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National Agri-Environmental Standards Initiative (NAESI)

Report No. 2-44

Developing Risk-Based Rankings for Pesticides in Support of Standard Development at Environment Canada

Technical Series 2006

Photos:
Bottom Left- clockwise

Fraser Valley near Abbotsford, B.C.: Wayne Belzer, Pacific Yukon Region, Environment Canada
Crop spraying: Corel CD photo # 95C2840
Elk Creek, BC: Joseph Culp, National Water Research Institute, Environment Canada
Prairie smoke and bee: Emily Wallace, Prairie Northern Region, Environment Canada

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DEVELOPING RISK-BASED RANKINGS FOR PESTICIDES IN SUPPORT OF STANDARD DEVELOPMENT AT ENVIRONMENT CANADA

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NOTE TO READERS

The National Agri-Environmental Standards Initiative (NAESI) is a four-year (2004-2008) project between Environment Canada (EC) and Agriculture and Agri-Food Canada (AAFC) and is one of many initiatives under AAFC's Agriculture Policy Framework (APF). The goals of the National Agri-Environmental Standards Initiative include:

- Establishing non-regulatory national environmental performance standards (with regional application) that support common EC and AAFC goals for the environment
- Evaluating standards attainable by environmentally-beneficial agricultural production and management practices; and
- Increasing understanding of relationships between agriculture and the environment.

Under NAESI, agri-environmental performance standards (i.e., outcome-based standards) will be established that identify both desired levels of environmental condition and levels considered achievable based on available technology and practice. These standards will be integrated by AAFC into beneficial agricultural management systems and practices to help reduce environmental risks. Additionally, these will provide benefits to the health and supply of water, health of soils, health of air and the atmosphere; and ensure compatibility between biodiversity and agriculture. Standards are being developed in four thematic areas: Air, Biodiversity, Pesticides, and Water. Outcomes from NAESI will contribute to the APF goals of improved stewardship by agricultural producers of land, water, air and biodiversity and increased Canadian and international confidence that food from the Canadian agriculture and food sector is being produced in a safe and environmentally sound manner.

The development of agri-environmental performance standards involves science-based assessments of relative risk and the determination of desired environmental quality. As such, the National Agri-Environmental Standards Initiative (NAESI) Technical Series is dedicated to the consolidation and dissemination of the scientific knowledge, information, and tools produced through this program that will be used by Environment Canada as the scientific basis for the development and delivery of environmental performance standards. Reports in the Technical Series are available in the language (English or French) in which they were originally prepared and represent theme-specific deliverables. As the intention of this series is to provide an easily navigable and consolidated means of reporting on NAESI's yearly activities and progress, the detailed findings summarized in this series may, in fact, be published elsewhere, for example, as scientific papers in peer-reviewed journals.

This report provides scientific information to partially fulfill deliverables under the Pesticide Theme of NAESI. This report was written by K. Harding, P. Mineau, M. Whiteside, M.R. Fletcher, and D. Garthwaite of Environment Canada. The report was edited and formatted by Denise Davy to meet the criteria of the NAESI Technical Series. The information in this document is current as of when the document was originally prepared. For additional information regarding this publication, please contact:

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NOTE À L'INTENTION DES LECTEURS

L'Initiative nationale d'élaboration de normes agroenvironnementales (INENA) est un projet de quatre ans (2004-2008) mené conjointement par Environnement Canada (EC) et Agriculture et Agroalimentaire Canada (AAC) et l'une des nombreuses initiatives qui s'inscrit dans le Cadre stratégique pour l'agriculture (CSA) d'AAC. Elle a notamment comme objectifs :

- d'établir des normes nationales de rendement environnemental non réglementaires (applicables dans les régions) qui soutiennent les objectifs communs d'EC et d'AAC en ce qui concerne l'environnement;
- d'évaluer des normes qui sont réalisables par des pratiques de production et de gestion agricoles avantageuses pour l'environnement;
- de faire mieux comprendre les liens entre l'agriculture et l'environnement.

Dans le cadre de l'INENA, des normes de rendement agroenvironnementales (c.-à-d. des normes axées sur les résultats) seront établies pour déterminer les niveaux de qualité environnementale souhaités et les niveaux considérés comme réalisables au moyen des meilleures technologies et pratiques disponibles. AAC intégrera ces normes dans des systèmes et pratiques de gestion bénéfiques en agriculture afin d'aider à réduire les risques pour l'environnement. De plus, elles amélioreront l'approvisionnement en eau et la qualité de celle-ci, la qualité des sols et celle de l'air et de l'atmosphère, et assureront la compatibilité entre la biodiversité et l'agriculture. Des normes sont en voie d'être élaborées dans quatre domaines thématiques : l'air, la biodiversité, les pesticides et l'eau. Les résultats de l'INENA contribueront aux objectifs du CSA, soit d'améliorer la gérance des terres, de l'eau, de l'air et de la biodiversité par les producteurs agricoles et d'accroître la confiance du Canada et d'autres pays dans le fait que les aliments produits par les agriculteurs et le secteur de l'alimentation du Canada le sont d'une manière sécuritaire et soucieuse de l'environnement.

L'élaboration de normes de rendement agroenvironnementales comporte des évaluations scientifiques des risques relatifs et la détermination de la qualité environnementale souhaitée. Comme telle, la Série technique de l'INENA vise à regrouper et diffuser les connaissances, les informations et les outils scientifiques qui sont produits grâce à ce programme et dont Environnement Canada se servira comme fondement scientifique afin d'élaborer et de transmettre des normes de rendement environnemental. Les rapports compris dans la Série technique sont disponibles dans la langue (français ou anglais) dans laquelle ils ont été rédigés au départ et constituent des réalisations attendues propres à un thème en particulier. Comme cette série a pour objectif de fournir un moyen intégré et facile à consulter de faire rapport sur les activités et les progrès réalisés durant l'année dans le cadre de l'INENA, les conclusions détaillées qui sont résumées dans la série peuvent, en fait, être publiées ailleurs comme sous forme d'articles scientifiques de journaux soumis à l'évaluation par les pairs.

Le présent rapport fournit des données scientifiques afin de produire en partie les réalisations attendues pour le thème des pesticides dans le cadre de l'INENA. Ce rapport a été rédigé par K. Harding, P. Mineau, M. Whiteside, M.R. Fletcher et D. Garthwaite d'Environnement Canada. De plus, il a été révisé et formaté par Denise Davy selon les critères établis pour la Série technique de l'INENA. L'information contenue dans ce document était à jour au moment de sa rédaction. Pour plus de renseignements sur cette publication, veuillez communiquer avec l'organisme suivant :

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1 INTRODUCTION

Environment Canada has been tasked with developing environmental standards for implementation in Agriculture and Agri-Food Canada's Agricultural Policy Framework (AAFC; APF). The Wildlife Toxicology Division of the Wildlife and Landscape Science Directorate of EC's Science and Technology Branch was tasked specifically with developing comparative environmental risk assessment tools for pesticides in support of standard development. The development of standardised pesticide assessment tools will enable Environment Canada to prioritise in-use pesticides for the development of Ideal Performance Standards. It will also provide environmentally-oriented advice to AAFC under the APF, allowing for the promotion of reduced risk pest management strategies. Furthermore, standardised pesticide assessment tools will capacitate EC to objectively assess the environmental impact of alternative pesticide products and prioritize them for research and monitoring.

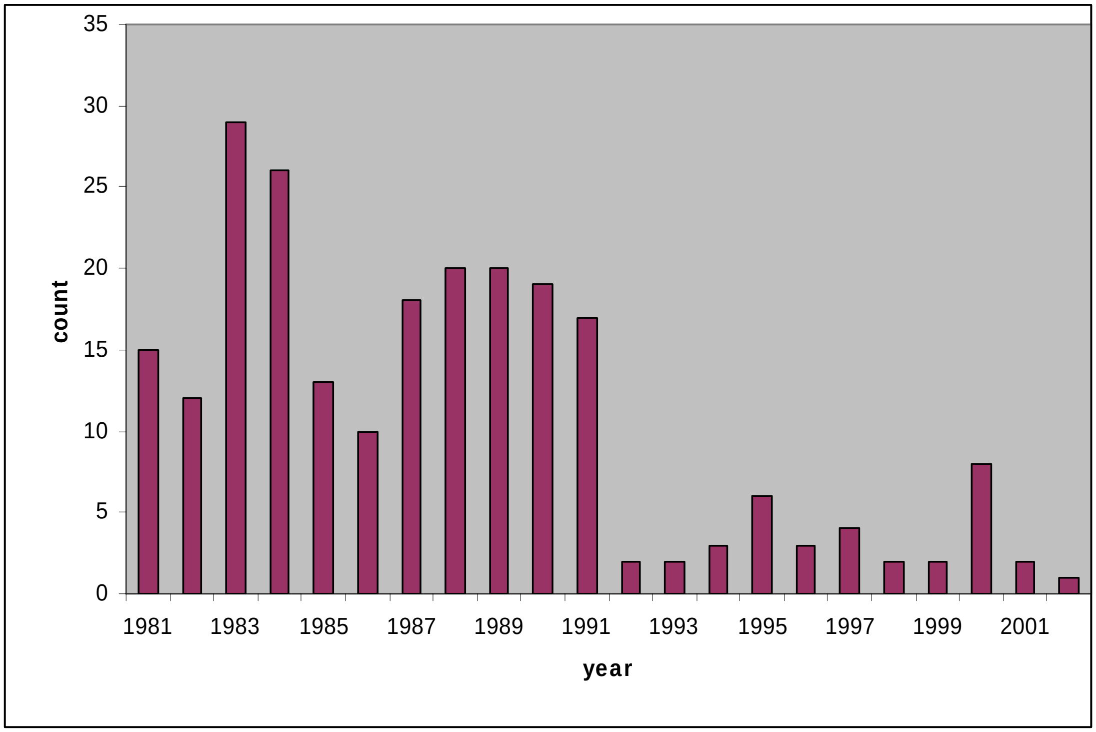
Non target invertebrates and pollinators in particular are valued components of agro-ecosystems and render well defined ecological services. The Ecological Society of America, on the basis of current models, estimates the value of wild pollinators to U.S. agriculture alone to be between 4.1 and 6.6 billion U.S. dollars (http://www.esa.org/ecoservices/poll/body.poll.scie.valu.html). The same organisation identifies agricultural pesticide use as a major threat to pollinators. Given the similarity in our agricultural practices, the situation is likely similar in Canada. Yet, field tests that consider the impact of pesticides on bees or wild pollinators are seldom, if ever, carried out as a condition of pesticide registration in Canada. Instead, laboratory tests are performed and the results of these may trigger a label warning. These label recommendations may help in reducing the impact of spraying on the main crop pollinator (often imported bees) but are likely not adequate to protect native pollinators in the surrounding habitat. To develop an understanding of a chemical or compound's environmental impact, it is possible to rank products on the basis of their relative acute toxicity based on laboratory results. Because toxicity is not necessarily correlated with risk in a linear fashion, the aim of this undertaking was to investigate whether reported bee incidents from the field could be used to 'calibrate' risk scores obtained from the laboratory. Unfortunately, Canada has no centralised registry of bee mortality incidents nor does it collect comprehensive pesticide use or sales data. The U.K. however does both of these things. We therefore obtained a database containing honeybee (*Apis mellifera*) poisoning incidents from the United Kingdom Wildlife Incident Investigation Scheme (WIIS), as well as pesticide use surveys for the corresponding period. The objective was to explain honeybee poisoning incidents in the field based on pesticide use information, laboratory-generated bee toxicity data, and physico-chemical properties of the pesticides.

1.1 Data included in analysis:

1.1.1 Bee incident data

Bee incidents in England and Wales from the period 1981-2002 were obtained from the UK Wildlife Incident Investigation Scheme (WIIS -- Mark Fletcher, DEFRA's Central Science Laboratory, York). The WIIS relies on beekeepers and other interested organizations or individuals to report suspected poisoning incidents, and submit dead bee samples for analysis. The bee samples are analyzed to rule out non-poisoning incidents (for example disease due to mite infestations), and to determine any pesticide residues that may have caused bee mortality. Pollen is also analyzed to determine the crops on which the bees have been foraging. For more information see Fletcher and Barnett (2003). Bee mortality incidents resulting from improper use were excluded from the analysis, for example situations when pesticides were applied to the hive directly either to kill the bees or to kill bee pests such as the varroa mite (*Varroa jacobsoni)*. The database however still contains mortality incidents resulting from pesticides used in the wrong season, on the wrong crop, or in ways otherwise inconsistent with the label. There were 234 total poisoning incidents in the data set spanning the years 1981 to 2002, several of which resulted from improper timing of pesticide applications to a crop in flower or to a crop with weeds in flower. The number of reported bee poisoning occurrences peaked in 1983 with 29 incidents. From 1992-2002 there were fewer than 10 reported poisoning incidents per year (figure 1).

Figure 1: Number of honeybee mortality incidents per year from 1981-2002.



Overall, the mortality incidents reported showed residues of 15 pesticides on 10 crops. Many factors influence differences in the likelihood of bee mortality for different crops. For example, differences in pesticide uptake and wash off are dependant on leaf cuticle properties of the plant, and also bee foraging behaviour will vary from crop to crop as well. In order to help isolate pesticide properties responsible for kills, the analysis was restricted to the two crops with the most mortality incidents: oilseed rape and pulses. Oilseeds (primarily 000 varieties equivalent to our canola, but also including flax, sunflower and safflower) had 145 mortality incidents over the 21 year period, while pulses (dried beans and lentils) had 36 mortality incidents for the same time period. In order to match incidents to agricultural statistics, some assumptions were made. Mortality incidents in 'peas and beans' could mean either field crops of dry pulses or of vegetables (which includes fresh peas or beans for immediate human consumption). In practice, when determining the crop source of the bee mortality, it is difficult to determine if a crop is destined for fresh or dried consumption. However, the dried vs. fresh determination is important when choosing crop information from the UK pesticide survey database. The mortality incidents from bean crops listed as 'broad beans' and 'vining peas' were therefore assumed to be fresh crops (2 incidents), while 'field beans' were assumed to be field pulse crops (36 incidents).

1.1.2 Pesticide use data

Information on the total area treated and weight of all active ingredient for all insecticides applied to pulses and oilseeds was taken from the UK Pesticide Usage Survey. The chemical DDT was excluded because it is highly persistent and therefore behaves differently than other insecticides used today. Two herbicides, paraquat and diquat were added to the insecticide database because they have been implicated in bee mortality events. We did not include chemicals that were only used as soil treatments (i.e., aldicarb and phorate), and chemicals were also not included if only applied in one or two years to a small area (less than 1000 ha; see Appendix A). Exceptions to this rule include the application of permethrin and azinphos-methyl mixed with demeton-S-methyl sulphone to oilseeds, both of which caused bee mortality Information was obtained, for pesticides that were applied as multiple active ingredients, on the formulation and the total weight of formulation that was applied throughout the UK. Except for azinphos-methyl mixed with demeton-S-methyl sulphone, no other pesticides that were applied as mixtures of multiple insecticides were included because the area treated, weight applied and/or application rate were negligible compared to treatments with single active ingredients.

Pesticide usage data were obtained from crop surveys that were conducted every 2-6 years. Both pulses and oilseeds were surveyed in 1977, 82, 88, 90, 92, 94, 96, 98, 2000, and 2002. The area treated with any one insecticide ranged from 42 - 390,118 ha (see Appendix A). In some cases, the area treated changed greatly from one survey to the next (i.e., dimethoate applied to pulses went from 33,122 ha in 1998, to 9,883 ha by 2000). Because of this variance, two separate analyses were carried out. The most rigorous analysis included focusing on the individual years that were surveyed, while excluding bee mortality from years that were not surveyed. A more 'liberal' analysis, that encompassed all the bee mortality data available, used linear interpolation techniques to derive areas treated for the unsurveyed years. The methods used in calculating areas treated are explained in detail later.

