	7.8	33.6
	Median	62.2	39.8	5.5	35.1
	N	4	15	9	28

[1] The Poly tarp group includes both Low Density Polyethylene (LDPE) and High Density Polyethylene (HDPE) tarps that receive no buffer zone reduction credit on the current labels. See Appendix 1 for details.

Figure 4. Maximum 6-hr flux (ug/m2sec) grouped by tarp type and whether the maximum flux occurred during the day or at night. Flux values are normalized to a 200lb/ac broadcast application rate.

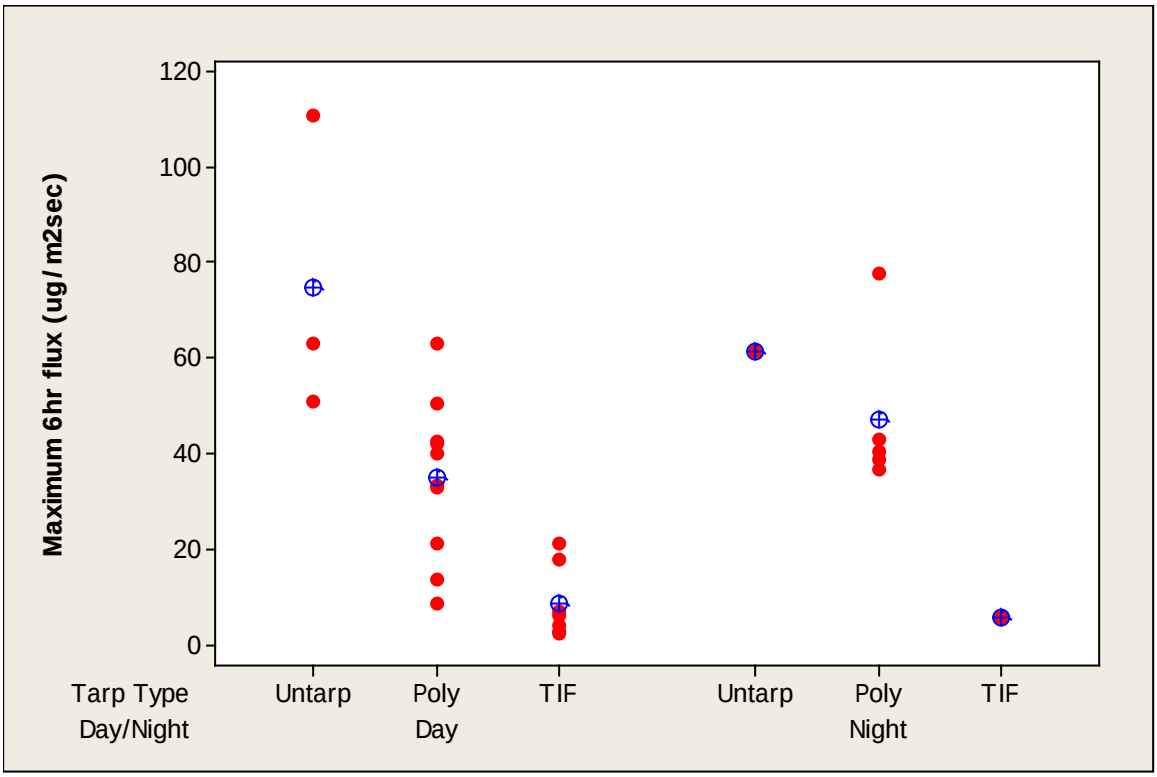


Figure 5 shows the start of application time grouped by whether an application showed a maximum flux occurring during the day versus at night. A Kruskal-Wallis nonparametric test indicates that the start time for applications showing a maximum flux during the day is not significantly different from those showing a maximum flux at night (p=0.55). Therefore, placing a restriction on time of day when an application can be made will not be effective as a mitigation measure to prevent the maximum 6-hour flux from occurring at night.

Figure 5. Start of application time (military hours) versus whether the maximum 6 hr flux (ug/m^{2}sec) occurrence during the day or at night.

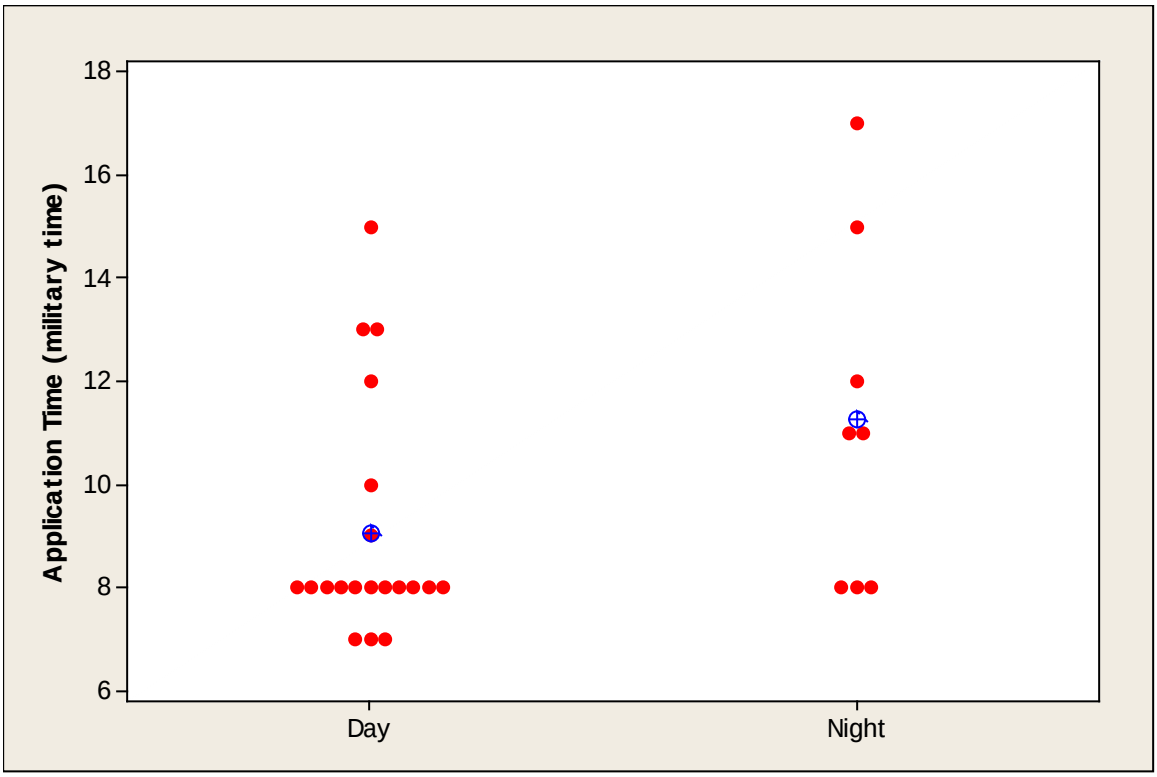


Figure 6 shows a plot of hours after application the maximum 6-hour flux occurs versus the application start time. In addition, whether the maximum flux occurred during the day or at night is indicated. There is no correlation and it appears there is no relationship between hours after application and the application start time. However, there is a clear break in the hours after application that the maximum flux occurs. The break is at approximately 18 hours after application. A code separating the applications by that break was generated. Results are shown in Table 4.

Figure 6. Number of hours post application that the maximum 6-hr flux occurs versus application time. Whether the maximum flux occurred at day or at night is also indicated.

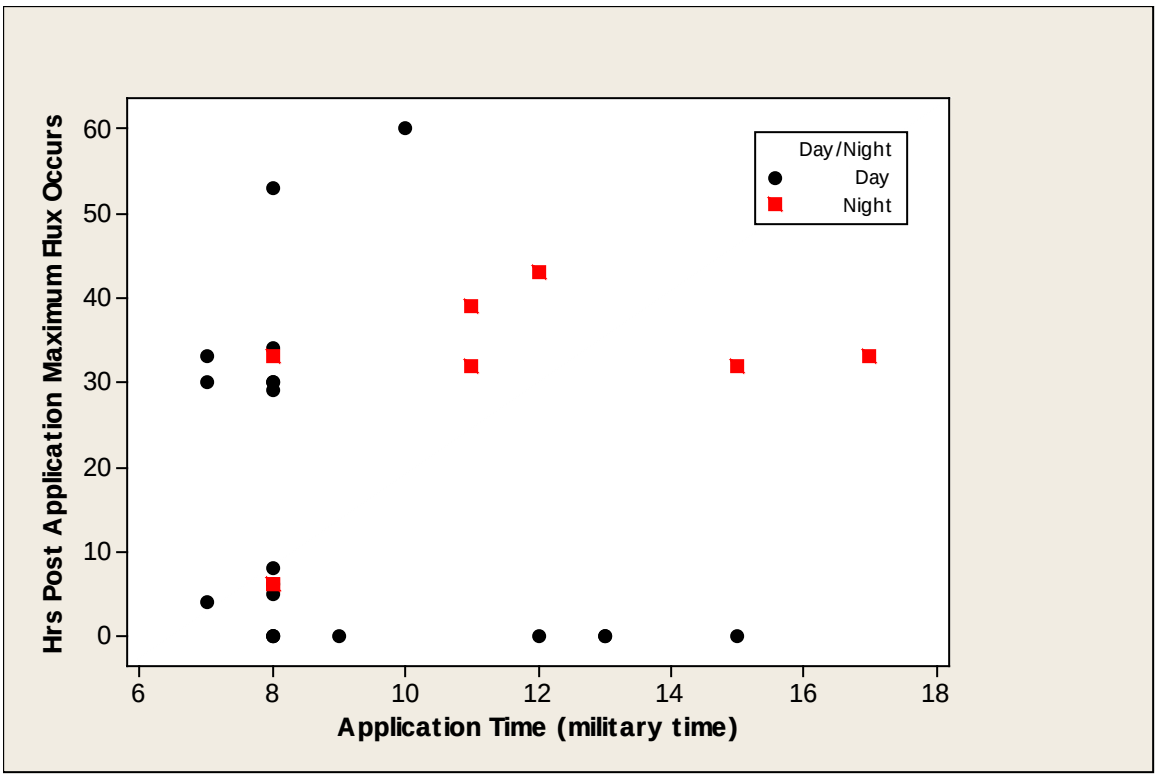


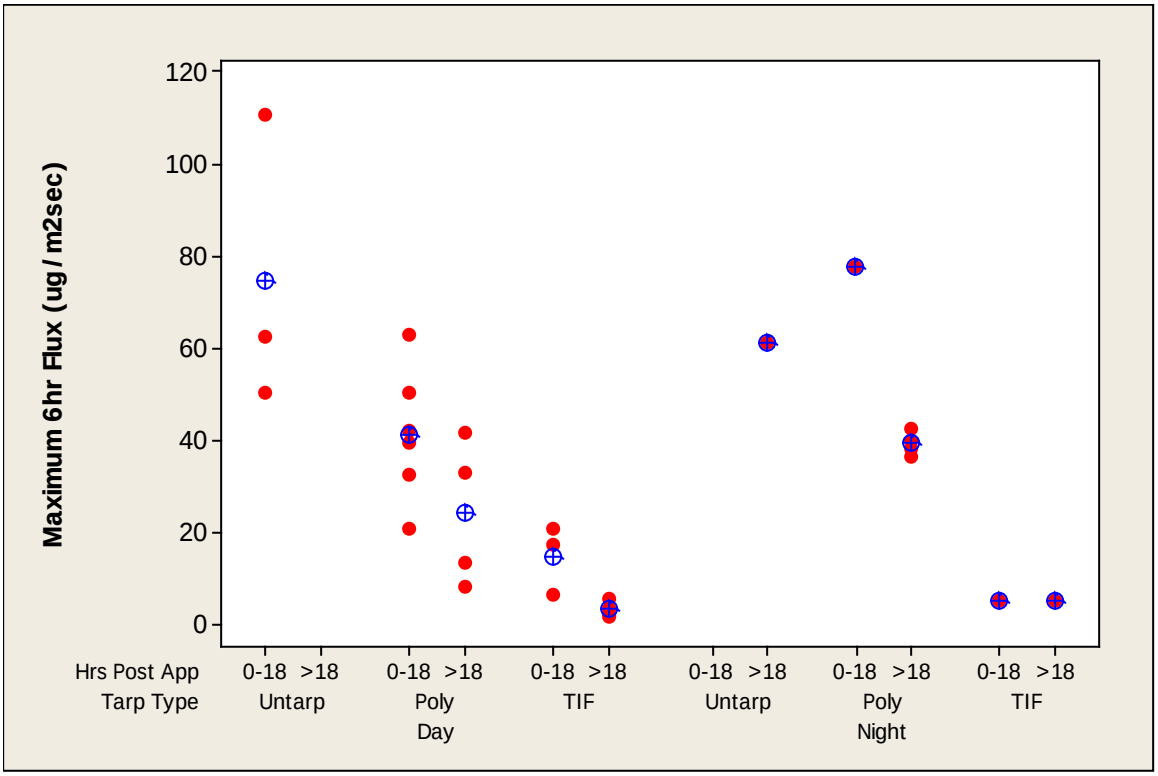
Table 4. Maximum 6-hr flux (ug/m^{2}sec) grouped by tarp type and hours after application start that the maximum flux occurred. Flux values are normalized to a 200lb/ac broadcast application rate.

Time After App		Tarp Type			
		Untarp	Poly[1] (No Credit Tarp)	TIF (60% Credit Tarp)	All
0-18hours	Mean	74.9	46.8	12.7	43.1
	Median	62.9	42.3	12.2	41.1
	N	3	7	4	14
>18hours	Mean	61.4	32.0	3.9	24.1
	Median	61.4	37.7	3.7	23.5
	N	1	8	5	14
All	Mean	71.5	38.9	7.8	33.6
	Median	62.2	40.0	5.5	35.1
	n	4	15	9	28

[1] The Poly tarp group includes both Low Density Polyethylene (LDPE) and High Density Polyethylene (HDPE) tarps that receive no buffer zone reduction credit on the current labels. See Appendix 1 for details.

Figure 7 shows the three layer breakdown of maximum flux at day versus night, tarp type, and hours post application that the maximum flux occurred. The 4 untarp applications show 3 maximum flux values early in the flux profile and one late in the flux profile. The 15 Poly Tarp applications are comprised of 7 with maximum flux early in the flux profile and 8 with maximum flux late in the flux profile. The 9 TIF Tarp applications are approximately equally divided with 4 early and 5 late.

Figure 7. The 6-hr maximum flux (ug/m2sec) grouped by whether the maximum flux occurred at day or at night, tarp type and number of hours post application that the maximum flux occurred. Flux values are normalized to a 200lb/ac broadcast application rate.



Within Day group it can be seen that untarp maximum flux occurs early in the flux profile. Poly Tarp and TIF Tarp are about equally divided between early and late occurrence of maximum flux and the mean maximum flux for both tarp types is somewhat lower for the greater than 18 hour group. Within the Night group the same basic patterns are evident. Comparing Day and Night groups show results consistent with previous analysis, on average there is no difference in maximum 6-hour flux associated with whether it occurs during the day or at night.

The maximum 6-hour flux occurs between 0 hours (max 6-hour flux occurring during application) to 60 hours after the start of application (Appendix 2). Thus, the longest 8-hour interval after the start of application that a maximum 6-hour flux would occur is from the period 60 hours to 68 hours. The current label sets buffer zone duration at 48 hours after application is completed. Most applications take hours to complete so based on the data in Appendix 2 the 48-hour buffer zone duration following completion of the application should be sufficient.

C. Discussion

This analysis examined the flux for various fumigation methods, and mitigation measures that are assigned U.S. EPA buffer zone credits. These factors include: tarp type (high barrier tarp), organic matter, clay content, soil temperature, Symmetry System, KTS, water seal applied over the tarp. Organic matter, clay content and soil temperature are likely not enforceable. Symmetry System is not currently used in California. The effect of soil moisture on chloropicrin flux was examined in a separate memorandum (Barry, 2013; Appendix3) and found to be unsubstantiated. The only factor supported by this analysis is the TIF Tarp. Thus, it is recommended that DPR develop buffer zones separately for untarp, Poly Tarp, and TIF Tarp applications. As stated above, DPR is conducting a separate evaluation of the buffer zone credits using modeling (HYDRUS), but this work is not complete. After the Hydrus analysis is completed, DPR may revisit the remainder of the U.S. EPA factors to determine if buffer zone credits are supported.

III. Chloropicrin Buffer Zone Development

The Probabilistic Exposure and Risk Model for Fumigants Version 2 (PERFUM2) modeling system (Reiss and Griffin, 2005) was used to develop the buffer zones presented in this memorandum. This model uses the Industrial Source Complex Short Term Version 3 (ISCST3) Gaussian dispersion model to estimate air concentrations. Front end and back end processing code allows multi-year simulations using historical weather data and construction of buffer zone distributions generated from the multi-year runs. PERFUM2 has previously been used by DPR to develop buffer zones for methyl isothiocyanate (Barry, 2006).

Based upon analysis and results shown in the previous sections, buffer zone development proceeded by tarp type: 4 untarped, 15 Poly Tarp, and 9 TIF Tarp applications. Each individual application was simulated separately using the PERFUM model (Reiss and Griffin, 2005) and five years of Ventura meteorological data (included in the PERFUM model). The PERFUM model was modified by DPR staff to output the daily maximum direction buffer zone. The rationale for selecting the maximum direction approach and Ventura weather are described in sections V and VI. The full flux profile was not used in the simulations. Instead, the maximum 6-hour flux from a study application was input as an 8-hour flux beginning at the first hour it occurred in the flux profile for each application. For example, if the maximum 6-hour flux occurred from 0800 hours to 1400 hours then that flux value was input from 0800 hours to 1600 hours and the buffer zone was calculated only for those hours. Examination of the period by period flux values and the screening level buffer zones produced for other periods found no buffer zones that were larger than screening level buffer zone produced using the maximum 8-hour flux in each flux profile. Screening level buffer zones are produced using worst case meteorology coupled with the flux for a particular sampling period. Thus, maximum 8-hour flux

in the database flux profiles results in the largest buffer zones for a specific application flux profile and it is not necessary to simulate the remainder of the flux profile.

The maximum direction buffer zone approach was used so, for each application one 8-hour buffer zone was produced for each day of the five year Ventura, California weather record in the PERFUM2 model. The maximum direction approach results in an individual application having a buffer zone distribution composed of a potential set of 1825 buffers zones (5 years x 365 days), one buffer zone for each day over 5 years (ignoring leap years). However, the total number of buffer zones for each application is usually smaller than 1825 buffer zones because missing data in the meteorological file. After the sets of PERFUM2 simulations for a tarp type (15 Poly Tarp, 9 4 TIF Tarp, or untarp) were completed a composite distribution of buffer zones was constructed by combining the buffer zone results from all the applications within each tarp type. For example, the Poly Tarp distribution contained buffer zones from 15 applications for a total of 26501 buffer zones. The buffer zone sets were sorted and the 95th percentile was located directly using the standard equation $p_i = 100*[(i – 0.5)/n]$ where the buffer zones are sorted and assigned a position, i. The composite buffer zone distribution accounts for variation in the magnitude of the maximum 6-hour flux observed in the database and for night and day differences in maximum 6-hour flux occurrences.. The resulting buffer zones are shown in Tables 5 compared to the Tri-Clor Phase 2 label buffer zones (Table 6).

Figures 8 to 11 give a visual step by step guide to how the buffer zones shown in Tables 5 were developed. The Poly Tarp 40 acres and 350 pounds (lbs) per acre case is used because it gives nonzero buffers zones for most applications and days within applications. This result makes it easier to explain the process. However, the same steps were used for all three tarp types: Untarp, Poly, and TIF Tarp. This approach gives each application direct representation in the buffer zone distribution used to select the final buffer zones. Thus, an aggregate distribution for each tarp type (untarp, Poly Tarp, and TIF Tarp) was used in buffer zone development. Appendix 2 contains a summary of the maximum 6-hour flux (used as an 8-hour flux) for 350 lb/ac for each application and the 90th and 95th percentile maximum direction buffer zones from the individual application distributions. The summary in Appendix 2 illustrates the wide range of required buffer zones even within the same tarp type, supporting the composite distribution approach of buffer zone development to account for expected variability in conditions from application to application. Appendix 4 contains sets of buffer zones for each tarp type.

Table 5. The 95th percentile composite distribution Maximum Direction Poly Tarp buffer zones (ft) using 15 Poly Tarp applications.

App Rate (lb/ac)	App Size (AC)				
	5	10	20	30	40
100	16	16	216	322	412
150	171	338	571	765	941
200	352	560	903	1185	1441
250	475	769	1212	1576	1916
300	607	960	1504	1957	2371
350	731	1141	1777	2325	2842

Table 6. U. S EPA Tri-Clor Label Table 5 No Credit Buffer Zones (ft). No credits.

App Rate (lb/ac)	App Size (AC)				
	5	10	20	30	40
100	25	25	25	25	33
150	25	42	104	144	179
200	61	139	207	272	354
250	125	204	303	407	499
300	165	265	395	495	625
350	215	315	475	610	725

Figure 8. Example flux profile Volume 0199-0130 Wasco, California Broadcast/Poly Tarp 350lb/ac. Sampling intervals are typically 6 or 12 hours.

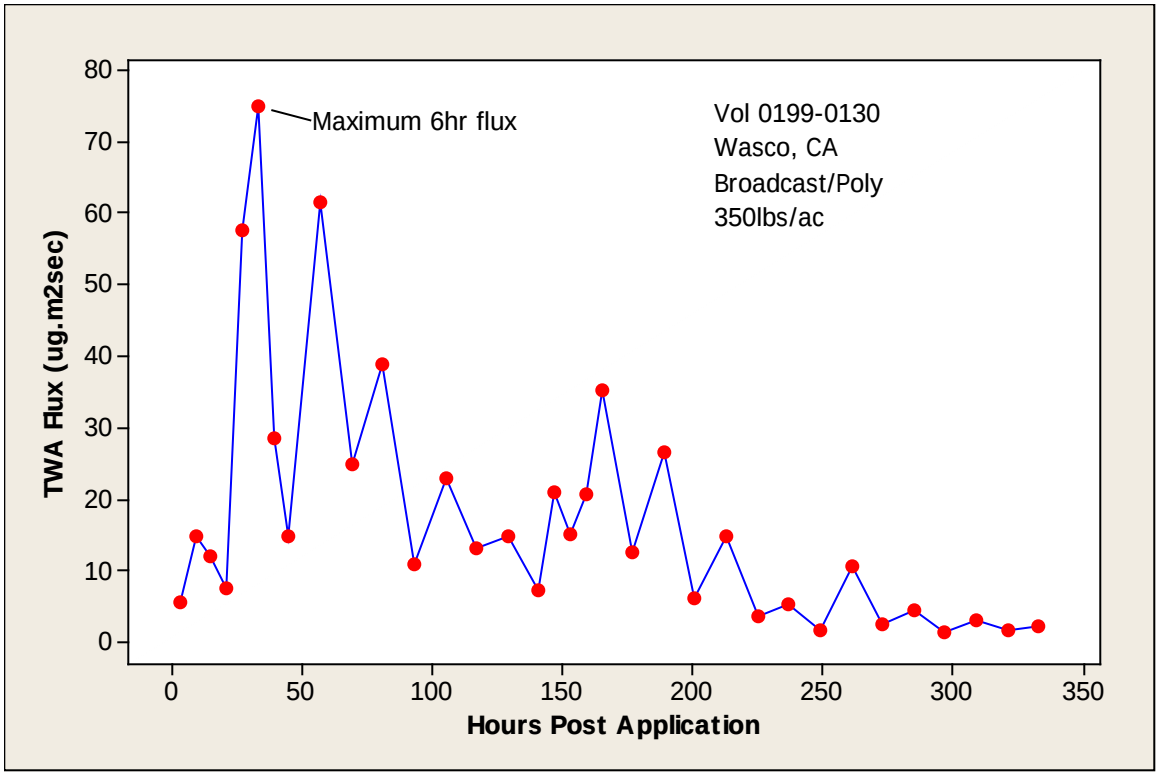


Figure 9. Resulting Buffer Zone Distribution for Volume 0199-0130 Wasco, California Broadcast/Poly Tarp 350lb/ac and 40 acres using the maximum 6-hour flux shown in Figure 8 as an 8-hour flux.

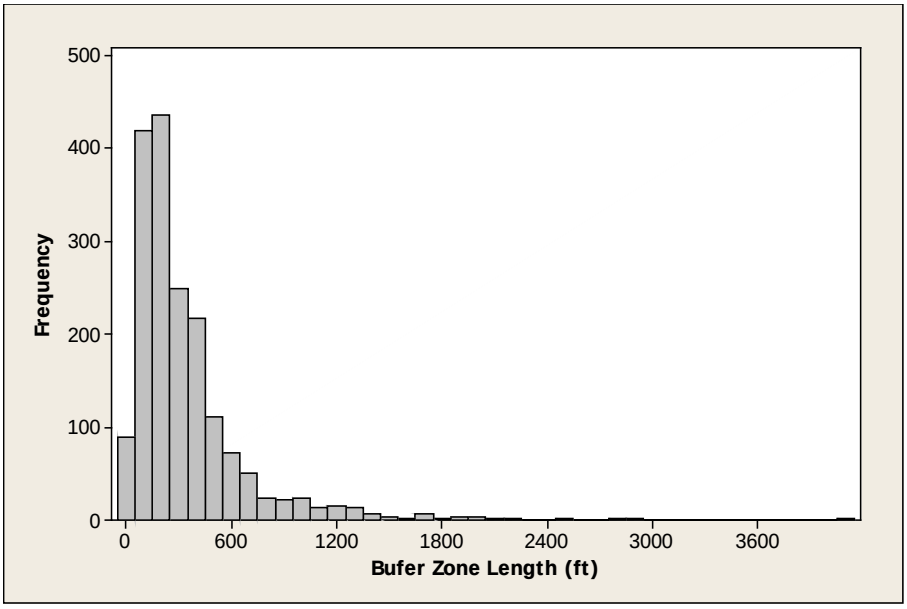


Figure 10. Distributions of buffer zone lengths (ft) for the 15 Poly Tarp Applications. Scenario = 40 acres and 350 lbs/ac. Each application name is coded as follows: application ID (e.g. 05), State (e.g. WA), Application Type (e.g Broad). Maximum 8 hour flux is noted (e.g., 24ug/m2sec). Frequency is raw frequency (maximum frequency = 1825, excluding leap years).

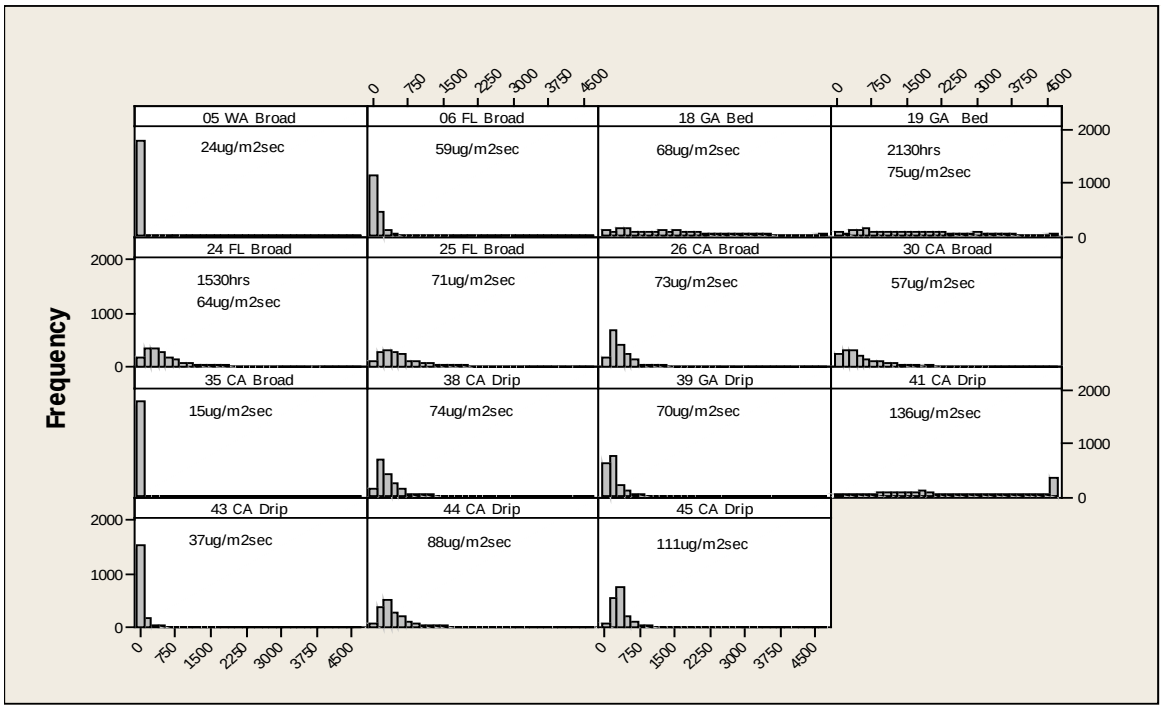
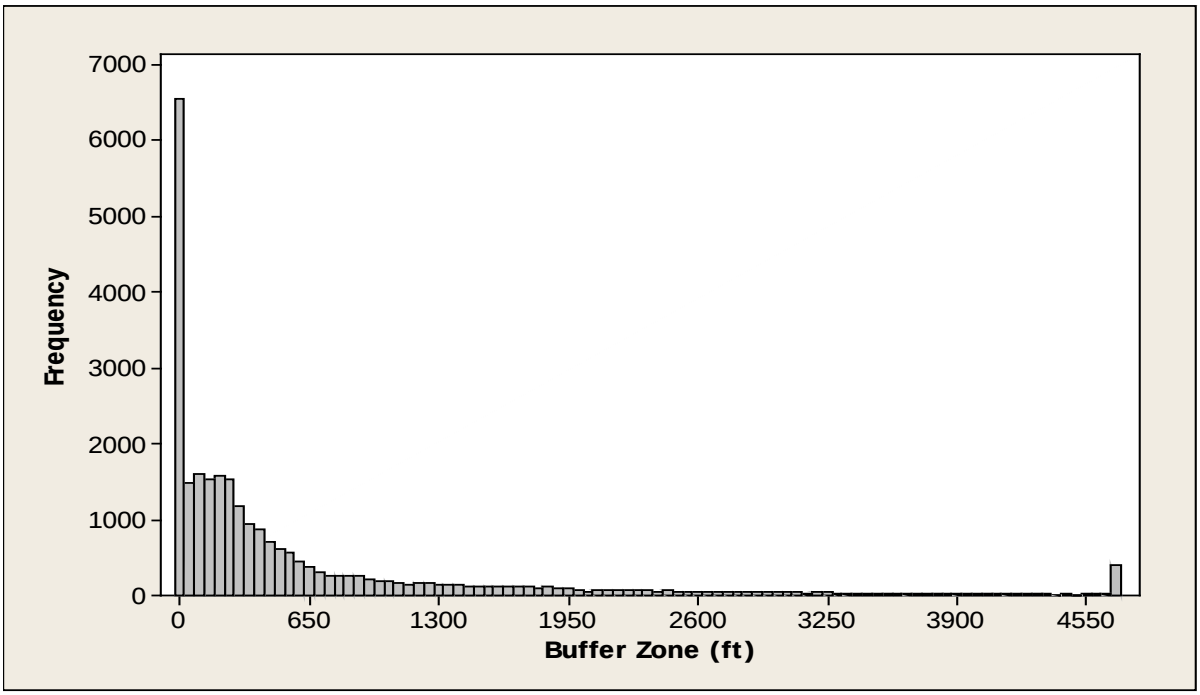


Figure 11. Composite distribution of buffer zone lengths (ft) from the 15 Poly Tarp applications shown above. This distribution contains a total of 26501 buffer zones.



Percentile buffer zones (ft):

95th	90th	85th	80th	75th	50th
2842	1808	1269	893	657	240

Conditions requiring a 25 ft chloropicrin buffer zone for tree hole applications were developed using the untarp buffer zone results. Table 7 shows the number of tree holes allowed within 1 acre when each tree hole is treated with 1 lb (1.0 lb/tree hole = 1 lb/100 sq ft).

Table 7. Chloropicrin tree hole limitations in order to maintain a 25 ft buffer zone for a 1 acre field.

Buffer distribution zone percentile	Maximum Number of Tree Holes	Resulting App Rate* (lb/ac) w/ 100 ft buffer
80%	230	230
85%	220	220
90%	190	190
95%	160	160

*****Effective broadcast rate

This buffer zone development only used the PERFUM2 model. Barry (2007a) presents and discusses three methods to develop buffer zones that are based on the ISCST3 model: screening meteorological conditions used directly in the ISCST3 model, the Fumigant Emissions Modeling System v5.074 (FEMS) modeling system (Sullivan et al., 2006) and the PERFUM2 model (Appendix 5). Screening meteorological conditions are "…worst-case meteorological conditions to provide conservative estimates of the air quality impacts of a specific source…" (U.S. EPA, 2003) to develop buffer zones in the absence of fully developed input data. This is the least refined method to develop buffer zones. Similar to PERFUM, the FEMS model performs multi-year simulations using historical weather data to generate buffer zones. However, there are features of the FEMS model that make it difficult to use to generate chloropicrin buffer zones. The difference between FEMS and PERFUM2 are discussed in detail in Barry (2007a). Briefly, rather than inputting specific flux data, FEMS has a set of default flux profiles. Inputting other flux profiles is difficult and would be time consuming for the 28 applications in the chloropicrin database, but could be accomplished. The most important drawback of the FEMS model is the manner in which it develops buffer zones. FEMS does not construct distributions of buffer zone lengths. Instead it counts exceedances of a target threshold at each receptor around a source. This method is problematic when attempting to account for the observed properties present in the chloropicrin maximum 6-hour flux database such as whether or not the maximum 6-hour flux occurred during the day or at night.

IV. TIF Tarp Cutting Interval

Use of TIF Tarps has raised the concern that off-site air concentrations immediately following tarp cutting may exceed target concentration. The chloropicrin database contains four broadcast/shallow shank injection/TIF Tarp applications appropriate for determining a Tarp Cutting Interval (TCI). Two applications are from the Lost Hills study (Ajwa and Sullivan, 2012; 50046-0198), one from Wasco (Ajwa and Sullivan, 2010a; 0123-0220), and one from Ventura (Sullivan and Ajwa, 2010; 0199-0142). Chloropicrin 6-hour flux for a 350 lb/ac application following tarp cutting is shown in Table 8.