The application rate, which is calculated from the total weight of active ingredient applied and the total area treated (g ai/ha), is essentially an average application rate for the UK. For most pesticides, the application rate did not change appreciably over the 22 years included in the survey (e.g., cypermethrin, see Appendix A); however for others the application rate varied greatly (e.g., lindane, see Appendix A). The most dramatic changes in application rate occurred when the area treated was very low (less than 1000 ha), suggesting that the calculation of an average application rate is less reliable when based on limited sampling. Therefore, a weighted mean of the application rate was calculated, using the area treated as the weighting factor. This was done using only the data from survey years, and did not change in other analyses.

In order to check the validity of calculated average application rates, we compared them to published sources. These include on-line pesticide labels from the Canadian PMRA (Pest Management Regulatory Agency), California's Pesticide Action Network, the USDA (US Department of Agriculture), and individual pesticide company websites. All application rates were converted to g ai/ha (see Appendix B) In all cases, the weighted mean fell either within or below the range suggested. This comparison suggests that reported rates of insecticide application in the UK are typically lower than North American labelled rates for the same active ingredients.

1.1.3 Bee toxicity data

The honeybee oral (through the mouth) and contact (through the skin) LD50s (given in Appendix C) were obtained from the BCPC (British Crop Protection Council) Pesticide Manual, the USEPA one-liner database, INRA's (Institut National de la Recherche Agronomique) AGRITOX, publications from the University of California, and other published sources. Where there was more than one LD50 record available, a geometric mean was calculated and used in the analysis. This information combined with the application rate was used to construct a hazard ratio (HR) defined as follows:

$$\text{HR (million LD50's/ha)} = \text{application rate (g/ha)}/ \text{LD50 } (\mu\text{g/bee})$$

For honeybees, both contact and oral LD50's are typically measured in laboratory analyses. Both were included in our analysis, and the two are clearly correlated. Since our calculation of the area-weighted mean application rate often gave a lower value than suggested application rates, our calculations of HR tended to be lower than they would be for equivalent applications elsewhere.

1.1.4 *Physicochemical data*

Several databases of physicochemical properties were obtained and used including: the USEPA's GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) database, the USDA toxicology database, and the Oregon State University pesticide database. In cases where one source differed from another, information was taken from the databases in the order listed above. If there were missing data we then consulted the pesticide manual, followed by other published sources. The properties taken from these databases included: K_{oc}, soil DT50 and foliar DT_{50}. The vapour pressure, log P (log K_{ow}), molecular weight and water solubility were taken from the Pesticide Manual (Tomlin 2003).

The factors log P and molecular weight (mw) were normally distributed. The other factors including K_{oc}, vapour pressure, soil DT_{50}, foliar DT_{50} and water solubility were all log transformed to achieve normal distributions. The factors molecular weight (mw), log K_{oc}, log vapour pressure (vp), log soil DT_{50}, log water solubility and log K_{ow} are inter-correlated (table 1). Additionally, the $HR_{contact}$ is correlated with water solubility, and log K_{ow}, while the HR_{oral} is correlated with vapour pressure. We therefore subjected several of the main physicochemical variables to Principle Component Analysis (PCA) which is a method of identifying patterns in data and highlighting their similarities and differences. The first factor was used as the only variable, which explained over 79% of the total variance (see below).

1.1.5 *Principal Components Analysis (PCA) of physicochemical properties*

The factors log K_{ow}, molecular weight, vapour pressure, and water solubility are inter-correlated (table 1). In order to include all of these variables in one analysis, the factors were analyzed with PCA to create an eigenvector that combines all 4 factors. For insecticides used on oilseeds, the first eigenvector explained 79.5% of total variance (table 2-3). Results were similar for insecticides used on pulses. Weightings of the four properties to the first eigenvector (called PCA 1 in subsequent analyses) are shown in table 4.

Table 1: Correlations between factors in this analysis. Red Highlight = significant correlations between variables. mw= molecular weight, vp= vapour pressure, PCA 1= Principal Components Analysis factor 1 calculated with log P (log K_{ow}), mw, log vp, and log water solubility.

	log HR contact	log HR oral	**log K_{ow}**	mw	**log Koc**	log vp	log soil DT50	log foliar DT50	log water solubility	PCA 1
log area	-.2263	-.2023	-.0888	.1317	.2426	-.2143	.0312	.2885	.0378	.1219
	p=.150	p=.199	p=.576	p=.406	p=.122	p=.173	p=.845	p=.064	p=.812	p=.442
log HR contact		.7997	.3941	.1811	.1894	.0849	.1498	-.2856	-.3216	.1923
		p=.000	p=.010	p=.251	p=.230	p=.593	p=.344	p=.067	p=.038	p=.222
log HR oral			.0289	-.3008	-.1731	.5101	.1329	-.2570	.1217	-.2916
			p=.856	p=.053	p=.273	p=.001	p=.402	p=.100	p=.443	p=.061
log Kow				.6934	.1791	-.4010	.0272	-.4503	-.9127	.7190
				p=.000	p=.256	p=.008	p=.864	p=.003	p=.000	p=.000
mw					.6784	-.7949	.1648	-.0835	-.8872	.9993
					p=.000	p=.000	p=.297	p=.599	p=.000	p=0.00
log K_{oc}						-.6263	.3509	.4704	-.4687	.6645
						p=.000	p=.023	p=.002	p=.002	p=.000
log vp							-.1567	-.0500	.6117	-.7919
							p=.322	p=.753	p=.000	p=.000
log soil DT_{50}								.0357	-.1739	.1632

Table 1: Correlations between factors in this analysis. Red Highlight = significant correlations between variables. mw= molecular weight, vp= vapour pressure, PCA 1= Principal Components Analysis factor 1 calculated with log P (log K_{ow}), mw, log vp, and log water solubility.

	log HR contact	log HR oral	**log K_{ow}**	mw	**log Koc**	log vp	log soil DT50	log foliar DT50	log water solubility	PCA 1
								p=.822	p=.271	p=.302
log foliar DT_{50}									.2481	-.1012
									p=.113	p=.523
log water solubility										-.9030
										p=.000

Table 2: Results from PCA analysis, eigenvalues for 4 eigenvectors (oilseed insecticides).

value number	**Eigenvalue**	**% Total variance**	**Cumulative Eigenvalue**	**Cumulative %**
1	3.18	79.49	3.18	79.49
2	0.68	17.00	3.86	96.49
3	0.11	2.86	3.97	99.35
4	0.03	0.65	4.00	100.00

Table 3: Contributions of each variable (log K_{ow}, molecular weight, vapour pressure, and water solubility) to the eigenvector (oilseed insecticides).

	factor 1	**factor 2**	**factor 3**	**factor 4**
log K_{ow}	0.23	0.37	0.22	0.19
MW	0.29	0.05	0.46	0.21
log vp	0.19	0.51	0.29	0.00
log solubility	0.29	0.07	0.03	0.60

Table 4: Eigenvectors for Factor 1 only.

	Oilseeds	**Pulses**
log K_{ow}	0.48	0.48
MW	0.53	0.53
log vp	-0.44	-0.43
log solubility	-0.54	-0.54

2 ANALYSIS FOR SURVEY YEARS ONLY

In the analysis of only the survey years, 8 pesticides were implicated in mortality events in oilseeds and 4 pesticides in pulses. Two pesticides with recorded mortality incidents in oilseeds (deltamethrin and permethrin) dropped out of this analysis (Appendix D). In analyzing models with multiple dimensions, whether logistic or linear, we selected the best model by the best subset method, an iterative method based on maximum likelihood estimation, and Akaike's Information Criterion (AIC). The AIC penalizes for the number of independent variables in the model. Since our sample size was small, (at best, 21 pesticides in two crops n= 42) we used the correction for small sample size (AICc). Burham and Anderson (2002) suggest that models with a delta AICc of 2 or less show a substantial level of empirical support. Values over 10 show no or almost no empirical support. The relative difference between models was assessed using a ratio of the Akaike weights of each model with the best (smallest) AICc. In order to reduce several potential models to a few likely models, we only show those models with a weight ratio of <10. The significance of these models was found using the R^2 or Chi^2 and p value for each of the model types.

2.1 Linear regression analyses

The Hazard Ratio (HR) has been used in the past, in an older database of UK bee incidents, to group pesticides into high, medium, and low risk groups (Aldridge and Hart 1993). The authors attempted a simple correlation of HR with the number of mortality incidents (pre-1991) but this was not successful. We repeated the same analysis here with the updated dataset. The log normalized number of mortality events per area treated for each pesticide that caused mortality incidents was used as the dependent variable, and the crop (either oilseed or pulses) was used as a categorical variable. Because we considered it likely that the mortality events were linked to the LD_{50} and the application rate, we *a priori* excluded any models that did not include hazard ratio (either $HR_{contact}$ or HR_{oral}). Also, due to the small sample size we excluded models with more than two variables (the exception being when the model included crop). We found the best predictor models included HR and either molecular weight (mw), solubility, log K_{ow} or log K_{oc}; however none of these models had an acceptable degree of prediction ($R^2<0.37$ $p>0.12$; table 5).

Table 5: Multiple regression results using bee mortality per area treated in both oilseed and pulse crops. Data includes only survey years, and only pesticides that caused bee mortality.

K	**variable 1**	**variable 2**	**variable 3**	**df**	**AIC_c**	**Δ AIC_c**	**Akaike weight**	**weight ratio**	**R^2**	**p**
4	log HR con	mw		2	35.448	0.000	0.117		0.37	0.12
4	log HR oral	mw		2	35.475	0.027	0.115	1.01	0.37	0.12
4	log HR oral	log solubility		2	35.791	0.343	0.098	1.19	0.35	0.14
4	log HR con	log solubility		2	35.854	0.406	0.095	1.23	0.35	0.14
4	log HR oral	log K_{ow}		2	36.906	1.458	0.056	2.07	0.29	0.21
4	log HR con	log K_{oc}		2	37.036	1.588	0.053	2.21	0.28	0.22
4	log HR oral	log K_{oc}		2	37.170	1.722	0.049	2.37	0.27	0.24
4	log HR con	log K_{ow}		2	37.495	2.047	0.042	2.78	0.25	0.27

Table 5: Multiple regression results using bee mortality per area treated in both oilseed and pulse crops. Data includes only survey years, and only pesticides that caused bee mortality.

K	variable 1	variable 2	variable 3	df	AIC_c	ΔAIC_c	Akaike weight	weight ratio	R^2	p
3	log HR oral			1	37.501	2.053	0.042	2.79	0.09	0.36
5	log HR con	mw	crop	3	37.994	2.546	0.033	3.57	0.37	0.27
5	log HR oral	mw	crop	3	38.048	2.600	0.032	3.67	0.37	0.27
5	log HR oral	log solubility	crop	3	38.370	2.922	0.027	4.31	0.35	0.30
5	log HR con	log solubility	crop	3	38.436	2.988	0.026	4.46	0.35	0.30
3	log HR con			1	38.512	3.064	0.025	4.63	0.01	0.82
4	log HR oral	log soil DT50		2	38.715	3.267	0.023	5.12	0.17	0.42
4	log HR con	log soil DT50		2	39.332	3.884	0.017	6.97	0.13	0.53
5	log HR oral	log K_{ow}	crop	3	39.491	4.043	0.015	7.55	0.29	0.41
4	log HR con	log vp		2	39.537	4.089	0.015	7.73	0.12	0.57
5	log HR con	log K_{oc}	crop	3	39.585	4.137	0.015	7.91	0.28	0.42
4	log HR oral	log vp		2	39.647	4.199	0.014	8.16	0.11	0.62
5	log HR oral	log K_{oc}	crop	3	39.689	4.241	0.014	8.33	0.28	0.43
4	log HR oral	log foliar DT50		2	39.911	4.463	0.013	9.32	0.09	0.67
4	log HR oral	crop		2	39.923	4.475	0.012	9.37	0.09	0.66

Factors included are log vapor pressure (vp), log K_{ow}, log K_{oc}, molecular weight (mw), log foliar DT_{50}, log soil DT_{50}, and log water solubility as continuous variables and crop type as categorical variable. Only models with weight ratio less than 10 are included. Pesticides included= 12

2.2 Logistic regression analyses

One obvious drawback of this analysis is that it ignores pesticides which were not responsible for any mortality events (12 to 17 for pulses and oilseeds respectively). The severe lack of normality in the full dataset prevents us from using a multiple linear regression approach. Also, there is a high probability that many mortality events are not reported by the monitoring scheme, making the number of poisoning incidents inaccurate. For both of these reasons, running logistic regressions was the best option for the data analysis. All active ingredients were therefore classed as either 'causing' or 'not causing' bee mortality. This also removed the asymmetric effect of triazophos and dimethoate which caused 115 mortality events in oilseeds, and 26 mortality events in pulses respectively. These numbers are high compared with all other pesticides which had fewer than 7 mortality events. The same *a priori* conditions described above were applied to the logistic analyses. Data for oilseed crops and for pulses were run separately.

The logistic models that best predict mortality in oilseed crops, and have a weight ratio less than 4 include area treated, HR_{oral}, $HR_{contact}$ and vapour pressure (table 6). The best models in pulses only include HR_{oral}, and area treated (table 7). Because there are only 4 pesticides causing mortality (and 17 that do not), the logistic regression in pulses should be viewed with caution. The similarity between the best variables and their coefficients in the best pulse and oilseed models (table 8), as well as inspection of the resulting plots (not shown), suggests that the two crops could be combined in the same model, keeping crop type as a categorical variable (table 9).

Table 6: Logistic regression results for bee mortality in oilseed crops on survey years only.

K	**variable 1**	**variable 2**	**df**	**AIC_c**	**ΔAIC_c**	**Akaike weight**	**weight ratio**	**Chi^2**	**p**
4	log area	log HR oral	2	29.52	0.00	0.26		6.89	0.031
3	log HR oral		1	30.62	1.10	0.15	1.73	2.70	0.100
4	log area	log HR con	2	31.65	2.13	0.09	2.90	4.76	0.092
4	log HR oral	log vp	2	31.98	2.46	0.08	3.42	4.43	0.11
3	log HR con		1	32.16	2.64	0.07	3.74	1.16	0.28
4	log HR oral	log K_{oc}	2	32.66	3.14	0.05	4.81	3.75	0.15

Table 6: Logistic regression results for bee mortality in oilseed crops on survey years only.

K	variable 1	variable 2	df	AIC$_c$	Δ AIC$_c$	Akaike weight	weight ratio	Chi^2	p
4	log HR oral	log soil DT50	2	33.09	3.56	0.04	5.94	3.32	0.19
4	log HR oral	log solubility	2	33.65	4.13	0.03	7.87	2.76	0.25
4	log HR oral	Mw	2	33.66	4.14	0.03	7.92	2.75	0.25
4	log HR oral	log K$_{ow}$	2	33.68	4.16	0.03	8.01	2.73	0.26
4	log HR oral	log foliar DT50	2	33.70	4.18	0.03	8.08	2.71	0.26

Factors included are calculated area treated, log vapour pressure (vp), log K_{ow}, log K_{oc}, molecular weight (mw), log foliar DT_{50}, log soil DT_{50}, and log water solubility as continuous variables. Only models with weight ratio less than 10 are included. Pesticides included= 21

Table 7: Logistic regression results for bee mortality in pulse crops on survey years only.

K	variable 1	variable 2	df	AIC$_c$	Δ AIC$_c$	Akaike weight	weight ratio	Chi^2	p
4	log area	log HR con	2	21.561	0.000	0.240		7.39	0.025
4	log area	log HR oral	2	21.734	0.173	0.220	1.09	7.22	0.027
3	log HR con		1	23.641	2.080	0.085	2.83	2.22	0.14
3	log HR oral		1	24.055	2.493	0.069	3.48	1.81	0.18
4	log HR con	log solubility	2	24.515	2.953	0.055	4.38	4.44	0.11
4	log HR con	log K$_{ow}$	2	24.799	3.237	0.048	5.05	2.34	0.31
4	log HR con	log K$_{oc}$	2	25.256	3.695	0.038	6.34	3.69	0.16
4	log HR con	mw	2	25.941	4.379	0.027	8.93	3.01	0.22

Factors included are calculated area treated, log vapour pressure (vp), log K_{ow}, log K_{oc}, molecular weight (mw), log foliar DT_{50}, log soil DT_{50}, and log water solubility as continuous variables. Only models with weight ratio less than 10 are included. Pesticides included= 21

Table 8: Regression coefficients from logistic models with pulses and oilseeds

Model:	Intercept	Area	HR oral	HR contact	Crop
oilseeds	-7.16	1.02		0.77	
	-8.72	1.15	1.23		
pulses	-15.87	2.18	1.66		
	-15.34	1.95		1.80	

When the crops are entered in the same logistic regression analysis but differentiated by a dummy variable, the important predictors of honeybee mortality are: area treated, HR, molecular weight, and water solubility (table 9). However, the best model includes HR_{oral} and area treated alone, and the addition of a third variable does not greatly improve model likelihood. Because $HR_{contact}$ is correlated with log K_{ow} and water solubility, while HR_{oral} is correlated with vapour pressure (table 1), it is likely that the slight model improvements resulting from the addition of physicochemical data is mostly due to the correlations between variables, and not a true increase in model fit.

Table 9: Logistic regression results for bee mortality in pulse and oilseed crops on survey years only.

K	variable 1	variable 2	variable 3	variable 4	df	AIC_c	ΔAIC_c	Akaike weight	weight ratio	Chi^2	p
4	log area	log HR oral			2	45.22	0.00	0.14		13.54	0.0012
5	log area	log HR con	mw		3	46.28	1.06	0.08	1.70	15.97	0.0011
5	log area	log HR con	log solubility		3	46.44	1.22	0.08	1.84	15.82	0.0012
5	log area	log HR oral	crop		3	46.93	1.71	0.06	2.35	15.33	0.0016
4	log area	log HR con			2	47.24	2.02	0.05	2.74	11.52	0.0032
5	log area	log HR oral	mw		3	47.96	2.74	0.04	3.94	14.29	0.0025
5	log area	log HR oral	log solubility		3	47.98	2.76	0.04	3.98	14.28	0.0026
5	log area	log HR con	log K_{ow}		3	48.11	2.89	0.03	4.24	14.15	0.0027
6	log area	log HR con	mw	crop	4	48.28	3.06	0.03	4.62	17.97	0.0012
5	log area	log HR oral	log K_{ow}		3	48.35	3.13	0.03	4.79	13.90	0.0030
5	log area	log HR oral	log vp		3	48.35	3.14	0.03	4.80	13.90	0.0031
5	log area	log HR oral	log K_{oc}		3	48.52	3.30	0.03	5.21	13.73	0.0033

Table 9: Logistic regression results for bee mortality in pulse and oilseed crops on survey years only.

K	variable 1	variable 2	variable 3	variable 4	df	AIC$_c$	ΔAIC$_c$	Akaike weight	weight ratio	Chi^2	p
5	log area	log HR oral	log foliar DT50		3	48.60	3.38	0.03	5.43	13.65	0.0034
5	log area	log HR oral	log soil DT50		3	48.66	3.44	0.03	5.58	13.60	0.0035
6	log area	log HR con	log solubility	crop	4	48.79	3.57	0.02	5.97	17.46	0.0016
5	log area	log HR con	log K_{oc}		3	48.91	3.69	0.02	6.34	13.34	0.0040
5	log area	log HR con	crop		3	49.30	4.08	0.02	7.69	12.96	0.0047

Factors included are calculated area treated, log vapour pressure (vp), log K_{ow}, log K_{oc}, molecular weight (mw), log foliar DT_{50}, log soil DT_{50}, and log water solubility as continuous variables and crop type as categorical variable. Only models with weight ratio less than 10 are included. Pesticides included= 42

3 ANALYSIS FOR ALL YEARS

3.1 Calculation of area treated:

Linear interpolation was used to estimate the area treated in non-survey years. For some chemicals, the area applied drops to zero or near zero between surveys (e.g. oilseeds were treated with oxydemeton-methyl on 780 ha in 1990, and 956 ha in 1994, with no recorded treatments in 1992; paraquat was applied to 7009 ha in 1994, 360 ha in 1996, and 2540 ha in 1998; see Appendix E). As mentioned previously, the area treated data are less accurate in low use periods. In cases where the area treated dropped to zero, or when it dropped below 1000 ha treated before increasing for a third survey, an average incremental increase or decrease in area treated was calculated from the first survey to the third survey.

No pesticide use surveys were conducted between 1983 and 1988. Therefore, the first application of many chemicals was reported in 1988. For example, alpha-cypermethrin was applied to 53,943 ha of oilseeds in 1988 and increasing areas in subsequent surveys. Ancillary information (Tomlin 2003) suggest that the chemical was marketed as early as 1983 even though there was no record of its use in 1983. We therefore used the 1988 to 1992 linear relationship in the area treated to regress backwards to 1983. In other cases (e.g. cyfluthrin in pulses), we used peak area treated to regress both backward and forward from a survey year. In a few cases, our regressions were used to estimate small treatment areas even though surveys did not report any use.

A different approach had to be taken for the two small use products that caused bee mortality: permethrin and azinphos-methyl/demeton-S-methyl sulphone mixture. The survey reported permethrin use in oilseeds only in 1988 (836 ha treated); however a bee mortality incident was recorded in 2001. It is likely permethrin was applied to a small number of oilseed fields between 1988 and 2001, but this use did not appear in the surveys. We had to assume therefore that the area treated remained roughly constant for the 13 year period.. The area treated with azinphos-methyl and demeton-S-methyl sulphone mixture was 126 ha in 1982 (when 2 mortality events were noted), 0 ha in 1989, and 615 ha in 1990. We thus calculated an incremental increase in area treated from 1982-1990.

3.2 Linear regression analyses

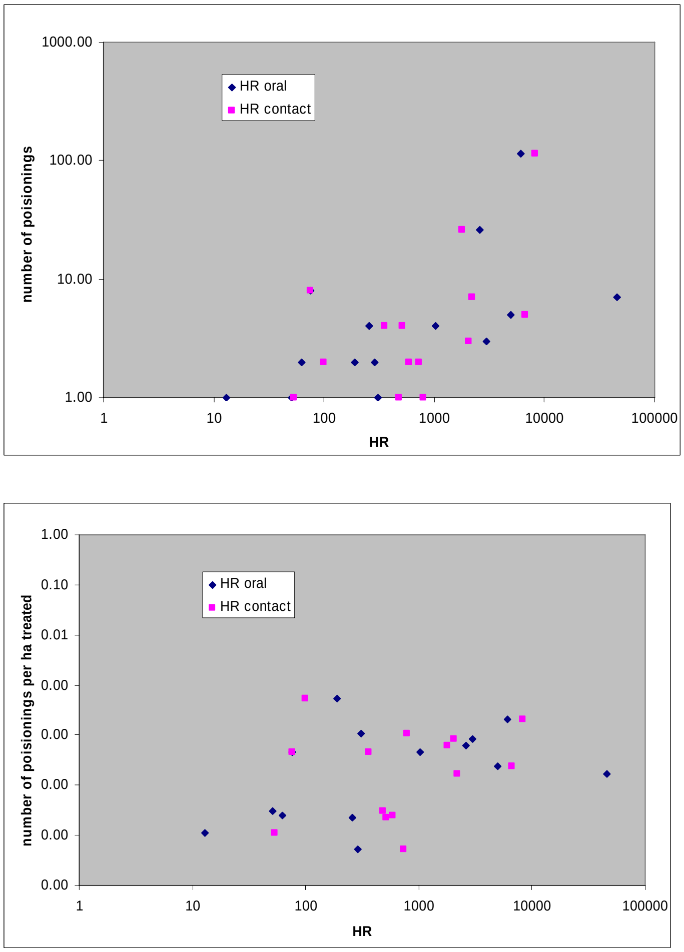
The linear regression analysis was conducted, once again, following the approach taken by Aldridge and Hart (1993). This involved plotting the number of poisoning incidents or number of incidents per ha treated against the HR. It was found that when only pesticides causing mortality events were included, both $HR_{contact}$ and HR_{oral} were significantly correlated with mortality counts when both crops were combined (r^2=0.56 p= 0.039 and r^2=0.62 p= 0.019) (table 10, figure 2).

This did not occur when they were considered separately. Inspection of the plots revealed, however, that the triazophos and dimethoate data alone were largely responsible for the significant regressions. There was no correlation with log mortality per area treated, even though this factor is normally distributed.

Table 10: Correlations between single factors hazard ratio (HR) and mortality counts and counts per area treated. Only pesticides causing mortality included.

	Both crops		**Pulses**		**Oilseeds**	
	log mortality	**log mortality/ ha**	**log mortality**	**log mortality/ ha**	**log mortality**	**log mortality/ha**
Log HR contact	0.56	0.21	0.45	0.27	0.58	0.20
	p=.039	p=.47	p=.55	p=.73	p=.077	p=.58
Log HR oral	0.62	0.19	0.78	0.85	0.57	0.38
	p=.019	p=.12	p=.22	p=.15	p=.086	p=.28

Figure 2: Correlation of Hazard ratio with number of poisoning incidents (a) and number of mortality incidents per area treated (b). The pesticides causing mortality events in both pulses and oilseeds have been combined, and insecticides that do not cause mortality events have been excluded.



Initial results show that there are 4 pesticides that caused mortality in pulses, and 10 in oilseeds. In order to investigate whether there were other explanatory variables for mortality, we combined these data into a single multiple linear regression analysis, keeping crop as a categorical variable. We again used AIC$_c$ to compare models using mortality per area treated as the dependant variable (table 11). We chose to model mortality incidents per area treated rather than the simple number of incidents, to reduce the influence of the two extreme values – triazophos and dimethoate. As before, we excluded *a priori* any models that did not have the hazard ratio (either $HR_{contact}$ or HR_{oral}), and also excluded models with more than two variables. The 'best' 4 models all have an Akaike weight ratio of about 1, which means that they explain the variance in mortality/ha equally well. The models include HR and molecular weight or PCA 1. The only other variables with significant multiple regression ($p<0.05$) were HR_{oral} or $HR_{contact}$ with water solubility (a factor in PCA 1). The factors in PCA 1 are molecular weight, log K_{ow} , log vapour pressure and log water solubility. The model with HR_{oral} alone has a weight ratio of 6.58, meaning that it is clearly inferior to the models with HR combined either with molecular weight or PCA 1. The latter explain a substantial proportion of overall variance (R^2=0.48, p=0.027); HR_{oral} alone does not (R^2=0.19, p=0.12).

Table 11: Multiple regression results for bee mortality in both pulse and oilseed crops (dependant variable mortality/ha). Pesticides not causing mortality are excluded.

K	variable 1	variable 2	variable 3	df	AIC_c	Δ AIC_c	Akaike weight	weight ratio	R^2	p
4	log HR cont	mw		2	34.147	0.000	0.129		0.48	0.027
4	log HR cont	PCA 1		2	34.185	0.038	0.127	1.02	0.48	0.027
4	log HR oral	mw		2	34.196	0.049	0.126	1.02	0.48	0.027
4	log HR oral	PCA 1		2	34.245	0.098	0.123	1.05	0.44	0.028
4	log HR oral	log solubility		2	35.251	1.104	0.074	1.74	0.43	0.041
4	log HR cont	log solubility		2	35.503	1.355	0.066	1.97	0.41	0.046
4	log HR oral	log K_{ow}		2	36.040	1.893	0.050	2.58	0.49	0.056
5	log HR cont	mw	crop	3	36.460	2.313	0.041	3.18	0.49	0.069
5	log HR cont	PCA 1	crop	3	36.466	2.319	0.040	3.19	0.49	0.069
5	log HR oral	mw	crop	3	36.570	2.423	0.038	3.36	0.49	0.072

Table 11: Multiple regression results for bee mortality in both pulse and oilseed crops (dependant variable mortality/ha). Pesticides not causing mortality are excluded.

K	variable 1	variable 2	variable 3	df	AIC_c	Δ AIC_c	Akaike weight	weight ratio	R^2	p
5	log HR oral	PCA 1	crop	3	36.594	2.447	0.038	3.40	0.49	0.072
4	log HR cont	log K_{ow}		2	37.241	3.094	0.027	4.70	0.41	0.056
5	log HR oral	log solubility	crop	3	37.422	3.275	0.025	5.14	0.46	0.094
5	log HR cont	log solubility	crop	3	37.509	3.362	0.024	5.37	0.45	0.098
3	log HR oral			1	37.915	3.768	0.020	6.58	0.19	0.12
5	log HR oral	log K_{ow}	crop	3	38.381	4.234	0.016	8.31	0.42	0.13

Factors included are, log vapour pressure (vp), log K_{ow}*, log* K_{oc}*, molecular weight (mw), log foliar* DT_{50}*, log soil* DT_{50}*, PCA factor 1 and log water solubility as continuous variables and crop type as categorical variable. PCA 1= Principal Components Analysis factor 1 calculated with log P (log* K_{ow}*), mw, log vp, and log water solubility. N= 14*

3.3 Logistic regression analyses

As explained above, logistic regression can be used as a method to combine data for all pesticides whether or not the pesticides gave rise to mortality incidents. In oilseeds, the best model (which had twice as much predictive power as the next best one) was HR_{oral} and vapour pressure (table 12). The other models were not significant (p>0.05). In pulses, the best two models (weight ratio= 1.15) were HR_{oral} or $HR_{contact}$ combined with the area treated (table 13). These were also the only two models that were significant in a classical null-hypothesis framework (Chi^2= 7.740, p=0.02; Chi^2=7.460, p=0.02). Both pulses and oilseeds had HR and area treated in the top models. The difference between the models is that mortality in oilseeds was also affected by vapour pressure.

On account of the coefficients between the different models, as well as the model structures being similar (table 14), a final analysis was conducted on the two crops together. The crop type was differentiated by a simple categorical variable. Since the combination of crops resulted in a larger sample size, models with more variables were considered and ranked than in the individual crop models (table 15). All of the best models included area treated; indicating that for this data set area treated greatly influenced the probability that bee mortality would be reported. $HR_{contact}$ provided a better fit overall than HR_{oral}. Of the physicochemical properties, vapour pressure was the best contributor to overall model fit and surpassed the overall PCA1 factor. The logistic regression plots of $HR_{contact}$ and HR_{oral} are shown in figure 3.

Table 12: Logistic regression results for bee mortality in oilseed crops.

K	variable 1	variable 2	df	AIC_c	Δ AIC_c	Akaike weight	weight ratio	Chi^2	p
4	log HR oral	log vp	2	29.89	0.00	0.28		7.67	0.022
4	log area	log HR cont	2	31.52	1.62	0.12	2.25	6.05	0.049
4	log area	log HR oral	2	31.85	1.96	0.10	2.67	5.71	0.058
3	log HR cont		1	32.37	2.48	0.08	3.45	7.79	0.051
3	log HR oral		1	32.55	2.66	0.07	3.78	7.20	0.065
4	log HR oral	log K_{oc}	2	32.72	2.83	0.07	4.11	4.85	0.089
4	log HR cont	log vp	2	33.82	3.93	0.04	7.12	6.58	0.087
4	log HR oral	log soil DT50	2	34.20	4.31	0.03	8.63	3.36	0.18
4	log HR cont	log K_{oc}	2	34.36	4.47	0.03	9.34	3.20	0.20

Factors included are log vapour pressure (vp), log K_{ow}, log K_{oc}, molecular weight (mw), log foliar DT_{50}, log soil DT_{50}, log water solubility, and PCA 1 (Principal Components Analysis factor 1; calculated with log P (log K_{ow}), mw, log vp, and log water solubility). Only models with weight ratio less than 10 are included. N= 21

Table 13. Logistic regression results for bee mortality in pulse crops.