Table 8. Chloropicrin 6-hour flux at various TIF Tarp cutting intervals

CDPR Data Volume	Location	Tarp Cutting Interval (days)	350 lb/ac 6-hour flux (ug/m^{2}sec)
50046-0198	Lost Hills, CA	5	42.0
		10	3.7
		16	0.9
0123-0220	Wasco, CA	6	5.9
0199-0142	Ventura, CA	6	6.5

Figure 12 shows data from the Lost Hills study only (Ajwa and Sullivan, 2012; 50046-0198). The measured flux values are shown as circles. It can be argued that the Lost Hills data only should be used because these three applications were done in the same location and in close proximity. In that case the recommendation would be to require a 10 day TCI. However, while the fit of the function in this graph is very good, the true function of change in maximum 6-hour flux following tarp cutting versus TCI is not well quantified with these data alone. In addition, the variability of flux between locations should be considered.

Figure 12. Lost Hills, California study chloropicrin 6-hr flux (ug/m^{2}sec) for a 350 lb/ac application at TIF Tarp cutting.

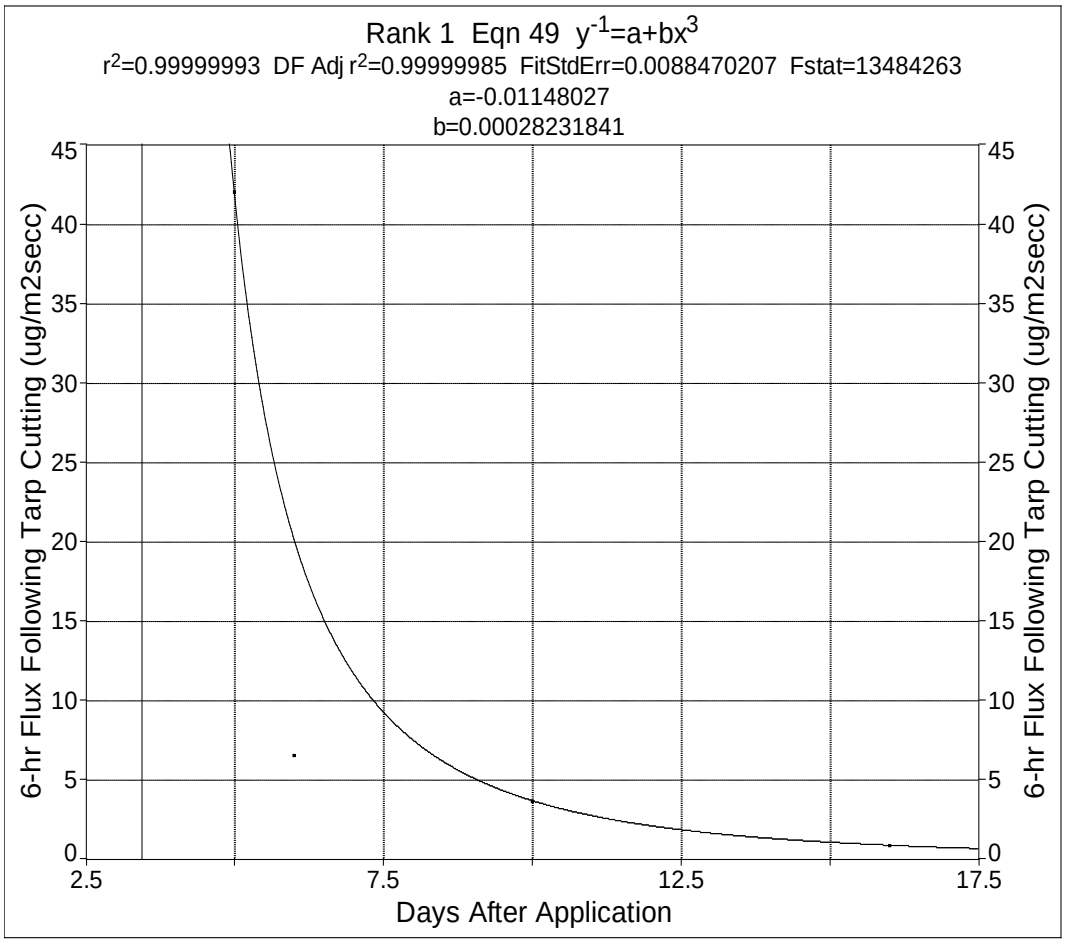
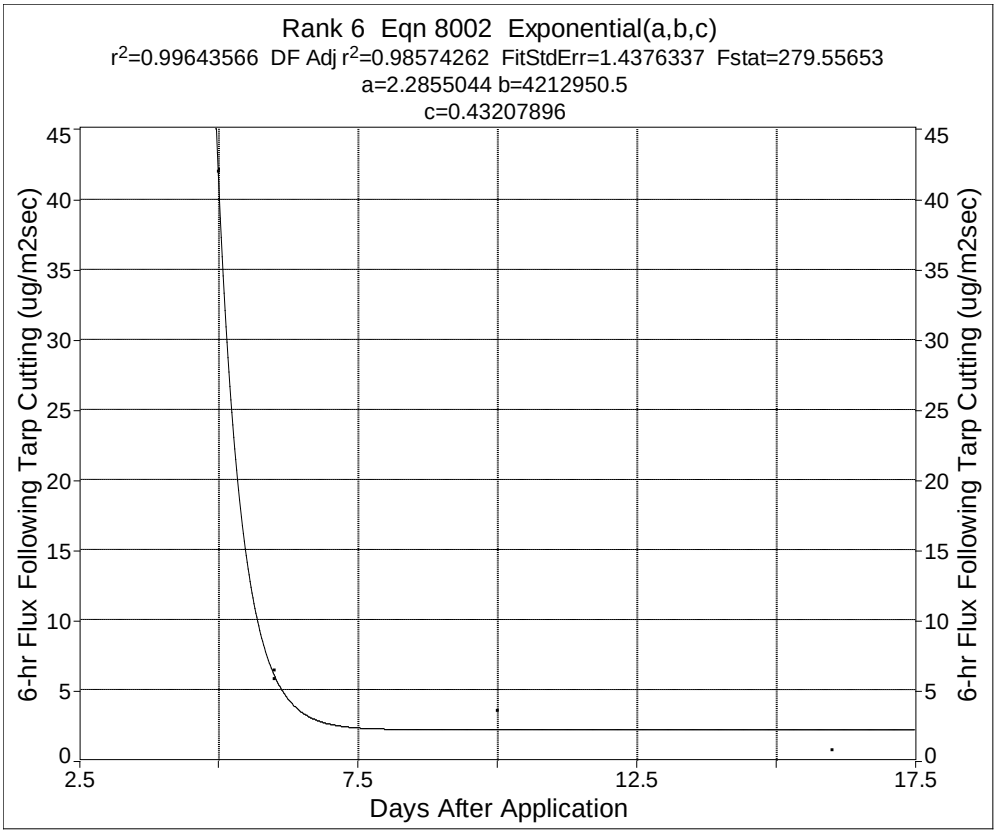


Figure 13 shows all of the tarp cutting data from Table 8. When the two flux values for tarp cutting at 6 days are included there is a much steeper decline in flux as a function of days. Since tarp cutting intervals are set in one day time steps, 6 days would be the minimum tarp cutting interval that could be recommended based upon the full data set.

Figure 13. Chloropicrin 6-hr flux (ug/m^{2}sec) for a 350 lb/ac application at TIF Tarp cutting for the three studies shown in Table 8.



These data indicate that a 10 Day Tarp Cutting Interval may not be necessary. However, the difference between the 5 Day Tarp Cutting flux (42.0 ug/m^{2}sec) versus the average of the two 6 Day Tarp Cutting flux (6.2 ug/m^{2}sec) is substantial. An alternative mitigation measure would be to choose a Tarp Cutting Interval midway between 6 and 10 days, e.g. 8 or 9 Days. No buffer zones are required at tarp cutting for either of the 6 Day Tarp Cutting Interval applications. So, any TCI 6 days or larger would not require buffer zones at tarp cutting.

V. Whole Field versus Maximum Direction Buffer Zones

The PERFUM model includes two methods for constructing buffer zone distributions: whole field and maximum direction. The two different distributions are constructed during the same model run. Barry and Johnson (2007) described and analyzed the difference between whole field and maximum direction buffer zone distributions. Details of the two methods and the differences between them can be found in that memorandum (Appendix 6).

Briefly, both methods use “spokes” of receptors that surround a source (the fumigated field). However the difference between the two methods is how those receptors are used to generate the buffer zone distributions. The target concentration is the air concentration reference level set by DPR. For each day during an averaging period (e.g. 8 hours), the maximum direction method finds along each spoke the distance away from the source edge where the target concentration occurs. Then for each day, the maximum direction method selects the one distance amongst all of the spokes that is the largest for that day. . A 5-year simulation would provide (1 buffer zone X 365 days x 5 years) = 1825 maximum direction buffer zones which would be compiled into a buffer zone distribution.

The whole field approach finds the distance to the target concentration along each spoke of receptors and adds that distance to the buffer zone distribution. Thus, the number of distances recorded for each day is equal to the number of spokes. For example, if the simulated application had 200 spokes of receptors surrounding the application then each day of the simulation would yield 200 buffer zones. These distances include distances along spokes that are in both the predominately upwind as well and the predominately downwind directions during that day. The maximum buffer zone distance among all the spokes for a particular day is also the single maximum direction buffer zone. For the example of 200 spokes around the application, the completed whole field buffer zone buffer zone distribution will have (200 buffer zones x 365 days x 5 years) = 365,000 buffer zones. This distribution of 365,000 distances will include distributional values heavily weighted to small buffer zone lengths because the distances to the target concentration on the predominately upwind spokes will be zeros or small.

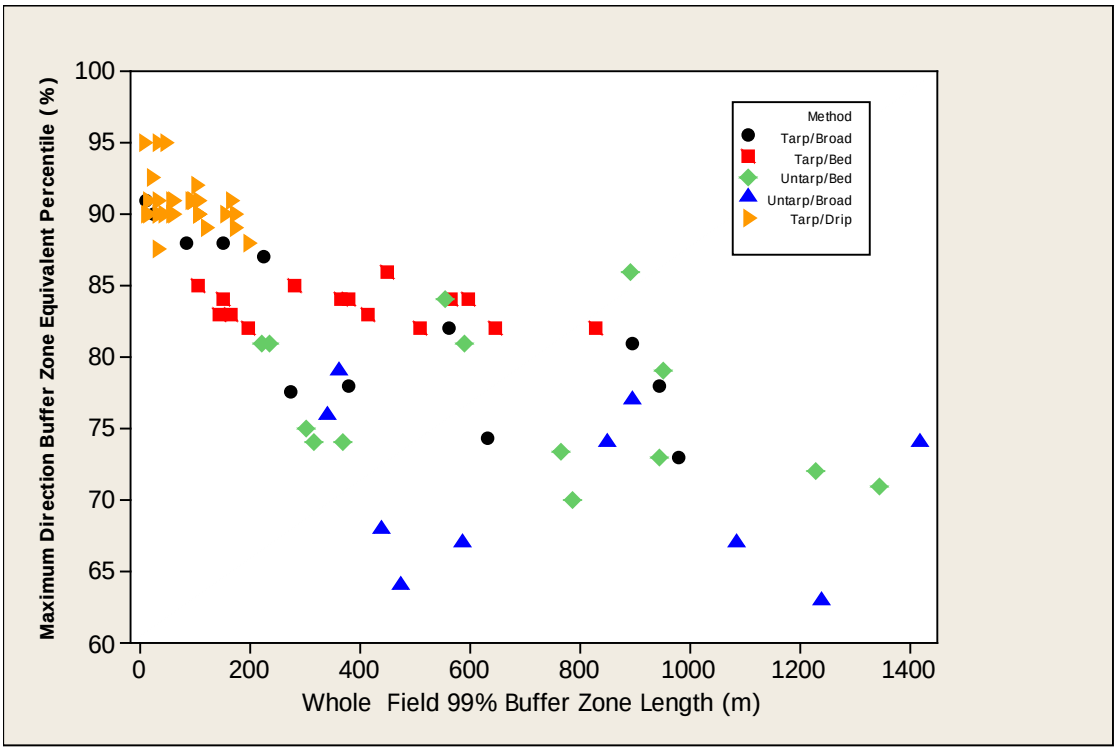
DPR has generally controlled buffer zone protection level probabilities at the individual application level (Segawa et al., 2000; Johnson, 2001; Barry, 2006). The maximum direction

buffer zone approach provides buffer zones that achieve this probability. The whole field approach provides a buffer zone that gives the probability that the target concentration is exceeded at any random location along the edge of the buffer zone of a random application. The whole field buffer zone percentiles do not correspond to a specific level of protection for an individual application (Barry and Johnson 2007). It, instead, relies on a low probability of bystanders being at the specific spot that the target concentration occurs. However, it cannot be assumed that this probability is low. Barry (2005) found homes or schools within 50 feet of buffer zone distances for 20% of methyl bromide applications in several coastal counties.

Figure 16 (Originally shown in Barry and Johnson, 2007, Appendix 6) shows the equivalent chloropicrin maximum direction buffer zone percentile compared to the 99% whole field buffer zone length. The buffer zones in Figure 16 are for a 4-hour averaging time rather than the current 8-hour averaging time for chloropicrin. However, the relationship between the maximum direction and whole field percentiles does not change with the increase to an 8-hour averaging time as demonstrated by the metam sodium analysis conducted in Barry and Johnson (2007). The critical conclusions are: (1) regardless of averaging time, a buffer zone distance based on the 99th percentile whole field approach will be at a lower percentile protection level when evaluated under the maximum direction/individual application protection level methodology, (2) the individual field protection level is lower than for whole field for all averaging time. However, the difference is largest for averaging times less than 24 hours, (3) as whole field buffer zone length increases the maximum direction/individual protection level drops, and (4) the whole field buffer zones with the lowest maximum direction equivalent percentiles occurred at night. As stated in Barry and Johnson (2007): “Thus, shorter threshold averaging time coupled with a flux profile that caused whole field buffer zone size to be driven by nighttime averaging periods was associated with the lowest maximum buffer zone equivalent percentiles.”

Table 3 showed that 8 of the 28 applications used to develop the chloropicrin buffer zones show maximum flux occurring at night. The lack of ability to quantify the failure rate of a whole field developed buffer zone at the individual field level is the most compelling reason to consider maintaining the DPR practice of controlling buffer zone protection level probabilities as the individual application level.

Figure 16. Relationship between the chloropicrin 99% whole field buffer zone length (m) and the equivalent maximum direction buffer zone percentile. Equivalent maximum direction percentile = individual application level protection probability = (1 – individual application buffer zone failure rate). From Barry and Johnson (2007).

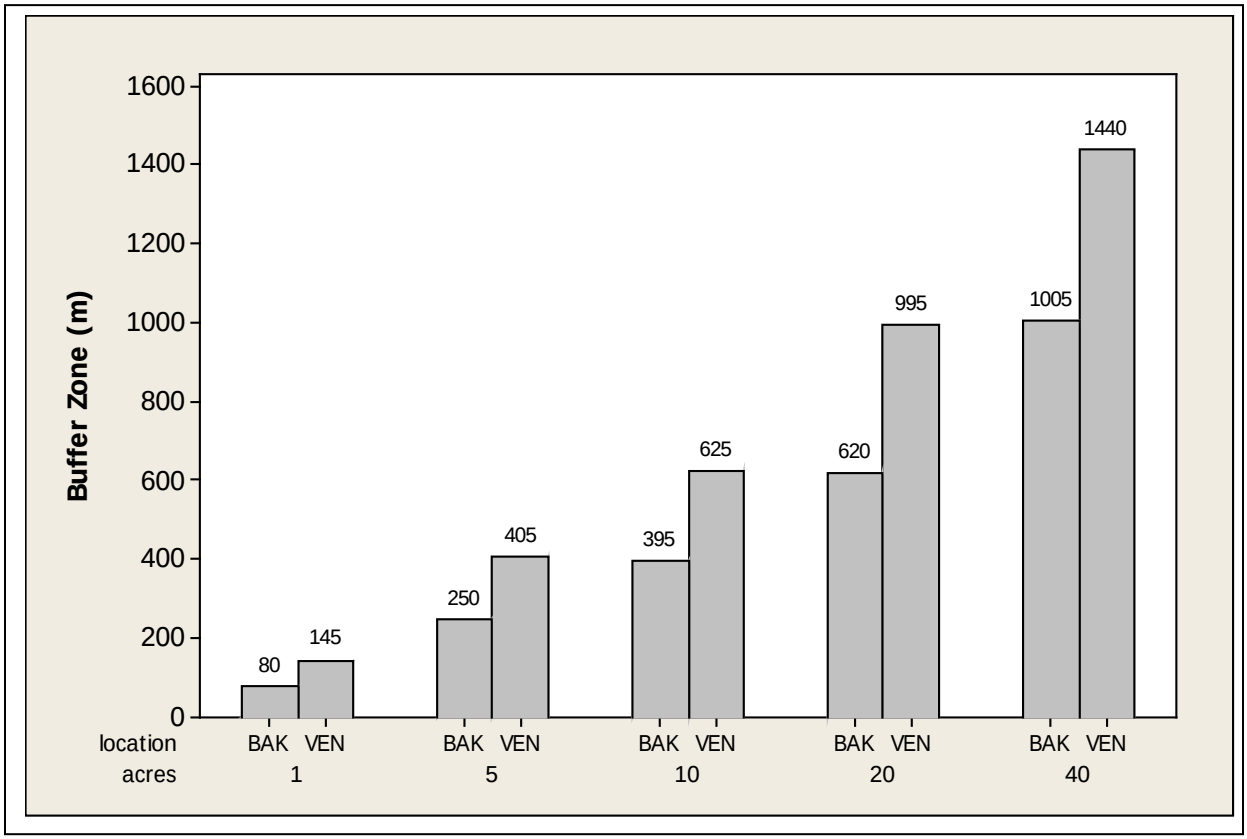


VI. Choice of Meteorological Station

The PERFUM model includes weather from various locations in the U.S. with two stations in California, Bakersfield and Ventura. Buffer zone size for the same flux profile can vary significantly depending upon which meteorological data is used. Ventura meteorological data was used to generate the buffer zones shown in Tables 5 and 6 and Appendix 3. Ventura weather data was used because it is more representative of the regions with the most chloropicrin use, although it may over-estimate buffer zones in different regions of the State. Barry (2007b) examined the difference between Bakersfield and Ventura buffer zone size (Appendix 7). The analysis indicates that for target concentration averaging times less than 24 hours that Ventura meteorological data yields longer buffer zones than Bakersfield. Figure 17 taken from Barry (2007b) shows the comparison for metam sodium standard shank application method with a maximum 8-hour flux that occurred between 2400 hours and 0700 hours. At every acreage the

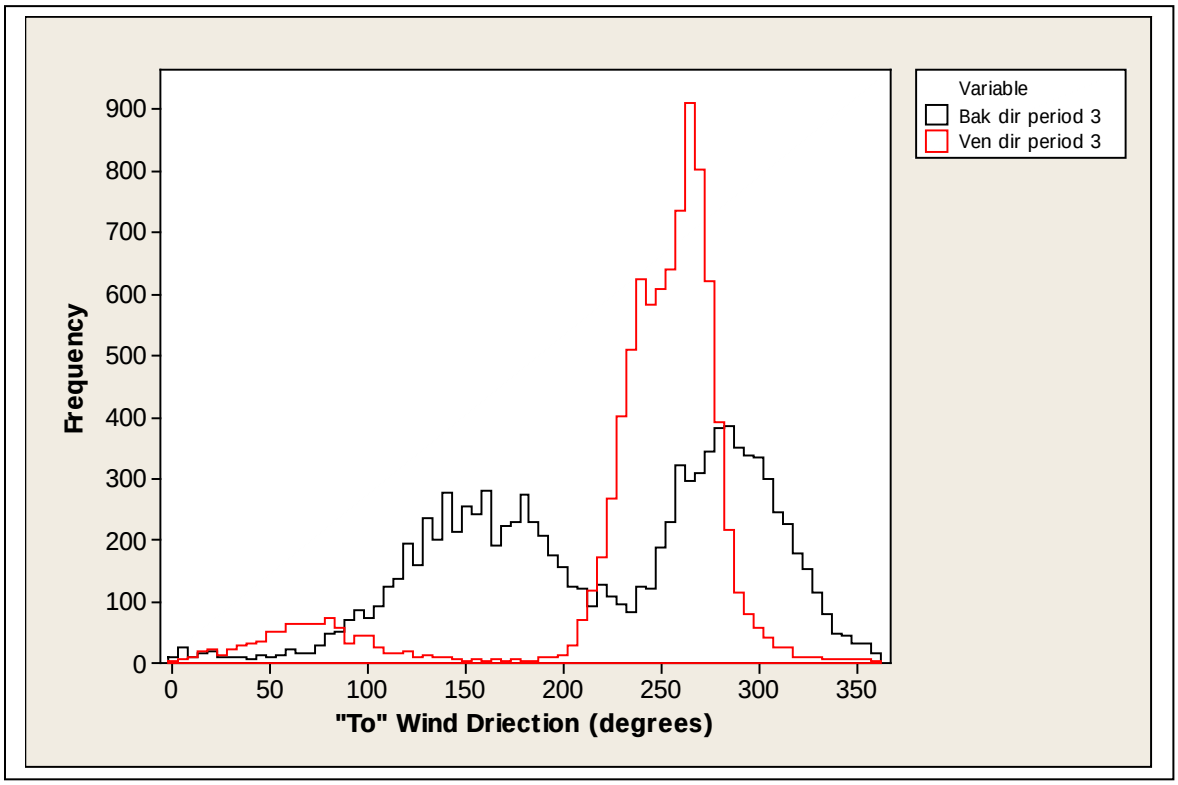
buffer zones develop using Ventura meteorology were longer than those using Bakersfield meteorology. For the 40 ac case, the 1440 m buffer is some unknown distance longer than 1440 m because the PERFUM model has a maximum buffer length of 1440 m. Any buffer larger than 1440 m is indicated as >1440 m.

Figure 17. Standard standard shank, period 3 (2400 hours – 0700hours). Comparison of buffer zone length (m). BAK – Bakersfield. VEN – Ventura. From Barry (2007b).



Wind direction frequency for the same period, 2400 hour – 0700 hours clearly shows the higher frequency of wind direction in a narrow direction in Ventura relative to Bakersfield (Figure 18). The frequency distribution of wind direction in Ventura tends to produce longer buffer zones because receptors in one general direction are potentially downwind of the plume for much of an averaging period.

Figure 18. Metam sodium standard sprinkler and standard shank, period 3 (2400 hours – 0700hours) wind direction frequency distribution. Frequency is number of hours. BAK = Bakersfield. VEN = Ventura. From Barry (2007b).



VII. Summary and Conclusions

This memorandum presents DPR's chloropicrin flux database (Appendix 1), analyzes that data and develops chloropicrin buffer zones based upon the analysis results. The PERFUM model (Riess and Griffin, 2005) modified to output daily maximum direction buffer zone length was used to generate the buffer zones. The analysis found that the only factor statistically separating the maximum 6-hour flux values in the database is the tarp type: untarp, Poly Tarp, or TIF Tarp. Other factors on the U.S. EPA Phase 2 label that are assigned credits to reduce buffer zone size are not supported by the analysis in this memorandum but are being further evaluated in a separate analysis. In addition, this memorandum discusses three issues related to buffer zone development: tarp cutting interval, maximum direction versus whole field buffer zone distributions generated by the PERFUM model, and choice of meteorological data in the PERFUM model. This analysis indicates that the interval for cutting TIF tarps should be 6 – 10 days following application. DPR has used the maximum direction distribution of buffer zones to develop mitigation measures in the past. The basis for using the maximum direction distribution is explained above and should be considered in setting buffer zones. Two California meteorological stations are available in the PERFUM model for use in developing buffer zones: Ventura and Bakersfield. The use of the Ventura meteorological station results in the largest buffer zones compared to Bakersfield and representative of high use chloropicrin areas. DPR buffer zones are presented in Appendix 2. Appendix 3 shows that the effect of soil moisture on chloropicrin flux was examined and found to be unsubstantiated.

Greenhouse applications have not been specifically examined in this analysis, although U.S. EPA developed separate buffer zone tables. It is likely that the most appropriate greenhouse buffer zone table will use data from the applications in the database in Appendix 1.

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APPENDIX 1												
Database of Chloropirin Applications												
MRID	DPR Volume #	Location	App type (As listed in data volume)	Tarp Type	notes		Industry ID	App rate lb/ac	Flux	ave time (hrs)	200lb/ac Flux	Total Mass loss (%)
44149201	0199-0072	Phoenix, AZ	Bed/untarp	untarp		1996	Beard et al. (1996)	149.0	112.8	6.0	151.4	61.4
		Phoenix, AZ	Bed/LDPE Tarp	Poly				189.0	142.1	6.0	150.4	68.6
		Phoenix,AZ	Broadcast/untarp	untarp				171.0	180.3	6.0	210.9	62.5
		Phoenix, AZ	Broadcast/LDPE tarp	Poly				332.0	211.0	6.0	127.1	62.6
		Yakima, WA	Broadcast/LDPE tarp	Poly				343.0	23.3	6.0	13.6	33.8
		Bradenton, FL	Broadcast/LDPE tarp	Poly				346.0	57.8	6.0	33.4	36.5
48033801	0199-0137	Elkton, FL	Bed/untarp	untarp		2010	CMTF PRS09006	47.7	15.0	5.7	62.9	6.5
		Elkton, FL	Bed/untarp	untarp				52.0	13.2	5.8	50.8	4.9
48011601	not submitted	Coloma, WA	Bed/untarp	untarp								
47295203	52875-0129	Bainbridge, GA	Bed/VIF (hytiblock)	TIF		2007	Arysta PTRL RptNo 1619W-1	71.2	0.4	5.0	1.1	1.6
47295202	52875-0128	Dover, FL	Bed/metallized tarp	Metal		2007	Arysta PTRL RptNo 1595W-1	36.2	9.0	5.5	49.7	13.5
47295204	52875-0130	Hart, MI	Bed/XL Black Blockade VIF tarp	VIF		2007	Arysta PTRL RptNo 1646W-1	41.2	0.6	6.0	2.9	0.35
N/A	50046-0198	Lost Hills, CA	Broadcast/TIF tarp/16Days	TIF	Field 1	2012	USDA-ARS HA2011A	340.5	6.3	6.0	3.7	4.5
			Broadcast/TIF tarp/10Days	TIF	Field 2			326.0	3.2	6.0	2.0	3.6
			Broadcast/TIF tarp/5Days	TIF	Field 3			353.8	4.3	6.0	2.4	10
			Broadcast/TIF tarp/KTS/5Days	TIF	Field 4			355.5	10.6	12.0	5.9	11.8
48200001	52971-0112	Tifton, GA	Bed/Pliant Blockade TIF tarp	TIF	Field 1	2009	USDA 2009B	61.4	1.7	6.0	5.5	2.5
		Tifton, GA	Bed/LDPE Tarp	Poly	Field 2			64.3	12.4	6.0	38.6	8.51
		Tifton, GA	Bed/LDPE Tarp	Poly	Field 3			68.1	14.6	6.0	42.9	7.93
47813901	0199-0138	Duette, FL	Bed/metallized tarp	Metal	Field 1	2009	USDA 2009A	51.1	18.7	6.0	73.2	2.9
		Duette, FL	Bed/Olefinas 1.2mil Guardian VIF tarp	VIF	Field 2			57.3	2.2	6.0	7.7	0.3
		Duette, FL	Bed/metallized tarp w/1,3-D	Metal	Field 3			53.5	4.5	6.0	16.8	0.4
48107601	0199-0140	Ft. Pierce, FL	Bed/TIF tarp	TIF		2010	MBIP HA201001	134.5	14.1	5.0	21.0	3.4
48085701	0199-0143	Ft. Pierce, FL	Broadcast/LDPE tarp/low dist std rig	Poly	Site 1	2010	USDA 2009H	254.8	46.8	6.0	36.8	34.56
		Ft. Pierce, FL	Broadcast/LDPE tarp/std rig	Poly	Site 2			230.4	46.5	6.0	40.3	43.87

MRID	DPR Volume #	Location	App type		notes		Industry ID	App rate lb/ac	Flux	ave time (hrs)	200lb/ac Flux	Total Mass loss (%)
47576901	0199-0130	Wasco, CA	Broadcast/LDPE tarp	Poly	Field 1	2008	Study ID 200801	358.0	75.1	6.0	42.0	47.8
		Wasco, CA	Strip/LDPE tarp	Poly	Field 2			165.0	38.1	6.0	46.2	47.6
		Wasco, CA	Broadcast/untarp	untarp	Field 3			197.0	60.5	6.0	61.4	46.36
		Wasco, CA	Broadcast/Deep/untarp	untarp	Field 4			321.0	74.8	6.0	46.6	46.3
48006001	0123-0220	Wasco, CA	Broadcast/LDPE tarp	Poly	Field 1	2010	MBIP HA20091	189.1	31.0	6.0	32.8	18.29
		Wasco, CA	Broadcast/vaporsafe tarp	TIF	Field 2			180.3	15.8	6.0	17.5	12.68
		Wasco, CA	Broadcast/vaporsafe tarp + KTS	TIF	Field 3			177.9	63.8	6.0	71.7	9.77
		Wasco, CA	Strip/vaporsafe tarp/deep	TIF	Field 4			101.3	2.8	6.0	5.5	17.92
		Wasco, CA	Broadcast/deep/vaporsafe tarp	TIF	Field 5			181.1	5.9	6.0	6.5	9.37
*	0199-0142	Ventura, CA	Broadcast/Polyethylene tarp	Poly	Field 1	2010	HA200902-2	145.8	6.1	6.0	8.3	10.8
		Ventura, CA	Broadcast/TIF tarp	TIF	Field 2			135.2	4.6	6.0	6.8	14.1
		Ventura, CA	Drip/TIF/KTS	TIF	Field 3			177.7	13.3	6.0	15.0	30.4
45112901	50046-0153	Salinas, CA	drip/bed/VIF	Poly		2000	DowAgroSciences Study ID 980070.01	70.5	14.9	6.0	42.3	8.6
45112902	50046-0152	GA	drip/bed/poly tarp	Poly		2000	DowAgroSciences Study ID 990072	36.8	7.3	5.3	39.8	12.3
47456001	0199-0093	Yuma, AZ	buried drip/bed/poly	Poly		1999	TRICAL Project #TC350	*	*	*	*	*
		Yuma, AZ	buried drip/bed/untarp	untarp			study rejected					
47679301	0199-0131	Yuma, AZ	buried drip/bed/untarp	untarp		2008	CMTF PRS08004	70.8	39.3	6.0	111.0	36.6
48087401	0199-0136	Salinas, CA	drip/bed/LDPE tarp	Poly		2010	Study ID 2007-D	200.0	77.7	6.0	77.7	22.3
		Salinas, CA	drip/bed/TIF tarp	TIF				200.0	5.5	6.0	5.5	3
		Salinas, CA	drip/bed/LDPE w/KTS	Poly				200.0	21.2	5.5	21.2	9.2
		Salinas, CA	drip/bed/LDPE w/water seal	Poly				200.0	50.4	5.5	50.4	14.4
46420201	199-0112	Salinas, CA	drip/bed/LDPE	Poly	Site 16	2004	CMTF PRS02004	148.7	47.0	8.0	63.2	15.2

APPENDIX 2									
Reduce Set of Chloropicrin Applications									
						Hrs after		40ac	40ac
					Max Flux	app Max	flux (ug/m2sec)	Buffer (ft)	Buffer (ft)
DPR Volume #	Location	App type	Analysis ID	notes	Time (hrs)	Flux occurs	350lb/ac	90th	95th
0199-0072	Yakima, WA	Broadcast/LDPE tarp	05		1230	53	23.8	16	16
	Bradenton, FL	Broadcast/LDPE tarp	06		1200	29	58.5	261	406
0199-0137	Elkton, FL	Bed/untarp	07		1300	0	110.1	388	539
	Elkton, FL	Bed/untarp	08		1600	0	88.8	2353	2948
50046-0198	Lost Hills, CA	Broadcast/TIF tarp/16Days	13	Field 1	1230	30	6.5	0	0
		Broadcast/TIF tarp/10Days	14	Field 2	1230	30	3.5	0	0
		Broadcast/TIF tarp/5Days	15	Field 3	1230	30	4.2	0	0
		Broadcast/TiF tarp/KTS/5Days	16	Field 4	700	60	10.4	0	0
52971-0112	Tifton, GA	Bed/Pliant Blockade TIF tarp	17	Field 1	930	43	9.7	0	0
	Tifton, GA	Bed/LDPE Tarp	18	Field 2	2130	32	67.5	3081	3548
	Tifton, GA	Bed/LDPE Tarp	19	Field 3	2130	33	75.0	3484	3988
0199-0140	Ft. Pierce, FL	Bed/TiF tarp	23		945	0	36.7	16	16
0199-0143	Ft. Pierce, FL	Broadcast/LDPE tarp/low dist std rig	24	Site 1	1530	32	64.3	1242	1587
	Ft. Pierce, FL	Broadcast/LDPE tarp/std rig	25	Site 2	1530	33	70.6	1406	1787
0199-0130	Wasco, CA	Broadcast/LDPE tarp	26	Field 1	1330	33	73.4	668	996
	Wasco, CA	Broadcast/untarp	28	Field 3	1930	39	107.5	4481	>4724
0123-0220	Wasco, CA	Broadcast/LDPE tarp	30	Field 1	1600	8	57.4	1355	1672
	Wasco, CA	Broadcast/vaporsafe tarp	31	Field 2	1100	0	30.7	16	16
0199-0142	Ventura, CA	Broadcast/Polyethylene tarp	35	Field 1	1230	34	14.6	0	0
	Ventura, CA	Broadcast/TIF tarp	36	Field 2	1230	0	12.0	0	0
50046-0153	Salinas, CA	drip/bed/VIF	38		1300	6	74.0	678	1009
50046-0152	GA	drip/bed/poly tarp	39		1200	0	69.7	393	574
0199-0131	Yuma, AZ	buried drip/bed/untarp	40		1300	5	194.3	829	1051
0199-0136	Salinas, CA	drip/bed/LDPE tarp	41		1900	6	136.0	>4724	>4727
	Salinas, CA	drip/bed/TIF tarp	42		1900	6	9.6	16	16
	Salinas, CA	drip/bed/LDPE w/KTS	43		1300	0	37.1	120	231
	Salinas, CA	drip/bed/LDPE w/water seal	44		1300	0	88.3	910	1313
199-0112	Salinas, CA	drip/bed/LDPE	45	Site 16	1130	4	110.6	565	802

Department of Pesticide Regulation

Brian R. Leahy
Director

Edmund G. Brown Jr.
Governor

M E M O R A N D U M

APPENDIX 3

TO: Randy Segawa
Environmental Program Manager I
Environmental Monitoring Branch

FROM: Terrell Barry, Ph.D. *Original signed by*
Research Scientist III
Environmental Monitoring Branch
916-324-4140

DATE: February 12, 2013

SUBJECT: AVAILABLE SOIL MOISTURE EFFECT ON MAXIMUM SIX HOUR FLUX

The Chloropicrin Manufacturers Task Force (CMTF) submitted a proposal to the Department of Pesticide Regulation dated October 27, 2011 (CMTF, 2011) which included four sections: regulatory exposure levels, appropriate field data, buffer zones development for mitigation, and conclusions. A key element in this proposal was the argument by the CMTF that certain field study applications should be eliminated from use in analysis because the CMTF contends that the applications in question do not meet new federal label language related to soil moisture. The question of appropriate field data and the basis used by CMTF to argue for removal of certain applications is related to Good Agricultural Practices (GAPs). GAPs were developed with the intent to aid in mitigation of off-site exposure. However, there is no comprehensive data analysis supporting GAPs. Instead, both the CMTF the U.S. Environmental Protection Agency (EPA) use single study observations to conclude that the GAPs are effective. This amounts to GAPs being supported only by expert opinion. The U.S. EPA Phase II labels require that for shank applications soil moisture at 9 inches below the surface must be equal to or greater than 50% of Available Water Capacity (AWC).