K	variable 1	variable 2	df	AIC_c	Δ AIC_c	Akaike weight	weight ratio	Chi^2	p
4	log area	log HR cont	2	21.213	0.000	0.284		7.740	0.021
4	log area	log HR oral	2	21.492	0.280	0.247	1.15	7.460	0.024
3	log HR cont		1	23.641	2.429	0.084	3.37	2.220	0.140

Table 13. Logistic regression results for bee mortality in pulse crops.

K	variable 1	variable 2	df	AIC$_c$	Δ AIC$_c$	Akaike weight	weight ratio	Chi^2	p
3	log HR oral		1	24.055	2.842	0.069	4.14	1.820	0.180
4	log HR cont	log solubility	2	24.515	3.302	0.054	5.21	4.460	0.110
4	log HR cont	log K_{oc}	2	25.586	4.373	0.032	8.91	2.880	0.240
4	log HR cont	log K_{ow}	2	24.799	3.586	0.046	6.01	4.150	0.130

Factors included are log vapour pressure (vp), log K_{ow}, log K_{oc}, molecular weight (mw), log foliar DT_{50}, log soil DT_{50}, log water solubility, and PCA 1 (Principal Components Analysis factor 1; calculated with log P (log K_{ow}), mw, log vp, and log water solubility). Only models with weight ratio less than 10 are included. N= 21

Table 14: Coefficients from logistic models with pulses and oilseeds.

	intercept	Log area	log HR contact	log HR oral	log vp	crop
pulses	-17.04	2.16	1.77			
pulses	-17.46	2.34		1.63		
pulses	-19.19	2.76	1.64		0.42	
pulses	-17.53	2.41		1.56	0.10	
pulses	0.13	2.16	1.77			-0.17
pulses	0.14	2.34		1.63		-0.17
pulses	0.12	2.76	1.64		0.42	-0.19
pulses	0.11	2.41		1.56	0.10	-0.17
oilseeds	-8.76	1.21	1.07			
oilseeds	-8.18	1.13		1.05		
oilseeds	-9.71	1.18	1.24		-0.33	
oilseeds	-14.64	1.32		2.59	-1.01	
oilseeds	0.14	1.21	1.07			-0.088
oilseeds	0.16	1.13		1.05		-0.083
oilseeds	0.13	1.18	1.24		-0.33	-0.097
oilseeds	0.15	1.32		2.59	-1.01	-0.15

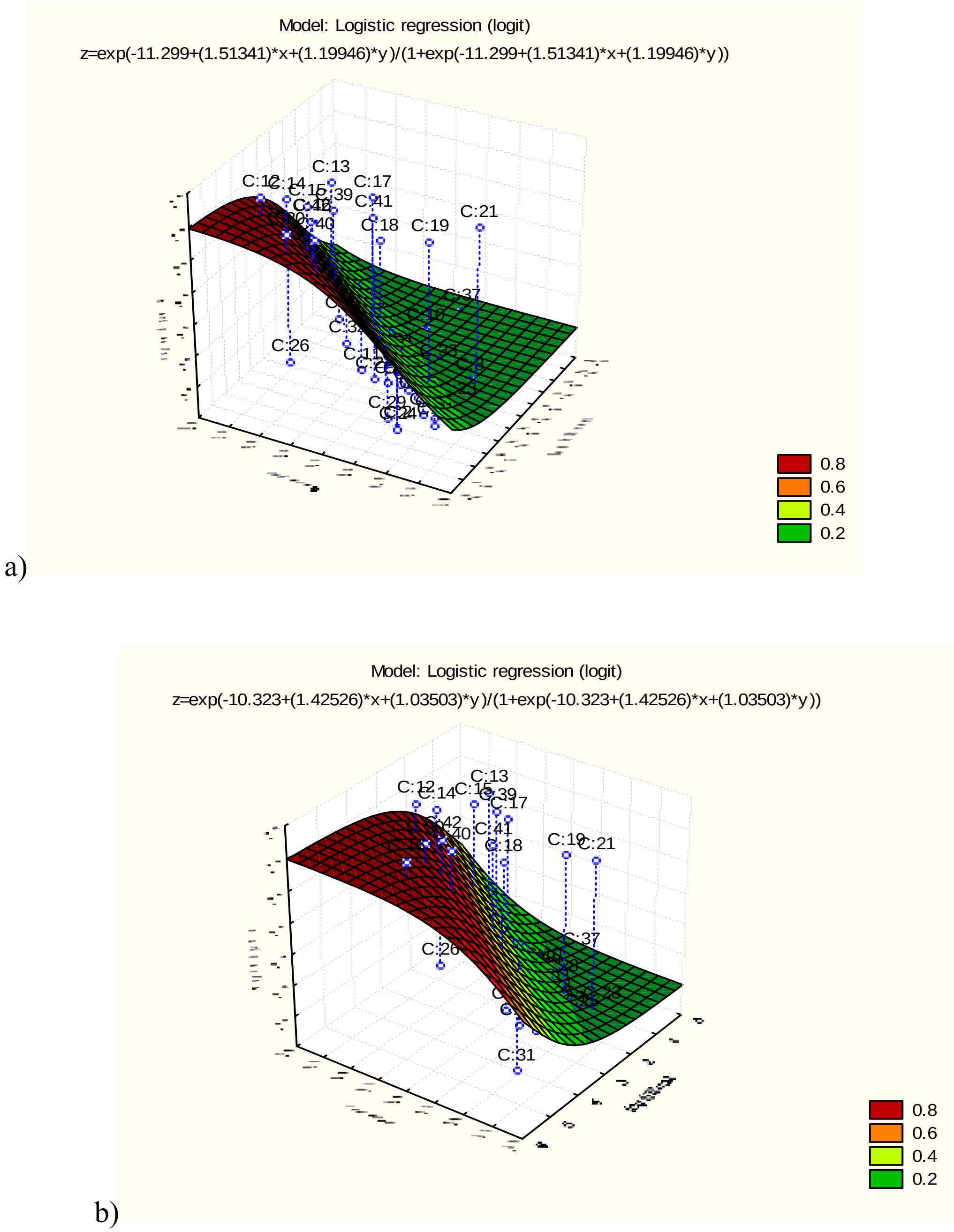
Table 15. Logistic regression results for bee mortality in pulse and oilseed crops. The continuous variables included are log vapour pressure (vp), log K_{ow}, log K_{oc}, molecular weight (mw), log foliar DT_{50}, log soil DT_{50}, log water solubility, and PCA 1 (Principal Components Analysis factor 1; calculated with log P (log K_{ow}), mw, log vp, and log water solubility). Crop type included as a categorical variable. Only models with weight ratio less than 10 are included. N= 42

K	variable 1	variable 2	variable 3	variable 4	df	AIC_c	Δ AIC_c	Akaike weight	weight ratio	Chi^2	p
5	log area	log HR cont	crop		3	46.04	0.00	0.08		17.09	0.0007
6	log area	log HR oral	log vp	crop	4	46.69	0.65	0.06	1.39	19.17	0.0007
5	log area	log HR oral	crop		3	46.87	0.83	0.06	1.51	16.26	0.0010
4	log area	log HR cont			2	47.08	1.04	0.05	1.68	13.46	0.0012
6	log area	log HR cont	log solubility	crop	4	47.36	1.32	0.04	1.93	18.51	0.0010
6	log area	log HR cont	mw	crop	4	47.41	1.37	0.04	1.98	18.46	0.0010
6	log area	log HR cont	PCA 1	crop	4	47.43	1.39	0.04	2.00	18.44	0.0010
6	log area	log HR cont	log K_{ow}	crop	4	47.48	1.43	0.04	2.05	18.39	0.0010
5	log area	log HR oral	log vp		3	47.82	1.78	0.03	2.43	15.31	0.0016
4	log area	log HR oral			2	48.19	2.14	0.03	2.92	12.36	0.0215
6	log area	log HR cont	log K_{oc}	crop	4	48.34	2.30	0.03	3.16	17.52	0.0015
5	log area	log HR cont	log solubility		3	48.40	2.35	0.03	3.24	14.74	0.0021
5	log area	log HR cont	log K_{ow}		3	48.50	2.45	0.02	3.41	14.64	0.0022
6	log area	log HR cont	log foliar DT50	crop	4	48.58	2.53	0.02	3.55	17.29	0.0017
6	log area	log HR cont	log soil DT50	crop	4	48.59	2.55	0.02	3.57	17.28	0.0017
5	log area	log HR cont	mw		3	48.59	2.55	0.02	3.58	14.54	0.0023
5	log area	log HR cont	PCA 1		3	48.61	2.56	0.02	3.60	14.53	0.0023
6	log area	log HR cont	log vp	crop	4	48.69	2.65	0.02	3.75	17.18	0.0018
6	log area	log HR oral	log foliar DT50	crop	4	48.90	2.86	0.02	4.17	16.97	0.0020
5	log area	log HR cont	log K_{oc}		3	49.33	3.29	0.02	5.17	13.80	0.0032
6	log area	log HR oral	log soil DT50	crop	4	49.37	3.33	0.02	5.29	16.49	0.0024
5	log area	log HR cont	log soil DT50		3	49.38	3.34	0.02	5.31	13.75	0.0033
5	log area	log HR cont	log foliar DT50		3	49.54	3.50	0.01	5.74	13.60	0.0035

Table 15. Logistic regression results for bee mortality in pulse and oilseed crops. The continuous variables included are log vapour pressure (vp), log K_{ow}, log K_{oc}, molecular weight (mw), log foliar DT_{50}, log soil DT_{50}, log water solubility, and PCA 1 (Principal Components Analysis factor 1; calculated with log P (log K_{ow}), mw, log vp, and log water solubility). Crop type included as a categorical variable. Only models with weight ratio less than 10 are included. N= 42

K	variable 1	variable 2	variable 3	variable 4	df	AIC_c	Δ AIC_c	Akaike weight	weight ratio	Chi^2	p
5	log area	log HR cont	log vp		3	49.54	3.50	0.01	5.76	13.59	0.0035
6	log area	log HR oral	log K_{oc}	crop	4	49.55	3.50	0.01	5.77	16.32	0.0026
6	log area	log HR oral	PCA 1	crop	4	49.58	3.54	0.01	5.87	16.28	0.0027
6	log area	log HR oral	mw	crop	4	49.59	3.55	0.01	5.89	16.28	0.0027
6	log area	log HR oral	log solubility	crop	4	49.59	3.55	0.01	5.90	16.27	0.0027
6	log area	log HR oral	log K_{ow}	crop	4	49.60	3.56	0.01	5.93	16.27	0.0027
5	log area	log HR oral	log foliar DT50		3	50.17	4.13	0.01	7.88	12.96	0.0047
5	log area	log HR oral	log soil DT50		3	50.49	4.45	0.01	9.26	12.64	0.0055

Figure 3: Three dimensional representation of logistic regression models area treated with a) $HR_{contact}$ and b) HR_{oral}. In order to show the results graphically, data from both pulses and oilseeds have been combined although the best model includes a variable to separate the two.



In figures 3a, case #26 is an outlier that did not cause mortality when expected. This point refers to cypermethrin in pulse crops. This pesticide did cause two mortality events in oilseeds. Additionally, in the same figures, points # 19 (permethrin) and #21 (azinphos-methyl) in oilseeds are outliers that caused unexpected mortality. Both of these chemicals were implicated in mortality events in years when, according to the surveys, this chemical was not applied to oilseeds. It is likely therefore that the area treated was incorrectly estimated from our simplistic regression methods.

3.4 Dividing the data into different periods

Analysis of the data revealed a drop in observed bee mortality starting in 1991 (figure 1). This was likely due to a decrease in the area that was treated by dimethoate and triazophos from 1990-1994. Changes in reporting rates, as well as an increase in awareness of the options for protecting pollinators from pesticides (i.e. spraying when bees are not active, increased communication between the farmer and beekeeper) could also be factors that contributed to the drop in bee mortality starting in 1991. Given the distinct date that lower bee mortality was observed, mortality events were separated into two groups for additional analysis; those occurring from 1981-1991 and those occurring from 1992-2002 (Appendix F). The new models turned out to be very similar to those in previous analyses (table 16-17). The best models included area treated and HR_{oral} or $HR_{contact}$. The addition of other variables did not increase Akaike weights. The general shape of the models was also very similar between the two periods, as well as being similar to the models shown above for the entire dataset (Figure 3 and 4). It can therefore be concluded that there is no reason to develop separate models for the two time periods. This in turn suggests that the relationship between pesticide use and incident reporting has not changed appreciably over time.

Table 16: Logistic regression results for bee mortality in pulse and oilseed crops. Mortality used occurred between 1981-1991.

K	variable 1	variable 2	variable 3	df	AIC$_c$	Δ AIC$_c$	Akaike weight	weight ratio	Chi^2	p
4	log A 81	log HR oral		2	33.39	0.00	0.19		13.85	0.0010
4	log A 81	log HR con		2	34.61	1.22	0.10	1.84	12.61	0.0018
5	log A 81	log HR oral	log foliar DT50	3	35.58	2.19	0.06	2.98	15.13	0.0017
5	log A 81	log HR con	log K_{oc}	3	35.65	2.25	0.06	3.09	15.09	0.0018
5	log A 81	log HR oral	log K_{oc}	3	36.30	2.91	0.04	4.28	14.45	0.0023
5	log A 81	log HR oral	crop	3	36.67	3.28	0.04	5.16	14.10	0.0028
5	log A 81	log HR oral	log K_{ow}	3	36.78	3.39	0.04	5.44	13.97	0.0030
5	log A 81	log HR con	mw	3	36.81	3.42	0.03	5.54	14.30	0.0025
5	log A 81	log HR oral	log vp	3	36.81	3.42	0.03	5.54	13.93	0.0030
5	log A 81	log HR oral	log soil DT50	3	36.84	3.45	0.03	5.61	13.91	0.0030
5	log A 81	log HR oral	log solubility	3	36.89	3.49	0.03	5.74	13.86	0.0031
5	log A 81	log HR oral	mw	3	36.89	3.50	0.03	5.75	14.22	0.0026
5	log A 81	log HR con	log solubility	3	37.10	3.71	0.03	6.39	13.60	0.0035
5	log A 81	log HR con	log vp	3	37.20	3.81	0.03	6.72	13.52	0.0036
5	log A 81	log HR con	log foliar DT50	3	37.28	3.89	0.03	7.00	13.42	0.0038
5	log A 81	log HR con	log K_{ow}	3	37.78	4.38	0.02	8.96	12.92	0.0048
5	log A 81	log HR con	crop	3	38.00	4.61	0.02	10.03	12.73	0.0053

Factors included are log vapour pressure (vp), log K_{ow}, log K_{oc}, molecular weight (mw), log foliar DT_{50}, log soil DT_{50}, and log water solubility as continuous variables and crop type as categorical variable. Only models with weight ratio less than 10 are included. N=38

Table 17: Logistic regression results for bee mortality in pulse and oilseed crops. Mortality used occurred between 1992-2002.

K	variable 1	variable 2	variable 3	df	AIC$_c$	Δ AIC$_c$	Akaike weight	weight ratio	Chi^2	p
4	log A 02	log HR con		2	42.251	0.000	0.141		7.85	0.020
4	log A 02	log HR oral		2	44.434	2.183	0.047	2.98	5.67	0.059
5	log A 02	log HR con	log solubility	3	44.635	2.383	0.043	3.29	8.97	0.030
5	log A 02	log HR con	log K_{ow}	3	44.678	2.427	0.042	3.36	8.93	0.030
5	log A 02	log HR con	crop	3	44.696	2.445	0.042	3.40	8.91	0.031
5	log HR con	mw	log vp	3	44.924	2.673	0.037	3.81	8.68	0.034
5	log A 02	log HR con	mw	3	45.168	2.916	0.033	4.30	8.44	0.038
5	log HR con	log vp	log solubility	3	45.199	2.947	0.032	4.36	6.92	0.075
3	log HR con			1	45.332	3.081	0.030	4.67	1.52	0.220
5	log A 02	log HR con	log vp	3	45.363	3.112	0.030	4.74	8.24	0.041
5	log A 02	log HR con	log foliar DT50	3	45.409	3.157	0.029	4.85	8.19	0.042
5	log A 02	log HR con	log soil DT50	3	45.748	3.496	0.025	5.74	7.86	0.049
5	log A 02	log HR con	log K_{oc}	3	45.751	3.500	0.025	5.75	7.85	0.049
4	log HR oral	log vp		2	45.791	3.540	0.024	5.87	3.01	0.220
4	log HR con	log vp		2	45.863	3.611	0.023	6.08	3.12	0.210
5	log A 02	log HR oral	log vp	3	46.263	4.012	0.019	7.43	5.71	0.130
5	log HR oral	mw	log vp	3	46.336	4.085	0.018	7.71	7.27	0.064
3	log HR oral			1	46.702	4.450	0.015	9.25	0.32	0.570
5	log A 02	log HR oral	crop	3	46.864	4.613	0.014	10.04	6.74	0.081

Factors included are log vapour pressure (vp), log K_{ow}, log K_{oc}, molecular weight (mw), log foliar DT_{50}, log soil DT_{50}, and log water solubility as continuous variables and crop type as categorical variable. Only models with weight ratio less than 10 are included. N=38

3.5 Modeling the greater of $HR_{contact}$ and HR_{oral}

Both $HR_{contact}$ and HR_{oral} appear to be equally suitable to use as toxicity values in models, in that they alternate in their relative importance to the outcome. Although highly correlated, some pesticides vary greatly in the contact hazard ratio as opposed to the oral hazard ratio. We ran the models with the more toxic (i.e. showing the most hazard) of the two toxicity values (table 18). We found the resulting model to be very similar to those based on either contact or oral toxicity alone developed in previous analyses (table 15). The best model that included area treated and HRmax was slightly behind the model with $HR_{contact,}$ and only slightly ahead of the equivalent model with HR_{oral}. Realistically, there was little separation between the three models (all within ΔAICc of 0.8). The addition of physicochemical variables (with one exception – vapour pressure) consistently increased the AIC_c, and increased the Akaike weight ratio beyond 2 indicating the resulting model was no longer the most parsimonious. We can conclude therefore that the best model uses one of the two measures of HR and area treated, and that the addition of extra variables is not necessary.

Table 18. Logistic regression results for bee mortality in pulse and oilseed crops. Toxicity factors include HR contact, HR oral and the more toxic of the two values, HR max.

K	variable 1	variable 2	variable 3	variable 4	df	AIC$_c$	Δ AIC$_c$	Akaike weight	ratio	Chi^2	p
5	log area	log HR cont	crop		3	46.04	0.00	0.06		17.09	0.0007
5	log area	log HR max	crop		3	46.65	0.60	0.05	1.35	16.49	0.0009
6	log area	log HR oral	log vp	crop	4	46.69	0.65	0.04	1.39	19.17	0.0007
5	log area	log HR oral	crop		3	46.87	0.83	0.04	1.51	16.26	0.0010
4	log area	log HR cont			2	47.08	1.04	0.04	1.68	13.46	0.0012
6	log area	log HR cont	log solubility	crop	4	47.36	1.32	0.03	1.93	18.51	0.0010
6	log area	log HR cont	mw	crop	4	47.41	1.37	0.03	1.98	18.46	0.0010
6	log area	log HR cont	PCA 1	crop	4	47.43	1.39	0.03	2.00	18.44	0.0010
6	log area	log HR cont	log K$_{ow}$	crop	4	47.48	1.43	0.03	2.05	18.39	0.0010
5	log area	log HR oral	log vp		3	47.82	1.78	0.03	2.43	15.31	0.0016
4	log area	log HR max			2	47.85	1.80	0.02	2.46	12.70	0.0017
4	log area	log HR oral			2	48.19	2.14	0.02	2.92	12.36	0.022
6	log area	log HR cont	log K$_{oc}$	crop	4	48.34	2.30	0.02	3.16	17.52	0.0015
5	log area	log HR cont	log solubility		3	48.40	2.35	0.02	3.24	14.74	0.0021

Table 18. Logistic regression results for bee mortality in pulse and oilseed crops. Toxicity factors include HR contact, HR oral and the more toxic of the two values, HR max.

K	variable 1	variable 2	variable 3	variable 4	df	AIC$_c$	Δ AIC$_c$	Akaike weight	ratio	Chi^2	p
5	log area	log HR cont	log K$_{ow}$		3	48.50	2.45	0.02	3.41	14.64	0.0022
6	log area	log HR cont	log foliar DT50	crop	4	48.58	2.53	0.02	3.55	17.29	0.0017
6	log area	log HR cont	log soil DT50	crop	4	48.59	2.55	0.02	3.57	17.28	0.0017
5	log area	log HR cont	mw		3	48.59	2.55	0.02	3.58	14.54	0.0023
5	log area	log HR cont	PCA 1		3	48.61	2.56	0.02	3.60	14.53	0.0023
6	log area	log HR cont	log vp	crop	4	48.69	2.65	0.02	3.75	17.18	0.0018
6	log area	log HR max	log vp	crop	4	48.75	2.71	0.02	3.87	17.12	0.0018
6	log area	log HR oral	log foliar DT50	crop	4	48.90	2.86	0.01	4.17	16.97	0.0020
6	log area	log HR max	mw	crop	4	48.91	2.87	0.01	4.20	16.95	0.0020
6	log area	log HR max	log solubility	crop	4	48.93	2.89	0.01	4.24	16.93	0.0020
6	log area	log HR max	PCA 1	crop	4	48.93	2.89	0.01	4.25	16.93	0.0020
6	log area	log HR max	log K$_{ow}$	crop	4	48.98	2.93	0.01	4.34	16.89	0.0020
6	log area	log HR max	log foliar DT50	crop	4	49.16	3.11	0.01	4.74	16.71	0.0022
6	log area	log HR max	log soil DT50	crop	4	49.25	3.21	0.01	4.98	16.61	0.0023

Table 18. Logistic regression results for bee mortality in pulse and oilseed crops. Toxicity factors include HR contact, HR oral and the more toxic of the two values, HR max.

K	variable 1	variable 2	variable 3	variable 4	df	AIC_c	Δ AIC_c	Akaike weight	ratio	Chi^2	p
6	log area	log HR max	log K_{oc}	crop	4	49.31	3.27	0.01	5.12	16.56	0.0024
5	log area	log HR cont	log K_{oc}		3	49.33	3.29	0.01	5.17	13.80	0.0032
6	log area	log HR oral	log soil DT50	crop	4	49.37	3.33	0.01	5.29	16.49	0.0024
5	log area	log HR cont	log soil DT50		3	49.38	3.34	0.01	5.31	13.75	0.0033
5	log area	log HR cont	log foliar DT50		3	49.54	3.50	0.01	5.74	13.60	0.0035
5	log area	log HR cont	log vp		3	49.54	3.50	0.01	5.76	13.59	0.0035
6	log area	log HR oral	log K_{oc}	crop	4	49.55	3.50	0.01	5.77	16.32	0.0026
6	log area	log HR oral	PCA 1	crop	4	49.58	3.54	0.01	5.87	16.28	0.0027
6	log area	log HR oral	log solubility	crop	4	49.59	3.55	0.01	5.9	16.27	0.0027
6	log area	log HR oral	mw	crop	4	49.59	3.55	0.01	5.89	16.28	0.0027
6	log area	log HR oral	log K_{ow}	crop	4	49.6	3.56	0.01	5.93	16.27	0.0027
5	log area	log HR max	log vp		3	49.67	3.63	0.01	6.13	13.46	0.0037
5	log area	log HR max	log solubility		3	50.10	4.05	0.01	7.59	13.04	0.0046
5	log area	log HR max	log K_{ow}		3	50.13	4.09	0.01	7.71	13.01	0.0046

Table 18. Logistic regression results for bee mortality in pulse and oilseed crops. Toxicity factors include HR contact, HR oral and the more toxic of the two values, HR max.

K	variable 1	variable 2	variable 3	variable 4	df	AIC_c	Δ AIC_c	Akaike weight	ratio	Chi^2	p
5	log area	log HR max	mw		3	50.16	4.12	0.01	7.84	12.97	0.0047
5	log area	log HR oral	log foliar DT50		3	50.17	4.13	0.01	7.88	12.96	0.0047
5	log area	log HR max	PCA 1		3	50.18	4.13	0.01	7.90	12.96	0.0047
5	log area	log HR max	log soil DT50		3	50.26	4.22	0.01	8.25	6.64	0.084
5	log area	log HR max	log foliar DT50		3	50.27	4.23	0.01	8.29	12.86	0.0049
5	log area	log HR max	log K_{oc}		3	50.40	4.36	0.01	8.85	12.73	0.0053
5	log area	log HR oral	log soil DT50		3	50.49	4.45	0.01	9.26	12.64	0.0055

Factors included are log vapour pressure (vp), log K_{ow}*, log* K_{oc}*, molecular weight (mw), log foliar* DT_{50}*, log soil* DT_{50}*, and log water solubility as continuous variables and crop type as categorical variable. Only models with weight ratio less than 10 are included. N=38. The model in bold is used to generate probabilities of incidents in table 21 below.*

3.6 Evidence for a ‘pyrethroid effect’

In all of the analyses several factors (especially vapour pressure in table 18 above, but also molecular weight, and PCA1; note that VP and MW are highly correlated – table 1) often appear in the top models predicting the likelihood of a reported bee kill. An examination of the data revealed that the importance of these physicochemical descriptors in predicting the likelihood of mortality is driven by a group of 5 pesticides with high molecular weight, all of which are synthetic pyrethroids (figure 4). Despite low rates of application their HRs are substantial and, therefore, the small number of incidents is not a result of lesser toxicity (figure 5). As seen in table 19, these products are responsible for the significant inverse linear relationships between MW or PCA1 and mortality rates. These relationships disappear when pyrethroids are excluded. There appears to be a clear under-representation of the number of kills with this class of compounds.

Table 19: Correlations between log mortality per ha (both crops combined, calculated area treated, only pesticides with mortality represented) and physicochemical properties when all pesticides are included and when pyrethroids are excluded from analysis.

	All pesticides N=14		**No pyrethroids N=8**	
	R^2	**p**	**R^2**	**p**
log foliar DT50	0.20	0.48	-0.20	0.63
log K_{oc}	-0.44	0.12	-0.053	0.90
log K_{ow}	-0.54	**0.044**	0.12	0.78
log soil DT50	-0.33	0.25	-0.49	0.22
log solubility	0.64	**0.013**	-0.11	0.80
log vp	0.47	0.09	-0.65	0.08
mw	-0.69	**0.006**	0.28	0.51
PCA 1	-0.69	**0.006**	0.28	0.49

Figure 4: Correlation between molecular weight and mortality per area treated.

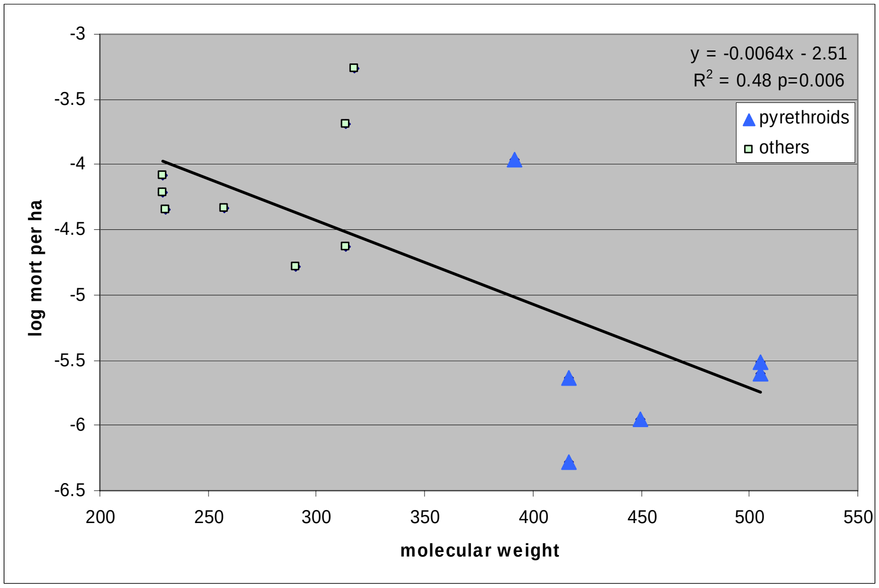
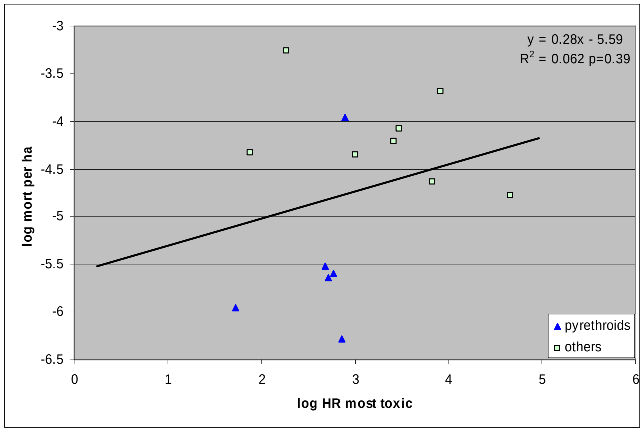
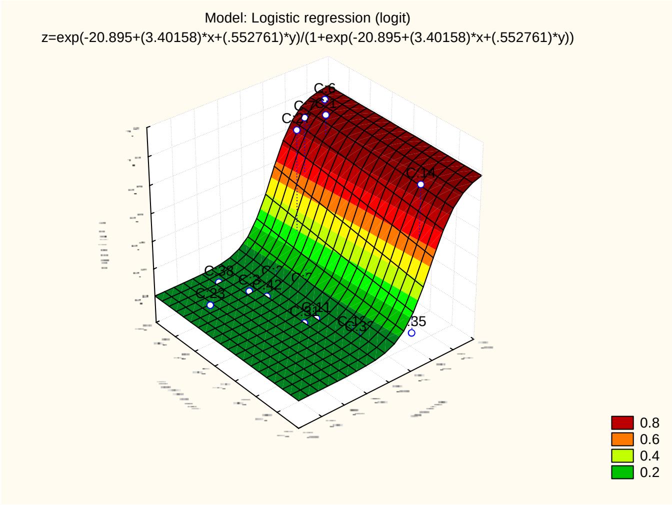


Figure 5: Correlation between HR and mortality per area treated.



Pyrethroids have a quick knock down effect (bursts of contractions as a result of sodium channels in neurons being maintained for a longer length of time than usual in an open conformation, which culminates with paralysis (Bloomquist, 1996)) , and some are bee repellents. The quick knock down means that bees are more likely to die away from the hive, and not be reported to the WIIS. As the area that is treated increases, the distance between the sprayed field and the hive is likely to decrease, which in turn heightens the likelihood that the bees will return to the hive to die. When pyrethroids are analysed separately, there is no effect of HR (the range being quite small), and area treated becomes the only factor of importance in predicting an incident (Chi^2 =10.62 p=0.005; figure 6). Unfortunately, attempts to build predictive models without the pyrethroids ran in to sample size problems and lower overall model performance.