This memorandum presents analysis of the relationship between AWC and the magnitude of the maximum 6 hour (6hr) flux. The studies and applications within the studies used for this analysis are shown in Table 1. In order to perform the analysis the AWC has to be estimated using soil moisture measurements in the reports for each application. AWC is soil-specific and may be estimated with considerable uncertainty for a particular soil. Soil moisture information from the studies is presented in the form of soil characteristics (clay/silt/sand, bulk density) and soil moisture by weight. Soil moisture calculators can be used to estimate AWC. U.S. EPA label language does not require the use of a specific method or Soil Water Calculator to determine if post application soil moisture at 9 inch below the surface met the GAP criteria. Three Soil Water

Calculators were used in this analysis: Saxton et al. (1986) and Saxton and Rawls (2006) from the Soil-Plant-Air-Water Model version 6.02.75, and Nelson (1997). Soil moisture was calculated for the 15 applications from the 3 studies shown in Table 10. Soil cores were taken to various depths at each of the applications. This analysis closely followed the U.S. EPA labels specification to calculate to soil moisture. Thus, only the soil core sections that provided the closest bracketing of the 9 inch depth were used in this analysis. The soil moisture parameters were estimated by the three methods: Saxton et al. (1986), Saxton and Rawls (2006) and Nelson (1997). Results are shown in Figure 1. Each study is separated and the applications listed in order within study. The depth for soil moisture calculation is shown under each study. Application #11 in Beard et al. (1996) had to be excluded because the percent sand was outside of the range for Saxton et al. (1986) and Saxton and Rawls (2006). AWC is shown on the y-axis with the 50% - 75% range bracketed by the red horizontal lines.

There are large differences between the AWC estimates obtained using the three different models. The largest differences occur for applications with low Organic Matter Content. Of particular interest for this analysis is whether any of the bars for a particular application exceed the 50% AWC line. For estimated AWC calculated with Nelson (1997) and Saxton et al. (1986) most do not exceed 50% AWC. Three of the four applications in the CMTF (2008) study do not achieve the 50% AWC line with any of the estimate models, yet these applications were performed under conditions argued to be GAP-compliant. Soil cores in the CMTF (Ajwa and Sullivan, 2008; volume 0199-0130) study were taken to a depth of 30in. The soil moisture reported in the text of this study was averaged over the entire soil core. Averaging over the entire 30 in soil core does not follow the U.S. EPA label language. When only the soil core section bracketing 9 inch (6-12 inches core section) is used, it is clear that the soil was very dry at the measurement depth specified by the U.S. EPA label language. The deeper sections of the core were moist and must be included to achieve the 50% AWC. However, this does not meet the label language. Application #9 the Beard et al (1996) study also does not achieve the 50% AWC line.

The effect of soil moisture on the maximum 6 hr flux is shown in Figure 2. The maximum 6 hr flux is important because it is the driving factor in determining the size of acute buffer zones for the mitigation of off-site exposure to chloropicrin. There is not a discernible pattern and no statistical correlation between AWC and the magnitude of the maximum 6 hr flux. Thus, there does not appear to be a detectable relationship between AWC and maximum 6hr flux. The flux values do generally separate out according to study, thus the studies actually appear to be a surrogate for tarp type. The highest maximum 6hr flux values are the Arizona applications from the Beard (1996) study. All but one of the Vaporsafe tarp applications from the MBIP (Ajwa and Sullivan, 2010; 0123-0220) show the lowest flux values.

This analysis does not support the exclusion of the Arizona applications in Beard et al. (1996) due to soil moisture.

References

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Nelson, R. 1997. Soil Hydraulic Properties Calculator. Available at: <http://www.afrc.uamont.edu/ficklinr/soils/soiltexture.htm>. Web site last accessed December 31, 2012.

Saxton, K. E., W. J. Rawls, J. S. Romberger, and R. I. Papendick. 1986. Estimating generalized soil water characteristics from texture. Soil Sci. Soc. Amer. J. 50(4):1031-1036.

Saxton, K.E. and Rawls, W.J. (2006). Soil water characteristic estimates by texture and organic matter for hydrologic solutions. Soil Science Society of America Journal, 70, 1569-1578.

Table 1. Studies used to examine the relationship between soil AWC and maximum 6hr flux.

MRID	DPR Volume #	Location	App type	Year	Figure ID
48006001	0123-0220	Wasco, CA	Broadcast/LDPE tarp	2010	MBIP 2010
		Wasco, CA	Broadcast/vaporsafe tarp		
		Wasco, CA	Broadcast/vaporsafe tarp+KTS		
		Wasco, CA	Broadcast/vaporsafe tarp/deep		
44149201	0199-0072	Phoenix, AZ	Bed/untarp	1996	Beard et al 1996
		Phoenix, AZ	Bed/LDPE Tarp		
		Phoenix, AZ	Broadcast/untarp		
		Phoenix, AZ	Broadcast/LDPE tarp		
		Yakima, WA	Broadcast/LDPE tarp		
		Bradenton, FL	Broadcast/LDPE tarp		
47576901	0199-0130	Wasco, CA	Broadcast/LDPE tarp	2008	CMTF 2008
		Wasco, CA	Strip/LDPE tarp		
		Wasco, CA	Broadcast/untarp		
		Wasco, CA	Broadcast/Deep/untarp		

Figure 1. AWC (% of Available Water) for each of 15 applications from 3 studies as shown in Table 1. Note: Application #11 soil was 242% AWC by the Nelson (1997) method and was outside the bounds of Saxton et al. (1986) and Saxton and Rawls (2006).

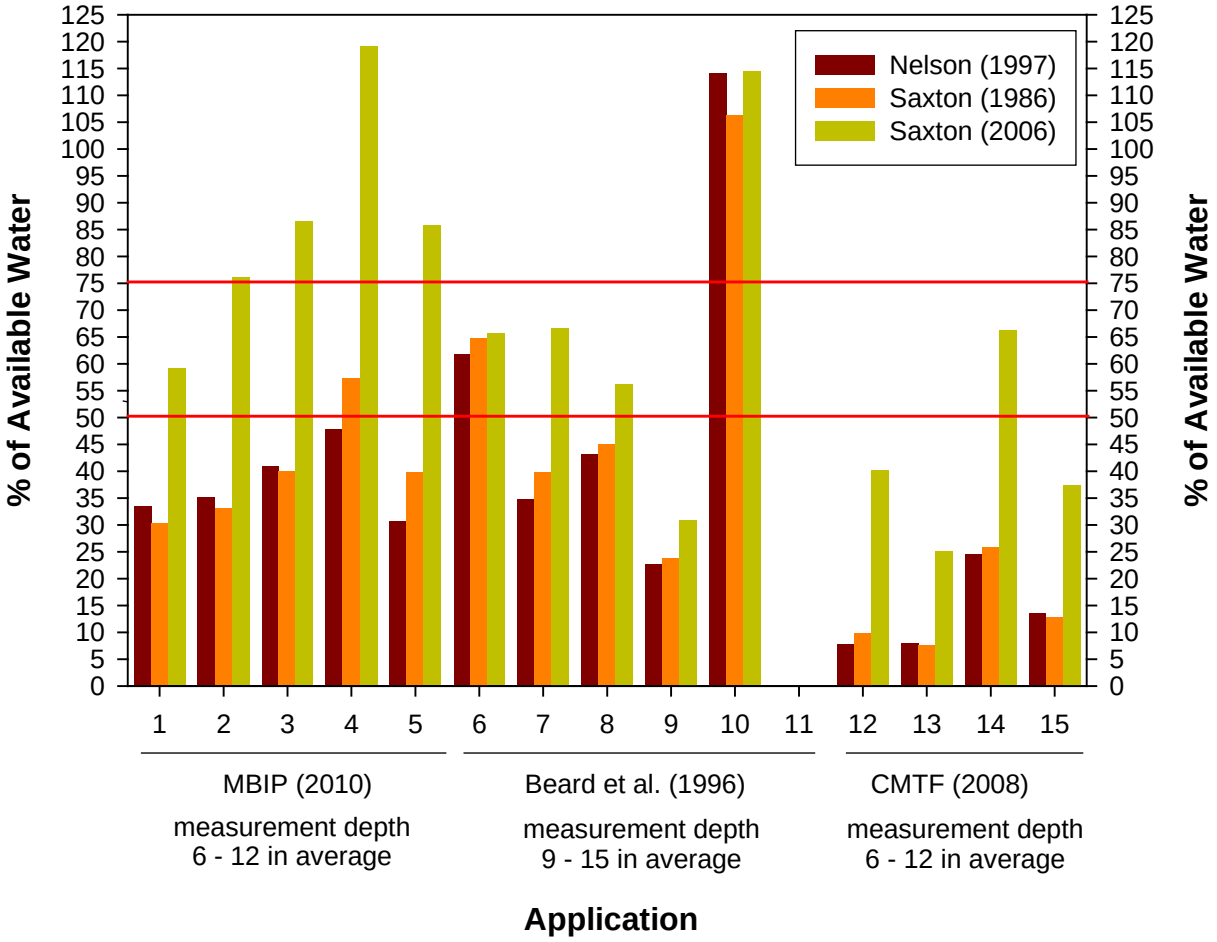
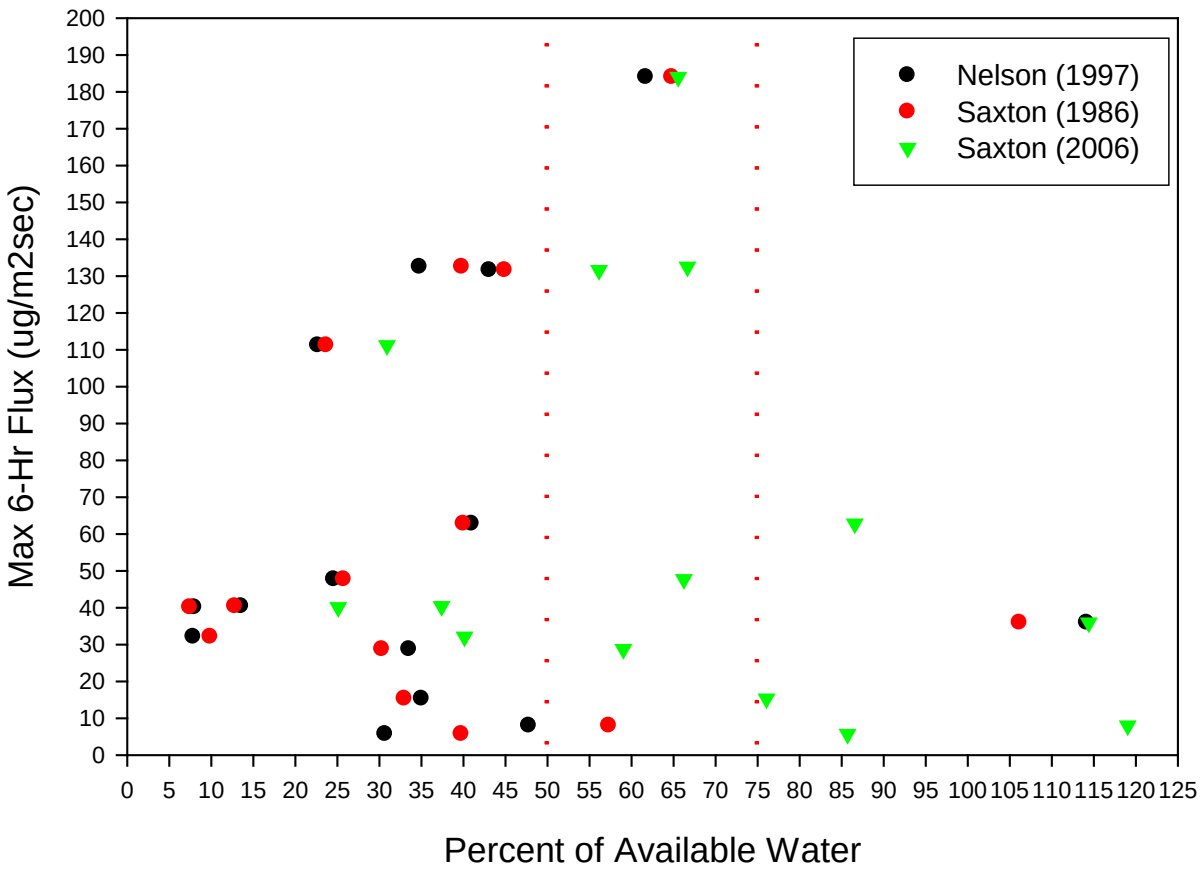


Figure 2. The effect of soil moisture level on maximum 6hr flux (ug/m2sec). The AWC (Percent of Available Water) estimates from the three models for each of the 15 applications listed in Table 1 are shown. The legend shows each model. The 50% - 75% AWC bracket is shown as the red vertical dashed lines.



Appendix 4. Percentile Buffer Zone Tables

Untarp Maximum Direction Percentile Buffer Zones (ft)

50%

App Rate (lb/ac)	App Size (AC)					
	1	5	10	20	30	40
100	0	16	16	16	16	16
150	0	16	16	98	146	186
200	16	57	137	236	314	385
250	16	137	234	376	492	614
300	16	203	329	521	675	815
350	45	268	425	661	853	1026

75%

App Rate (lb/ac)	App Size (AC)					
	1	5	10	20	30	40
100	0	16	16	68	123	167
150	16	69	164	292	397	488
200	16	183	315	512	675	822
250	10	285	463	731	954	1162
300	95	381	602	945	1225	1487
350	139	471	739	1161	1502	1809

80%

App Rate (lb/ac)	App Size (AC)					
	1	5	10	20	30	40
100	0	16	16	115	176	228
150	16	103	209	359	482	597
200	16	225	378	616	813	993
250	62	336	544	864	1133	1375
300	117	443	704	1106	1435	1733
350	165	545	860	1339	1727	2084

85%

App Rate (lb/ac)	App Size (AC)					
	1	5	10	20	30	40
100	0	16	61	170	253	322
150	16	145	272	461	615	755
200	16	281	467	756	987	1195
250	88	405	651	1027	1334	1623
300	145	523	825	1295	1682	2048
350	201	637	1004	1562	2031	2478

90%

App Rate (lb/ac)	App Size (AC)					
	1	5	10	20	30	40
100	16	16	134	274	383	481
150	16	214	375	620	825	1010
200	38	368	602	961	1252	1521
250	123	514	814	1275	1651	2005
300	195	645	1013	1588	2052	2515
350	256	773	1207	1888	2468	3025

95%

App Rate (lb/ac)	App Size (AC)					
	1	5	10	20	30	40
100	16	100	258	454	613	755
150	16	323	540	873	1148	1402
200	88	509	819	1291	1690	2066
250	197	687	1084	1686	2188	2683
300	278	848	1321	2059	2686	3290
350	345	1001	1543	2426	3209	3922

Poly Tarp Percentile Buffer zones (ft)

50%

App Rate (lb/ac)	App Size (AC)				
	5	10	20	30	40
100	0	0	0	0	0
150	0	16	16	16	16
200	16	16	16	16	16
250	16	16	16	49	75
300	16	25	85	124	156
350	16	79	146	196	240

75%

App Rate (lb/ac)	App Size (AC)				
	5	10	20	30	40
100	0	0	16	16	16
150	16	16	16	16	16
200	16	16	79	133	177
250	16	95	191	266	322
300	80	174	301	412	494
350	140	249	409	538	658

80%

App Rate (lb/ac)	App Size (AC)				
	5	10	20	30	40
100	0	16	16	16	16
150	16	16	16	39	93
200	16	28	152	227	291
250	41	156	289	394	489
300	128	251	425	576	693
350	198	342	557	733	893

85%

App Rate (lb/ac)	App Size (AC)				
	5	10	20	30	40
100	0	16	16	16	16
150	16	16	79	156	216
200	16	119	266	370	468
250	118	254	441	598	738
300	212	373	621	838	1005
350	293	491	793	1043	1269

90%

App Rate (lb/ac)	App Size (AC)				
	5	10	20	30	40
100	16	16	16	16	96
150	16	104	249	355	446
200	145	271	479	644	794
250	249	430	706	929	1136
300	348	575	924	1220	1471
350	444	716	1139	1490	1808

95%

App Rate (lb/ac)	App Size (AC)				
	5	10	20	30	40
100	16	16	216	322	412
150	171	338	571	765	941
200	352	560	903	1185	1441
250	475	769	1212	1576	1916
300	607	960	1504	1957	2371
350	731	1141	1777	2325	2842

60% Credit Tarp Percentile Buffer Zones (ft)

The majority of the 60% Credit Tarp buffers were zero so the format of the buffer zone tables are formatted to show only the application combinations and percentiles that require buffer zones.

App Rate	Acres	Percentile			
		80	85	90	95
300	20	0	0	0	0
	30	0	0	0	16.4
	40	0	0	0	16.4
350	20	0	0	16.4	16.4
	30	0	0	16.4	16.4
	40	0	16.4	16.4	16.4

Department of Pesticide Regulation

Mary-Ann Warmerdam
Director

Arnold Schwarzenegger
Governor

M E M O R A N D U M

APPENDIX 5

TO: Charles Andrews, Chief
Worker Health and Safety Branch

VIA: Randy Segawa, Agriculture Program Supervisor IV
Environmental Monitoring Branch

FROM: Terrell Barry, Ph.D., Research Scientist III
Environmental Monitoring Branch
(916) 324-4140

Original signed by

DATE: February 8, 2007

SUBJECT: DEVELOPMENT OF ADDITIONAL METHYL ISOTHIOCYANATE BUFFER ZONES FOR THE METAM SODIUM MITIGATION PROPOSAL

Background

The Department of Pesticide Regulation (DPR) is drafting a risk management strategy to meet its regulatory goal of ensuring no exposures causing methyl isothiocyanate (MITC) associated eye or respiratory irritation result from the use of metam sodium (MS) and other MITC generating pesticides (Gosselin, MITC Risk Management Directive, December 2002). Buffer zones restricting where and under what circumstances MS applications can be made are an integral part of the risk management strategy. A previous memorandum (Barry, 2006) documented development of MITC buffer zones using the Probabilistic Exposure and Risk model for Fumigants, version 2 (PERFUM2) modeling system (Reiss and Griffin, 2005) for an 8-hour time weighted average (TWA) air concentration threshold of 220 ppb for applications smaller than 40 acres. Barry (2006) provides background information on the application methods and development of flux profiles. This memorandum documents the development of MTIC buffer zones under several additional conditions: (1) screening meteorological conditions, (2) using the FEMS (Fumigant Emissions Modeling System v5.074) model system (Sullivan et al., 2006) to both generate buffer zone estimates for companion to those generated using the PERFUM model system and also to generate buffer zones for acreage larger than the capability of the PERFUM model system, and (3) an additional air concentration threshold of 22ppb 8-hr time TWA.

Buffer Zone Development Methods

Screening Conditions

Screening condition buffer zones are developed under a simplified set of input conditions with respect to the meteorological conditions and the flux. Typically screening meteorological conditions are "…worst-case meteorological conditions to provide conservative estimates of the air quality impacts of a specific source…" (U.S. EPA, 2003) in order to be assured that they will produce protective buffer zones in the absence of more detailed input conditions. The screening flux is the critical flux that produces the largest buffer zones when used with appropriate screening meteorological conditions (Barry et al., 2004). For example, a night flux is only used with night screening meteorological conditions and a day flux is only used with day screening meteorological conditions. DPR methyl bromide (mebr) buffer zones were developed under screening conditions (Segawa et al., 2000). Subsequent analysis demonstrated that DPR mebr screening buffer zones were protective at approximately the 95% level meaning that over the long term for every 100 mebr applications made, the screening buffer zones are long enough for 95 of those applications (Johnson, 2001).

The critical flux values used to generate the screening buffer zones for MITC were developed from the sprinkler and shank application method flux profiles shown in Appendix A of Barry (2006). Rolling 8-hr average fluxes were calculated for all 96-hr flux profiles. Rolling average flux values for each application method are shown in Table 1. The relationship between the hour of day and the flux profile was maintained. The day scenario assumes 4 or more hours of the 8-hr averaging interval occurs under daylight. Conversely, the night scenario assumes 4 or more hours of the 8-hr averaging interval occurs at night. Maintaining the alignment of critical flux with hour of the day required that for intermittent sprinkler methods that both a day and a night table be produced because the day and night flux values were similar. The intermittent sprinkler application method has the same critical flux for day and night because of the timing of the flux sampling intervals. The standard methods have 8-hr rolling night flux values large enough that it is not necessary to show 8-hr rolling day flux values.

The Industrial Source Complex 3 (ISCST3) air dispersion model (U.S. EPA, 1995) was used to simulate for square fields of sizes 1 to 80 acres screening scenario downwind centerline air concentrations and generate the screening buffer zones. The simulations to produce the screening buffer zones used the flux values shown in Table 1 as the uniform flux for the entire 8-hr run for each scenario. The flux values have a MS base effective broadcast application rate of 320lbs/acre. This means that the flux values shown in Table 1 are those associated with an application of each method made at the MS broadcast application rate of 320lb/acre. The meteorological data was also uniform for the entire 8-hr run. Day scenario screening meteorological conditions were wind speed 1m/s and atmospheric stability class D (neutral).

Night scenario screening meteorological conditions were wind speed 1m/s and atmospheric stability class F (high stable). The generated buffer zones are shown in Tables 2 for field sizes 40 acres or less and Table 3 for large fields.

Buffer zones generated using the FEMS modeling system (v5.074)

The FEMS modeling system (Sullivan et al, 2006) was used to generate buffer zones for square fields of sizes 1 to 50 acres for sprinkler methods and sizes 1 to 80 acres for shank methods. Both PERFUM2 and FEMS use the ISC model to estimate air concentrations. However, there are three important differences between the PERFUM model and modeling process and the FEMS model and modeling process.

The first difference is in the flux profiles. The FEMS default flux profiles were used. The flux was not randomized for these FEMS runs; the mean flux value for each sampling period was used in all runs. These flux profiles differ in some averaging periods from those shown in Appendix A of Barry (2006). Specifically, the first two days of all flux profiles in Barry (2006) are those obtained from U.S. EPA while the last two days are the Sullivan flux estimates. See Barry (2006) for further discussion on the construction of the 4-day flux profiles. Tables 4 through 7 show the U.S. EPA flux profiles versus the FEMS default flux profiles.

The second difference is in the meteorological data sets and how those data sets are used in the modeling. PERFUM uses Ventura meteorological data from the California Irrigation Management and Information System (CIMIS) network for the years 1995 to 1999 while FEMS uses Ventura meteorological data from the National Weather Service (NWS) Automated Surface Observing System (ASOS) station for the years of 2000 to 2004. PERFUM and FEMS both use Bakersfield NWS ASOS–1999 to 2003. However, FEMS uses the meteorological data differently than PERFUM. PERFUM cycles a 4-day flux profile through the 5 years of meteorological data in such a way that the result is 1825 (365 days/years times 5 years) realizations of each day of the flux profile (for sake of discussion, assume 1825 days in 5 years). The PERFUM model effectively runs each day of the flux profile on each day of the meteorological record. Thus, each maximum direction buffer zone distribution has 1825 buffer zones as members. However, with respect to the meteorology the PERFUM output is deterministic. Specifically, if the PERFUM model is run a second time with the same inputs, the same outputs will result. In contrast, for these FEMS runs the FEMS model is stochastic with respect to the meteorological data. The FEMS model uses the 5 years of weather data as a base from which to randomly create the number of realizations of an application designated by the user. The FEMS documentation uses the term “years” in the following sense: one year refers to a single run of the ISC model using n days of weather with the n days in the flux profile. For example, a flux profile consisting of one day divided into 3 eight hour periods, totaling a single 24-hour day, would run with 24 hours of meteorological data. In the FEMS terminology, that single run of 24 hours would be called a year. Each “year” corresponds to the realization of an

"application." In this FEMS analysis, 5000 "years" (or 5000 applications) were used to generate the buffer zone distributions. The FEMS model does not cycle through the meteorological data, instead it randomly chooses a day from a year in which to start an application. Then it randomly perturbs the hourly records in the 4 days of meteorological data to produce a new 4-day set. Results from the FEMS runs will never be exactly the same even if the same inputs are used. Thus, even though PERFUM and FEMS use the same Bakersfield NWS ASOS 1999 to 2003 as a base, the actual meteorological data used by the two models will not be exactly the same.

The third important difference between FEMS and PERFUM2 is the method that FEMS uses to report buffer zone results. FEMS counts exceedances of the chosen threshold at each of the FEMS receptors for each of the averaging time periods of the application process and reports the distance at which various exceedance rates occur. In contrast, the PERFUM2 model constructs the maximum direction buffer zone distributions at the conclusion of the model run. For each averaging period thePERFUM2 distributions consist of the 1825 buffer zone lengths (meters) that were produced during the 5-year model run. The percentile in PERFUM2 is found simply by ordering the buffer zone lengths and locating the appropriate position in the distribution. For example, the 95th percentile of the maximum direction buffer zone length is that distance below which 95% of the members of the entire distribution of buffer zone lengths for that sampling period would fall below. Thus, the chosen 95 percentile buffer zone is long enough that in long-term averaging 95 out of 100 applications made under the same conditions will not have air concentrations above the chosen threshold at the buffer zone distance. An implied, but important assumption in using both models, is that the meteorology which is used is representative of meteorology at that site.

The FEMS approach is different. The FEMS model does not construct distributions of buffer zone lengths. Instead it counts exceedances of the designated air concentration threshold at each of the receptors that are placed around the source. The FEMS output reports the farthest distance at which various exceedance rates occurred during the run. Table 8 shows an example FEMS output. The percentiles shown on the left column must be correctly interpreted to be meaningful. The right-hand column lists buffer zone lengths corresponding to the percentiles in the left-hand column. However, in the FEMS context the meaning of "percentile" is based on exceedance rates of the buffer zones in terms the total number of averaging periods. The straight numerical percentile given in the FEMS table is not the same as in PERFUM2. Thus, to choose a buffer zone in FEMS that has the same meaning as a buffer zone from PERFUM2, the correct "percentile" in FEMS must be chosen.

In order to develop a correspondence between an exceedance rate as defined in FEMS to an exceedance rate based on the application, it is necessary to assume that each exceedance counted in FEMS occurs during a different application. Since FEMS counts exceedances based on the averaging period time, under the assumption above it will be possible to obtain exceedance counts which are larger than the number of applications. For example, in a

5000 year (application) simulation, if for a given receptor the reference concentration were exceeded during every period, then the number of exceedances counted by FEMS would be 5000*3(periods/application)=15000. This is larger than the 5000 applications simulated by the run.

The formula used by FEMS to calculate the percentile based on exceedances is a straightforward implementation of the idea of using the averaging times as the denominator for the percentile. The formula below is from the FEMS documentation. This is the FEMS percentile equation:

$$Percentile = \left[1 - \left[\frac{(\#exceedances / \#simulations)}{(24hrs / averaging\ time) * basis * (\#App / year)}\right]\right] * 100$$

where:

#exceedances = the count of occurences that the reference concentration was exceeded in any averaging time during the entire sequence of simulations.

#simulations = the number of “years” or, in this case since there is one application/year it is the number of applications. The minimum number of simulations is 200.

averaging time = the threshold averaging time or in other words, the exposure duration time associated with the health reference concentration (must be less than or equal to 24 hours), e.g. 8 hrs for MITC

basis = the window of tallying. For example, if the entire 4-day flux profile is tallied over then the basis is 4.

#App/year = the number of times FEMS will initiate an application per calendar year.

This equation is clearer if the number of simulations is placed into the denominator. This results in the following formula:

$$Percentile = \left[1 - \left[\frac{(\#exceedances)}{(24hrs / averaging\ time) * basis * (\#App / year) * (\#simulations)}\right]\right] * 100 = \left[1 - \frac{\#exceedances}{total\ \#averaging\ periods}\right] * 100$$

The denominator now contains the total number of averaging periods. In order to calculate a percentile based on the number of applications, it is necessary to divide by the number of applications, instead of the total number of averaging periods. The number of applications is defined as #simulations in the equation above. Therefore, the percentile which is based on applications will use #simulations in the denominator. Since it is possible to have more than one application per year, this factor must be included as well. The percentile is labeled as $\text{Percentile}_{\text{App}}$, to denote that it is a percentile based on applications:

$$Percentile_{App} = \left[1 - \frac{\min(\#App/year * \#simulations, \#exceedances)}{\#App/year * \#simulations}\right] * 100$$

The minimum function in the numerator is necessary to avoid getting negative numbers when the number of exceedances is larger than the total number of applications.

The 95th percentile based on applications will be used to show how to derive the corresponding FEMS percentile for MITC buffer zone generation. The 95th percentile based on applications means that 1 out of 20 applications has at least 1 period which exceeded the reference concentration. For 5000 applications, this means that 250 applications had at least 1 period in which the reference concentration was exceeded. If the number 250 is plugged into the equation above, the resulting value for $\text{Percentile}_{\text{App}}$ is 95%. Thus, the number of exceedances is 250 and by the assumption above, these occurred in different applications. This number of exceedances can be plugged into the first equation above to determine the corresponding FEMS percentile:

$$Percentile = \left[1 - \left[\frac{(\#exceedances/\#simulations)}{(24hrs/averaging\ time) * basis * (\#App/year)}\right]\right] * 100 = \left[1 - \frac{250/5000}{(24/8) * 1 * 1}\right] * 100 = 98.33 \approx 98.5\%$$

The values used above for the MITC buffer zone generation are as follows:

#exceedances = 250 = 0.05*5000

#simulations = 5000

averaging time = 8 hrs

basis = 1 day (FEMS uses the maximum air concentration day)

#App/year = 1

Thus for 5000 runs (translates to 5000 applications) where the long term average exceedance rate at the buffer zone distance is specified as 1 in 20 applications results in a 95% level of protection per application and corresponds to approximately the 98.5% level used in the FEMS approach.

Table 9 translates the results shown in Table 8 into terminology that matches the terminology that DPR typically uses in buffer zone development. In Tables 8 and 9 the summarization window (scenario period in the FEMS user's manual) is one day and the air concentration threshold is an 8-hour TWA, producing three intervals in which to tally exceedances of the air concentration threshold per application. As discussed above, for MITC buffer zones the FEMS percentile chosen was 98.5, rounding up rather than down. In Tables 8 and 9 the 98.5 percentile buffer zone of 530 meters is the receptor location where 0.045 intervals per year (application) over the 5000 runs exceeded the 220 ppb 8-hr time. This generally means that a total of 225 years (applications) showed exceedances in 5000 runs, which is equivalent to 4.5 exceedances per 100 applications. Thus, approximately 95% of applications in long term averaging are protected by a buffer zone of 530 m.

However, it should be noted that in FEMS, operationally, for the 1-day summarization window there are 15000 8-hr averaging periods in 5000 runs. The exceedances are counted over the 15000 8-hr averaging periods without regard to how those averaging periods are associated with individual years (applications). The 98.5 percentile is where 675 exceedances in the 15000 8-hr averaging periods were counted. The assumption in the calculations shown in the previous paragraph, in the FEMS summary, in Tables 8 and 9, and in the interpretation of the FEMS percentiles is that for the most part only one of the three 8-hr averaging periods per year (application) shows an exceedance. This is probably a reasonable assumption for most flux profiles. However, it would be possible to have more than one exceedance per year, in which case less than 225 years (applications) would show an exceedance.

The FEMS generated buffer zones are shown in Tables 10 through 13. FEMS estimates the actual buffer zone length for all buffer zones. There is no upper limit of 1440 m as in PERFUM. Therefore, some FEMS buffers will be "longer" simply because estimate is given rather than some upper limit.

Air concentration threshold of 22 ppb 8-hr time weighted average

Simulations to generate buffer zones for the 22 ppb 8-hr TWA threshold were conducted using PERFUM2 according to the methods presented in Barry (2006) and using FEMS according to the description of methods above. Tables 14 through 19 show the results.

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Table 1. Critical flux values used in generation of the screening buffer zones. All critical flux values have been adjusted to a base effective broadcast application rate of 320 lb/acre.

Application Method	Day/Night	Flux (ug/m^{2}sec)
Intermittent Chemigation	Day	40.2
Intermittent Shank	Day	59.3
Standard Chemigation	Night	149.5
Standard Shank	Night	147.0
Intermittent Chemigation	Night	40.2
Intermittent Shank	Night	46.3

Table 2. Metam sodium application screening buffer zones (meters).

Method/Flux/Scenario		Application rate			
	Acres	320	240	160	80
Chemigation Sprinkler Intermittent Watering-In 40.2 ug/m^{2}sec Day	1	39	22	0	0
	5	98	59	23	0
	10	149	91	37	0
	20	233	138	57	0
	40	367	215	91	0
Chemigation Sprinkler Intermittent Watering-In 40.2 ug/m^{2}sec Night	1	320	207	103	22
	5	328	208	103	22
	10	518	333	167	37
	20	864	531	269	62
	40	1529	905	434	100
Chemigation Standard Sprinkler 149.0 ug/m^{2}sec Night	1	1493	1088	681	287
	5	1719	1304	797	291
	10	2852	2153	1346	461
	20	4908	3709	2309	756
	40	8512	6493	4167	1333
Shank Intermittent Watering-In 59.3 ug/m^{2}sec Day	1	76	45	21	0
	5	185	119	57	0
	10	284	180	89	15
	20	442	278	134	23
	40	693	437	208	39
Shank Intermittent Watering-In 46.3 ug/m^{2}sec Night	1	387	257	135	32
	5	403	260	135	32
	10	643	413	213	50
	20	1107	668	341	86
	40	1970	1170	555	142
Shank Standard 147.0 ug/m^{2}sec Night	1	1472	1075	673	283
	5	1698	1290	787	287
	10	2816	2129	1329	454
	20	4847	3671	2280	743
	40	8405	6428	4116	1309

Table 3. Metam sodium application screening buffer zones (meters)–large acreage.