Figure 6: Relationship between the most toxic HR and area with synthetic pyrethroids alone. Permethrin in oilseeds was excluded due to uncertainty with area treated (see above).



4 DISCUSSION/CONCLUSION:

Both oral and contact toxicity, along with the scale of pesticide use, can be used to predict the likelihood that honeybee mortality will occur, and in turn be reported to the United Kingdom Wildlife Incident Investigation Scheme (WIIS). Additionally, including physicochemical properties in the models did not greatly increase their power of prediction and whatever influence they did have likely resulted from a difference between pyrethroid and non-pyrethroid insecticides. This is most likely because of a differential reporting rate for the two groups. Therefore, simple comparisons of HR values should be adequate to compare the toxicity of different pesticides to bees. From this analysis, it is clear that the lack of any mortality incident data is no grounds to declare a product 'safe' to bees. The area treated has an overwhelming influence on predicting whether incidents with any particular insecticide are reported.

The pesticides used in this analysis have correlated HR_{oral} and $HR_{contact}$. This is partly due to the fact that they act both on contact and through stomach action. It is reasonable therefore that both hazard ratios create acceptable models. Most of the bee mortalities observed in this database were cases where contaminated pollen was brought back to the hive, killing large numbers of hive bees. Chemicals that kill bees only in the field are likely to be under-reported as argued above for pyrethroids. This may be one reason why some pesticides that would be expected to kill bees on the basis of high HR values (or at least values higher than other insecticides for which there are mortality events on record) do not have any recorded incidents. It would be interesting to see whether 'time to knockdown', assuming it were available for all products, is a good model predictor.

To better show the effect of the area treated, we used the best overall model equation from table 18 (containing HR, area treated and crop) to estimate the probability that a bee mortality incident would be reported to the scheme if the area treated equalled 81,500 ha for each insecticide (table 20). This surface area was chosen because it is the geometric mean of the 20-year cumulative area treated for each insecticide in our sample. This shows that some insecticides (e.g.

chlorpyrifos) with no documented incidents carry an extreme risk for bees and should be considered highly hazardous until demonstrated otherwise.

One observation is that mortality is much more likely to be observed in oilseeds than in pulses given equivalent hazard ratios. This may be because bees are more vulnerable in oilseeds on account of their foraging behaviour or that beekeepers are more likely to associate mortality with pesticide use in that crop. Because the reason for this difference is not known, it would be prudent to use the HR values established for oilseed crops in setting risk classes based on HR.

We found that pyrethroid-induced incidents are under-represented relative to their toxicity. Pyrethroids are very toxic compounds with a rapid mode of action (Tomlin 2003), which means that they have the potential to kill bees in the field away from the hive. The mortality in these cases is not likely to be observed. Also, because of the low application rate, bees that were killed by pyrethroids are likely to contain very small concentrations of pesticide, making analysis difficult. Some pyrethroids however have a repellent action (Tomlin 2003), which means that the number of mortality incidents may be lower despite high toxicity. Not knowing whether this reported repellency is sufficient to prevent mortality, or whether mortality is occurring undetected, makes protecting wild pollinators from this class of chemicals problematical.

Although, it is difficult from this exercise to set strict HR limits, a few rules of thumb are plausible. There appears to be negligible risk from applications with $HR_{contact}$ values below 50. This is a very nice validation of the first Tier cutoff value of 50 proposed in the EU Guidance Document on Terrestrial Ecotoxicology (SANCO/10329/2002 rev2 final). The latter was apparently established form unpublished field trials. Beyond an $HR_{contact}$ of 400 the risk of recording hive mortality incidents is extreme (circa 50% probability) for any pesticide in broad usage.

Table 20: Predictive capability of the best overall model (from table 18). We calculated the probability of observing mortality in the two crop types when area treated is 81 500 ha based on the best model including HR_{cont}.

Chemical	Crop	HR_{cont}	HR_{oral}	observed incidents	area treated	application rate	Probability of observed incident
Pirimicarb	Oilseeds	3.6	19.0	0	78370	115	5.9%
Diquat	Oilseeds	8.9	37.0	0	1463877	573	9.6%
Lambda-cyhalothrin	Oilseeds	53.5	13.0	1	894051	6	23.1%
Phosalone	Oilseeds	54.5	81.3	0	114734	729	23.3%
Oxydemeton-methyl	Oilseeds	63.3	255.7	0	5208	241	24.8%
Paraquat	Oilseeds	76.0	76.0	8	171721	689	26.9%
Fenvalerate	Oilseeds	80.3	82.3	0	87511	34	27.5%
Azinphos-methyl/demeton-S-methyl sulphone	Oilseeds	99.0	189.0	2	3642	48	30.0%
Esfenvalerate	Oilseeds	148.7	29.4	0	55587	6	35.2%

Table 20: Predictive capability of the best overall model (from table 18). We calculated the probability of observing mortality in the two crop types when area treated is 81 500 ha based on the best model including HR_{cont}.

Chemical	Crop	HR_{cont}	HR_{oral}	observed incidents	area treated	application rate	Probability of observed incident
Zeta-cypermethrin	Oilseeds	286.1	113.1	0	153994	10	44.3%
Demeton-S-methyl	Oilseeds	453.0	1294.3	0	48224	272	50.9%
Bifenthrin	Oilseeds	464.4	68.4	0	23651	7	51.3%
Alpha-cypermethrin	Oilseeds	513.9	257.0	4	1748947	15	52.7%
Deltamethrin	Oilseeds	585.9	62.7	2	792750	9	54.6%
Cypermethrin	Oilseeds	728.5	288.1	2	3861419	25	57.7%
Permethrin	Oilseeds	789.8	312.3	1	9196	50	58.9%
Gamma-HCH	Oilseeds	1707.2	45835.3	7	422362	504	69.1%
Dimethoate	Oilseeds	2049.8	2973.1	3	36368	336	71.4%
Cyfluthrin	Oilseeds	2132.6	259.4	0	7449	13	71.8%
Triazophos	Oilseeds	8221.7	6110.8	115	557798	452	84.8%

Table 20: Predictive capability of the best overall model (from table 18). We calculated the probability of observing mortality in the two crop types when area treated is 81 500 ha based on the best model including HR_{cont}.

Chemical	Crop	HR_{cont}	HR_{oral}	observed incidents	area treated	application rate	Probability of observed incident
Chlorpyrifos	Oilseeds	9346.6	2445.2	0	10656	556	85.7%
pirimicarb/Lambda-cyhalothrin	Pulses	0.3	1.7	0	48523	11	0.3%
Pirimicarb	Pulses	3.4	17.9	0	994851	109	1.2%
Diquat	Pulses	8.5	35.1	0	545392	543	2.1%
Oxydemeton-methyl	Pulses	45.0	181.8	0	18712	171	5.3%
Paraquat	Pulses	46.8	46.8	0	97121	424	5.4%
Lambda-cyhalothrin	Pulses	48.8	11.9	0	539127	5	5.5%
Fenvalerate	Pulses	68.8	70.5	0	87925	29	6.7%
Esfenvalerate	Pulses	151.6	29.9	0	31720	6	10.2%
Zeta-cypermethrin	Pulses	356.4	140.9	0	32735	12	15.7%

Table 20: Predictive capability of the best overall model (from table 18). We calculated the probability of observing mortality in the two crop types when area treated is 81 500 ha based on the best model including HR_{cont}.

Chemical	Crop	HR_{cont}	HR_{oral}	observed incidents	area treated	application rate	Probability of observed incident
Demeton-S-methyl	Pulses	358.0	1022.8	4	89590	215	15.7%
Alpha-cypermethrin	Pulses	431.5	215.8	0	83344	13	17.2%
Deltamethrin	Pulses	480.0	51.3	1	326721	7	18.1%
Bifenthrin	Pulses	501.8	74.0	0	3786	7	18.5%
Cypermethrin	Pulses	712.2	281.7	0	1561383	24	21.8%
Permethrin	Pulses	734.6	290.5	0	13685	47	22.1%
Dimethoate	Pulses	1807.3	2621.3	26	424996	297	32.3%
Cyfluthrin	Pulses	2137.3	260.0	0	5107	13	34.5%
Gamma-HCH	Pulses	3417.0	91743.1	0	4046	1009	40.9%
Fenitrothion	Pulses	5715.1	3098.0	0	18952	545	48.3%
Triazophos	Pulses	6701.4	4980.8	5	213772	369	50.6%

Table 20: Predictive capability of the best overall model (from table 18). We calculated the probability of observing mortality in the two crop types when area treated is 81 500 ha based on the best model including HR_{cont}.

Chemical	Crop	HR_{cont}	HR_{oral}	observed incidents	area treated	application rate	Probability of observed incident
Chlorpyrifos	Pulses	10089.2	2639.5	0	10305	600	56.5%

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6 APPENDICES

APPENDIX A: Chemicals used and omitted from the Analysis.

Table A.1: Chemicals used in analysis

Pesticide	**crop**	**survey years**	**area treated ha min**	**area treated ha max**	**appl rate g ai/ha min**	**appl rate g ai/ha max**	**Mean application rate g ai/ha**
Alpha-cypermethrin	oilseeds	1988, 90, 92, 94, 96, 98, 2000, 2002	2820	173145	12.11	19.24	15.42
Alpha-cypermethrin	Pulses	1988, 90, 92, 94, 96, 98, 2000, 2002	1162	29502	10.33	19.37	12.95
Azinphos-methyl/demeton-S-methyl sulphone	oilseeds	1982, 1990	126	615	8.25	56	47.88
Bifenthrin	oilseeds	1988, 90, 92, 94, 96, 2002	720	5189	5.56	8.47	6.84
Bifenthrin	Pulses	1992	1893		7.4		
Chlorpyrifos	oilseeds	1990, 92, 94, 96, 2000	91	1907	213.82	720	555.93
Chlorpyrifos	Pulses	1990, 92, 96, 98	410	2208	153.66	720.76	600.1
Cyfluthrin	oilseeds	88, 90, 92	673	1936	11.89	13.43	12.97
Cyfluthrin	Pulses	1988, 90	662	1261	12.69	13.6	13
Cypermethrin	oilseeds	1988, 90, 92, 94, 96, 98, 2000, 2002	54238	390118	24.13	26.79	25.01

Table A.1: Chemicals used in analysis

Pesticide	**crop**	**survey years**	**area treated ha min**	**area treated ha max**	**appl rate g ai/ha min**	**appl rate g ai/ha max**	**Mean application rate g ai/ha**
Cypermethrin	Pulses	1988, 90, 92, 94, 96, 98, 2000, 02	48042	134722	22.12	26.85	24.45
Deltamethrin	oilseeds	1988, 90, 92, 94, 96, 98, 2000, 2002	11074	110839	6.23	15.63	8.53
Deltamethrin	Pulses	1988, 90, 92, 94, 96, 98, 2000, 02	7906	28416	6.39	10.5	6.99
Demeton-S-methyl	oilseeds	1977, 1990, 92, 96	277	5475	202.17	291.32	271.81
Demeton-S-methyl	Pulses	1977, 82, 88, 90, 92, 94, 96, 98,	365	11205	189.29	264.72	214.78
Dimethoate	oilseeds	1988, 90, 92, 94, 96, 98, 2000, 2002	268	6822	224.91	423.17	336.36
Dimethoate	Pulses	1977, 88, 90, 92, 94, 96, 98, 2000, 02	433	33122	262.01	351.6	296.57
Diquat	oilseeds	1977, 82, 88, 90, 92, 94, 96, 98, 2000, 02	2158	160083	531.28	656.06	573.06
Diquat	Pulses	1982, 88, 90, 92, 94, 96, 98, 2000, 02	5379	59418	509.82	656.63	543.42
Esfenvalerate	oilseeds	94, 96, 98, 2000, 2002	792	9002	2.53	8.11	6.17
Esfenvalerate	Pulses	1994, 96, 98, 2000, 02	85	6077	4.26	11.76	6.29
Fenitrothion	Pulses	1990, 94, 98	1097	1927	394.91	700.09	545.25
Fenvalerate	oilseeds	1988, 90, 92, 94, 98	244	25727	24.59	35.02	33.57

Table A.1: Chemicals used in analysis

Pesticide	crop	survey years	area treated ha min	area treated ha max	appl rate g ai/ha min	appl rate g ai/ha max	Mean application rate g ai/ha
Fenvalerate	Pulses	1988, 90, 92, 94	2848	15447	27.27	29.78	28.75
Gamma-HCH	oilseeds	1977, 82, 88, 90, 92, 94, 96, 98, 2000	1047	43758	310.67	1230.03	504.19
Gamma-HCH	Pulses	1988, 90, 92, 98, 2000, 02	42	807	839.57	1100.37	1009.17
heptenophos/Deltamethrin	Pulses	1988, 90, 92, 94, 96, 98, 2000, 02	567	16626	43.03	52.28	49.63
Lambda-cyhalothrin	oilseeds	1992, 94, 96, 98, 2000, 2002	27397	129390	5.48	6.24	5.91
Lambda-cyhalothrin	Pulses	1992, 94, 96, 98, 2000, 02	9153	110224	4.86	6.38	5.39
Oxydemeton-methyl	oilseeds	1990, 94	780	956	239.54	242.31	240.78
Oxydemeton-methyl	Pulses	1990, 02	74	6188	148.65	171.46	171.19
Paraquat	oilseeds	1977, 82, 88, 90, 92, 94, 96, 98, 2000, 02	360	23507	372.02	887.74	688.89
Paraquat	Pulses	1977, 88, 90, 92, 94, 96, 98, 2000, 02	797	10660	288.23	887.65	423.85
Permethrin	oilseeds	1988	836		50.24		
Permethrin	Pulses	1982, 88	392	2818	25.51	49.68	46.73
Phosalone	oilseeds	1977, 82, 1988, 1990	2082	17458	460.13	860.38	729.13

Table A.1: Chemicals used in analysis

Pesticide	crop	survey years	area treated ha min	area treated ha max	appl rate g ai/ha min	appl rate g ai/ha max	Mean application rate g ai/ha
Pirimicarb	oilseeds	1988, 90, 92, 94, 96, 98, 2000, 2002	867	18600	50.81	209.95	115.26
Pirimicarb	Pulses	1977, 88, 90, 92, 94, 96, 98, 2000, 02	2208	97677	92.14	173.34	108.96
Triazophos	oilseeds	1977, 82, 88, 90, 92, 94, 96, 98	335	56667	388.51	800	452.2
Triazophos	Pulses	1977, 88, 90, 92, 94, 96, 98, 2000	873	29697	302.67	799.54	368.58
Zeta-cypermethrin	oilseeds	1998, 00, 02	19228	32197	9.04	10.25	9.82
Zeta-cypermethrin	Pulses	1998, 2000, 02	1638	15985	9.77	12.7	12.24

Table A.2: Chemicals omitted from the analysis

Pesticide	crop	survey years	area treated ha min	area treated ha max	application rate gai/ha min	application rate g ai/ha max	Mean application rate gai/ha
Aldicarb (soil application)	oilseeds	1990	35			514	
Azinphos-methyl	oilseeds	1977	2820			310	
Azinphos-methyl/demeton-S-methyl sulphone	Pulses	1990	415	415	216.87	216.87	
Benfuracarb	oilseeds	1992	139			655	
Chemicals not used in analysis	oilseeds						
DDT	Pulses	1977, 82	742	1181	979.78	1049.96	1022.88
Deltamethrin/heptenophos	oilseeds	1992, 1994, 1998	566	1534	2.35	5.32	3.79
Deltamethrin/heptenophos	Pulses	1988, 90, 92, 94, 96, 98, 2000, 02	567	16626	2.69	3.27	3.1
Deltamethrin/pirimicarb	oilseeds	1998	2275			115.6	
Deltamethrin/pirimicarb	Pulses	1996, 98, 2000, 02	1497	5421	0.73	0.85	0.79
Disulfoton	Pulses	1977, 1998	102	818	196.08	1315.4	1191.3
heptenophos/Deltamethrin	oilseeds	1992, 1994, 1998	566	1534	37.55	85.06	60.7
heptenophos/Deltamethrin	Pulses	1988, 90, 92, 94, 96, 98, 2000, 02	567	16626	43.03	52.28	49.63

Table A.2: Chemicals omitted from the analysis

Pesticide	crop	survey years	area treated ha min	area treated ha max	application rate gai/ha min	application rate g ai/ha max	Mean application rate gai/ha
Lambda-cyhalothrin/pirimicarb	oilseeds	1998	1280				
Lambda-cyhalothrin/pirimicarb	Pulses	1998, 2000, 02	667	13862	0.52	0.67	0.53
Malathion	oilseeds	1977, 1988	57	947	1263.16	1500528	1487.05
Nicotine	oilseeds	2002	32				
Phorate	oilseeds	1988, 90, 92	286	3427	1790.51	2249.78	2194.36
Phorate (soil application)	Pulses	1982, 88, 90, 92, 96	191	2731	1099.29	2550.85	1621.8
pirimicarb/Deltamethrin	Pulses	1996, 98, 2000, 02	1497	5421	9.78	11.36	10.49
pirimicarb/Lambda-cyhalothrin	Pulses	1998, 2000, 02	667	13862	10.37	13.34	10.58
Tau-fluvalinate	oilseeds	1998, 2002	409	411	22.01	46.23	34.15

APPENDIX B: Comparison of the weighted mean application rates from the UK surveys to those published in other sources.