	Application rate				
Method/Flux/Scenario	Acres	320	240	160	80
Chemigation Sprinkler Intermittent Watering-In 40.2 ug/m^{2}sec Day	50	426	249	103	<10
Chemigation Sprinkler Intermittent Watering-In 40.2 ug/m^{2}sec Night	50	1836	1084	507	120
Shank Intermittent Watering-In 59.3 ug/m^{2}sec Day	60	932	571	274	50
	80	1180	698	333	64
Shank Intermittent Watering-In 46.3 ug/m^{2}sec Night	60	2864	1639	763	191
	80	3847	2139	973	237

Table 4. Standard chemigation sprinkler. Base application rate is 320lb/acre broadcast.

Averaging Period	U.S. EPA flux ug/m^2sec	FEMS Flux ug/m^2sec
1	35.8	39.3
2	91.7	75.7
3	41.4	112.1
4	119.3	148.4
5	66.7	83.4
6	232.3	358.1
7	6.3	9.0
8	7.2	31.1
9	62.3	53.1
10	41.4	75.2
11	41.0	63.0
12	51.0	7.7
13	39.2	39.2
14	35.8	35.8
15	32.3	32.3
16	28.8	28.8
17	18.3	18.3
18	17.8	17.8
19	15.9	15.9
20	20.1	20.1
21	24.3	24.3
22	28.5	28.5
23	15.6	15.6
24	12.5	12.5

Table 5. Intermittent chemigation sprinkler. Base application rate is 320lb/ac broadcast.

Averaging Period	U.S. EPA flux ug/m^{2}sec	FEMS Flux ug/m^{2}sec
1	60.5	12.3
2	12.6	6.1
3	53.4	71.7
4	26.9	48.0
5	11.4	8.0
6	9.7	3.3
7	21.2	3.7
8	3.2	1.7
9	17.5	29.7
10	13.2	15.8
11	5.5	2.5
12	1.8	1.3
13	1.3	1.3
14	1.3	1.3
15	8.3	8.3
16	19.5	19.5
17	5.8	5.8
18	5.9	5.9
19	0.9	0.9
20	0.9	0.9
21	1.6	1.6
22	10.4	10.4
23	7.0	7.0
24	2.4	2.4

Table 6. Standard shank. Base application rate 160lb/ac broadcast.

Averaging Period	U.S. EPA flux ug/m^2sec	FEMS Flux ug/m^2sec
1	3.5	3.2
2	21.4	27.1
3	15.9	19.4
4	51.1	82.4
5	62.5	57.0
6	32.9	40.1
7	3.5	23.2
8	5.2	6.3
9	5.0	6.3
10	82.7	118.3
11	64.3	101.0
12	63.3	51.5
13	2.0	0.0
14	1.8	1.8
15	1.3	1.3
16	15.5	15.5
17	27.4	27.4
18	14.9	14.9
19	2.5	2.5
20	1.7	1.7
21	1.0	1.0
22	0.3	0.3
23	5.0	5.0
24	5.0	5.0

Table 7. Intermittent shank. Base application rate 160lb/acre broadcast.

Averaging Period	U.S. EPA flux ug/m^2sec	FEMS Flux ug/m^2sec
1	6.0	4.3
2	28.4	36.3
3	30.9	26.0
4	15.4	15.7
5	3.9	4.9
6	10.3	2.8
7	2.6	0.8
8	4.0	6.7
9	6.5	12.2
10	3.3	4.4
11	1.6	1.7
12	2.3	2.7
13	0.5	0.5
14	1.5	1.5
15	2.4	2.4
16	1.6	1.6
17	0.7	0.7
18	0.2	0.2
19	0.2	0.2
20	0.2	0.2
21	0.2	0.2
22	0.2	0.2
23	0.2	0.2
24	0.2	0.2

Table 8. FEMS output example. This output is taken directly from the FEMS output file and is for a 1-day summarization basis, 8-hour TWA threshold of 660 ug/m^3. The Percentile column represents 100 percentage of exceedances, as calculated by the FEMS percentile equation (See text). The right hand column is the distance, in meters, of the receptor from the source which had the maximum number of exceedances at that distance.

BUFFER ZONES (METERS) FOR 100.00 % OF MAXIMUM APPLICATION RATE

Percentile	660 THRESHOLD (UG/M3)
25.00	0
50.00	0
75.00	130
85.00	190
90.00	250
95.00	330
97.50	460
98.00	500
98.50	530
99.00	570
99.25	630
99.50	730
99.60	780
99.80	870
99.90	930
99.92	1010
99.94	1120
99.96	1240
99.98	1420
99.99	1790

Table 9. Expansion of FEMS output example interpreted in terms of “applications” rather than “years.” The summarization window is one day and the air concentration threshold is an 8 hour TWA, producing three intervals per application in which to tally exceedances of the air concentration threshold. For comparison with Barry (2006) PERFUM generated MITC 95 percentile maximum direction buffer zones, the corresponding FEMS percentile is 98.5. The buffer zone of 530 meters is the receptor location where on average 0.045 (≈0.05) periods per application over the 5000 runs exceeded the 220 ppb 8-hr time. Thus, approximately 95% of applications in long term averaging are protected by a buffer zone of 530 m.

Percentile as calculated by FEMS using the FEMS percentile equation	Buffer zone (m)	Number of 8-hr periods exceeding the threshold per application	Exceedance of health reference concentration per 100 Applications
25.00	0	2.25	100
50.00	0	1.5	100
75.00	130	0.75	75
85.00	190	0.45	45
90.00	250	0.30	30
95.00	330	0.15	15
97.50	460	0.075	7.5
98.00	500	0.06	6.0
98.50	530	0.045	4.5
99.00	570	0.03	3.0
99.25	630	0.0225	2.25
99.50	730	0.015	1.5
99.60	780	0.012	1.2
99.80	870	0.006	0.6
99.90	930	0.003	0.3
99.92	1010	0.0024	0.24
99.94	1120	0.0018	0.18
99.96	1240	0.0012	0.12
99.98	1420	0.0006	0.06
99.99	1790	0.0003	0.03

Table 10. Chemigation (Sprinkler). FEMS 5000 run one-day basis 98.5 percentile buffer zones in meters (feet). This scenario is approximately equivalent to the 95 percentile maximum direction buffer zones from PERFUM. Bakersfield NWS meteorological data with 5000 runs (wind direction and speed randomized). 8-hr 220 ppb target.

App Type		App Rate (lb/acre)			
	Acres	320	240	160	80
Intermittent Sprinkler Kern	1	0	0	0	0
	5	0	0	0	0
	10	0	0	0	0
	20	10 (33)	0	0	0
	40	50 (164)	0	0	0
	50	70 (230)	0	0	0
		App Rate (lb/acre)			
	Acres	320	240	160	80
Standard Sprinkler Bakersfield	1	120 (394)	90 (295)	50 (164)	0
	5	340 (1115)	260 (853)	160 (525)	70 (230)
	10	540 (1772)	390 (1279)	280 (919)	120 (394)
	20	790 (2592)	570 (1870)	430 (1411)	190 (623)
	40	1260 (4134)	1000 (3281)	670 (2198)	330 (1083)
	50	1470 (4823)	1190 (3904)	800 (2625)	400 (1312)

Table 11. Chemigation (Sprinkler). FEMS 5000 run one-day basis 98.5 percentile buffer zones in meters (feet). This scenario is approximately equivalent to the 95 percentile maximum direction buffer zones from PERFUM. Five years Ventura NWS meteorological data with 5000 runs (wind direction and speed randomized). 8-hr 220 ppb target.

App Type		App Rate (lb/acre)			
	Acres	320	240	160	80
Intermittent Sprinkler Kern	1	0	0	0	0
	5	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	40	50 (164)	0	0	0
	50	70 (230)	0	0	0
		App Rate (lb/acre)			
	Acres	320	240	160	80
Standard Sprinkler Bakersfield	1	120 (394)	90 (295)	50 (164)	0
	5	340 (1115)	240 (787)	170 (558)	70 (230)
	10	520 (1706)	380 (1247)	270 (886)	120 (394)
	20	810 (2657)	610 (2001)	420 (1378)	200 (656)
	40	1280 (4199)	1020 (3346)	660 (2165)	320 (1050)
	50	1550 (5095)	1190 (3904)	780 (2559)	370 (1214)

Table 12. Shank injection. FEMS 5000 run one-day basis 98.5 percentile buffer zones in meters (feet). This scenario is approximately equivalent to the 95 percentile maximum direction buffer zones from PERFUM. Bakersfield NWS meteorological data with 5000 runs (wind direction and speed randomized). 8-hr 220 ppb target.

App Type		App Rate (lb/acre)			
	Acres	320	240	160	80
Intermittent Shank Lost Hills	1	0	0	0	0
	5	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	40	10 (33)	0	0	0
	80	90 (295)	0	0	0
		App Rate (lb/acre)			
	Acres	320	240	160	80
Standard Shank Bakersfield	1	80 (262)	50 (164)	0	0
	5	260 (853)	180 (590)	130 (426)	0
	10	370 (1214)	280 (919)	190 (623)	60 (197)
	20	530 (1739)	430 (1411)	290 (951)	125 (410)
	40	800 (2625)	660 (2165)	430 (1411)	200 (656)
	80	1370 (4495)	1030 (3379)	650 (2132)	310 (1017)

Table 13. Shank Injection. FEMS 5000 run one-day basis 98.5 percentile buffer zones in meters (feet). This scenario is approximately equivalent to the 95 percentile maximum direction buffer zones from PERFUM. Ventura NWS meteorological data with 5000 runs (wind direction and speed randomized). 8-hr 220 ppb target.

App Type		App Rate (lb/acre)			
	Acres	320	240	160	80
Intermittent Shank Lost Hills	1	0	0	0	0
	5	0	0	0	0
	10	0	0	0	0
	20	0	0	0	0
	40	20 (66)	0	0	0
	80	100 (328)	0	0	0
		App Rate (lb/acre)			
	Acres	320	240	160	80
Standard Shank Bakersfield	1	70 (230)	50 (164)	0	0
	5	230 (755)	160 (545)	100 (328)	0
	10	350 (1148)	260 (853)	180 (590)	40 (131)
	20	520 (1706)	410 (1345)	270 (886)	100 (328)
	40	800 (2625)	660 (2165)	420 (1378)	180 (590)
	80	1340 (4396)	1000 (3281)	620 (2034)	290 (951)

Table 14. PERFUM 95 percentile Metam Buffers (meters)–5 years Bakersfield ASOS Maximum Direction Buffers. 8-hr 22 ppb target.

App Type		App Rate (lb/acre)			
	Acres	320	240	160	80
Intermittent Sprinkler Kern	1	230	160	100	15
	5	660	470	290	115
	10	1095	755	455	190
	20	>1440	1255	740	310
	40	>1440	>1440	1225	495
		App Rate (lb/acre)			
	Acres	320	240	160	80
Standard Sprinkler Bakersfield	1	930	760	560	310
	5	>1440	>1440	>1440	860
	10	>1440	>1440	>1440	1395
	20	>1440	>1440	>1440	>1440
	40	>1440	>1440	>1440	>1440

App Type		App Rate (lb/acre)			
	Acres	320	240	160	80
Intermittent Shank Lost Hills	1	225	165	95	15
	5	655	470	295	120
	10	1065	740	470	195
	20	>1440	1245	750	320
	40	>1440	>1440	1240	505
		App Rate (lb/acre)			
	Acres	320	240	160	80
Standard Shank Bakersfield	1	745	595	435	235
	5	>1440	>1440	1215	650
	10	>1440	>1440	>1440	1040
	20	>1440	>1440	>1440	>1440
	40	>1440	>1440	>1440	>1440

Table 15. PERFUM 95 percentile Metam Buffers (meters)–5 years Ventura CIMIS Maximum Direction Buffers. 8-hr 22 ppb target.

App Type		App Rate (lb/acre)			
	Acres	320	240	160	80
Intermittent Sprinkler Kern	1	285	215	140	40
	5	800	600	400	170
	10	1305	950	625	280
	20	>1440	1435	995	440
	40	>1440	>1440	1430	715
		App Rate (lb/acre)			
	Acres	320	240	160	80
Standard Sprinkler Bakersfield	1	1175	970	740	435
	5	>1440	>1440	>1440	1215
	10	>1440	>1440	>1440	>1440
	20	>1440	>1440	>1440	>1440
	40	>1440	>1440	>1440	>1440

App Type		App Rate (lb/acre)			
	Acres	320	240	160	80
Intermittent Shank Lost Hills	1	260	190	125	40
	5	720	535	355	165
	10	1150	845	545	260
	20	>1440	1395	860	415
	40	>1440	>1440	1410	660
		App Rate (lb/acre)			
	Acres	320	240	160	80
Standard Shank Bakersfield	1	935	765	580	340
	5	>1440	>1440	1435	920
	10	>1440	>1440	>1440	1435
	20	>1440	>1440	>1440	>1440
	40	>1440	>1440	>1440	>1440

Table 16. Chemigation (Sprinkler). FEMS 5000 run one-day basis 98.5 percentile buffer zones in meters (feet). This scenario is approximately equivalent to the 95 percentile maximum direction buffer zones from PERFUM. Bakersfield NWS meteorological data with 5000 runs (wind direction and speed randomized). 8-hr 22 ppb target.

App Type		App Rate (lb/acre)			
	Acres	320	240	160	80
Intermittent Sprinkler Kern	1	100 (328)	70 (230)	50 (164)	0
	5	240 (787)	200 (656)	130 (426)	60 (197)
	10	350 (1148)	300 (984)	190 (623)	90 (295)
	20	500 (1640)	440 (1444)	270 (886)	130 (426)
	40	720 (2362)	640 (2100)	390 (1279)	200 (656)
	50	840 (2756)	730 (2395)	450 (1476)	220 (722)
		App Rate (lb/acre)			
	Acres	320	240	160	80
Standard Sprinkler Bakersfield	1	730 (2395)	620 (2034)	460 (1509)	280 (919)
	5	1910 (6266)	1570 (5151)	1180 (3871)	700 (2297)
	10	3190 (10466)	2610 (8563)	1900 (6234)	1100 (3642)
	20	5020 (16470)	4140(13583)	3060(10040)	1760 (5774)
	40	8410 (27592)	6920(22703)	5050(16568)	2850 (9350)
	50	9820 (32218)	8200(26903)	6010(19718)	3420 (11220)

Table 17. Chemigation (Sprinkler). FEMS 5000 run one-day basis 98.5 percentile buffer zones in meters (feet). This scenario is approximately equivalent to the 95 percentile maximum direction buffer zones from PERFUM. Five years Ventura NWS meteorological data with 5000 runs (wind direction and speed randomized). 8-hr 22 ppb target.

App Type		App Rate (lb/acre)			
	Acres	320	240	160	80
Intermittent Sprinkler Kern	1	120 (394)	90 (295)	60 (197)	0
	5	280 (919)	250 (820)	160 (525)	70 (230)
	10	400 (1312)	360 (1181)	230 (755)	110 (361)
	20	620 (2034)	530 (1739)	330 (1083)	160 (525)
	40	1050 (3445)	770 (2526)	490 (1608)	240 (787)
	50	1180 (3871)	870 (2854)	570 (1870)	260 (853)
		App Rate (lb/acre)			
	Acres	320	240	160	80
Standard Sprinkler Bakersfield	1	740 (2428)	620 (2034)	470 (1542)	280 (919)
	5	2000 (6562)	1610 (5282)	1220 (4003)	710 (2329)
	10	3320(10892)	2640 (8661)	1990 (6529)	1150(3773)
	20	5300(17388)	4360(14304)	3130(10269)	1840(6037)
	40	9010(29560)	7400(24278)	5460(17913)	3040(9974)
	50	9680(31758)	8350(27395)	6100(20013)	3450(11319)

Table 18. Shank injection. FEMS 5000 run one-day basis 98.5 percentile buffer zones in meters (feet). This scenario is approximately equivalent to the 95 percentile maximum direction buffer zones from PERFUM. Bakersfield NWS meteorological data with 5000 runs (wind direction and speed randomized). 8-hr 22 ppb target.

App Type		App Rate (lb/acre)			
	Acres	320	240	160	80
Intermittent Shank Lost Hills	1	80 (262)	60 (197)	30 (98)	0
	5	220 (722)	160 (525)	110 (361)	50 (164)
	10	340 (1115)	230 (755)	180 (590)	80 (262)
	20	500 (1640)	370 (1214)	270 (886)	130 (426)
	40	760 (2493)	590 (1936)	410 (1345)	200 (656)
	80	1180 (3871)	940 (3084)	610 (2001)	300 (984)
		App Rate (lb/acre)			
	Acres	320	240	160	80
Standard Shank Bakersfield	1	530 (1739)	450 (1476)	330 (1083)	190 (623)
	5	1470 (4823)	1140 (3740)	870 (2854)	500 (1640)
	10	2280 (7480)	1850 (6069)	1370 (4495)	780 (2559)
	20	3610(11844)	2940 (9646)	2110 (6922)	1220 (4003)
	40	6190(20308)	4770(15650)	3540(11614)	1980 (6496)
	80	10350(33957)	8240(27034)	5870(19259)	2950(9678)

Table 19. Shank Injection. FEMS 5000 run one-day basis 98.5 percentile buffer zones in meters (feet). This scenario is approximately equivalent to the 95 percentile maximum direction buffer zones from PERFUM. Ventura NWS meteorological data with 5000 runs (wind direction and speed randomized). 8-hr 22 ppb target.

App Type		App Rate (lb/acre)			
	Acres	320	240	160	80
Intermittent Shank Lost Hills	1	120 (394)	80 (262)	50 (164)	0
	5	280 (919)	250 (820)	160 (525)	60 (197)
	10	450 (1476)	370 (1214)	230 (755)	110 (361)
	20	720 (2362)	540 (1772)	350 (1148)	160 (525)
	40	1110 (3609)	790 (2592)	580 (1903)	240 (787)
	80	1720 (5643)	1350 (4429)	930 (3051)	360 (1181)
		App Rate (lb/acre)			
	Acres	320	240	160	80
Standard Shank Bakersfield	1	570 (1870)	460 (1509)	330 (1083)	190 (623)
	5	1560 (5118)	1250 (4101)	930 (3051)	520 (1706)
	10	2410 (7907)	2010 (6594)	1440 (4724)	820 (2690)
	20	3900(12795)	3160(10367)	2190(7185)	1260(4133)
	40	6460(21194)	5070(16634)	3780(12401)	2000(6562)
	80	10710(35138)	8700(28543)	6250(20505)	3420(11220)

Department of Pesticide Regulation

Mary-Ann Warmerdam
Director

M E M O R A N D U M

Arnold Schwarzenegger
Governor

APPENDIX 6

TO: Randy Segawa, Environmental Program Manager (Supervisor) I
Environmental Monitoring Branch

FROM: Terrell Barry, Ph.D., Research Scientist III *Original signed by*
Bruce Johnson Ph.D., Research Scientist III *Original signed by*
Environmental Monitoring Branch
(916) 324-4140

DATE: October 23, 2007

SUBJECT: ANALYSIS OF THE RELATIONSHIP BETWEEN PERCENTILES OF THE WHOLE FIELD BUFFER ZONE DISTRIBUTION AND THE MAXIMUM DIRECTION BUFFER ZONE DISTRIBUTION

Background

In 1992 the Department of Pesticide Regulation (DPR) first implemented the use of air dispersion modeling in the development of mitigation measures for bystander exposure to methyl bromide. The initial buffer zone development employed screening level modeling techniques, including standard weather conditions, square field geometry, and 24 hour time weighted average (TWA) flux (Johnson 1999, Johnson and Barry 2005, Segawa et al. 2000). The buffer zones developed were approximately 95% protective on an individual application basis (Johnson, 2001). This means that for any given application, the probability that the TWA concentration at the buffer zone distance would exceed a specified exposure threshold anywhere around the field perimeter was approximately 5%.

In recent years, with the development of probabilistic modeling packages (PERFUM [Reiss and Griffin, 2006]; FEMS [Sullivan et al., 2004]; SOFEA [Cryer, 2005]), distributions of buffer zones for various application scenarios have been produced using five year sets of meteorological data. As explained later, a buffer zone length at a particular percentile of the distribution insures coverage at a level of protection (protection probability) equal to that percentile. This technique of selecting a buffer zone length that corresponds to a desired protection probability from a distribution of lengths is now one of the most important air dispersion modeling based mitigation tools. However, two very different methods have been used to construct distributions of buffer zone lengths for specific use scenarios. Even though the resulting buffer zone distributions represent fundamentally different philosophies of risk mitigation and are not equivalent, the terminology used to describe the protection probability

is the same. Consequently, there is substantial confusion over the meaning of “protection probability” and related concepts with these different methods.

The two methods for constructing a distribution of buffer zone lengths are known as the “whole field” method and the “maximum direction” method. The general modeling procedure used to determine the buffer zone distributions for either the maximum direction or whole field method starts with a given fumigant flux versus time function (“flux profile”, e.g. Figure 1), which describes the course of emissions following an application. For a specific scenario the size of the field is fixed, as is the application rate. What varies from simulation to simulation is the meteorology used to calculate the downwind air concentrations. The downwind air concentrations are averaged over the appropriate exposure time (also called the threshold averaging period). The threshold averaging period and the threshold concentration (or reference concentration) is fumigant specific. For example, the DPR methyl bromide threshold averaging time is 24 hours and the DPR threshold concentration is 815 ug/m^3 as a 24-hr time TWA. In each period, the concentration isopleths generated by the model are compared to the concentration exposure threshold (for example, 815 ug/m^3 for methyl bromide). Buffer zones are determined by the distance from the field edge to where the threshold concentration occurs. Thus, the resulting buffer zone distributions reflect the variations in period-to-period meteorology.

For both methods discrete directions are represented as “spokes” emanating outward from the center of the field (e.g. Figure 2), and are defined by the discretization scheme used in the modeling procedure. However, for the maximum direction method, the comparison of concentrations on each spoke yields a single distance that is equal to the maximum distance at which the modeled TWA concentration is equal to the exposure threshold. This procedure is repeated over the length of the meteorology record and the distances are compiled to obtain a distribution. For example, for methyl bromide and using a 24 hour threshold averaging time, each day (24 hours) of simulation yields a single buffer zone estimate. In this case a 5 year simulation would provide approximately 365 x 5 = 1825 daily, maximum buffer zones which would be compiled to form a distribution. The number is approximate because meteorological data sets may be incomplete.

In contrast, the whole field method compiles distances in every direction around the field during each threshold averaging period for each simulation. The number of distances selected in each averaging period is equal to the number of spokes, and each selected distance is equal to the distance along the spoke where the modeled TWA concentration equaled the exposure threshold. Then, similar to the maximum direction method, the procedure is repeated over the length of the meteorology record to generate the whole field buffer zone distribution. For example, a single threshold averaging period simulation for methyl bromide (24-hour) would yield 200 buffer zone estimates (if the field had 200 spokes). The maximum of the 200 buffer zone estimates is the maximum direction buffer zone distance for that day. The remaining 199 estimates will generally

be less than the maximum. In the whole field method, all 200 daily buffer zone estimates are compiled from each day to form the distribution. This results in approximately 365 x 5 x 200 = 365,000 estimates.

In developing fumigant buffer zones by both the screening approach and the probabilistic approach, DPR has controlled protection probabilities at the individual application level (Segawa et al. 2000, Johnson, 2001, Barry, 2006). To do this, for each threshold averaging period the single point farthest away from an application where the threshold concentration occurs determines the buffer zone for each realization of an application scenario. For example, over the long term, a buffer zone selected to be "95%" protective for a 24 hour TWA threshold will be long enough to capture the threshold air concentration everywhere around the perimeter of the field for 95% of all applications. Thus, on average over thousands of realizations, for every 100 applications, the buffer zone will be large enough for 95 of those applications–the buffer zone achieves the protection goal. However, 5 of those 100 applications will show air concentrations at the buffer zone that exceed the threshold air concentration. Thus, the buffer zone fails to achieve the protection goal at some locations around the perimeter of the field. This "maximum direction buffer zone" method (Reiss and Griffin, 2006) of constructing the protection probability controls individual application risk. Barry and Johnson (2005) previously verified the PERFUM maximum direction buffer zone protection probabilities.

While the whole field approach (Reiss and Griffin, 2006) employs the same general modeling procedure as the maximum direction method, the whole field buffer zone distributions are constructed using distances to the threshold air concentration in every direction around the field during each averaging period. Thus, the whole field approach includes in its distributions distances which are predominantly upwind and, therefore, small. The whole field buffer zone percentiles are equal to the probability that the TWA concentration is less than or equal to the threshold at any random location along the edge of the buffer zone of a random application. The whole field buffer zone percentiles do not correspond to a specified level of protection at the individual application level. Therefore it is important to determine the relationship between the maximum direction and whole field approaches in terms of the per application failure rate.

If risk managers are to make fully informed decisions, the method with which the protection probability is constructed must be completely transparent and well understood. The objective of this memorandum is four fold: (1) to describe procedures and assumptions used to derive the PERFUM whole field and maximum direction buffer zone distributions, (2) to provide a transparent comparison of the whole field method protection probabilities to the equivalent maximum direction protection probabilities using actual model fumigant datasets, (3) to verify in a specific scenario PERFUM2 calculations, and (4) to estimate in a specific scenario the distribution of perimeter fractions amongst days where the buffer zone was not protective. Our intent is to provide risk managers and stakeholders with a technical analysis that assists the process of risk mitigation.

Methods

Two types of data were used in this analysis to characterize the relationship between the maximum direction protection probability and the whole field protection probability: (1) Data collected from PERFUM outputs for modeling conducted by the U.S. Environmental Protection Agency (EPA) and (2) data calculated using PERFUM code modified to provide air concentration and buffer zone outputs not available from the distributed model.

Data collected from the USEPA PERFUM modeling outputs

PERFUM modeling results were obtained from U.S. EPA as part of the materials DPR staff reviewed related to U.S. EPA fumigant risk assessments. For the present analysis, PERFUM outputs for various soil applications of methyl bromide, chloropicrin and metam sodium under various meteorological data sets were used to assemble a database containing the 99th percentile (99%) whole field buffer zone length and its equivalent maximum direction percentile (rounded to the nearest 1%). The equivalent maximum direction percentile is the percentile of the maximum direction buffer zone distribution that corresponds to a buffer zone equal to the 99% whole field buffer zone length, and is numerically equal to the individual application level maximum direction protection probability. This procedure is illustrated graphically in Appendix F. The five meteorological data sets (locations) were: (1) Ventura, California, (2) Bakersfield, California, (3) Tallahassee, Florida, (4) Yakima, Washington, and (5) Flint, Michigan. Simulations were conducted at maximum application rates and differing application methods, specific to each fumigant. Comparisons between the 99% whole field buffer zones and the equivalent maximum direction percentiles are presented graphically and statistical summaries are included.

The objective was to characterize the relationship between the 99% whole field buffer zone length and its equivalent maximum direction buffer zone length distribution percentile over field sizes of 5, 20, and 40 acres. However, a significant limitation is the PERFUM 1440m upper limit on buffer zone length output. Because it is not possible to estimate percentiles for buffer zone lengths generated by PERFUM which are at or exceed 1440m, it was necessary to exclude from this analysis those fumigant application method, rate and size combinations that would produce large buffer zones which exceeded 1440m. Therefore, this analysis cannot fully characterize the relationship between the 99% whole field buffer zone distributions and the maximum direction buffer zone distributions.

PERFUM Code Modification

Modifications were made to the PERFUM2 source code in order to externally record internally generated values of interest (more on the modifications below). Using this modified code, 2 pesticide application situations were studied: 5 acre with fine grid and 20 acres with fine grid. The application scenario was shallow shank injection, tarped methyl bromide application using the maximum application rate of 430 lbs/acre. The flux profile is shown in Figure 1. While two 24-hour periods were included in the flux profile, the analysis focused on the first 24-hour period, which was the highest flux period. A listing of the PERFUM2 input file for 20 acres is shown in Appendix A. Ventura meteorology was used, though one day was removed due to a string of 24 hours of calms.

The PERFUM2.FOR source code was modified to print out daily concentrations ordered by both spoke/ring and spoke-specific buffer information. The modifications were exclusively in the subroutine "DAYCALC", which is contained in the PERFUM2.FOR file. The modifications are described more fully in Appendix B and a FORTRAN source code listing showing the modifications is presented in Appendix C. Briefly, code was inserted to open files and write out internal values. The code modifications did not change the logic or calculations of the program.

These modifications in the subroutine DAYCALC provided output which enabled (1) verification of the individual concentrations averages generated by PERFUM2, (2) analysis of the number of spokes each day where the reference concentration was exceeded along that spoke at the buffer zone distance, (3) verification of the 99% whole field buffer distance, and (4) further analysis of the fraction of the perimeter at the buffer zone distance where the health reference concentration would be exceeded. For (1) a single day was chosen, an independent ISCST3 control file was created and the discrete receptor concentrations from the single-day independent run were compared to the corresponding concentrations from PERFUM2 as found in CONCEN.OUT. For (2) the 99% whole-field buffer zone was compared to each spoke-specific buffer zone each day. The daily spoke exceedance information was used to estimate a daily fraction of the buffer perimeter where the reference concentration was exceeded. These daily lengths were compiled into a distribution. For (3) the individual spoke length "buffers" (distance to reach the reference concentration) were aggregated into a distribution and distributional points were compared to the PERFUM2 distribution points. For (4) an additional program was written to analyze output from the modified PERFUM2 to calculate a fraction of the perimeter where concentrations exceeded the reference concentration.

For days on which concentrations along the buffer zone exceeded the reference concentration, we calculated the fraction of the perimeter that exceeded the reference concentration with two methods: by a simple count of exceedance spokes divided by total spokes and by an edge/corner spoke perimeter calculation that adjusted for the different arc-length represented by the edge versus corner spokes. There was no substantive difference in these results, so the perimeter calculations based on the more accurate arc-length are presented. In this discussion, the edge/corner spoke method is the same as the arc-length method. Appendix D lists a FORTRAN

utility which estimated the fraction of perimeter at the buffer zone distance where the threshold concentration was exceeded and Appendix E presents results comparing the two methods for computing the perimeter distances where the threshold concentration was exceeded.

Results

Data collected from the USEPA PERFUM modeling outputs

Figures 3 through 5 show the change in the equivalent maximum direction buffer zone distribution percentile with the 99% whole field buffer zone length. The three figures are on the same scale to facilitate cross comparison. For methyl bromide (Figure 3) the equivalent maximum direction percentiles are clustered between about 85% and 90%. For metam sodium (Figure 4) and chloropicrin (Figure 5), the equivalent maximum direction percentiles show a greater range, from about 95% to 63%. There are several factors potentially contributing to differences observed between fumigants. The most significant factor may be the averaging time of the health threshold. The methyl bromide averaging time is 24 hours, the metam sodium averaging time is 8 hours, and the chloropicrin averaging time is 4 hours. It should be noted that the health threshold air concentration for metam sodium applications is actually for methyl isothiocyanate, which is a breakdown product of metam sodium and the contaminant of concern. An additional factor is that the 4-hr and 8-hr TWA whole field buffer zones with the lowest maximum direction buffer equivalent percentile occurred at night. Thus, shorter threshold averaging time coupled with a flux profile that caused the whole field buffer zone size to be driven by nighttime averaging periods was associated with the lowest maximum buffer zone equivalent percentiles.

Figure 6 summarizes the relationship between the 99% whole field buffer zone length and the equivalent percentile in the maximum direction buffer zone distributions for application methods used to apply the three fumigants. Figure 6 shows the distribution of maximum direction buffer zone percentiles with the median value labeled for each application scenario. The width of the box plots illustrates the variability for each application method in the equivalent maximum direction distribution percentiles. The methyl bromide 99% whole field buffer zones are the least variable with consistent median maximum direction buffer zone percentiles of 86 to 88. Thus, under the use scenarios characterized in this analysis on average about 12% to 14% of methyl bromide applications with a 99% whole field buffer zone will have a buffer zone failure somewhere along the whole field buffer zone perimeter. Figure 6 clearly shows variable performance of the 99% whole field buffer zones for metam sodium and chloropicrin. The median equivalent maximum direction percentiles vary between a high of the 92.5 and a low of 71. In addition to the large spread in the median equivalent maximum direction percentile for metam sodium and chloropicrin application methods, the variability within any particular application method is also quite different. For example, the metam sodium intermittent sprinkler

and intermittent shank methods show very little variation and median equivalent maximum direction buffer zone percentiles of 91% and 92.5% respectively. In contrast, chloropicrin untarped broadcast and untarped bed methods show highly variable equivalent maximum direction buffer zone percentiles with median percentiles of 71% and 74.5%, respectively.

PERFUM Code Modification

Verifications. The single day verification showed complete agreement between the PERFUM2-generated concentrations and those from an independent ISCST3 run. The independently assembled distributions of whole-field buffer zone lengths yielded a 99% whole field buffer zone which agreed with the PERFUM2 99% whole field buffer zone for the 5 acre and 20 acre find grid scenarios. There was a minor difference in that PERFUM2 appears to round the estimated buffer zones to the nearest 5m. These verifications provide additional confidence in the PERFUM2 calculations.

Distributions of exceedance perimeter lengths. From the total 1794 days simulated, the 99% whole field buffer was not protective at some point along the perimeter of the buffer zone distance from the field on 271 days and 230 days for the 5 acre and 20 acre fields, respectively. Thus the 99% whole field buffer corresponded to an 85%-tile (=100*(1794-271)/1794) and 87%-tile (=100*(1794-230)/1794) maximum direction buffer for the 5 and 20 acre scenarios, respectively. These independently derived calculations were consistent with the results in Figure 6 for methyl bromide method 1.

Amongst the days where exceedances occurred, Figures 7 and 8 provide distributions for the fraction of the buffer zone perimeter based on the arc-length method which exceeded the reference concentration. The two methods for calculating the fraction yielded somewhat different histograms, but the general limits and shapes were similar (details in Appendix E). In both cases perimeter fractions ranged from 0.01 to about 0.15. In part, the differences between the 2 methods resulted from the different number of edge versus corner spokes between 5 acre and 20 acres fields and the relatively different arc lengths represented by the 5 acre and 20 acre cases.

The histograms in Figures 7 and 8 provide some indication of the distribution of fractions of perimeters which are exceeded, when there is an exceedance somewhere along the buffer zone perimeter. Figures 9 and 10 provide the same data expressed as cumulative distributions of perimeter exceedance fractions and can be utilized more quantitatively to calculate probabilities.

Thus, for example, for the 20 acre field, amongst days when there is an exceedance, the probability is about 50% that the length along the buffer zone distance perimeter will be greater than about 7% of the perimeter, using the arc-length perimeter calculation method (Figure 10).

Given that the 20 acre buffer perimeter for a 99% whole field buffer of 200m is 2,395m, there will be a 50% probability that the distance of exceedance along the buffer perimeter is greater than 168m.

Discussion

The 99% whole field buffer zones show median equivalent maximum direction buffer zone percentile levels of between 71% and 92.5% (Figure 6). Thus, the individual application 99% whole field buffer zone median failure rate is between 7.5% and 29% of applications. The highest failure rate of 37% was for chloropicrin broadcast untarp application method at Tallahassee, Florida.

The failure rate appears to be related to the averaging time of the health threshold. Shorter averaging times show higher individual application failure rates. Thus, the per application buffer zone failure rate determined using the 99% whole field method (ostensibly a 1% failure rate) results in maximum direction median failure rates of between 7.5% and 29% of applications. These results are for application scenarios where both the whole field and the maximum direction buffer zones are less than or equal to 1440m. Performance of large (>1440m) 99% whole field buffer zones is unknown.

For the 20 acre methyl bromide application example that we analyzed, when there is a failure, the data extracted from PERFUM indicates that the perimeter distances along which the health reference level is exceeded can be larger than the length of a football field. We would expect that varying field size, flux profile, or exposure period would influence the shape of the distributions in Figures 7-10 and hence, influence the size of the expected perimeter lengths which would be expected to experience concentrations higher than the reference level.

While the “whole field” method (Reiss and Griffin, 2006) has the stated objective of characterizing “whole population” risk, that method does not incorporate a numeric or spatial distribution of potentially exposed bystander populations. Consequently the whole field method does not explicitly incorporate the probability that bystanders are located on or near the buffer zone perimeter. The implicit assumption is that the probability is low and uniformly distributed around the field (Freeman, 2004). However, analysis of DPR soil application methyl bromide worksite plans (Barry, 2005) shows approximately 20% of applications have at least one sensitive site (e.g., residences, high schools) within 50ft of the buffer zone. The majority of applications showed between 1 and 10 sensitive sites and fewer showed between 10 and 50 or more (e.g. larger residential developments).

Summary

- The relationship between maximum direction and whole field buffer zone procedures was studied.

- The 99% whole field buffer zones corresponded to median equivalent maximum direction percentiles of 71% to 92.5%. This corresponds to a median individual application buffer zone failure rate of between 7.5% and 29%. The highest individual application buffer zone failure rate was 37% for the chloropicrin broadcast untarp application method at Tallahassee, Florida.

- Metam sodium and chloropicrin exhibited a wider range of equivalent percentiles than methyl bromide due to the shorter exposure threshold periods.

- Additional verification of PERFUM2 calculations was satisfactory.

- For a 20 acre methyl bromide shallow tarped scenario, amongst days where a 99% whole field buffer was exceeded, there was a 50% probability that the length of the perimeter that was exceeded would be greater than 168m.

- The whole field method does not take into account specific population locations and in California, residential development can be found next to approximately 20% of treated fields at the buffer zone distance.

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Sullivan, D.A., M.T. Holdsworth, and D.J. Hlinka. 2004. Monte Carlo-based dispersion modeling of off-gassing releases from the fumigant metam-sodium for determining distances to exposure endpoints. Atmospheric Environment vol 38(16):2471-2481.

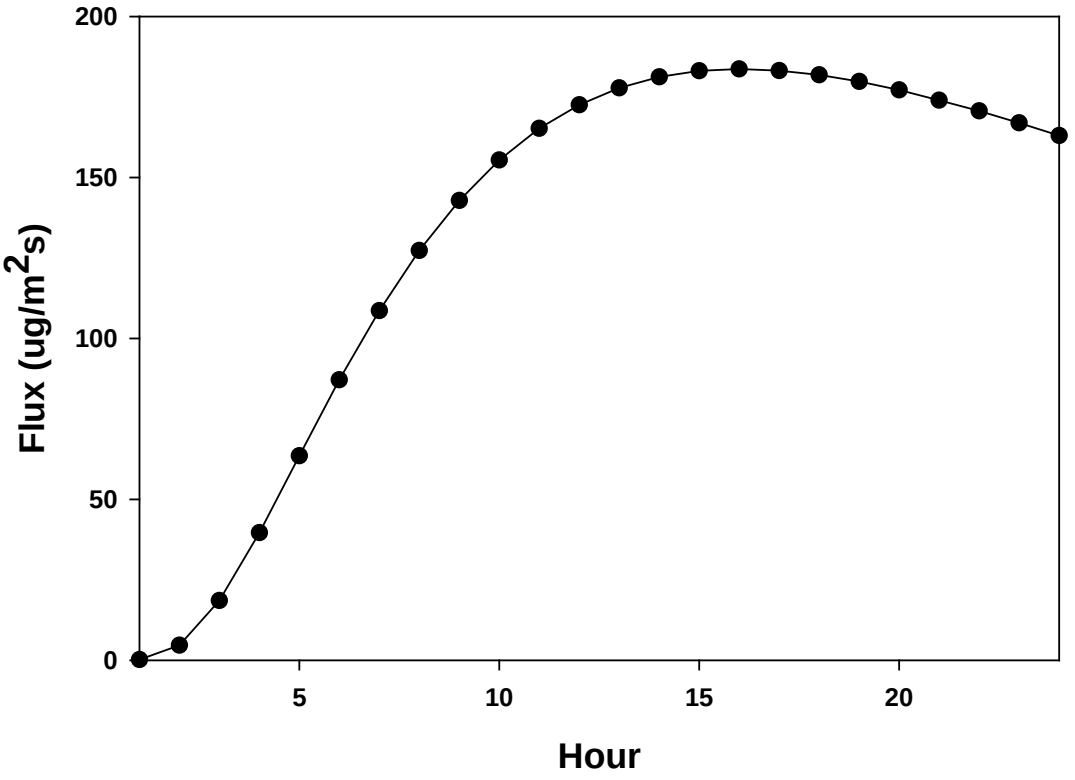


Figure 1. Flux profile for methyl bromide for first 24 hours.

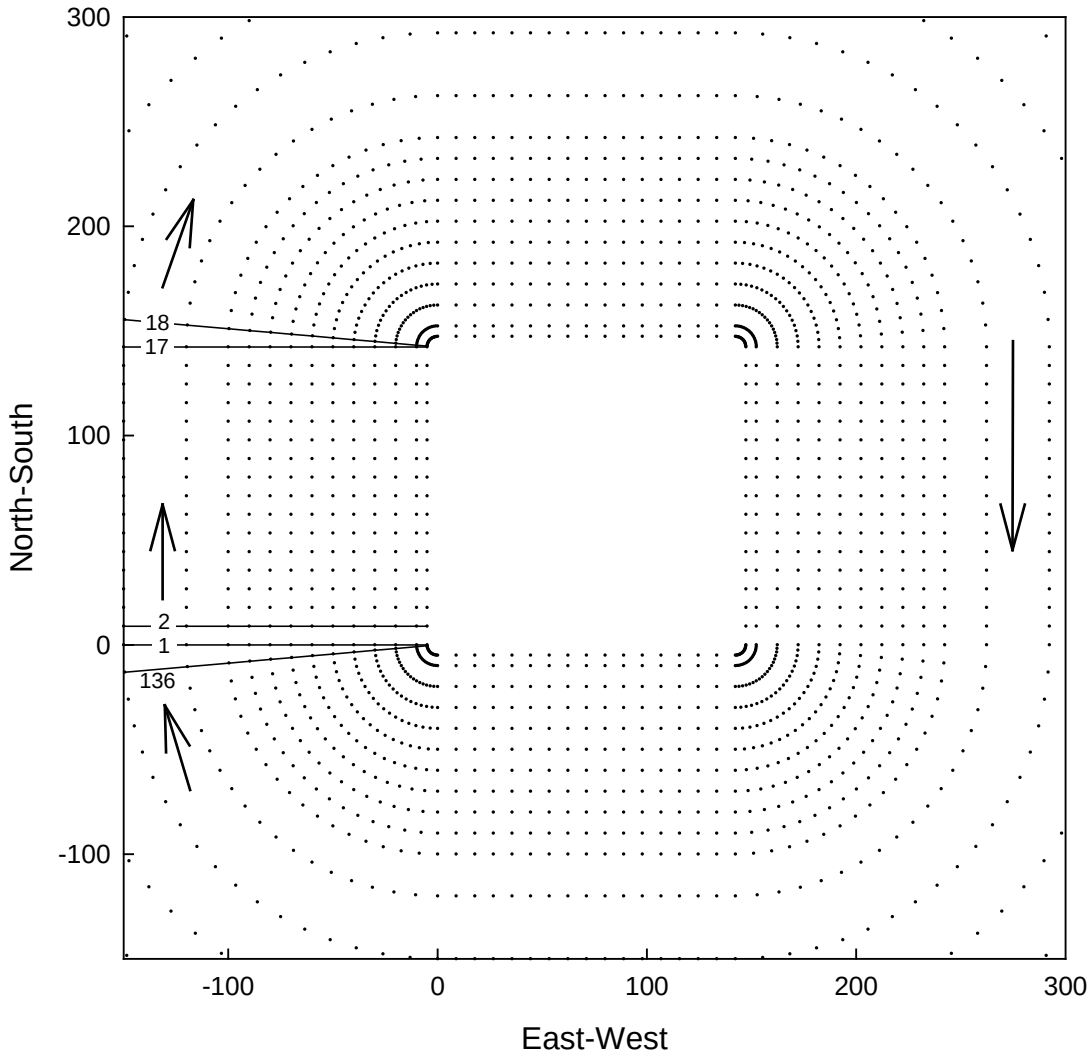


Figure 2. Spoke numbering scheme for 5 acre, square plot, fine grid. First spoke begins at southwest corner of field, extending due west. Subsequent spokes originate from the edge moving clockwise. There are 17 spokes along each straight edge and 17 spokes radiating from each corner, for a total of 136 spokes. Lines are drawn for illustration purposes for spokes 1,2,17,18 and 136.

Figure 3. Relationship between the methyl bromide 99% whole field buffer zone length (m) and the equivalent maximum direction buffer zone percentile. Equivalent maximum direction percentile = individual application level protection probability = (1 – individual application buffer zone failure rate).

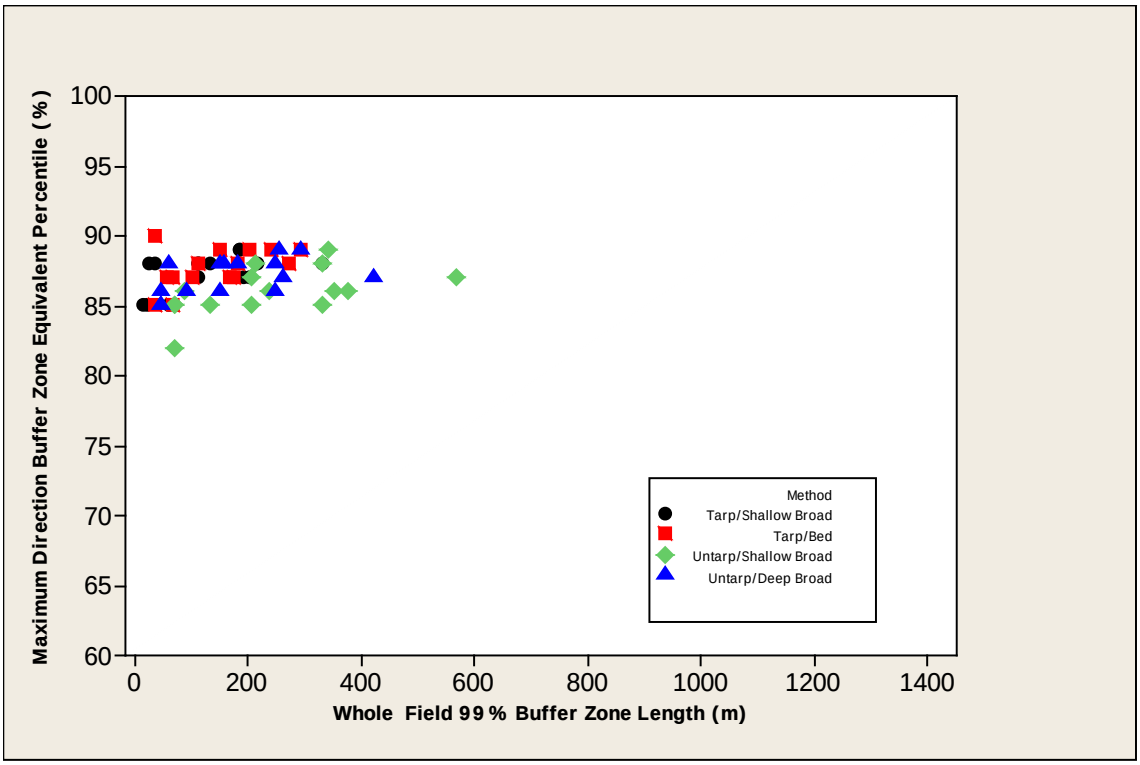


Figure 4. Relationship between the metam sodium 99% whole field buffer zone length (m) and the equivalent maximum direction buffer zone percentile. Equivalent maximum direction percentile = individual application level protection probability = (1 – individual application buffer zone failure rate).

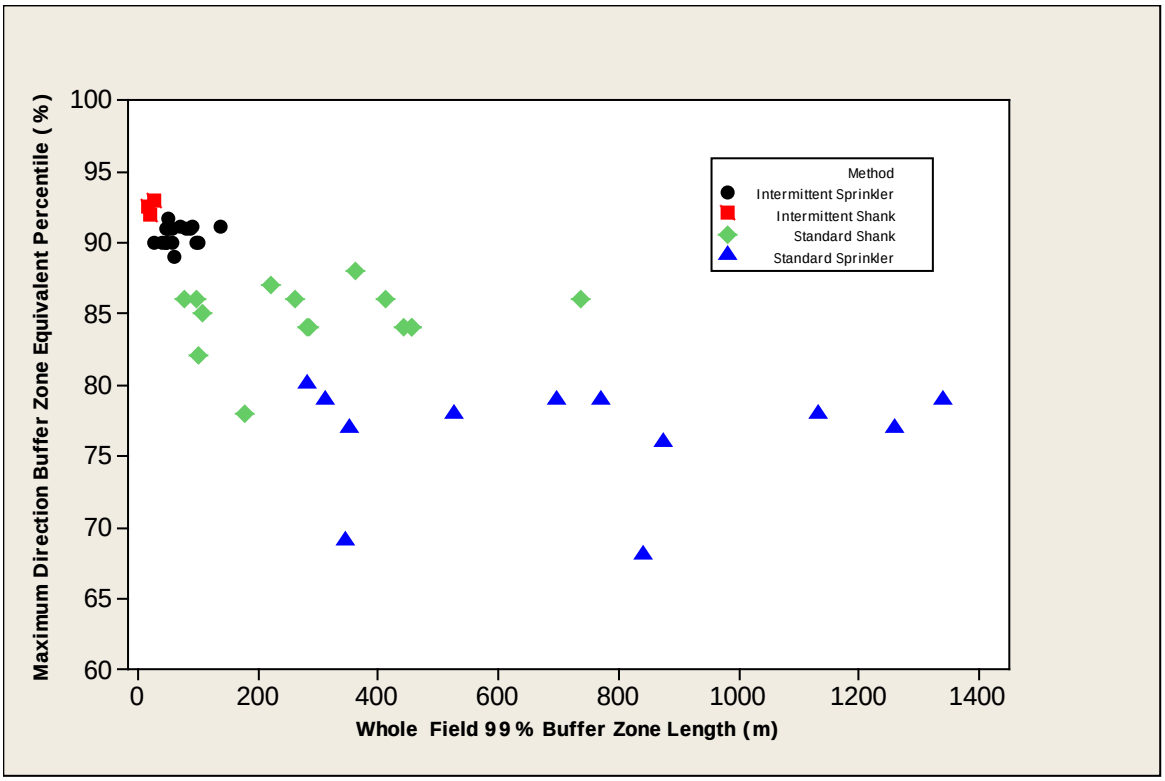


Figure 5. Relationship between the chloropicrin 99% whole field buffer zone length (m) and the equivalent maximum direction buffer zone percentile. Equivalent maximum direction percentile = individual application level protection probability = (1 – individual application buffer zone failure rate).

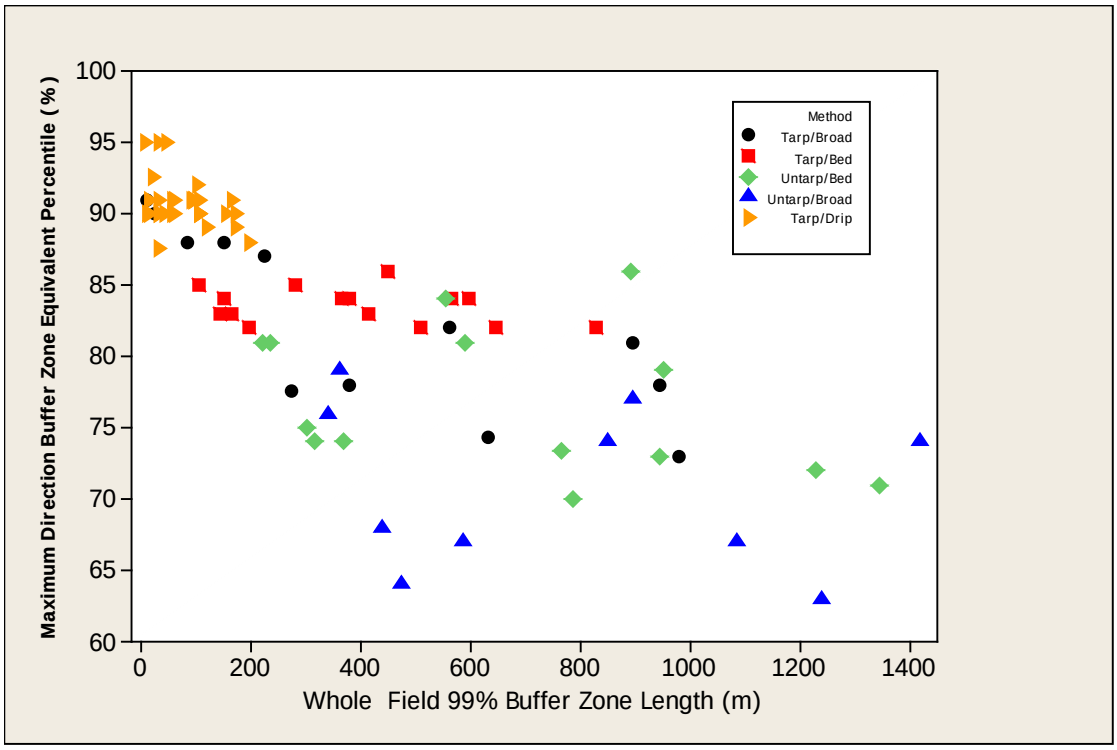
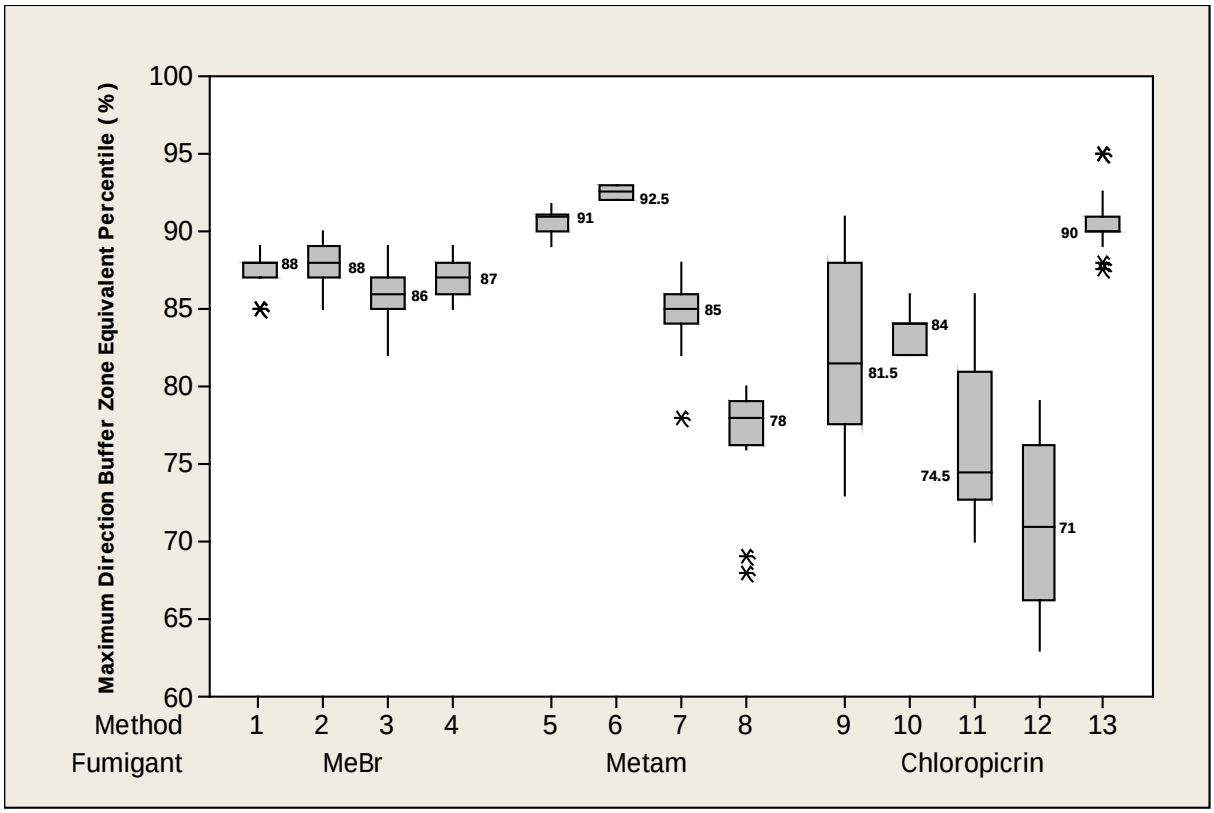


Figure 6. Summary of the maximum direction buffer zone equivalent percentiles for the 99% whole field buffer zone of application methods for methyl bromide, metam sodium and chloropicrin. The application methods within each fumigant are as follows: methyl bromide (MeBr) 1 = tarp/broadcast, 2 = tarp/bed, 3 = untarp/shallow, 4 = tarp/deep. Metam sodium (Metam) 5 = intermittent watering-in sprinkler, 6 = intermittent watering-in shank, 7 = standard shank, 8 = standard sprinkler. Chloropicrin (Chloropicrin) 9 = tarp/broadcast, 10 = tarp/bed, 11 = untarp/bed, 12 = untarp/broadcast, 13 = tarp/drip. Key to the boxplot: the median value is the line shown inside each box. The value of the median for each box is labeled next to the line. The top and both of the box indicate the lower and upper quartiles. The line (whisker) extends to the lower and upper values that are within 1.5 times the inter-quartile range. The stars indicate outlier values. Equivalent maximum direction percentile = individual application level protection probability = (1 – individual application buffer zone failure rate).



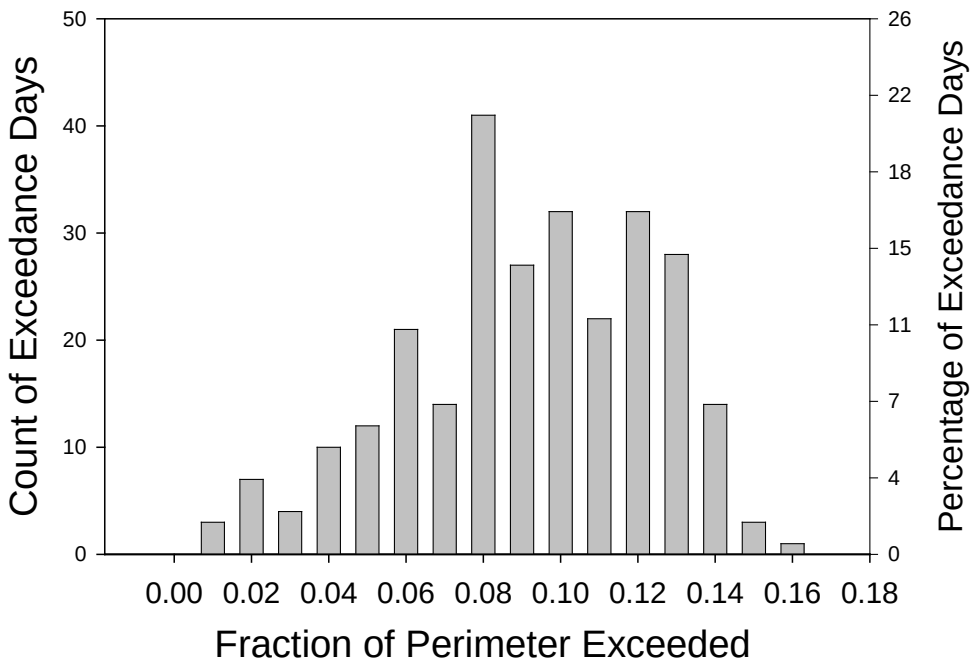


Figure 7. Fine grid, 5 acre scenario with histograms of the daily fractions of the perimeter where the concentration exceeded the reference level. The total days were 1794, of which 1523 days showed no exceedance. This figure plots the exceedances for the 271 days where 1 or more spokes showed an exceedance.

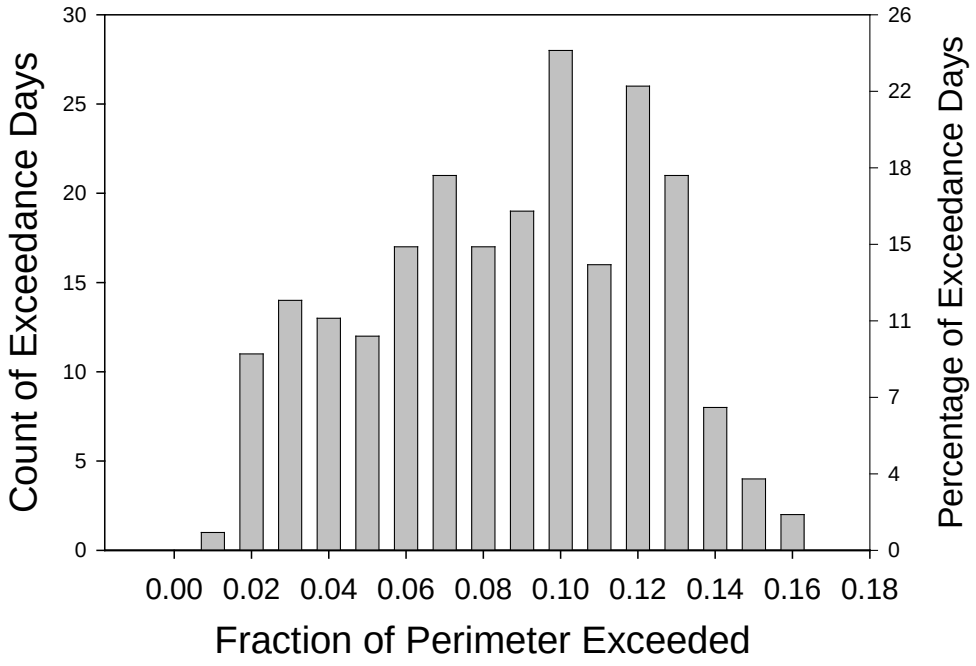


Figure 8. Fine grid, 20 acre scenario with histograms of the daily fractions of the perimeter where the concentration exceeded the reference level. The total days were 1794, of which 1564 days showed no exceedance. This figure plots the exceedances for the 230 days where 1 or more spokes showed an exceedance.

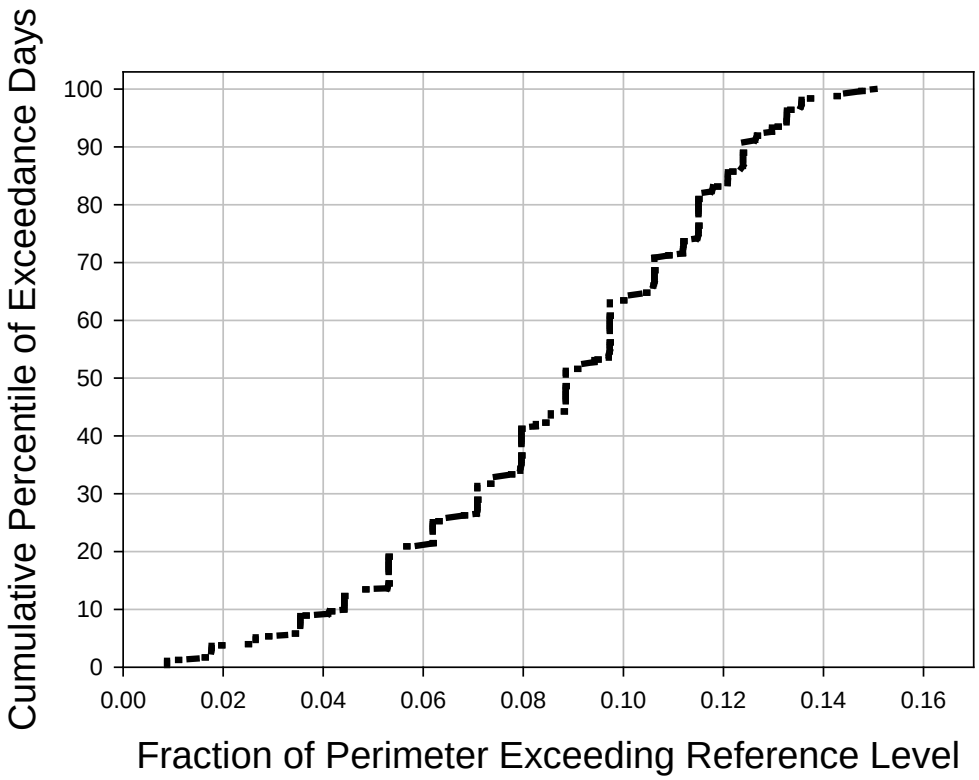


Figure 9. Cumulative distribution of perimeter length exceedances for 5 acre, fine grid scenario based on 271 days where at least one spoke exceeded the reference concentration at the buffer zone distance.

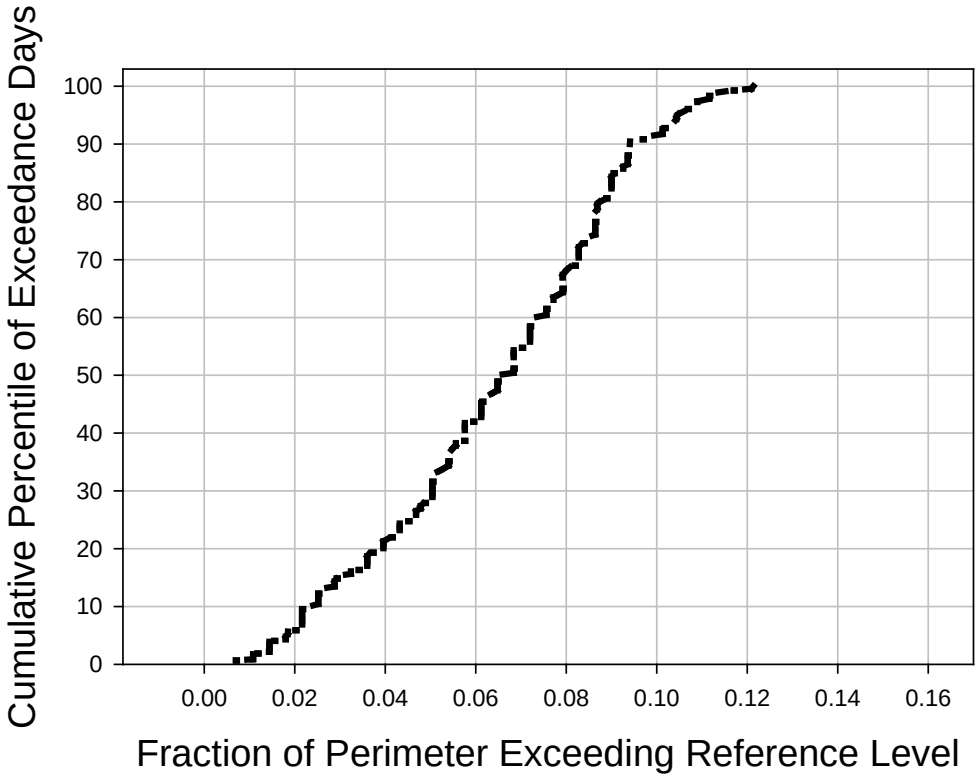


Figure 10. Cumulative distribution of perimeter length exceedances for 20 acre, fine grid scenario based on 230 days where at least one spoke exceeded the reference concentration at the buffer zone distance.