Canada: PMRA database of pesticide label information, 1985-2005. USA: USDA Crop Profiles, includes typical use information and that stated on pesticide labels, National Agricultural Statistics Service, and EPA Pesticide Product Label System (PPLS). PAN: Pesticide Action Network, California's record of pesticide use from 1991-2003. Europe: pesticide label information. All application rated in g ai/ha

chemical	crop	Mean application rate g ai/ha	Canada	USA	PAN	Europe	OTHER	COMMENT
Alpha-cypermethrin	oilseeds	15.42				100	16.7	Europe: pdfs, oilseed rape; other: INCHEM website
Alpha-cypermethrin	Pulses	12.95				10-15	16.7	Europe: pdfs, wheat/cabbage; other: INCHEM website
Bifenthrin	oilseeds	6.84	na	28-112	44.8			USA: beans only; PAN oilseeds, other crops 89.7-112.1
Bifenthrin	Pulses		na	28-112	89.7-112.1			USA: beans only; PAN beans and other crops
Chlorpyrifos	oilseeds	555.93	562-1125; 240-1152		516-2275			Canada, 1985 and 2005 data; PAN all crops
Chlorpyrifos	Pulses	600.1	562-1125; 240-576		516-2275			Canada, 1985 all crops and 2005 beans; PAN all crops
Cyfluthrin	oilseeds	12.97	na		33.6-44.8		14-56	PAN: cotton; other: Bayer world
Cyfluthrin	Pulses	13	na		33.6-44.8		14-56	PAN: cotton; other: Bayer world

chemical	crop	Mean application rate g ai/ha	Canada	USA	PAN	Europe	OTHER	COMMENT
Cypermethrin	oilseeds	25.01	20.4-28.5		44.8-123.3			Canada, 1994, 2005 rapeseed-other crops 35.6-71; PAN only cotton
Cypermethrin	Pulses	24.45	35.6-71		44.8-123.3			Canada, 1994, 2005 all crops; PAN only cotton
Deltamethrin	oilseeds	8.53	5-7.5		33.7		2.15-5.38	Canada 1992 oilseeds other crops same; PAN cotton only; other Bayer world
Deltamethrin	Pulses	6.99	5-7.5		33.7		2.15-5.38	Canada 1992 all crops; PAN cotton only; other Bayer world
Demeton-S-methyl	oilseeds	271.81	na	na	na			USA used in Michigan
Demeton-S-methyl	Pulses	214.78	na	na	na			USA used in Michigan
Dimethoate	oilseeds	336.36	408-432	190-560	392-785			Canada: 1996 rapeseed; USA several crops mostly beans; PAN: range all crops
Dimethoate	Pulses	296.57	336-1440; 132-480; 240-480	190-560	392-785			Canada: 1985 all crops- 1996 peas-2002 all veggies; USA beans; PAN: range beans
Diquat	oilseeds	573.06	300-550	280	930-1592			Canada: canola other crops 300-850; USDA potatoes; PAN all crops
Diquat	Pulses	543.42	300-550		549-3195			Canada: beans2001; PAN all crops
Esfenvalerate	oilseeds	6.17		33.6-56.0	33.6-67.3			all crops
Esfenvalerate	Pulses	6.29		33.6-56.0	44.8-56.0			beans only
Fenitrothion	Pulses	545.25	2000					Canada: agricultural use registered 1978-1996

chemical	crop	Mean application rate g ai/ha	Canada	USA	PAN	Europe	OTHER	COMMENT
Fenvalerate	oilseeds	33.57			22.417			average over all California
Fenvalerate	Pulses	28.75			22.417			average over all California
Gamma-HCH	oilseeds	504.19	55-110; 560-1130		4.82-1110			Canada: 1991and 2002 corn/celery; PAN all crops, safflower is lower appl rate
Gamma-HCH	Pulses	1009.17	55-110; 560-1130		4.82-1110			Canada: 1991and 2002 corn/celery; PAN all crops, safflower is lower application rate
heptenophos/Deltamethrin	Pulses	49.63						
Lambda-cyhalothrin	oilseeds	5.91	5-10		33.6			Canada: oilseed crops 2001-other crops max 15.2 same in 1996; PAN all crops, one application rate
Lambda-cyhalothrin	Pulses	5.39	5-10; 5-12.5; 5-15.2		33.6			Canada: all crops registered first 1996-1996-2001; PAN all crops, one application rate
Oxydemeton-methyl	oilseeds	240.78	420-564	460-560	527-560			Canada: 1995 all field crops; USA brassicas; PAN all crops 1991-2002
Oxydemeton-methyl	Pulses	171.19	420-564	460-560	527-560			Canada: 1995 all field crops; USA brassicas; PAN all crops 1991-2002
Paraquat	oilseeds	688.89	480-960		942-1054	180-1100		Canada: canola other crops 550-1100; PAN safflower, sunflower-other crops 549-3195; Europe pdfs all crops listed

chemical	crop	Mean application rate g ai/ha	Canada	USA	PAN	Europe	OTHER	COMMENT
Paraquat	Pulses	423.85	550-1100	280	1120	180-1100		Canada: beans; USDA potatoes; PAN beans; Europe: pdfs beans/veggies- fruiting veggies 360-600
Permethrin	Pulses	46.73	100; 20-50;		101-213			Canada: 1995 beans-1994 all crops: PAN all crops
Phosalone	oilseeds	729.13		415-751				USA: NASS only on pecans
Pirimicarb	oilseeds	115.26	75-275					Canada: all crops1995-1993
Pirimicarb	Pulses	108.96	75-138					Canada: all crops1995-1993
Triazophos	oilseeds	452.2						
Triazophos	Pulses	368.58						
Zeta-cypermethrin	oilseeds	9.82		31-56	33.6-56			USDA: cotton, cabbage; PAN all crops
Zeta-cypermethrin	Pulses	12.24		31-56	44.8-56			USDA: cotton, cabbage; PAN all crops

APPENDIX C: The honeybee oral and contact LD_{50}s.

Pesticide	Study Type	geomean LD_{50} (ug/bee)	values of LD50 (ug/bee)	Source	Reference
Alpha-cypermethrin	Contact	0.0300	0.03	AGRITOX	Agrishell
	oral	0.0600	0.06	INCHEM; Agritox	Murray (1985); Agrishell
Azinphos-methyl	Contact	0.4837	0.42	One liner 2004	UCR 1976
	Contact		0.423	AGRITOX	ATKINS
	Contact		0.637	University of California	
	Oral	0.2534	0.15	One liner 2004	REF 1968
	oral		0.428	University of California	
Bifenthrin	Contact	0.0147	0.0146	One liner 2004	FMC 1981
	Contact		0.01462	REF	PM 2000 (12th)
	Contact		0.015	AGRITOX	FMC Corporation
	oral	0.1000	0.1	AGRITOX; REF	FMC Corporation; PM 2000 (12th)
Chlorpyrifos	Contact	0.0595	0.01	One liner 2004	REF 1969
	Contact		0.059	AGRITOX	Dictionary of substances and their effects

Pesticide	**Study Type**	**geomean LD_{50} (ug/bee)**	**values of LD50 (ug/bee)**	**Source**	**Reference**
Chlorpyrifos	Contact		0.059	One liner 2004	REF 1978
	Contact		0.059-0.07	AGRITOX	Makhteshim (ISRAEL)
	Contact		0.07	AGRITOX; REF	DowElanco; PM 2000 (12th)
	Contact		0.114	One liner 2004	UCR 1976
	Contact		0.147	University of California	
	oral		0.11	University of California	
	oral		0.25	AGRITOX	Dictionary of substances and their effects
	Oral		0.25	One liner 2004	REF 1978
	oral		0.25-0.36	AGRITOX	Makhteshim (ISRAEL)
	oral		0.36	AGRITOX; REF	DowElanco; PM 2000 (12th)
Cyfluthrin	Contact	0.0061	0.037	One liner 2004	UCR 1984
	Contact		0.001	REF	Europa reports
	oral	0.0500	0.05	REF	Europa reports
Cypermethrin	Contact	0.0343	0.02	REF	PM 2000 (12th)

Pesticide	**Study Type**	**geomean LD_{50} (ug/bee)**	**values of LD50 (ug/bee)**	**Source**	**Reference**
Cypermethrin	Contact		0.023	One liner 2004	ICI 1980
	Contact		0.088	One liner 2004	ICI 1980
	oral	0.0868	0.035	REF	PM 2000 (12th)
	Oral		0.11	One liner 2004	ICI 1980
	Oral		0.17	One liner 2004	ICI 1980
Deltamethrin		0.0146	0.05	AGRITOX	Procida
	Contact		0.0015	One liner 2004	WLI 1991
	Contact		0.0015	REF	Europa reports
	Contact		0.01	REF	Europa reports
	Contact		0.051	INCHEM; REF	Stevenson et al. (1978); PM 2000 (12th); Europa reports
	Contact		0.067	One liner 2004	UCR 1976
	oral	0.1362	0.079	EXTOXNET	Leahey, J. P. (ed). 1985. The Pyrethroid Insecticides. Taylor and Francis. London and Philadelphia
	oral		0.079	INCHEM; REF	Stevenson et al. (1978); PM 2000 (12th); Europa reports
	oral		0.28	REF	Europa reports

Pesticide	**Study Type**	**geomean LD_{50} (ug/bee)**	**values of LD50 (ug/bee)**	**Source**	**Reference**
Deltamethrin	oral		0.4	EXTOXNET	Leahey, J. P. (ed). 1985. The Pyrethroid Insecticides. Taylor and Francis. London and Philadelphia
Demeton-S-methyl	Contact	0.6000	0.6	INCHEM	Westlake et al 1985
	Contact		0.26	INCHEM	Westlake et al 1985
	oral	0.2100	0.21	INCHEM	Westlake et al 1985
Dimethoate	Contact	0.1641	0.098-0.12	INCHEM	Stevenson (1968)
	Contact		0.1-0.2	REF	PM 2000 (12th)
	Contact		0.12	AGRITOX	Agrochemicals Handbook
	Contact		0.16	One liner 2004	HRC 1972
	Contact		0.17	One liner 2004	HRC 1974
	Contact		0.19	One liner 2004	UCR 1975
	Contact		0.316	University of California	
	Oral	0.1131	0.05	One liner 2004	HRC 1972
	Oral		0.08	One liner 2004	HRC 1974
	oral		0.093-0.15	INCHEM	Stevenson (1968)

Pesticide	**Study Type**	**geomean LD_{50} (ug/bee)**	**values of LD50 (ug/bee)**	**Source**	**Reference**
Dimethoate	oral		0.1-0.2	REF	PM 2000 (12th)
	oral		0.15	AGRITOX	Agrochemicals Handbook
	oral		0.191	University of California	
Diquat	Contact	64.1357	100	One liner 2004	UCR NR
	Contact		47	One liner 2004	ICI 1987
	Contact		60	REF	Europa reports
	oral	15.4918	13	REF	Europa reports
Esfenvalerate	Contact	0.0415	0.017	REF	PM 2000 (12th)
	Contact		0.06	REF	Europa reports
	Contact		0.07	AGRITOX	European Union
	oral	0.2100	0.21	REF; Agritox	Europa reports; European Union
Fenitrothion	Contact	0.0954	0.018	One liner 2004	REF 1978
	Contact		0.03	INCHEM	Okada & Hoshiba (1970)
	Contact		0.13	INCHEM; Agritox	Takeuchi et al. (1980); EHC 133

Pesticide	**Study Type**	**geomean LD_{50} (ug/bee)**	**values of LD50 (ug/bee)**	**Source**	**Reference**
Fenitrothion	Contact		0.294	University of California	
	Contact		0.383	One liner 2004	UCR 1975
	oral	0.1760	0.176	University of California	
Fenvalerate	Contact	0.4182	0.23	REF	PM 2000 (12th)
	Contact		0.41	INCHEM	Atkins et al. (1981)
	Contact		0.41	One liner 2004	REF 1981
	Contact		0.791	University of California	
	oral	0.4080	0.408	University of California	
Gamma-HCH	Contact	0.2953	0.23	REF	PM 2000 (12th)
	oral	0.0110	0.011	REF	PM 2000 (12th)
Lambda-cyhalothrin	Contact	0.1104	0.038	One liner 2004; Agritox	ICI 1984; European Union
	Contact		0.051	INCHEM	Gough et al. (1984)
	Contact		0.095	INCHEM	Gough et al. (1984)
	Contact		0.098	One liner 2004	ICI 1984

Pesticide	**Study Type**	**geomean LD_{50} (ug/bee)**	**values of LD50 (ug/bee)**	**Source**	**Reference**
Lambda-cyhalothrin	Contact		0.909	REF	PM 2000 (12th)
	oral	0.4545	0.038	REF	PM 2000 (12th)
	Oral		0.48	One liner 2004	ICI 1984
	oral		0.57	INCHEM	Gough et al. (1984)
	oral		0.91	AGRITOX	European Union
	Oral		0.96	One liner 2004	ICI 1984
	oral		0.97	INCHEM	Gough et al. (1984)
Oxydemeton-methyl	Contact	3.8019	0.54	AGRITOX	Bayer France
	Contact		2.15	One liner 2004	UCR 1980
	Contact		24.39	One liner 2004	UCR 1980
	Contact		3	One liner 2004; Agritox	UCR 1975; Atkins
	Contact		9.35	University of California	
	oral	0.9416	0.31	AGRITOX	Bayer France
	oral		2.86	University of California	