Appendix A. Control file used for 20 acre, fine grid, shallow, tarped methyl bromide application.

```
001  * PERFUM2 Input File
002  *** Specify scenario type ****
003  ** SF = single field
004  ** MF1 = multiple field no. 1 (4 fields surrounding main field
005  ** MF2 = multiple field no. 2 (large field broken into quadrants)
006  ** MOE = margin of exposure (for single fields only)
007  ** GRN = greenhouse scenario
008  Scenario Type:                SF
009  * ISCST3 Portion of Control File - Used for all scenarios
010  ISCST3 input file:            SF.inp
011  ISCST3 output file:           SF.out
012  Met station ID:               99999
013  Upper air station ID:         99999
014  Field length x-direction (m): 284.5
015  Field length y-direction (m): 284.5
016  Grid density (C/F):           F
017  ** Additional information for MF1 Scenario
018  Distance between sources (m): 450.0
019  Fluxes (enter or proportion): P
020  Flux proportion:              1.0
021  ** Additional information for MF2 Scenario
022  Main source:                  3
023  Flux choice (P/E):            P
024  Flux proportion for NE:       0.30
025  Flux proportion for NW:       0.15
026  Flux proportion for SW:       1.0
027  Flux proportion for SE:       0.05
028  ** Additional information for the Greenhouse scenario
029  Source type (P/A):            P
030  Building Height (meters):     15.0
031  Adjusted Height (meters):     15.0
032  Flux choice (C/E):            C
033  App rate (lbs/1000ft3):       3.0
034  Time spent applying (hours):  0.1
035  Time spent treating (hours):  4.0
036  AER (hr-1) treatment:         0.5
037  AER (hr-1) aeration:          2.0
038  Stack height, m (above bldg): 1.0
039  Stack diameter (m):           1.0
39A  Exit velocity (m/sec):        0.05
040  * Buffer zone model portion - general inputs for all scenarios
041  Flux data source:             CDPR Commodity Permit Conditions
042  Meterological source          Ventura, California
043  Number of simulation days:    2
044  Averaging Period:             24
045  Distribution Avg. Period:     24
046  Begin Year:                   1995
```

```
End Year:                       1999
Starting Hour:                  10
Meteorological file:            vtx.MET
Output file:                    PERFUM.OUT
Plot file:                      PERFUM.PLT
Contour file:                   PERFUM.CTR
Contour Percentile:             95
NOEL or HEC (ug/m3):            38830.0
UF:                             30.0
Buffer length (m):              165.0
** Include application rates for calculation
Number of Application rates:  1
Application rate no. 1:         430.0
Application rate no. 2:
Application rate no. 3:
Application rate no. 4:
Application rate no. 5:
Application rate no. 6:
Application rate no. 7:
Application rate no. 8:
Application rate no. 9:
Application rate no. 10:
** Flux data for Main Source
Hour1:                          183.68 100.28
Hour2:                          183.2 97.04
Hour3:                          181.85 93.9
Hour4:                          179.79 90.86
Hour5:                          177.16 87.92
Hour6:                          174.0 85.08
Hour7:                          170.63 82.34
Hour8:                          166.92 79.68
Hour9:                          163.01 77.12
Hour10:                         0.2 158.95
Hour11:                         4.63 154.81
Hour12:                         18.54 150.6
Hour13:                         39.63 146.38
Hour14:                         63.52 142.16
Hour15:                         87.1 137.98
Hour16:                         108.61 133.83
Hour17:                         127.26 129.75
Hour18:                         142.83 125.75
Hour19:                         155.4 121.82
Hour20:                         165.21 117.99
Hour21:                         172.57 114.25
Hour22:                         177.8 110.6
Hour23:                         181.21 107.06
Hour24:                         183.09 103.62
** Flux data for Multiple Source No. 1
Hour1:
Hour2:
```

```
Hour3:
Hour4:
Hour5:
Hour6:
Hour7:
Hour8:
Hour9:
Hour10:
Hour11:
Hour12:
Hour13:
Hour14:
Hour15:
Hour16:
Hour17:
Hour18:
Hour19:
Hour20:
Hour21:
Hour22:
Hour23:
Hour24:
** Flux data for Multiple Source No. 2
Hour1:
Hour2:
Hour3:
Hour4:
Hour5:
Hour6:
Hour7:
Hour8:
Hour9:
Hour10:
Hour11:
Hour12:
Hour13:
Hour14:
Hour15:
Hour16:
Hour17:
Hour18:
Hour19:
Hour20:
Hour21:
Hour22:
Hour23:
Hour24:
** Flux data for Multiple Source No. 3
Hour1:
Hour2:
```

```
Hour3:
Hour4:
Hour5:
Hour6:
Hour7:
Hour8:
Hour9:
Hour10:
Hour11:
Hour12:
Hour13:
Hour14:
Hour15:
Hour16:
Hour17:
Hour18:
Hour19:
Hour20:
Hour21:
Hour22:
Hour23:
Hour24:
** Flux data for Multiple Source No. 4
Hour1:
Hour2:
Hour3:
Hour4:
Hour5:
Hour6:
Hour7:
Hour8:
Hour9:
Hour10:
Hour11:
Hour12:
Hour13:
Hour14:
Hour15:
Hour16:
Hour17:
Hour18:
Hour19:
Hour20:
Hour21:
Hour22:
Hour23:
Hour24:
```

Appendix B. Discussion of modification of PERFUM2 to obtain daily spoke-specific buffer information.

Two situations were studied: 5 acre with fine grid and 20 acres with fine grid. The application scenario was shallow, tarped methyl bromide application using the maximum application rate of 430 lbs/acre. The flux is shown in Figure 1. While two 24-hour periods were included in the flux profile, the analysis focused on the first 24-hour period, which was the highest flux period. A listing of the PERFUM2 input file for 20 acres is shown in Appendix A. Ventura meteorology was used, though one day was removed due to a string of 24 hours of calms.

The PERFUM2.FOR source code was modified to print out both daily concentrations ordered by spoke/ring and spoke-specific buffer information. PERFUM2 calls ISCST3 (which has been adapted to become a subroutine for PERFUM2) and collects the concentration estimates at each spoke/ring coordinate for a day. Then PERFUM2 proceeds spoke by spoke and estimates the distance along each spoke to reach the reference concentration. The modifications were exclusively in the subroutine “DAYCALC”, which is contained in the PERFUM2.FOR file. The modifications are shown in full in Appendix B. Briefly, code was inserted to open files and write out internal values. The code modifications did not change the logic or calculations of the program.

Thus these modifications in the subroutine DAYCALC provided output which enabled (1) verification of the individual concentrations averages generated by PERFUM2, (2) analysis of the number of spokes each day where the reference concentration was exceeded along that spoke at the buffer zone distance, and (3) verification of the 99% whole field buffer distance. For (1) a single day was chosen, an independent ISCST3 control file was created and the discrete receptor concentrations from the single-day independent run were compared to the corresponding concentrations from PERFUM2 as found in CONCEN.OUT. For (2) the 99% whole field buffer zone was compared to each spoke-specific buffer zone each day. The daily spoke exceedance information was used to estimate a daily fraction of the buffer perimeter where the reference concentration was exceeded. These daily lengths were compiled into a distribution. For (3) the individual spoke length ‘buffers’ (distance to reach the reference concentration) were aggregated into a distribution and distributional points were compared to the PERFUM2 distribution points.

A small FORTRAN utility was written to analyze the results in SPOKEBUF.OUT. A listing of this program, COUNTXC.FOR, is provided in Appendix C. This program takes as user input, the whole-field buffer zone at a given percentile, and uses it to determine on a daily basis, the number of spokes where the actual concentration at the buffer zone distance exceeded the reference concentration. This was determined by comparing the ‘spoke bufferzone’ (in the last column of Table B1) to the whole field buffer zone and counting up the number of spokes for each day where the spoke bufferzone was larger than the whole-field buffer zone. This resulted

in a per day number ranging from 0 to a maximum possible NSPOKE, counting the number of spokes where the whole-field buffer zone would be smaller than the spoke-bufferzone, or

Table B1. Small excerpt from SPOKEBUF.OUT for fine grid, 5 acre simulation. Columns are Julian day, year, IAPP, IDAYS, IAVG, number of spokes per field (twice), spoke number, and spoke-buffer. The spoke-buffer is the distance determined along each spoke to reach the reference concentration.

2	95	1	1	1	136	136	1	5.00
2	95	1	1	1	136	136	2	5.00
2	95	1	1	1	136	136	3	5.00
2	95	1	1	1	136	136	4	5.00
2	95	1	1	1	136	136	5	5.00
2	95	1	1	1	136	136	6	5.00
2	95	1	1	1	136	136	7	5.00

equivalently, where the concentration at the whole-field buffer distance was greater than the reference concentration.

The use of .GT. ("greater than") versus .GE. ("greater than or equal to") was compared and found no differences in the 5 acre fine grid, but 1 extra exceedance spoke in the 20 acre fine grid. Thus the differences were negligible and results are reported using the "greater than" version.

At the beginning of COUNTXC the user enters a value for 'TRUBUF', which in this study was the whole-field buffer zone at the 99th percentile. This is the value used to compare to each of the spoke-buffers. For 5 acres the 99th percentile whole field buffer was 60m and for 20 acres it was 200m. COUNTXC outputs a file consisting of 1794 records, which is the number of valid days of meteorological data for the Ventura meteorological data set. The columns consist of several fields. The fields are the Julian day, two digit year, number of spokes in flux period 1 where the buffer-spoke distance exceeded the whole-field buffer distance and a similar number for period 2. The next field (P1EDG) gives a count of the number of "edge spokes" that exceeded TRUBUFF on that day during flux period 1. Following that is the number of corner spokes (P1COR) that exceeded the TRUBUFF on that day during flux period 1.

We calculated the fraction of the perimeter that exceeded the reference concentration with two methods: by a simple count of exceedance spokes divided by total spokes and by an edge/corner spoke perimeter calculation that adjusted for the different arc-length represented by the edge versus corner spokes.

The columns "FRAC BY COUNT" gives the spoke exceedance count divided by the total spoke number. In this case, Table B2, the 20 acre field fine grid utilized 200 spokes. So, for example, the second line is labeled as Julian day 3 for 1995. What this actually corresponds to is Ventura meteorology from 10:00 on January 2 through 9:00 on January 3 inclusive, since the application start hour was 10:00. This is labeled as Julian day 3. For this 24-hour meteorology period, 25 spokes saw an exceedance of the threshold at the buffer zone distance of 200m. All 25 spokes were from edge spokes. No corner spokes showed exceedances on this day. The fraction by simple counting was 0.125 (=25/200).

The second fraction, "FRAC BY LEN", shows the edge/corner perimeter calculation, which uses the arc-adjusted fraction of the perimeter. The total perimeter at the buffer zone distance, D, consists of the four sides, S, plus a circle with radius B (TRUBUFF, i.e. the 99% whole field buffer zone), which has a perimeter of $2\pi B$ and thus the entire perimeter is $D=4S+2\pi B$

In order to calculate the contribution from each edge spoke, it is necessary to determine the number of edge spokes. The general pattern of spokes is shown in Figure 2. For fine grids there are 17 spokes at each corner. This gives 18 divisions at the corner, which provides 5 degree separations between corner spokes. The file SPOKEBUF.OUT contains the total number of spokes for each field. By subtraction, the number of edge spokes can be determined. For the 20 acre fine grid, the total number of spokes was 200. The number of corner spokes was 68 (=4*17) and the number of edge spokes was 132. In order to get the perimeter contribution from each edge or each corner spoke, the corresponding perimeter is divided by the number of that kind of spoke. For edge spokes, CE=4S/#edge spokes and for corner spokes, $CC=2\pi B$/#corner spokes. For 20 acre fine grid, for example, CE=284.5*4/132=8.62m/spoke and for the corners, CC=2*3.14*200/68=18.47m/spoke.

Table B2. Small excerpt from COUNTXC.OUT, for the 20 acre, fine grid run, showing Julian day, year, number of spoke-buffers exceeding whole-field buffer zone distance for period 1 and period 2, count of edge spokes exceeding the buffer (i.e. when the reference concentration along a spoke occurred at a distance greater than the tested buffer zone), count of corner spokes exceeding the buffer, fraction of spokes exceeding the buffer and fraction of the perimeter exceeding the perimeter at the buffer distance from the field. The tested buffer was the 99th percentile whole-field buffer zone calculated by PERFUM.

```
THE TESTED BUFFER ZONE USED WAS     200.00
 THE STRAIGHT EDGES PERIMETER TOTAL         1138.00
 THE CIRCULAR PERIMETERS TOTAL              1256.64
 THE TOTAL PERIMETER AT THE BZ DIST         2394.64
 THE LENGTH PER EDGE SPOKE IS                8.6212
 THE LENGTH PER CORNER SPOKE IS             18.4799
 THE NUMBER OF CORNER SPOKES IS        68
 THE NUMBER OF EDGE SPOKES IS         132
 JULIAN DAY,YEAR,PERIOD 1 EXCEED COUNT, PERIOD 2 EXCEED COUNT
 PER 1 EDGE SPOKE CNT, PER 1 CORNER SPOKE CNT, PER 1 FRACTION BY CRUDE COUNT,
 PER 1 FRACTION BY PERIMETER LENGTH ADJST FOR CORN
```

JULDAY	YEAR	CNT1	CNT2	P1EDG	P1COR	FRAC BY COUNT	FRAC BY LEN
2	95	0	0	0	0	0.0000	0.0000
3	95	25	0	25	0	0.1250	0.0900
4	95	20	0	18	2	0.1000	0.0802
5	95	0	0	0	0	0.0000	0.0000
6	95	20	0	20	0	0.1000	0.0720
7	95	0	0	0	0	0.0000	0.0000
15	95	0	10	0	0	0.0000	0.0000
16	95	8	0	8	0	0.0400	0.0288
17	95	14	0	11	3	0.0700	0.0628
18	95	0	0	0	0	0.0000	0.0000
19	95	0	0	0	0	0.0000	0.0000
20	95	0	0	0	0	0.0000	0.0000

In line 3 of Table B2, there were 18 edge spokes and 2 corner spokes where the reference concentration was exceeded at the buffer zone distance. The simple count fraction was (=20/200). The corner/edge perimeter calculation fraction was 0.1 0.08 (=(17*8.62+2*18.47)/2394).

Finally, SORTSPOKE.FOR was written to process the output in the file, SPOKEBUF.OUT, by extracting the spoke-by-spoke distances to the reference concentration, sorting these distances and creating an output file called SORTSPOKE.OUT. The distance percentiles in SORTSPOKE.OUT corresponds to the whole-field cumulative distributions estimated by PERFUM2. Thus at for these two cases, the PERFUM2 whole-field buffer zone percentile calculation could be checked.

Appendix C. Modifications to the subroutine DAYCALC.

The DAYCALC code is shown below. The modifications made to this subroutine for our analysis are bolded and begin at line 1528 (line numbers not shown) of the PERFUM2 routine, DAYCALC, with a comment “BRJ070726 ADDED CODE HERE TO…”.

```
C*****************************************************************************************

      SUBROUTINE DAYCALC

C*****************************************************************************************
C                 DAYCALC
C
C        PURPOSE: Calculate daily average concentrations at each receptor
C                 point.  Then an interpolation is performed for each
C                 spoke in the receptor grid, and a buffer length is
C                 calculated for each spoke.  Also, the daily maximum
C                 buffer length is calculated.  All of these calculations
C                 are additionally performed on a monthly basis for
C                 seasonal analysis.
C
C        INPUTS:  Daily totals of concentrations by receptor points
C
C        OUTPUTS: Daily average buffer lengths
C
C        CALLED FROM:  ISCST3 subroutine
C
C*********************************************************************


       USE MAIN1
       USE BUFFER1

       IMPLICIT NONE

       INTEGER I,J,K,M


       NDAYS_PER = NDAYS_PER + 1

C      Start application rate loop
       DO 500 IAPP=1,NAPPRATES
C      Start flux day loop
       DO 500 IDAYS=1,NFLUXDAYS
C      Start avering time loop
       DO 500 IAVG=1,IAVG_PER

       IDIST_AVG = DIST_AVG(IAVG)

C      Calculate daily average concentration.  Use EPA's calms policy.  For a
C      24-hour period, divide daily concentration total by the maximum of the
C      non-calm hours, or 75% of the the number of hours (24)- +0.4 added per
C      ISCST3 code

      PER_HOURS = MAX(NON_CALM_HOURS(IAVG),NINT(AVG_TIME*0.75+0.4))
      IF(NON_CALM_HOURS(IAVG) .EQ. 0) THEN
        GOTO 500
      ENDIF
```

```
C      Divide by the number of non-calm hours to get the average concentration.
C      Adjust for the application rate.

C BRJ 070726 ADDED CODE HERE TO OUTPUT THE CONCENTRATIONS AND RING/SPOKE IDS
       OPEN(UNIT=27182,STATUS='UNKNOWN',POSITION='APPEND',
     1      FILE='CONCEN.OUT')  !CLOSE FILE AFTER 10 DO LOOP

       DO 10 I=1,NUMREC

         IRING = RINGID(I)
         ISPOKE = SPOKEID(I)

C        Averaging period calculation
         CONC_DISP_TMP(IRING,ISPOKE) =
     >     CONC_DISP(I,IDAYS,IAVG)/PER_HOURS


C        Adjustment for application rate
         CONC_DISP_TMP(IRING,ISPOKE) =
➢       CONC_DISP_TMP(IRING,ISPOKE)*(AppRate(IAPP)/AppRate(1))

C BRJ 070726 WRITE OUT THE DAY,YEAR, RING ID AND SPOKE ID AND CONCENTRATION
         WRITE(27182,37182)LJDAY,LYEAR,IDAYS,I,IRING,ISPOKE,
     1         CONC_DISP_TMP(IRING,ISPOKE)
37182    FORMAT(1X,6I6,F15.2)

10     CONTINUE
       CLOSE(27182)

        BUFFER_MAX = 0.                 ! initialize maximum buffer zone variable to zero

C BRJ 070724 OPEN FILE FOR APPENDING, INTERPOLATE SUBROUTINE PRODUCES 'BUFFER', WHICH IS
C BUFFER ALONG THAT SPOKE, FOR EACH SPOKE, SO WILL PRINTOUT NUMBER OF SPOKES PER FIELD, SPOKE
C NUMBER AND BUFFER, ARE ASSUMING 24 HOUR EXPOSURES
        OPEN(UNIT=31415,STATUS='UNKNOWN',POSITION='APPEND',
     1       FILE='SPOKEBUF.OUT')  !CLOSE THE FILE AFTER 110 DO LOOP BELOW
C
C       Begin to loop over each spoke
        DO 110 ISPOKE=1,NSPOKE_PER_FIELD

C         Call the interpolation subroutine to estimate the buffer distance for this spoke

          CALL INTERPOLATE(ISPOKE)

C BRJ 070724 INSERT THE PRINT STATEMENT TO GET THE TIME AND OTHER RELEVENAT INFO FOR THIS BUFFER

          WRITE(31415,61415)LJDAY,LYEAR,IAPP,IDAYS,IAVG,
     1                              NSPOKE_PER_FIELD
     2                                ,NSPOKE_PER_FIELD,ISPOKE,BUFFER
61415     FORMAT(1X,8I5,F10.2)


C         Update the buffer zone frequency arrays.  These arrays store the
C         frequency by which each buffer distance was found.
C         For the whole field calculation, the BUFFER_FREQ array is used
C         For the whole field monthly calculation, the BUFFER_FREQ_MON
C         array is used.  The first array indices refer to specific buffer
C         distances between 0 and 300, at *5 meters for each indice


          IASSIGN = 0                   ! Variable to check if a frequency was assigned
```

```
(……section of code omitted…….)

110     CONTINUE
C BRJ 070724 CLOSE THE SPECIAL OUTPUT FILE
        CLOSE(UNIT=31415)
```

The first modification opens a new file “CONCEN.OUT”, which receives the daily average concentrations by spoke. This file was used to directly compare independently run ISCST3 calculations for a selected day to verify the PERFUM2 calculations.

A few lines later a file called “SPOKEBUF.OUT” is opened for output. A few lines down, within the 110 Do Loop, the original code calls a subroutine, INTERPOLATE(ISPOKE). This subroutine computes the distance out along the particular spoke identified by the index, ISPOKE, until the reference concentration is reached. The value is returned in variable called BUFFER, which is not shown in this portion of the code. The second modification consists of a couple of lines which write out to the file, SPOKEBUF.OUT, the current values for several variables. The important variables are LJDAY, LYEAR, IDAYS, ISPOKE and BUFFER. LJDAY is the Julian day of the year. LYEAR is the last 2 digits of the calendar year (95, for example). IDAYS is the period number. In this case, there were two 24-hour flux periods and so IDAYS took on a value of either 1 or 2. ISPOKE is the spoke number, which in this case ranged from 1 to 40 for the 5 acre field. The control file was set up to only use one application rate, so that IAPP was always 1. Similarly, IAVG was equal to 1, as the number of averaging periods per 24 hour day. The final modification occurred just after the end of the 110 DO LOOP and closed the output unit.

Thus, these modifications to the PERFUM2 source code created two new files, CONCEN.OUT and SPOKEBUF.OUT, which respectively record the concentration calculations and list day by day, the distances along each spoke to reach the reference concentration. A single day of output consisted of 2*NSPOKE records (for five acres coarse grid, NSPOKE=40, 5 acres fine grid NSPOKE=136 and for 20 acres fine grid, NSPOKE=200) because there were two 24-hour flux periods in this example. Table 1 shows a small excerpt from SPOKEBUF.OUT for a 5 acre, coarse grid. The last column in Table B1, spoke buffer, gives the estimated distance along that particular spoke on that particular day to reach the reference concentration.

Appendix D. Listing of program COUNTXC.FOR.

```
C     Last change:  BRJ  30 Jul 2007    4:15 pm
        PROGRAM COUNTXC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C 070730 MODIFIED COUNTXB (WHICH WAS FOR 5 ACRES) TO COUNTXC, WHICH WILL BE
C FOR 20 ACRES. 20 ACRES, ACCORDING TO THE CONCEN.OUT (WHICH IS NOW ZIPPED
SINCE
C IT'S OVER 1GB) THERE ARE 200 SPOKES FOR THE 20 ACRE FIELD.  AND WITH THE
NORMAL CONFIGURATION OF 17 SPOKES
C AT EACH CORNER (TO GIVE THE 5 DEGREES OF SEPARATION, HAH, CLOSE THAN 6)
C SO, 200-4*17=132 AND 132/4 = 33 SPOKES PER EDGE.  AND THE EDGE LENGTH IS
284.5M
C SO THAT 284.5/32=8.89M, WHICH MATCHES THE DISCRETE RECEPTOR FILE, WHERE
C THE PROGRESSIVE INCREMENT BETWEEN SPOKES ALONG THE EDGE IS 8.89
(BUFSPOKE.OUT)
C
C
C 070727 COUNTXB USES COUNTXA, AND ADDS SEVERAL MORE COLUMNS.  TWO COLLUMNS
C WILL BE FOR COMPUTING THE FRACTION OF THE PERIMETER THAT IS EXCEEDED,
C USING EQUAL WEIGHTS FOR EACH SPOKE (136 SPOKES FOR FINE GRID FOR 5 ACRES)
C THE NEXT FOUR COLUMNS (2 FOR EACH PERIOD) WILL USE THE ACTUAL PERIMETER
C CALCULATIONS, THSU FOR THE STRAIGHT SIDES (WEST, NORTH, EAST, SOUTH) EACH
C SPOKE IS WORTH (4*142.3)/68=8.37M AND FOR THE CORNERS, EACH SPOKE IS WORTH
C (2*PI*B)/68, WHICH FOR 60M IS 5.54M, AND THE TOTAL PERIMETER IS 519.29 FOR
TRUBUF=60
C
C 070726 COUNTXA MODIFIED TO USE PARAMETER NSPOKE IN PLACE OF 40 TO GET
FLEXIBILITY
C ON THE NUMBER OF SPOKES, SINCE IT APPEARS WE USED COARSE GRID FOR FIRST GO
ROUND
C INSTEAD OF FINE GRID, WHICH HAS INSTEAD OF 40 SPOKES, (15+17)*4=128 SPOKES,
VOILA!
c ACTUALLY, BASED ON THE OUTPUT FROM PERFUM2BJ (WHICH PRINTS OUT NSPOKE), THE
NUMBER
C OF SPOKES FOR THE FINE GRID 5 ACRE PLOT IS 136, I THINK THAT THE 15+17
FIGURE COMES
C FROM THE FIXED ISCST3 TEMPLATE CONTROL FILES THAT REISS HAD AVAILABLE FROM A
PREVIOUS
C VERSION, NOW THE CONTROL FILES ARE BUILT ON THE FLY
C
C 070725 I TRIED USING GE AND GT, GAVE SAME RESULTS IN FIRST EXAMPLE
C
C
C PROGRAM COUNTX, USES AS INPUT A SPECIAL OUTPUT FILE FROM
C PERFUM2 WHICH CONTAINS DAY, YEAR, SPOKE BUFFER
C AND ALSO USER INPUT FOR THE 'BUFFER' HOWEVER DETERMINED
C THEN COUNTX RUNS THROUGH THE FILE AND CALCULATES FOR EACH 24 HOUR PERIOD
```

```
C WHAT FRACTION OF THE PERIMETER EXCEEDED THE THRESHOLD, AND
C OUTPUTS THAT NUMBER FOR SUMMARY INTO A FREQUENCY DISTRIBUTION
C-------FOLLOWING IS OUTPUT LINE IN PERFUM2BJ---------------
C
C          WRITE(31415,61415)LJDAY,LYEAR,IAPP,IDAYS,IAVG,
C     1                            NSPOKE_PER_FIELD
C     2                                 ,NSPOKE_PER_FIELD,ISPOKE,BUFFER
C61415     FORMAT(1X,8I5,F10.2)
C-------------------------------------------------------------
C LJDAY IS JULIAN DAY OF YEAR
C LYEAR IS 2 DIGITS OF YEAR
C IAPP IS COUNTER FOR THE APPLICATION RATE (SHOULD ALWAYS BE 1 IN THIS
EXAMPLE)
C IDAYS IS THE NUMBER OF FLUX DAYS (IS 1 OR 2 IN THIS EXAMPLE, SINCE 2 X 24
HOUR FLUX PERIODS)
C       I WILL ONLY BE USING THE FIRST 24 HOUR FLUX PERIOD
C IAVG IS A COUNTER FROM 1 TO IAVG_PER, THE LATTER IS THE NUMBER OF AVERGING
PERIODS PER DAY
C NSPOKE_PER_FIELD IS THE NUMBER OF SPOKES PER FIELD (40 FOR COARS GRID 5
ACRES, 136FOR FINE)
C ISPOKE IS THE SPOKE NUMBER
C BUFER IS A REAL NUMBER, THE DISTANCE AT WHCIH THE THRESHOLD CONCENTRATION IS
REACHED
C  LJDAY LYEAR IAPP IDAYS IAVG NS_P_F ISPOKE BUFFER
C12345678901234567890123456789012345678901234567890 1
C     2   95    1    1    1   40   40    1      5.00
C     2   95    1    1    1   40   40    2      5.00
C     2   95    1    1    1   40   40    3      5.00
C     2   95    1    1    1   40   40    4      5.00
C     2   95    1    1    1   40   40    5      0.00
C     2   95    1    1    1   40   40    6      0.00
C     2   95    1    1    1   40   40    7      0.00
C     2   95    1    1    1   40   40    1      5.00
C     2   95    1    1    1   40   40    2      5.00
C     2   95    1    1    1   40   40    3      5.00
C     2   95    1    1    1   40   40    4      5.00
C     2   95    1    1    1   40   40    5      0.00
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        IMPLICIT NONE
        INTEGER NSPOKE
        REAL SIDE !SIDE OF SQUARE FIELD
        REAL PI  !THE CONSTANT
C        PARAMETER (NSPOKE=136)  5 ACRES
C        PARAMETER (SIDE=142.3) !FOR 5 ACRES SIDE IS 142.3M
        PARAMETER (NSPOKE=200) !200 SPOKES FOR 20 ACRES, STILL 17 PER CORNER
        PARAMETER (SIDE=284.5) !FOR 20 ACRES SIDE IS 284.5M
        PARAMETER (PI=3.14159) !AHHHH, PI WONT CHANGE WITH ACREAGE
        INTEGER LJDAY(NSPOKE,2),LYEAR(NSPOKE,2),SPOKE(NSPOKE,2)
        REAL BUFF(NSPOKE,2),TRUBUF
```

```
        INTEGER COUNTDAYS, I,J,K, COUNT1,COUNT2,COUNTREC
        INTEGER IAPP(NSPOKE,2),IDAYS(NSPOKE,2),IAVG(NSPOKE,2)
        INTEGER NS_P_F(NSPOKE,2)
        INTEGER ISPOKE(NSPOKE,2)
        REAL PERIMETER, EDGELEN, EDGEPERSPOKE,ARCPERSPOKE, ARCLEN
        INTEGER EDGECNT,CORNCNT,KI
        REAL FRACPERI,FRACCNT
        INTEGER CORNSPOKE,EDGESPOKE !CALCULATED NUMBER OF CORNER SPOKES VS
EDGE SPOKES
        INTEGER EC20 !FUNCTION DETERMINES IF EDGE (=1) OR CORNER (=0) FOR 20
ACRES
        !PERIMETER IS TOTAL PERIMETER LENGTH AT A BUFFER ZONE DISTANCE
        ! EDGELEN IS LENGTH OF FIELD PERIMETER (SUM OF 4 SIDES)
        !EDGEPERSPOKE IS LINEAR DISTANCE EACH EDGE SPOKE REPRESENTS
        !ARCPERSPOKE IS ARC DISTANCE EACH CORNER SPOKE REPRESENTS
        !ARCLEN IS PERIMETER OF CIRCLE WITH BUFFER ZONE AS RADIUS
        OPEN(UNIT=1,STATUS='OLD',FILE='SPOKEBUF.OUT')
        OPEN(UNIT=2,STATUS='UNKNOWN',FILE='COUNTXC.OUT')
        WRITE(6,100)
100     FORMAT(1X,'ENTER THE REAL NUMBER FOR THE BUFFER ZONE ')
        READ (5,*)TRUBUF
        WRITE(6,110)TRUBUF
110     FORMAT(1X,'THE BUFFER DIST YOU ENTERED WAS ',F12.3,
     1         /1X,' ')
        WRITE(2,95)TRUBUF
95      FORMAT(1X,'THE TESTED BUFFER ZONE USED WAS ',F10.2)
        EDGELEN=4.*SIDE  !FIELD PERIMETER
        ARCLEN=TRUBUF*2.*PI
        PERIMETER=EDGELEN+ARCLEN  !PI TIMES D IS CIRCUMFERENCE, REMEMBER?
        CORNSPOKE=4*17  !REISS ALWYAS USES 17 SPOKES ON CORNERS (18 DIVISIONS
GIVES 5 DEGREE SEPARATION)
        EDGESPOKE=NSPOKE-CORNSPOKE !TOTAL NUMBER OF EDGE SPOKES ARE WHAT IS
LEFT OVER
        EDGEPERSPOKE=EDGELEN/FLOAT(EDGESPOKE)    !AMT OF STRAIGHT EDGE PER N E
S W SPOKE
        ARCPERSPOKE=ARCLEN/FLOAT(CORNSPOKE) !AMT OF ARC DIST PER NW, NE, SE,
SW SPOKE FROM CORNER

        WRITE (2,97) EDGELEN,ARCLEN,PERIMETER,EDGEPERSPOKE,ARCPERSPOKE,
     1               CORNSPOKE, EDGESPOKE
97      FORMAT(1X,'THE STRAIGHT EDGES PERIMETER TOTAL ',F15.2,
     1        /1X,'THE CIRCULAR PERIMETERS TOTAL      ',F15.2,
     2        /1X,'THE TOTAL PERIMETER AT THE BZ DIST ',F15.2,
     3        /1X,'THE LENGTH PER EDGE SPOKE IS       ',F15.4
     4        /1X,'THE LENGTH PER CORNER SPOKE IS     ',F15.4,
     5        /1x,'THE NUMBER OF CORNER SPOKES IS     ',I5,
     6        /1X,'THE NUMBER OF EDGE SPOKES IS       ',I5)
        WRITE(2,107)
107     FORMAT(1X,'JULIAN DAY,YEAR,PERIOD 1 EXCEED COUNT, ',
     1            'PERIOD 2 EXCEED COUNT',
```

```
     2        /1X,'PER 1 EDGE SPOKE CNT, PER 1 CORNER SPOKE CNT, '
     3           , 'PER 1 FRACTION BY CRUDE COUNT, '
     4        /1X,'PER 1 FRACTION BY PERIMETER LENGTH ADJST FOR CORN')

C             WRITE(2,350)LJDAY(1,1),LYEAR(1,1),COUNT1,COUNT2,EDGCNT,CORNCNT,
C     1              FRACCNT,FRACPERI
C350     FORMAT(1X,6I8,2F12.4)
        WRITE(2,101)
101     FORMAT(7X,'JULDAY',' YEAR ','  CNT1 ','   CNT2 ', '   P1EDG ',
     1            '  P1COR '
     1            'FRAC BY COUNT ','FRAC BY LEN ')
        COUNTDAYS=0
        COUNT1=0
        COUNT2=0
        COUNTREC=0
C THERE ARE NSPOKE SPOKES PER FIELD, SO USE THAT TO STRUCTURE CALCULATIONS

1       CONTINUE  !BIG READ LOOP STARTS HERE

         DO I=1,NSPOKE      !THIS SHOULD BE WITH IDAYS=1
          READ(1,170,END=1000)LJDAY(I,1),LYEAR(I,1),IAPP(I,1),IDAYS(I,1)
     1                       ,IAVG(I,1),NS_P_F(I,1),SPOKE(I,1),
     2                        BUFF(I,1)
         END DO

         DO I=1,NSPOKE      !THIS SHOLD BE WITH IDAYS=2
          READ(1,170,END=1000)LJDAY(I,2),LYEAR(I,2),IAPP(I,2),IDAYS(I,2)
     1                      ,IAVG(I,2),NS_P_F(I,2),SPOKE(I,2),BUFF(I,2)
170       FORMAT(1X,6I5,5X,I5,F10.2)
         END DO
         COUNTDAYS=COUNTDAYS+1
C DO SOME CHECKING
         DO I=1,NSPOKE
          IF((I.NE.SPOKE(I,1)).OR.(I.NE.SPOKE(I,2)).OR.(IDAYS(I,1).NE.1)
     1                      .OR.(IDAYS(I,2).NE.2).OR.(IAPP(I,1).NE.1).
     2                      OR.(IAPP(I,2).NE.1).OR.
     3                       (NS_P_F(I,1).NE.NSPOKE).
     4                      OR.(NS_P_F(I,2).NE.NSPOKE).OR.
     5                      (LJDAY(1,1).NE.LJDAY(MIN(NSPOKE,I+1),2))
     6                           .OR.
     7                      (LYEAR(1,1).NE.LYEAR(MIN(NSPOKE,I+1),2)))
     8                         THEN
C NOTE LAST PART OF PRECEEDING DOESN'T CHECK EVERYTHING BUT IF FIRST VALUE OF
C DAY AND YEAR EQUAL CORRESPONDING VALUES FOR THE NSPOKE RECORDS IN THE SECOND
HALF
C THEN I ASSUME THAT LYEAR, LJDAY VALUES FOR FIRST HALF ARE ALSO CONSTANT
             WRITE(6,203)
203          FORMAT(1X,'INDEXING ERROR..CHECK FOLLOWING DAY (1ST HALF ',
     1                 'SHOWN ')
             DO J=1,NSPOKE
```

```
              WRITE(6,205)LJDAY(J,1),LYEAR(J,1),IAPP(J,1),IDAYS(J,1),
     1                    IAVG(J,1),NS_P_F(J,1),SPOKE(J,1),BUFF(J,1)
205           FORMAT(1X,7I5,F10.2)
             END DO
             STOP
           ENDIF
         END DO

C DO SOME PROCESSING - SIMPLE CRUDE APPROACH, COUNT UP THOSE BUFFERS GREATER
THAN TRUBUF
C AND SOME ADDED PROCESSING FOR COUNTXB, USE THE ACTUAL PERIMETER CALCULATIONS
C ALSO COUNT THE INSTANCES OF EDGE VS CORNER SPOKE EXCEEDANCES, BASICALLY
FIRST
C 17 SPOKES ARE WEST, 2ND 17 ARE NW, 3 RD ARE NORTH, AND SO ON
C WILL DO THE EXTENDED CALCULATIONS ONLY FOR THE FIRST PERIOD
        COUNT1=0
        COUNT2=0
        EDGECNT=0
        CORNCNT=0
        DO I=1,NSPOKE
         IF(BUFF(I,1).GT.TRUBUF)THEN
C           KI=INT((I-1)/17)+1  !THIS FANCY-PANTS BIT WONT WORK FOR 20 ACRES,
USE FUNCTION EC20
            KI=EC20(I)  !GIVES VALUE OF 1 IF EDGE, VALUE OF 0 IF CORNER
           IF(MOD(KI,2).EQ.1)THEN
            EDGECNT=EDGECNT+1
           ELSEIF(MOD(KI,2).EQ.0)THEN
            CORNCNT=CORNCNT+1
           ENDIF
           COUNT1=COUNT1+1
         ENDIF
         IF(BUFF(I,2).GT.TRUBUF)COUNT2=COUNT2+1
        END DO
C HAVE TABULATED EXCEEDANCES FOR THIS DAY, NOW CALCULATE PERIMETERS AND
FRACTIONS
 !PERIMETER IS TOTAL PERIMETER LENGTH AT A BUFFER ZONE DISTANCE
        ! EDGELEN IS LENGTH OF FIELD PERIMETER (SUM OF 4 SIDES)
        !EDGEPERSPOKE IS LINEAR DISTANCE EACH EDGE SPOKE REPRESENTS
        !ARCPERSPOKE IS ARC DISTANCE EACH CORNER SPOKE REPRESENTS
        !ARCLEN IS PERIMETER OF CIRCLE WITH BUFFER ZONE AS RADIUS
        FRACPERI=FLOAT(EDGECNT)*EDGEPERSPOKE+FLOAT(CORNCNT)*ARCPERSPOKE !THE
WHOLE EXCEEDANCE LENGTH
        FRACPERI=FRACPERI/PERIMETER
        FRACCNT=FLOAT(COUNT1)/FLOAT(NSPOKE)
C RECORD THIS DAY OF RESULTS
        WRITE(2,350)LJDAY(1,1),LYEAR(1,1),COUNT1,COUNT2,EDGECNT,CORNCNT,
     1              FRACCNT,FRACPERI
350     FORMAT(1X,6I8,2F12.4)
        COUNTREC=COUNTREC+1
        GOTO1
```

```
1000    CONTINUE  !REACHED END OF FILE
        WRITE(6,1100)COUNTDAYS,COUNTREC
1100    FORMAT(1X,I10,' DAYS PROCESSED ',I10,' RECORDS WRITTEN')
        END PROGRAM

        INTEGER FUNCTION EC20(I)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C THIS FUNCTION RETURNS 1 IF I IS AN EDGE SPOKE AND 0 IF I IS A CORNER SPOKE
FOR 20 ACRES
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        IMPLICIT NONE
        INTEGER I,K
C 1-33 WEST EDGE                          1
C 34-50 NW CORNER                         0
C 51-83 NORTH EDGE                        1
C 84-100 NE CORNER                        0
C 101-133 EAST EDGE                       1
C 134-150 SE CORNER (MY LEAST FAVORITE)   0
C 151-183 S EDGE                          1
C 184-200 SW CORNER (MY MOST FAVORITE)    0
        IF(I.LT.1.OR.I.GT.200)GOTO10
        K=MOD(I-1,50) !MAPS 1-200 INTO 0-49
        IF(0.LE.K.AND.K.LE.32)THEN
          EC20=1                    !WE GOT A SIDE
          RETURN
        ELSEIF(33.LE.K.AND.K.LE.49)THEN
          EC20=0                    !WE GOT A CORNER
          RETURN
        ENDIF
10        WRITE(6,100)I
100     FORMAT(1X,'ERROR IN EC20 WITH I= ',I10)
        STOP
        END
```

Appendix E. Comparison of two methods for estimating the fraction of the perimeter where the threshold concentration was exceeded.

Amongst the days where exceedances occurred, Figures E1 and E2 provide distributions for the fraction of the buffer zone perimeter based on the arc-length method which exceeded the reference concentration. The two methods for calculating the fraction yielded somewhat different histograms, but the general limits and shapes were similar. In both cases the fractions ranged from 0.01 to about 0.15. In part, the differences between the 2 methods resulted from the different number of edge versus corner spokes between 5 acre and 20 acres fields and the relatively different arc lengths represented by the 5 acre and 20 acre cases.

For the 5 acre field, there were a total of 2447 edge spokes and 335 corner spokes where exceedances occurred. For the 20 acre field, edge spokes were also dominated where exceedances occurred with 3337 and 217 edge and corner spoke exceedances, respectively. A quick check against the 99th percentile whole field buffer, which was used to calculate these exceedances, provides satisfactory agreement. That is, for five acres, (2447+335)/(1794*136) is about 1%, as is, for twenty acres, (3337+217)/(1794*200). There were 136 and 200 spokes for the 5 and 20 acre field fine grid simulations.

The histograms in Figures E1 and E2 provide some indication of the distribution of fractions of perimeters which are exceeded, when there is an exceedance somewhere along the buffer zone perimeter. Figures E3 and E4 provide the same data expressed as cumulative distributions of perimeter exceedance fractions and can be utilized more quantitatively to calculate probabilities. Figures E3 and E4 depict the contrast between the 5 acre and 20 acre fields where the 2 methods provide comparatively reversed results. That is, for 5 acres, the corner/edge perimeter method gives higher perimeter fractions for 5 acres, but lower perimeter fractions for 20 acres. This reversal is caused by the difference in effect of the 99% whole field buffer, which for the 5 acre case results in an average arc length per corner spoke which was less than the arc length for the edge spoke (5.5m versus 8.4m), but in the 20 acre case, was larger than the edge spoke (18.5m versus 8.6m). This, in combination with the general prevalence of exceedances along the edge spokes instead of the corner spokes, accounts for the differences between the two methods for calculating the daily perimeter exceedance fraction.

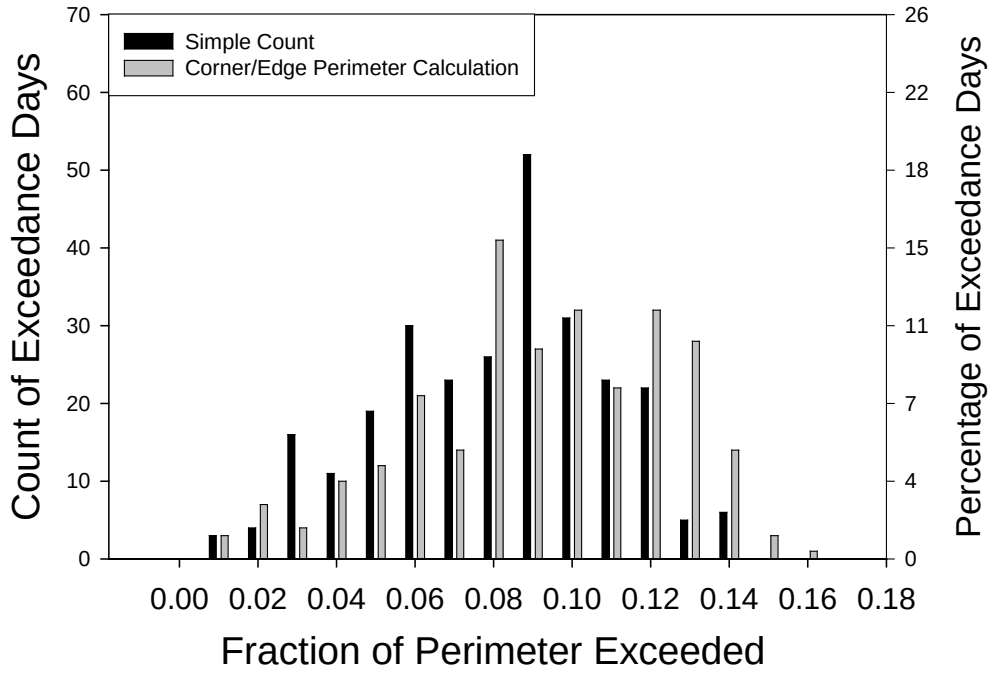


Figure E1. Fine grid, 5 acre scenario with histograms of the daily fractions of the perimeter where the concentration exceeds the reference level. The total days were 1794, of which 1523 days showed no exceedance. This figure plots the exceedances for the 271 days where 1 or more spokes showed an exceedance.

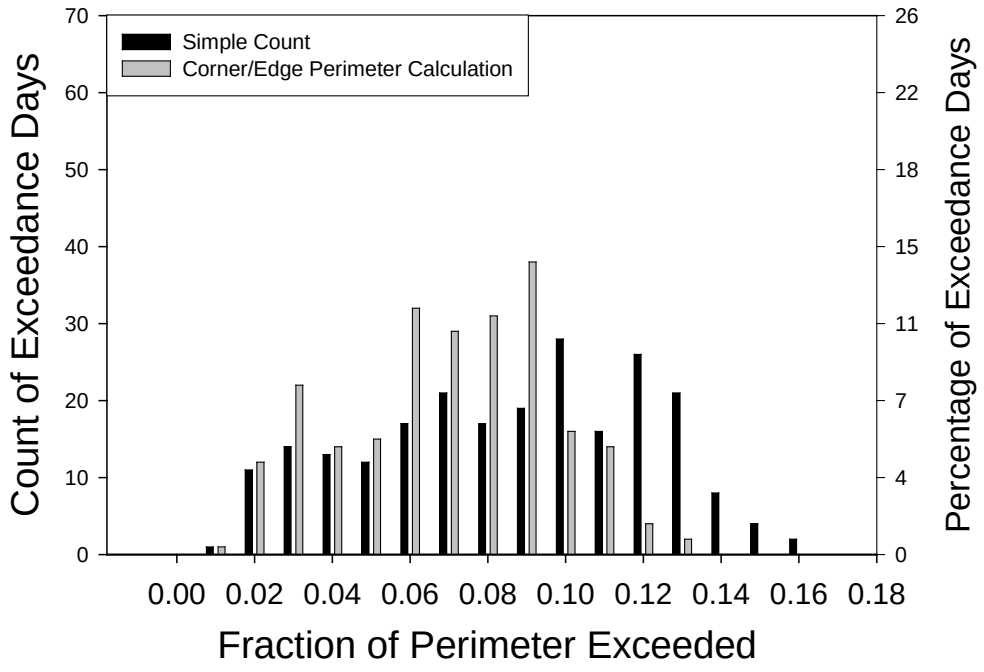


Figure E2. Fine grid, 20 acre scenario with histograms of the daily fractions of the perimeter where the concentration exceeds the reference level. The total days were 1794, of which 1564 days showed no exceedance. This figure plots the exceedances for the 230 days where 1 or more spokes showed an exceedance.

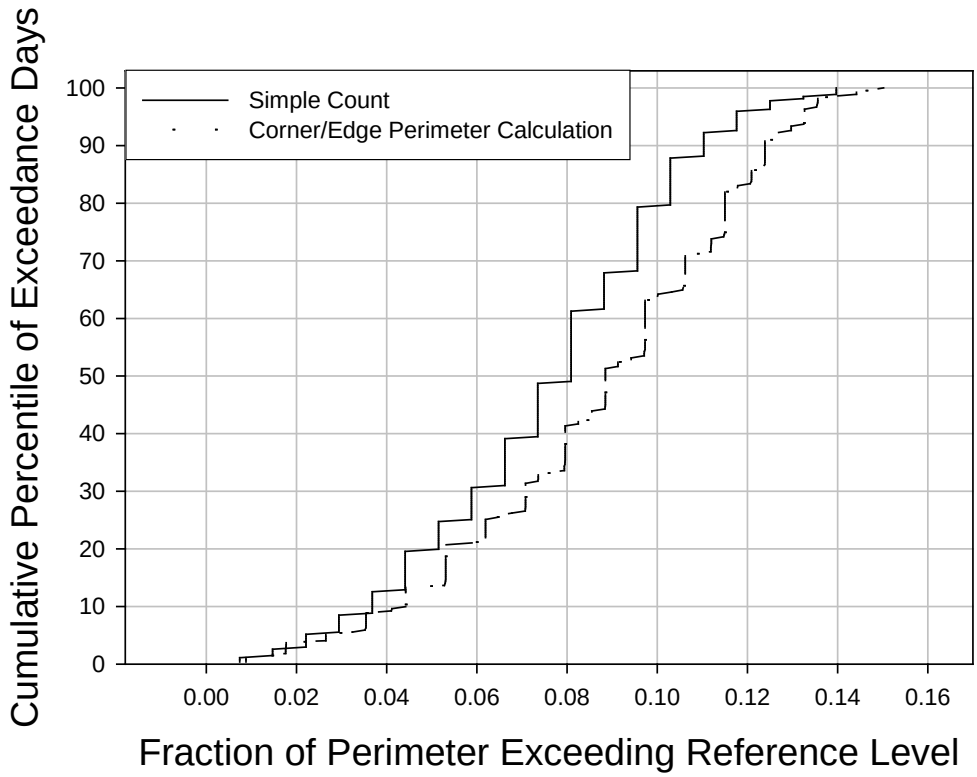


Figure E3. Cumulative distribution of perimeter length exceedances for 5 acre, fine grid scenario where 271 days showed at least one spoke exceeded the reference concentration at the buffer zone distance.

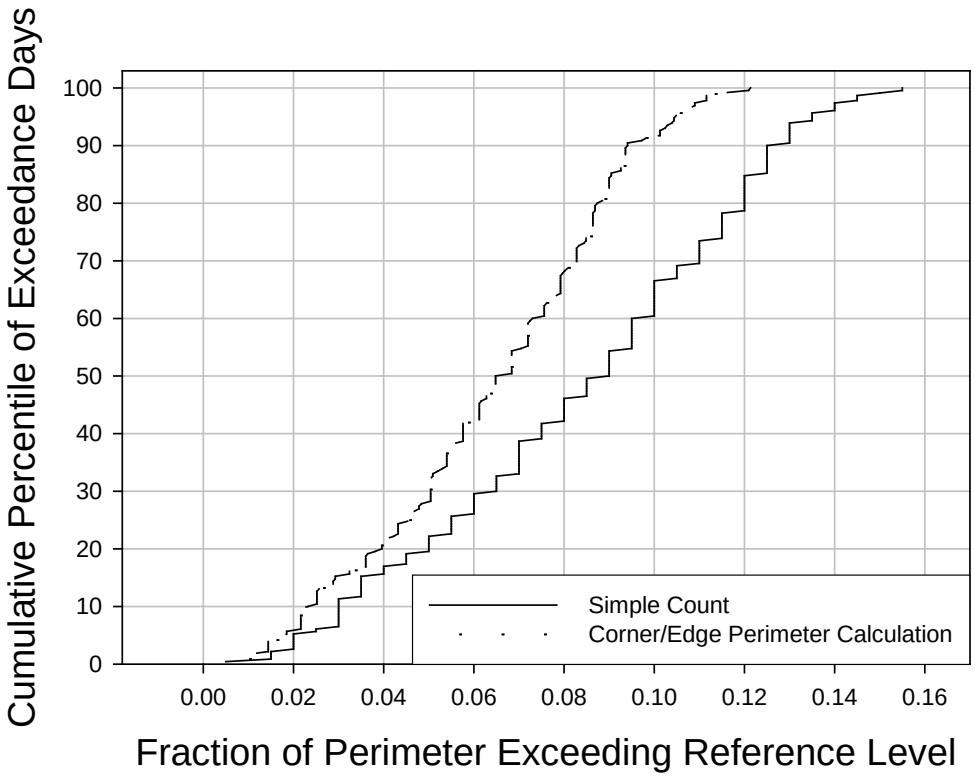


Figure E4. Cumulative distribution of perimeter length exceedances for 20 acre, fine grid scenario based on 230 days where at least one spoke exceeded the reference concentration at the buffer zone distance.

Appendix F. Procedure to compare the whole field buffer zone distributions with the maximum direction buffer zone distributions.

The whole field buffer zone distribution for each fumigant/application method/maximum application rate/meteorological data (scenario) combination was examined to find the 99% whole field buffer zone. Then for that same scenario the equivalent percentile at that buffer zone length in the maximum direction buffer zone distribution was found.

Results are presented by fumigant in the text of this memorandum. The tables below show an example of the PERFUM output used to locate the 99% whole field buffer zone length and the equivalent maximum direction buffer zone distribution percentile. Figure F1 illustrates the procedure graphically.

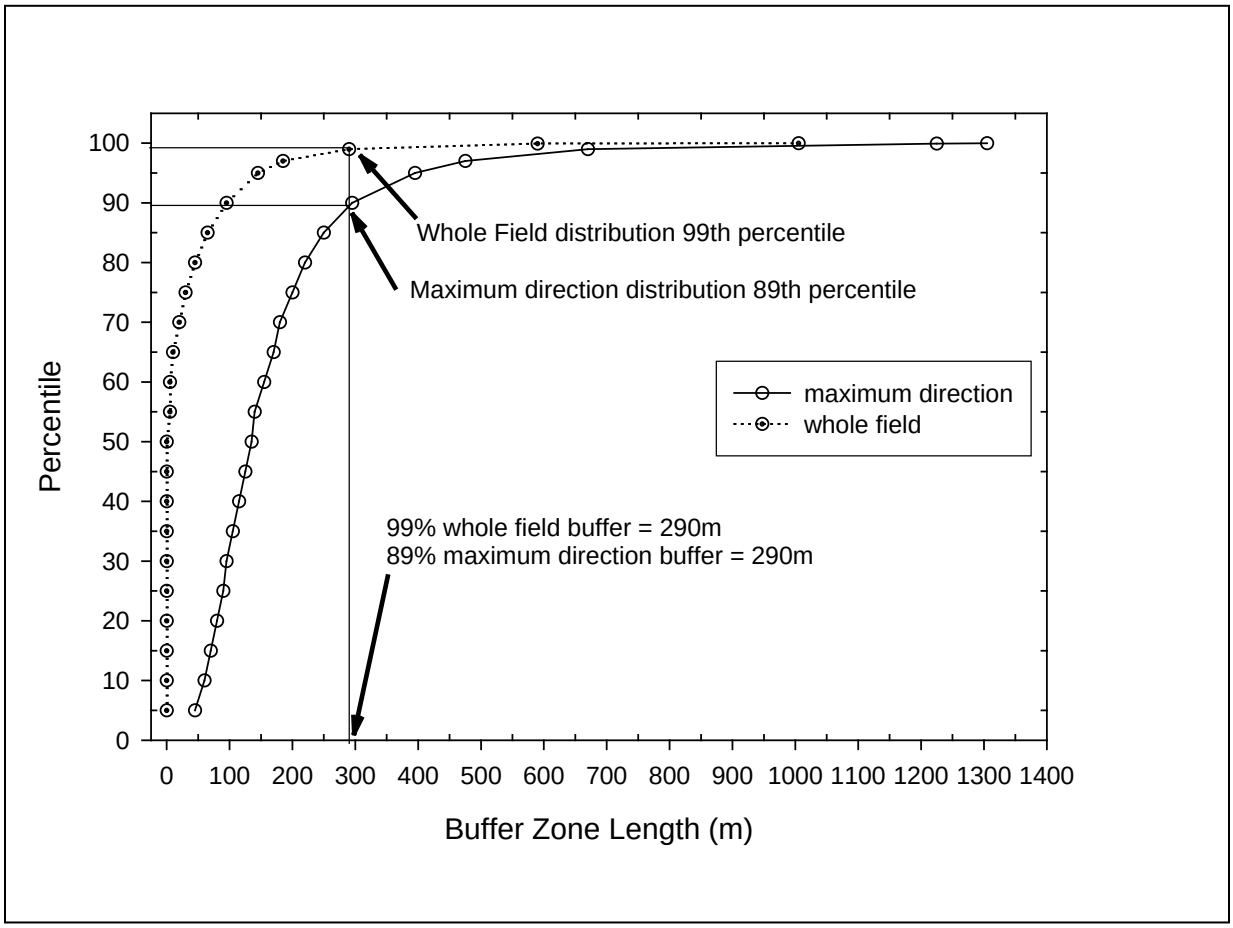
Table F1. Whole field buffer percentiles for an application rate of 250.0 for Flux Profile Day No. 1

Percentile	Buffer Zone(m)
5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	5
60	5
65	10
70	20
75	30
80	45
85	65
90	95
95	145
97	185
99	290
99.9	590
99.99	1005

Table F2. Maximum concentration buffer percentiles for an application rate of 250.0 for Flux Profile Day No. 1

Percentile	Buffer Zone (m)
5	45
10	60
15	70
20	80
25	90
30	95
35	105
40	115
45	125
50	135
55	140
60	155
65	170
70	180
75	200
80	220
85	250
90	295
95	395
97	475
99	670
99.9	1225
99.99	1305

Figure F1. Illustration of the relationship between the 99% whole field buffer zone length and the equivalent maximum direction distribution percentile for the same buffer zone length.



Department of Pesticide Regulation

Mary-Ann Warmerdam
Director

Arnold Schwarzenegger
Governor

M E M O R A N D U M

APPENDIX 7

TO: Linda O'Connell
Senior Environmental Scientist (Supervisor)
Worker Health and Safety Branch

FROM: Terrell Barry, Ph.D., Research Scientist III
Environmental Monitoring Branch
(916) 324-4140

Original signed by

DATE: November 2, 2007

SUBJECT: RESOLVING SOURCES OF DIFFERENCES IN PERFUM METHYL ISOTHIOCYANATE BUFFER ZONES BETWEEN BAKERSFIELD AND VENTURA

Background

The Department of Pesticide Regulation draft methyl isothiocyanate mitigation proposal (DPR, 2007) includes buffer zone tables developed using output from three air dispersion modeling approaches. Each approach has inherent strengths and weaknesses so all three were provided to risk managers, who make the final determination of the length of mitigation buffers zones. Those modeling approaches are: (1) screening method, (2) the Probabilistic Exposure and Risk Model for Fumigants (PERFUM) version 2 modeling system (Reiss and Griffin, 2005), and (3) the Fumigant Emissions Modeling System v5.074 (FEMS) modeling system (Sullivan et al., 2006). In addition, meteorological data from two locations were used, Bakersfield and Ventura, California. Details of buffer zone development and the modeling are presented in Barry (2006) and Barry (2007). The buffer zones developed using each of the models and locations for the same application methods and rates are expected to differ to varying degrees for a variety of reasons. You asked for a discussion of the sources of differences in PERFUM buffer zones between the Bakersfield and Ventura locations.

PERFUM uses weather data from the Bakersfield Automated Surface Observing System (ASOS) for the years 1999 through 2003 and the Ventura California Irrigation Management Information System (CIMIS) for the years 1995 through 1999. Figures 1 through 4 show the buffer zones for Bakersfield and Ventura applications made to square fields at the maximum application rate (320 lb metam sodium/acre) and application sizes of 1, 5, 10, 20, and 40 acres. When the buffer zones are different the Bakersfield buffer zones tend to be shorter (Figures 1 through 4). With the exception of the 10acre intermittent sprinkler scenario, Bakersfield buffer zones were between

27% and 45% shorter than Ventura. Most Bakersfield buffer zones were approximately 40% shorter than Ventura buffer zones. The 40acre standard sprinkler and standard shank scenarios cannot be examined because the PERFUM buffer zone length limit of 1440m is reach for both of these scenarios. The true length of the required buffer zone is unknown. The 10acre intermittent sprinkler scenario demonstrates an effect of the shape of the buffer zone distributions on final buffer zone size. The Ventura 90th percentile buffer zone length for this scenario is 5m but the 95th percentile buffer zone is 45m. Thus, the large difference between Bakersfield and Ventura for this scenario is a product of the difference in shapes at and near the 95th percentile position of these two buffer zone length distributions. This factor is one of several sources of differences between buffer zones developed using meteorological data from these two locations.

The objective of this memorandum is to explore and characterize sources of differences in PERFUM buffer zones between the two locations, Bakersfield and Ventura, California.

Analysis

The Bakersfield and Ventura meteorological files used with the PERFUM model to develop the MITC buffer zones were processed to extract the meteorological data for the averaging periods that determined the MITC buffer zones for each application method. The MITC threshold concentration is 220ppb 8-hr Time Weighted Average (TWA). So, there are three 8-hr periods per day. The 8-hr period with the longest buffer zone is the averaging period that determines the buffer zone length. The application methods and buffer zone determining averaging periods are shown in Table 1.

The calm hours were removed before analysis since those hours are not used by the PERFUM model. MINITAB (2005) statistical software was used to produce histograms and statistical summaries. The meteorological variables analyzed are not expected to conform to the normal distribution. Thus, results presented are limited to nonparametric measures such as the median and the inter-quartile range. The inter-quartile range is the difference between the third (75th percentile) and first quartile (25th percentile) of the data and its expectation is that 50% of the data is captured in that range. The inter-quartile range is unaffected by outlier values and gives a distribution free gauge of dispersion.

Results

Figures 5 through 7 show a comparison of frequency of wind direction between Bakersfield and Ventura. Frequency in these figures is number of hours. Both locations show bi-modal distributions with Ventura showing a very distinct and narrow peak of frequencies in each of the figures. The frequencies of Bakersfield directions are more scattered but still do exhibit the bi-modal distribution.

Figures 8 through 10 show box-plots of the wind speeds at Bakersfield and Ventura. The median wind speed is indicated by the line inside the box and is labeled. The median wind speed is similar between locations. Bakersfield shows higher maximum wind speed than Ventura for all three scenarios but tends to have a smaller inter-quartile range. This means that the mid-range (50%) of the wind speeds at Bakersfield fall within a narrower range than at Ventura. This feature will affect the stability class distributions at Bakersfield relative to Ventura.
Figures 11 through 13 show a comparison of frequency of stability classes between Bakersfield and Ventura. Figure 11 shows that for the standard sprinkler and shank scenario which has a buffer zone determined by night hours that Bakersfield has more hours of Stability classes 6 and 7 (highly stable). Ventura shows a more even distribution of frequency between Stability classes 4 through 6. Figure 12 shows Ventura with predominately Stability class 3, Bakersfield with Stability class 2. This scenario has a few early hours that may be night hours some times of the year but the period is predominately daytime. Figure 13 shows Ventura with Stability classes 3 and 4 as most common, Bakersfield with Stability Class 4 followed by Stability classes 5 and 6. This scenario has an averaging period that can be evenly split between night and day some times of the year but can also be mostly night hours during the winter months.

Discussion

The buffer zones developed using the Ventura meteorological data are longer than those developed using the Bakersfield meteorological data. These two data sets are from different sources, CIMIS (Ventura) versus ASOS (Bakersfield). In addition, the five year spans are different: 1999 through Ventura and 1995 through 1999 for Bakersfield. These two factors alone contribute an unknown but potentially substantial portion of the differences observed.

The wind direction histograms provide the most compelling evidence for the source of the differences. The Ventura wind direction histograms illustrate the well-known diurnal land/sea wind direction shift (Dorman and Winant, 2000; Ventura APCD, 2003). The wind directions at the Ventura CIMIS station exhibit narrow frequency peaks indicating persistent wind direction. The averaging time for MITC is 8 hours so effectively only half of the diurnal (24 hour) wind shift pattern is included in the averaging period. Thus, this wind direction pattern results in many hours of MITC mass distributed in the same direction. Conversely, the Bakersfield wind direction histograms exhibit a more spread out wind direction histogram where the direction tends to shift during the 8 hour averaging period. This Bakersfield wind direction pattern coupled with the lower wind speed and more frequent highly stable hours leads to a more narrow MITC plume that is less likely to have a downwind centerline concentration in one persistent direction over the threshold averaging period. Even a small shift in wind direction under the highly stable atmospheric conditions will spread the centerline contribution over a wider area and lead to a shorter maximum direction buffer zone. The land/sea diurnal wind direction pattern in Ventura that has the potential to generate smaller maximum direction buffer zones for fumigants with

threshold concentrations averaged over 24 hours leads to longer buffer zones when only half of that diurnal pattern is included a shorter averaging period.

In conclusion, the MITC 8-hour TWA buffer zones developed using the Ventura CIMIS meteorological data tend to be longer than those developed using the Bakersfield ASOS meteorological data because of the more persistent wind directions exhibited over the 8-hour averaging period at Ventura.

References

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Table 1. Application methods and averaging periods analyzed to characterize the source of buffer zone differences developed using the PERFUM model with Bakersfield versus Ventura meteorological data. The averaging period numbering is relative to the studies used to develop the flux profiles. Period 1 begins with the commencement of the application. Each averaging period is 8 hours. The periods are numbered 1 through 3 on each day of the 4-day flux profile. The Day/Night column indicates the predominant type of hours in the averaging period.

Application Method Flux Profile	Averaging Period	Hours	Day/Night
Standard Sprinkler	3	2400 – 0700 hrs	Night
Standard Shank	3	2400 - 0700 hrs	Night
Intermittent Sprinkler, Bakersfield	1	0600 – 1300 hrs	Day
Intermittent Shank, Lost Hills	2	1600 – 2300 hrs	Mix

Figure 1. Intermittent sprinkler, period 1 (0600 hrs–1300 hrs). Comparison of buffer zone length (m).

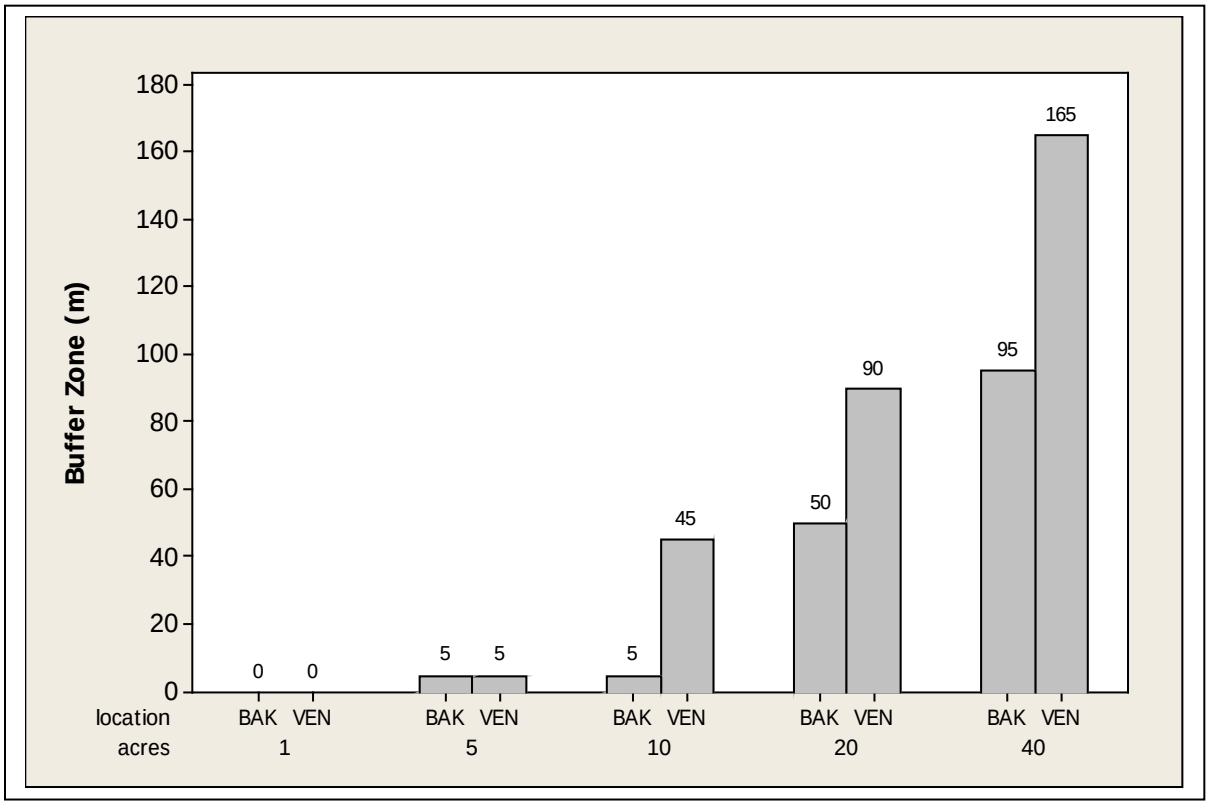

Figure 2. Intermittent shank, period 2 (1600 hrs–2300 hrs). Comparison of buffer zone length (m).

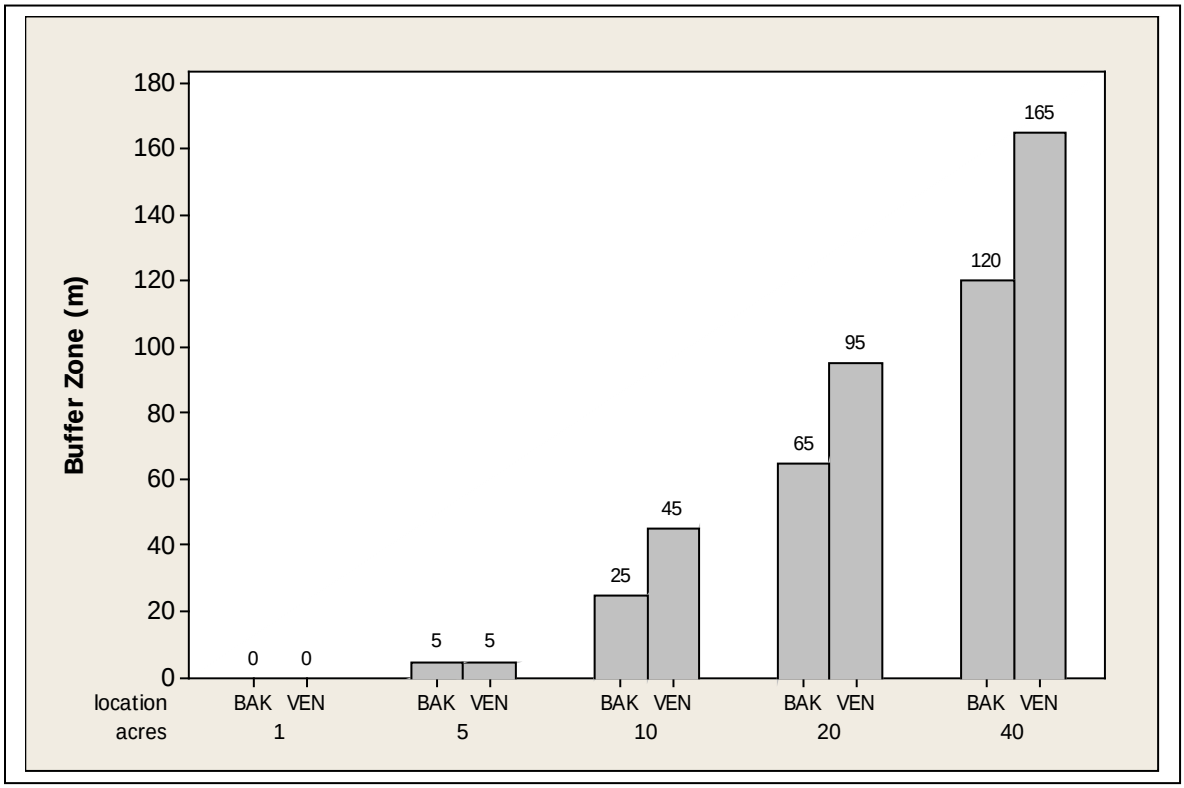

Figure 3. Standard sprinkler, period 3 (2400 hrs–0700hrs). Comparison of buffer zone length (m).

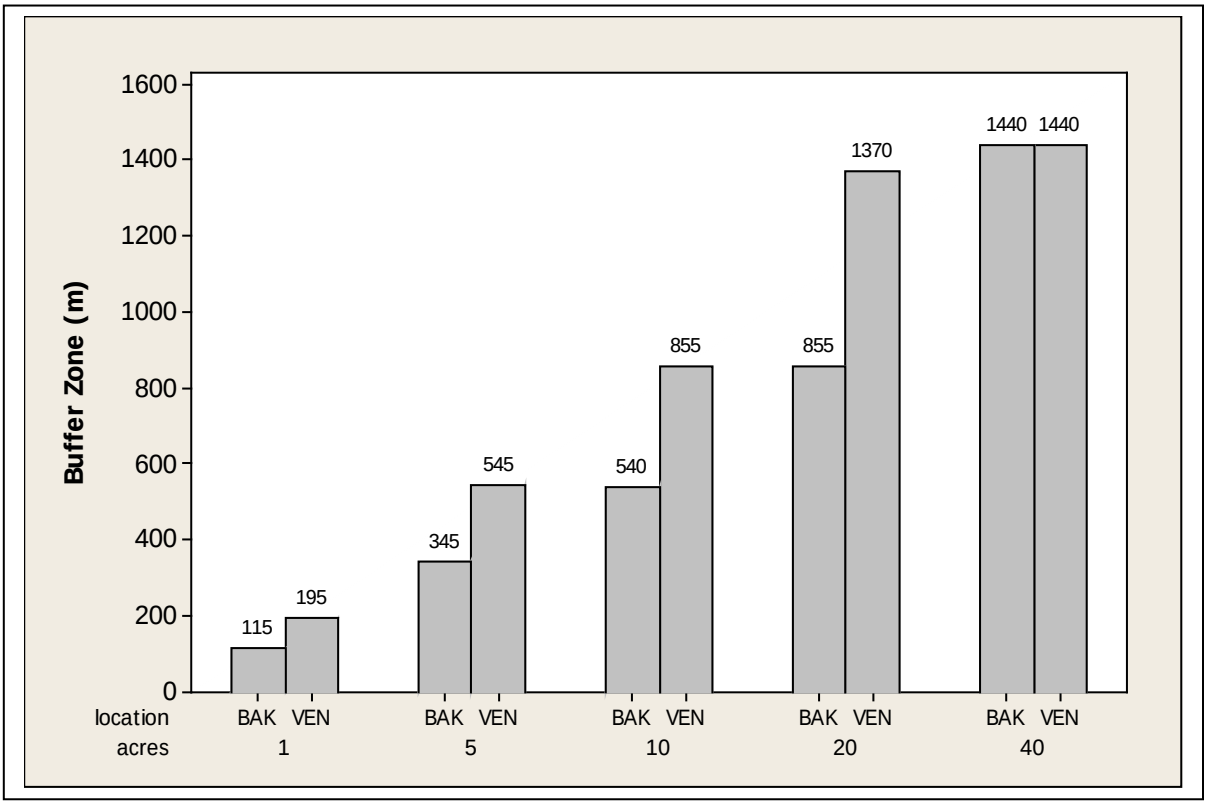

Figure 4. Standard shank, period 3 (2400 hrs–0700hrs). Comparison of buffer zone length (m).

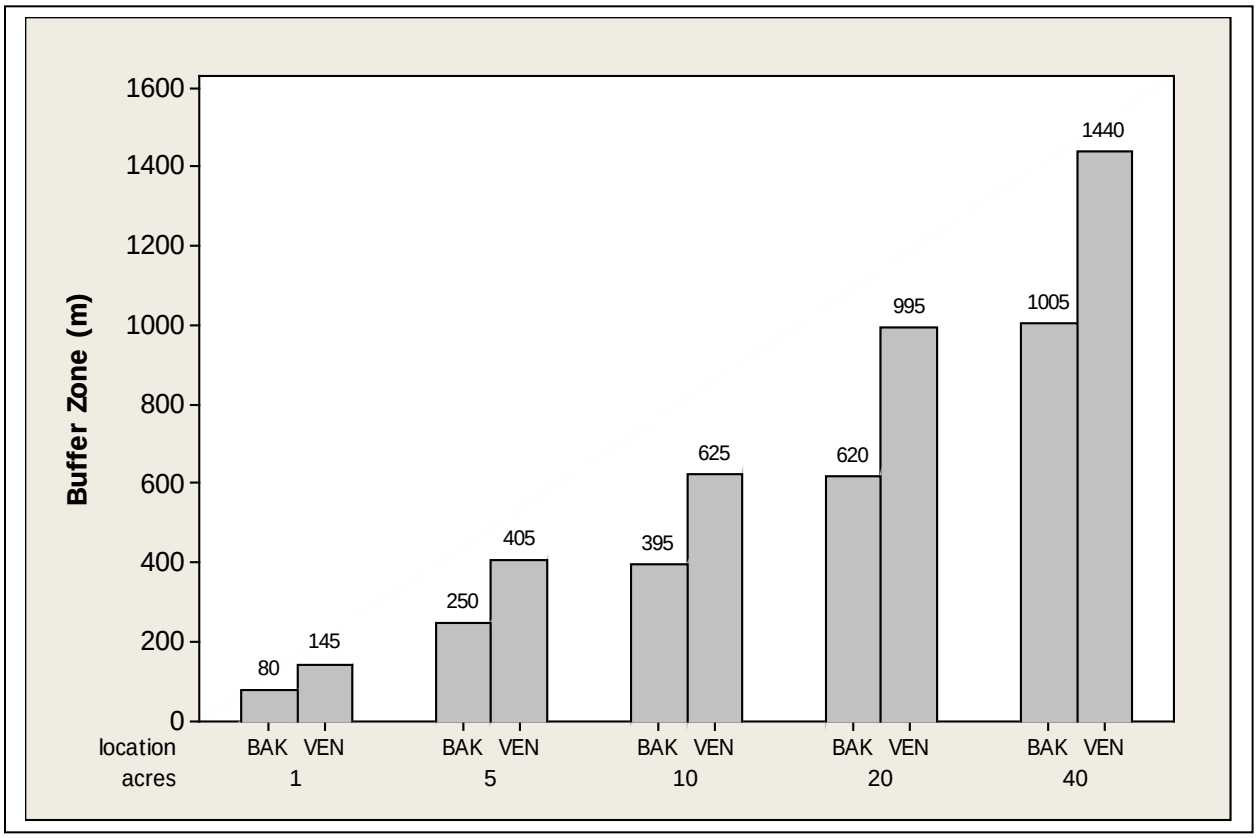

Figure 5. Standard sprinkler and standard shank, period 3 (2400 hrs–0700hrs) wind direction frequency distribution. Frequency is number of hours.

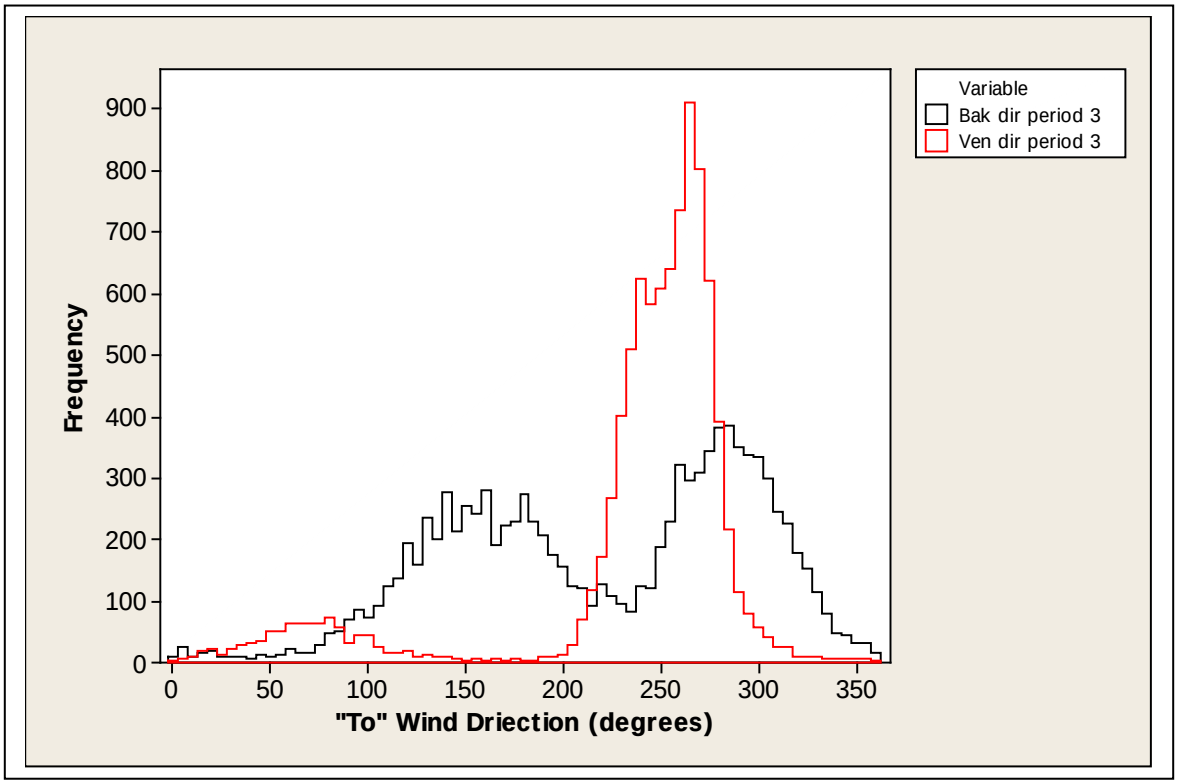

Figure 6. Intermittent sprinkler, period 1 (0600 hrs–1300 hrs) wind direction frequency distribution. Frequency is number of hours.

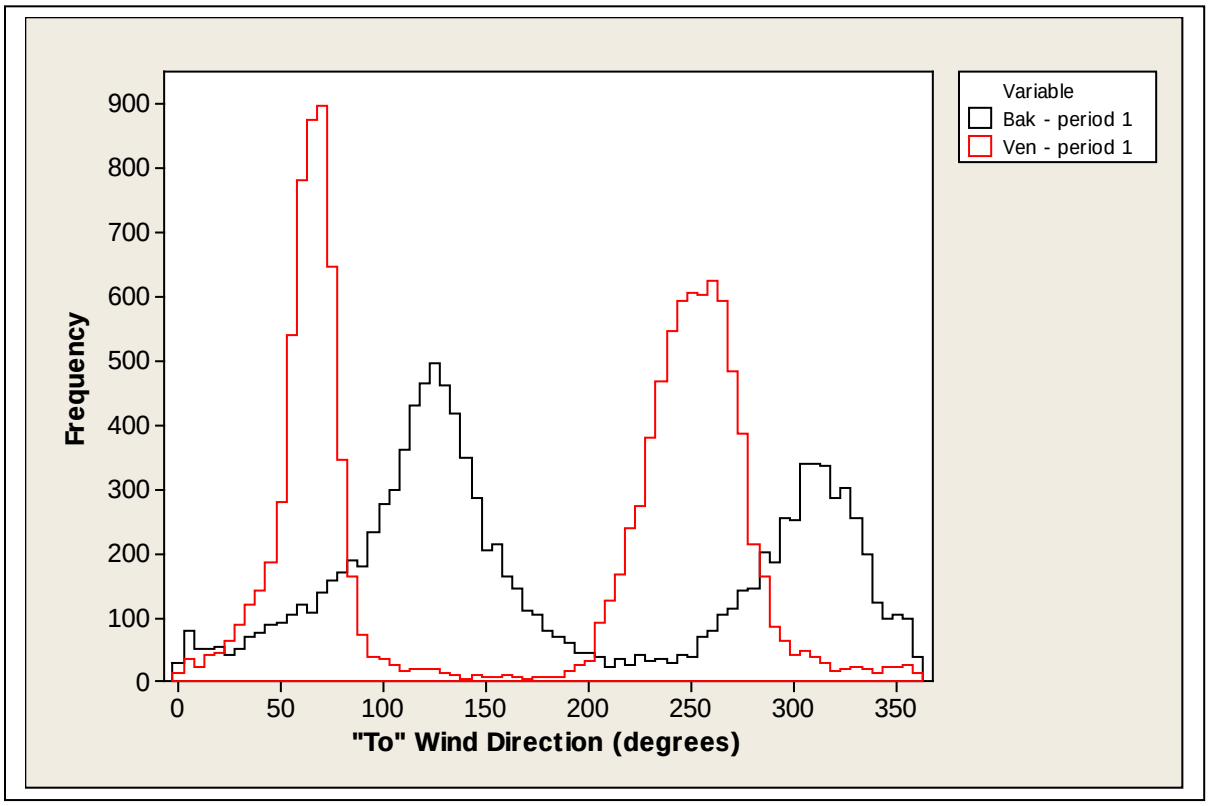

Figure 7. Intermittent shank, period 2 (1600 hrs–2300 hrs) wind direction frequency distribution. Frequency is number of hours.

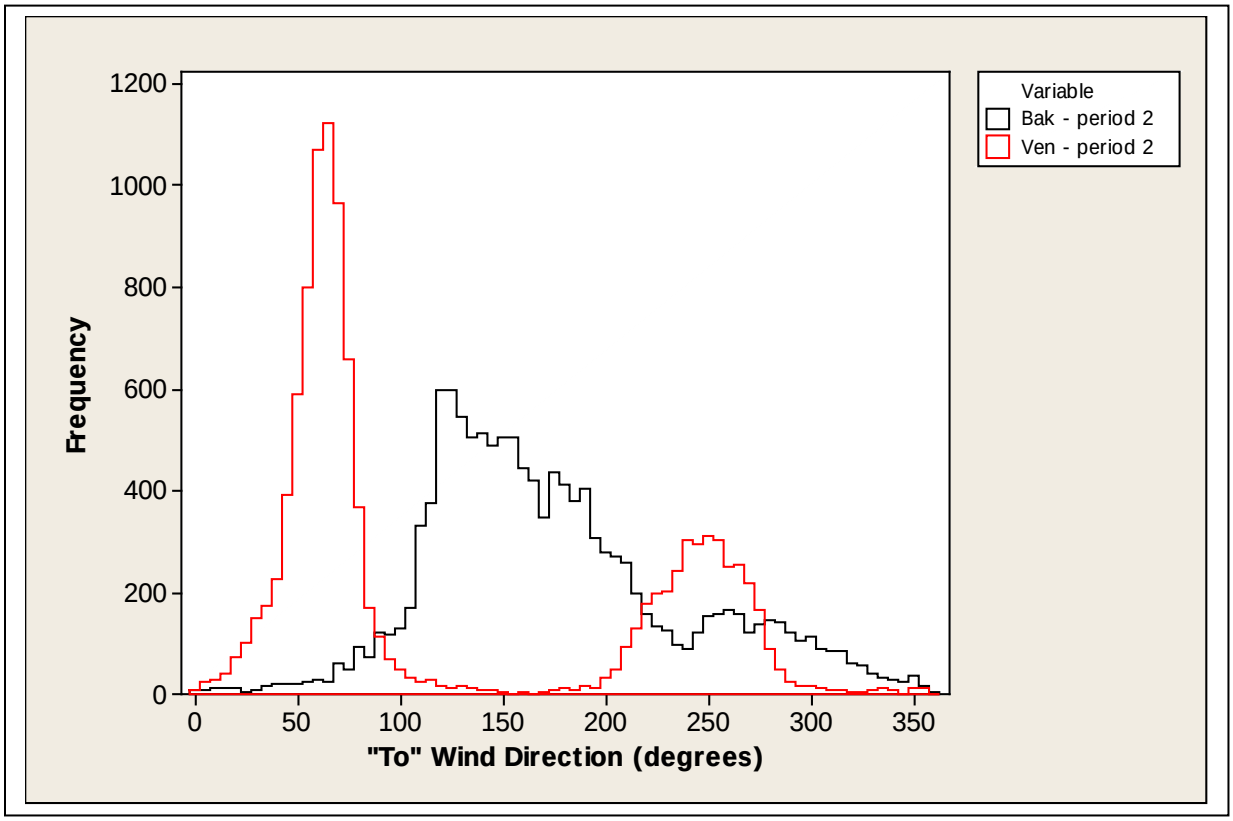

Figure 8. Standard sprinkler and standard shank, period 3 (2400 hrs–0700hrs) wind speed box plots.

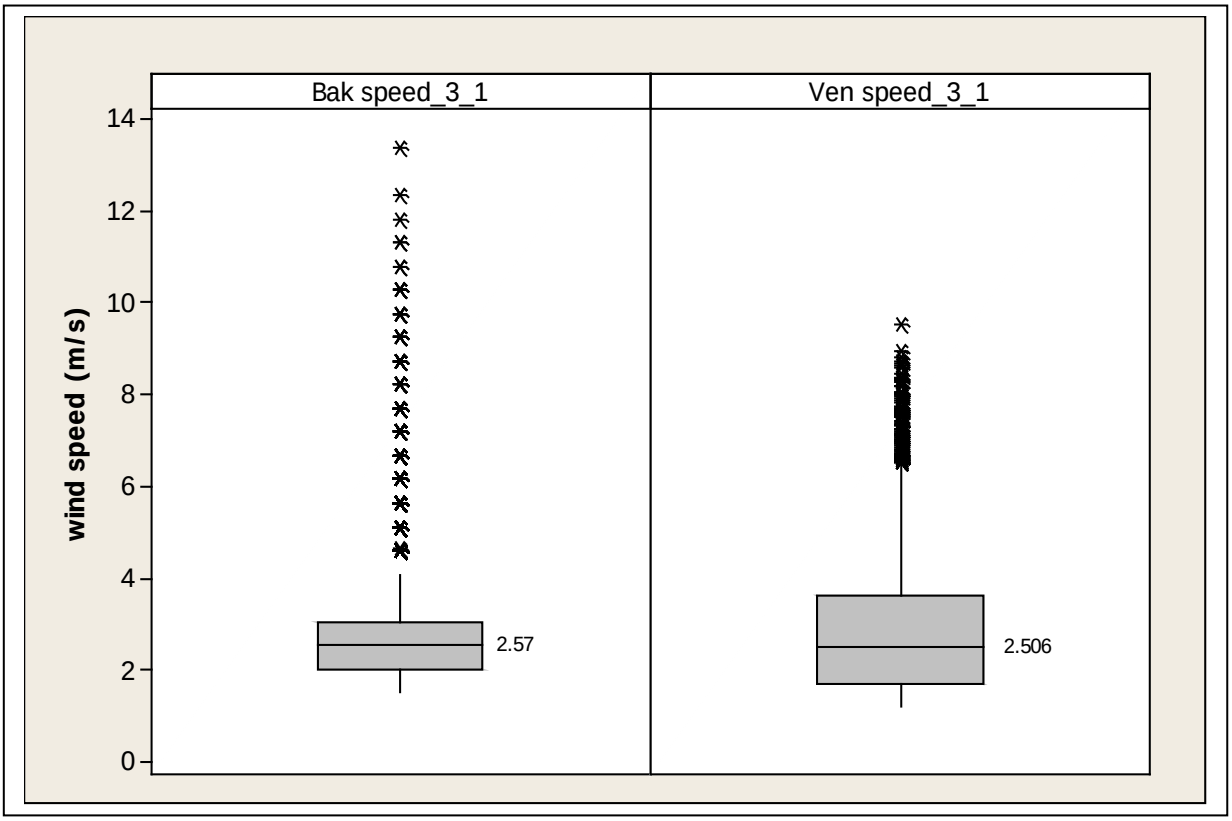

Figure 9. Intermittent sprinkler, period 1 (0600 hrs–1300hrs) wind speed box plots.

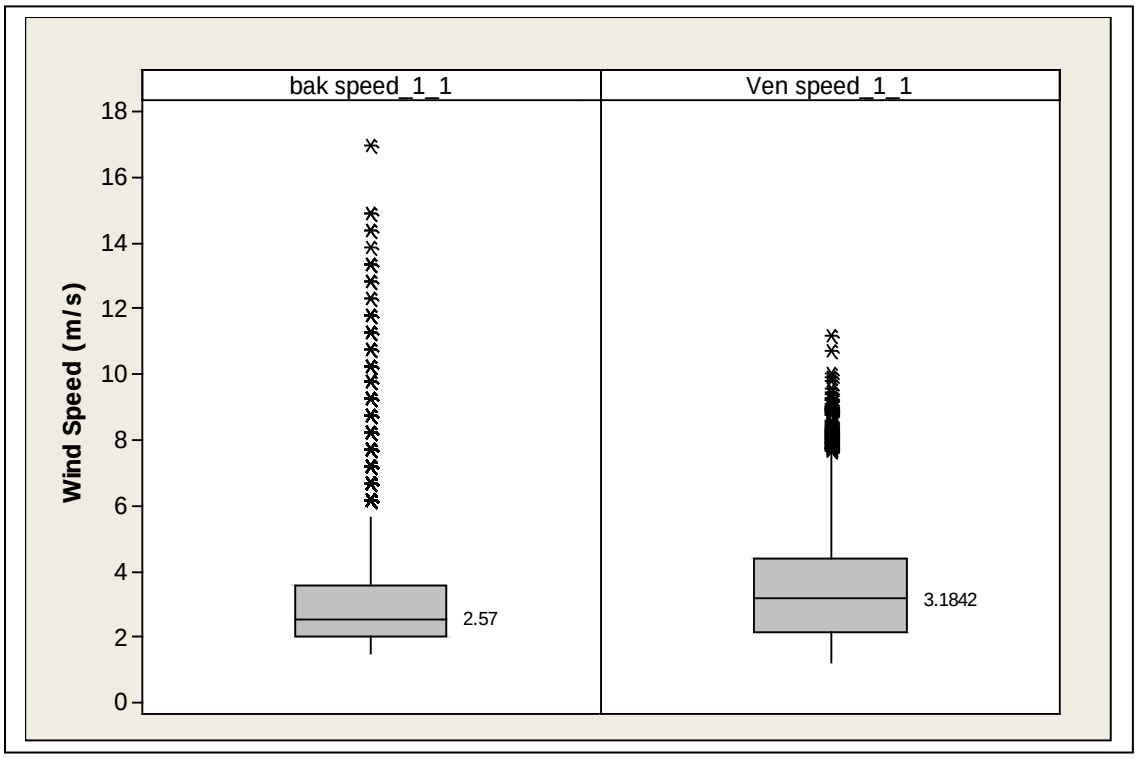

Figure 10. Intermittent Shank, period 2 (1600 hrs–2300 hrs) wind speed box plots.

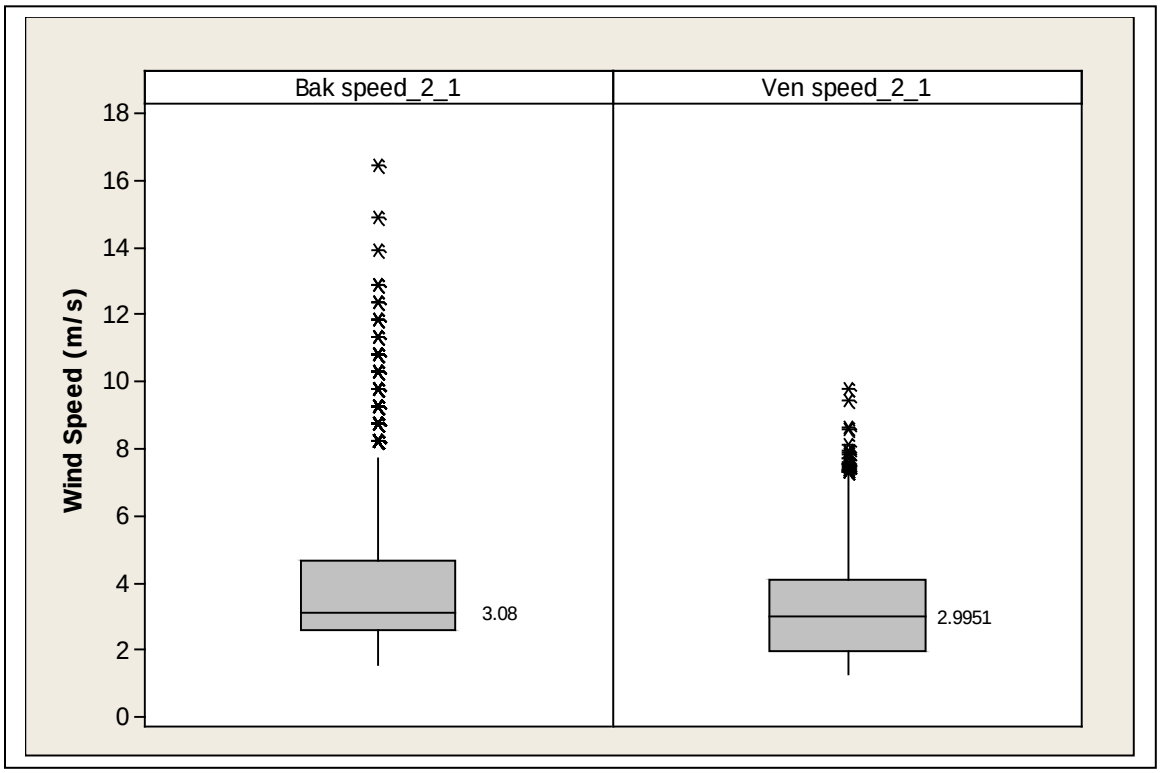

Figure 11. Standard sprinkler and standard shank, period 3 (2400 hrs–0700hrs) stability class frequency distribution. Frequency is number of hours.

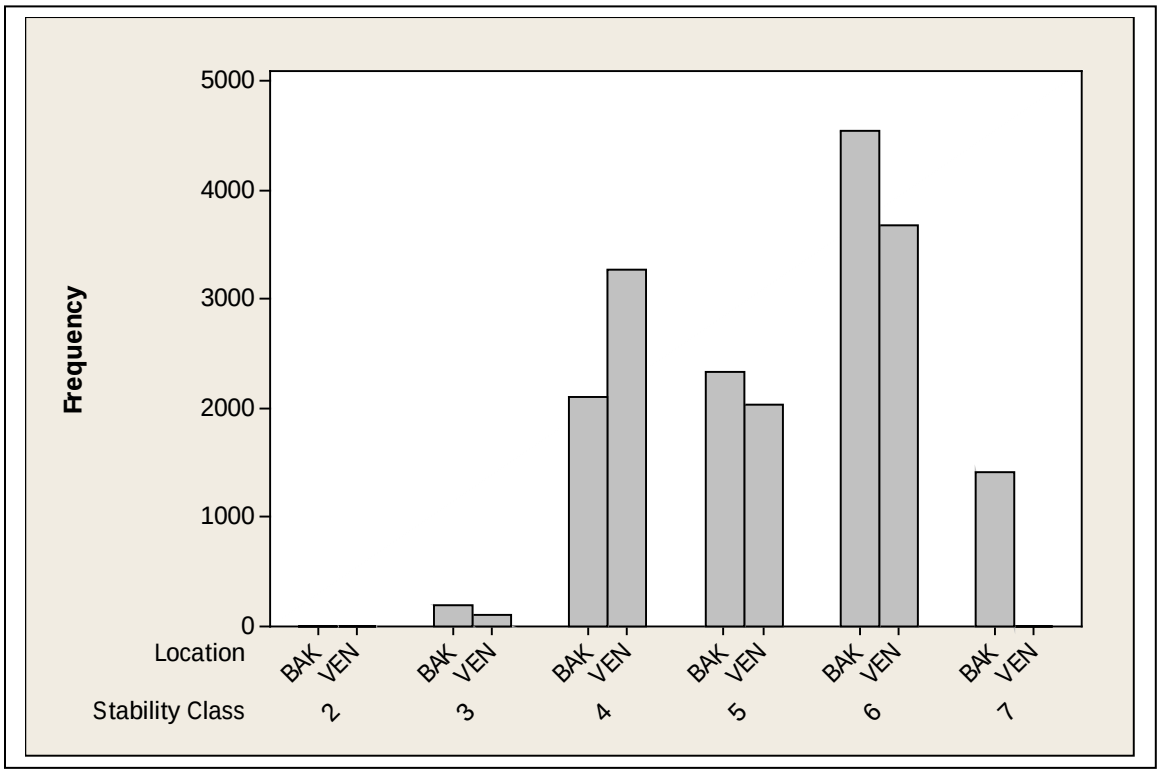

Figure 12. Intermittent sprinkler, period 1 (0600 hrs–1300 hrs) stability class frequency distribution. Frequency is number of hours.

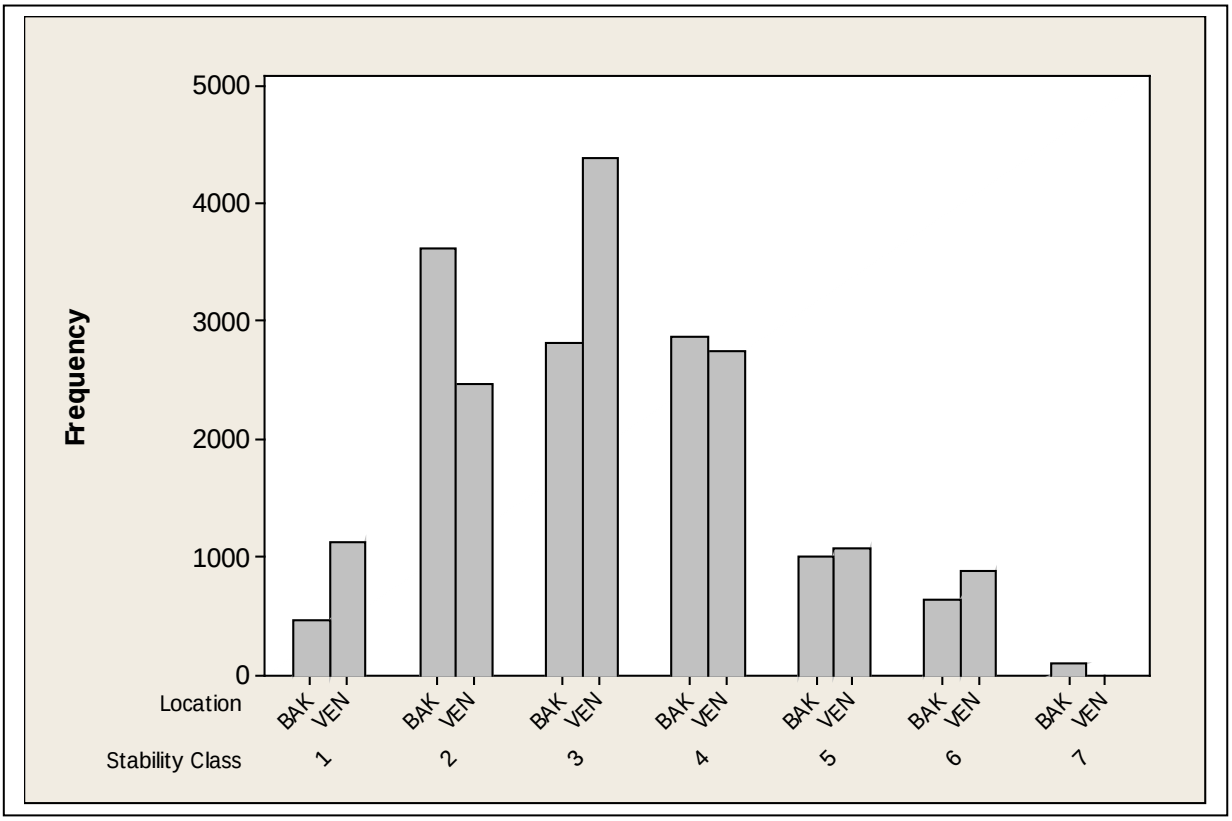
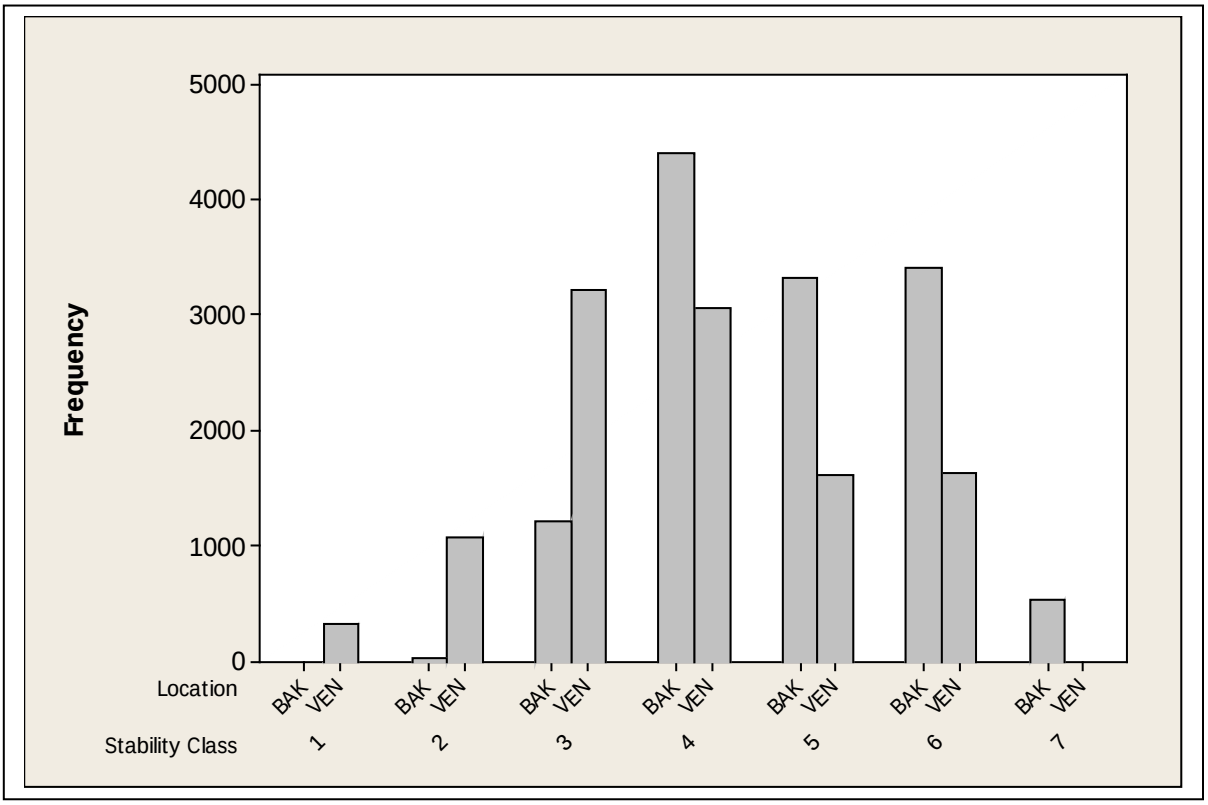
Figure 13. Intermittent shank, period 2 (1600 hrs–2300 hrs) stability class frequency distribution. Frequency is number of hours.