Pesticide	**Study Type**	**geomean LD_{50} (ug/bee)**	**values of LD50 (ug/bee)**	**Source**	**Reference**
Paraquat	Contact	9.0600	9.06	REF	Europa reports
	oral	9.0600	9.06	REF	Europa reports
Permethrin	Contact	0.0636	0.024	One liner 2004	ICI 1993
	Contact		0.029	REF	PM 2000 (12th)
	Contact		0.05	One liner 2004	ICI 1975
	Contact		0.11	INCHEM	Stevenson et al. (1978)
	Contact		0.272	University of California	
	oral	0.1609	0.098	REF	PM 2000 (12th)
	Oral		0.13	One liner 2004	ICI 1993
	oral		0.159	University of California	
	Oral		0.19	One liner 2004	REF 1975
	oral		0.28	INCHEM	Stevenson et al. (1978)
Phosalone	Contact	13.3716	20	University of California	
	Contact		8.94	AGRITOX	US department of Agriculture

Pesticide	Study Type	geomean LD_{50} (ug/bee)	values of LD50 (ug/bee)	Source	Reference
Phosalone	oral	8.9700	8.97	University of California	
Pirimicarb	Contact	32.0651	18.7	AGRITOX	ATKINS
	Contact		18.72	One liner 2004	UCR 1975
	Contact		20-50	AGRITOX	Imperial Chemical industries
	Contact		52.2	University of California	
	Contact		53	REF	PM 2000 (12th)
	oral	6.0790	1.0-5	AGRITOX	Imperial Chemical industries
	oral		18.72	University of California	
	oral		4	REF	PM 2000 (12th)
Triazophos	Contact	0.0550	0.055	REF	MAFF Evaluation Document #84
	oral	0.0740	0.074	REF	MAFF Evaluation Document #84

APPENDIX D: Bee mortality for survey year

chemicals	crop	CAS	area treated in survey years	mortality occurring in survey years
Alpha-cypermethrin	Oilseeds	67375308	851586	1
Alpha-cypermethrin	Pulses	67375308	48044	0
Azinphos-methyl/demeton-S-methyl sulphone	Oilseeds	86500	741	2
Bifenthrin	Oilseeds	82657043	13588	0
Bifenthrin	Pulses	82657043	1893	0
Chlorpyrifos	Oilseeds	2921882	5328	0
Chlorpyrifos	Pulses	2921882	3886	0
Cyfluthrin	Oilseeds	68359375	3469	0
Cyfluthrin	Pulses	68359375	1923	0
Cypermethrin	Oilseeds	52315078	1972337	1
Cypermethrin	Pulses	52315078	756560	0
Deltamethrin	Oilseeds	52918635	342722	0
Deltamethrin	Pulses	52918635	158952	1
Demeton-S-methyl	Oilseeds	919868	6278	0
Demeton-S-methyl	Pulses	919868	30869	3
Dimethoate	Oilseeds	60515	16937	1
Dimethoate	Pulses	60515	166856	11
Diquat	Oilseeds	2764729	599863	0
Diquat	Pulses	2764729	211524	0
Esfenvalerate	Oilseeds	66230044	24157	0
Esfenvalerate	Pulses	66230044	10813	0
Fenitrothion	Pulses	122145	4950	0
Fenvalerate	Oilseeds	51630581	39802	0

chemicals	**crop**	**CAS**	**area treated in survey years**	**mortality occurring in survey years**
Fenvalerate	Pulses	51630581	36239	0
Gamma-HCH	Oilseeds	58899	138105	2
Gamma-HCH	Pulses	58899	1417	0
Lambda-cyhalothrin	Oilseeds	91465086	437731	1
Lambda-cyhalothrin	Pulses	91465086	292543	0
Oxydemeton-methyl	Oilseeds	301122	1736	0
Oxydemeton-methyl	Pulses	301122	6262	0
Paraquat	Oilseeds	4685147	49992	1
Paraquat	Pulses	4685147	41481	0
Permethrin	Oilseeds	52645531	836	0
Permethrin	Pulses	52645531	3210	0
Phosalone	Oilseeds	2310170	28423	0
Pirimicarb	Oilseeds	23103982	38668	0
Pirimicarb	Pulses	23103982	488612	0
pirimicarb/Lambda-cyhalothrin	Pulses	23103982	18796	0
Triazophos	Oilseeds	24017478	173227	40
Triazophos	Pulses	24017478	80092	1
Zeta-cypermethrin	Oilseeds	52315078	75432	0
Zeta-cypermethrin	Pulses	52315078	19450	0

APPENDIX E: Extrapolated pesticide use data for non-survey years

chemical	crop	year	Survey data	Extrapolated data
Gamma-HCH	Oilseeds	1977	7525	
Gamma-HCH	Oilseeds	1981		36511.4
Gamma-HCH	Oilseeds	1982	43758	
Gamma-HCH	Oilseeds	1983		40132.0
Gamma-HCH	Oilseeds	1984		36506.0
Gamma-HCH	Oilseeds	1985		32880.0
Gamma-HCH	Oilseeds	1986		29254.0
Gamma-HCH	Oilseeds	1987		25628.0
Gamma-HCH	Oilseeds	1988	22002	
Gamma-HCH	Oilseeds	1989		20961.0
Gamma-HCH	Oilseeds	1990	19920	
Gamma-HCH	Oilseeds	1991		15837.0
Gamma-HCH	Oilseeds	1992	11754	
Gamma-HCH	Oilseeds	1993		16299.5
Gamma-HCH	Oilseeds	1994	20845	
Gamma-HCH	Oilseeds	1995		16892.5
Gamma-HCH	Oilseeds	1996	12940	
Gamma-HCH	Oilseeds	1997		9389.5
Gamma-HCH	Oilseeds	1998	5839	
Gamma-HCH	Oilseeds	1999		3443.0

chemical	crop	year	Survey data	Extrapolated data
Gamma-HCH	Oilseeds	2000	1047	
Gamma-HCH	Oilseeds	2001		523.5
Gamma-HCH	Oilseeds	2002	0	0.0
			sum	**422362.4**
Alpha-cypermethrin, introduced in 1983 by Agrochem. (PM 2003)				
Alpha-cypermethrin	Pulses	1977	0	0.0
Alpha-cypermethrin	Pulses	1982	0	
Alpha-cypermethrin	Pulses	1983		0.0
Alpha-cypermethrin	Pulses	1984		136.0
Alpha-cypermethrin	Pulses	1985		476.7
Alpha-cypermethrin	Pulses	1986		817.4
Alpha-cypermethrin	Pulses	1987		1158.1
Alpha-cypermethrin	Pulses	1988	1162	
Alpha-cypermethrin	Pulses	1989		1657.5
Alpha-cypermethrin	Pulses	1990	2153	
Alpha-cypermethrin	Pulses	1991		2625.5
Alpha-cypermethrin	Pulses	1992	3098	
Alpha-cypermethrin	Pulses	1993		2639.0
Alpha-cypermethrin	Pulses	1994	2180	
Alpha-cypermethrin	Pulses	1995		2296.5
Alpha-cypermethrin	Pulses	1996	2413	
Alpha-cypermethrin	Pulses	1997		3834.5

chemical	crop	year	Survey data	Extrapolated data
Alpha-cypermethrin	Pulses	1998	5256	
Alpha-cypermethrin	Pulses	1999		3768.0
Alpha-cypermethrin	Pulses	2000	2280	
Alpha-cypermethrin	Pulses	2001		15891.0
Alpha-cypermethrin	Pulses	2002	29502	
			sum	**83344.1**
Dimethoate, reported in 1951 (PM 2003)				
Dimethoate	Oilseeds	1981	0	
Dimethoate	Oilseeds	1982	0	0.0
Dimethoate	Oilseeds	1983		
Dimethoate	Oilseeds	1984		
Dimethoate	Oilseeds	1985		588.5
Dimethoate	Oilseeds	1986		1647.1
Dimethoate	Oilseeds	1987		2705.8
Dimethoate	Oilseeds	1988	2354	
Dimethoate	Oilseeds	1989		4588.0
Dimethoate	Oilseeds	1990	6822	
Dimethoate	Oilseeds	1991		4260.5
Dimethoate	Oilseeds	1992	1699	
Dimethoate	Oilseeds	1993		1471.0
Dimethoate	Oilseeds	1994	1243	
Dimethoate	Oilseeds	1995		755.5

chemical	crop	year	Survey data	Extrapolated data
Dimethoate	Oilseeds	1996	268	
Dimethoate	Oilseeds	1997		1337.0
Dimethoate	Oilseeds	1998	2406	
Dimethoate	Oilseeds	1999		2134.5
Dimethoate	Oilseeds	2000	1863	
Dimethoate	Oilseeds	2001		1072.5
Dimethoate	Oilseeds	2002	282	
			sum	**37497.4**
Deltamethrin, described in 1974, reviewed in1984 (PM 2003)				
Deltamethrin	Oilseeds	1977	0	
Deltamethrin	Oilseeds	1981		5165.9
Deltamethrin	Oilseeds	1982	0	7748.9
Deltamethrin	Oilseeds	1983		10331.8
Deltamethrin	Oilseeds	1984		25107.9
Deltamethrin	Oilseeds	1985		39883.9
Deltamethrin	Oilseeds	1986		54659.9
Deltamethrin	Oilseeds	1987		
Deltamethrin	Oilseeds	1988	54622	
Deltamethrin	Oilseeds	1989		82730.5
Deltamethrin	Oilseeds	1990	110839	
Deltamethrin	Oilseeds	1991		77110.0
Deltamethrin	Oilseeds	1992	43381	

chemical	crop	year	Survey data	Extrapolated data
Deltamethrin	Oilseeds	1993		34169.5
Deltamethrin	Oilseeds	1994	24958	
Deltamethrin	Oilseeds	1995		23258.5
Deltamethrin	Oilseeds	1996	21559	
Deltamethrin	Oilseeds	1997		32164.5
Deltamethrin	Oilseeds	1998	42770	
Deltamethrin	Oilseeds	1999		38144.5
Deltamethrin	Oilseeds	2000	33519	
Deltamethrin	Oilseeds	2001		22296.5
Deltamethrin	Oilseeds	2002	11074	
			sum	**795494.2**
Lambda-cyhalothrin, reported in 1984, introduced in Central America and far east in 1985 (PM 2003)				
Lambda-cyhalothrin	Oilseeds	1981		
Lambda-cyhalothrin	Oilseeds	1982	0	
Lambda-cyhalothrin	Oilseeds	1983		
Lambda-cyhalothrin	Oilseeds	1984		
Lambda-cyhalothrin	Oilseeds	1985		346.6
Lambda-cyhalothrin	Oilseeds	1986		1039.9
Lambda-cyhalothrin	Oilseeds	1987		1559.9
Lambda-cyhalothrin	Oilseeds	1988		2079.9
Lambda-cyhalothrin	Oilseeds	1989		11988.9
Lambda-cyhalothrin	Oilseeds	1990		21897.9

chemical	crop	year	Survey data	Extrapolated data
Lambda-cyhalothrin	Oilseeds	1991		31806.9
Lambda-cyhalothrin	Oilseeds	1992	28549	
Lambda-cyhalothrin	Oilseeds	1993		27973.0
Lambda-cyhalothrin	Oilseeds	1994	27397	
Lambda-cyhalothrin	Oilseeds	1995		55047.5
Lambda-cyhalothrin	Oilseeds	1996	82698	
Lambda-cyhalothrin	Oilseeds	1997		106044.0
Lambda-cyhalothrin	Oilseeds	1998	129390	
Lambda-cyhalothrin	Oilseeds	1999		112034.0
Lambda-cyhalothrin	Oilseeds	2000	94678	
Lambda-cyhalothrin	Oilseeds	2001		84848.5
Lambda-cyhalothrin	Oilseeds	2002	75019	
			sum	**894398.1**
Deltamethrin/heptenophos	Pulses	1982	0.0	0.0
Deltamethrin/heptenophos	Pulses	1983		0.0
Deltamethrin/heptenophos	Pulses	1984		0.0
Deltamethrin/heptenophos	Pulses	1985		1057.8
Deltamethrin/heptenophos	Pulses	1986		2115.5
Deltamethrin/heptenophos	Pulses	1987		3173.3
Deltamethrin/heptenophos	Pulses	1988	4231.0	
Deltamethrin/heptenophos	Pulses	1989		4410.0
Deltamethrin/heptenophos	Pulses	1990		4589.0

chemical	crop	year	Survey data	Extrapolated data
Deltamethrin/heptenophos	Pulses	1991		4768.0
Deltamethrin/heptenophos	Pulses	1992	4947.0	
Deltamethrin/heptenophos	Pulses	1993		10786.5
Deltamethrin/heptenophos	Pulses	1994	16626.0	
Deltamethrin/heptenophos	Pulses	1995		11627.5
Deltamethrin/heptenophos	Pulses	1996	6629.0	
Deltamethrin/heptenophos	Pulses	1997		7490.5
Deltamethrin/heptenophos	Pulses	1998	8352.0	
Deltamethrin/heptenophos	Pulses	1999		7024.0
Deltamethrin/heptenophos	Pulses	2000	5696.0	
Deltamethrin/heptenophos	Pulses	2001		3098.0
Deltamethrin/heptenophos	Pulses	2002	0.0	0.0
			sum	**106621.0**
Chlorpyrifos, commercially introduced 1965				
Chlorpyrifos	Pulses	1988	0	0.0
Chlorpyrifos	Pulses	1989	0	0.0
Chlorpyrifos	Pulses	1990	410	
Chlorpyrifos	Pulses	1991		629.5
Chlorpyrifos	Pulses	1992	849	
Chlorpyrifos	Pulses	1993		1188.8
Chlorpyrifos	Pulses	1994	0	1443.6
Chlorpyrifos	Pulses	1995		1634.7

chemical	**crop**	**year**	**Survey data**	**Extrapolated data**
Chlorpyrifos	Pulses	1996	2208	
Chlorpyrifos	Pulses	1997		1313.5
Chlorpyrifos	Pulses	1998	419	
Chlorpyrifos	Pulses	1999		209.5
Chlorpyrifos	Pulses	2000	0	
Chlorpyrifos	Pulses	2001		
			sum	**10305.5**
Esfenvalerate, first marketed 1987 (PM 2003)				
Esfenvalerate	Pulses	1988	0	
Esfenvalerate	Pulses	1989		
Esfenvalerate	Pulses	1990	0	0.0
Esfenvalerate	Pulses	1991		1519.3
Esfenvalerate	Pulses	1992	0	3038.5
Esfenvalerate	Pulses	1993		4557.8
Esfenvalerate	Pulses	1994	6077	
Esfenvalerate	Pulses	1995		5054.5
Esfenvalerate	Pulses	1996	4032	
Esfenvalerate	Pulses	1997		3120.0
Esfenvalerate	Pulses	1998	85	2208.0
Esfenvalerate	Pulses	1999		1296.0
Esfenvalerate	Pulses	2000	384	
Esfenvalerate	Pulses	2001		309.5

chemical	crop	year	Survey data	Extrapolated data
Esfenvalerate	Pulses	2002	235	
			sum	**31831.5**
Fenitrothion, reported in 1960				
Fenitrothion	Pulses	1982	0	
Fenitrothion	Pulses	1983		
Fenitrothion	Pulses	1984		
Fenitrothion	Pulses	1985		
Fenitrothion	Pulses	1986		0.0
Fenitrothion	Pulses	1987		481.8
Fenitrothion	Pulses	1988	0	963.5
Fenitrothion	Pulses	1989		1445.3
Fenitrothion	Pulses	1990	1927	
Fenitrothion	Pulses	1991		1926.8
Fenitrothion	Pulses	1992	0	1926.6
Fenitrothion	Pulses	1993		1926.4
Fenitrothion	Pulses	1994	1926	
Fenitrothion	Pulses	1995		1760.2
Fenitrothion	Pulses	1996	0	1594.4
Fenitrothion	Pulses	1997		1428.6
Fenitrothion	Pulses	1998	1097	
Fenitrothion	Pulses	1999		548.5
Fenitrothion	Pulses	2000	0	

chemical	crop	year	Survey data	Extrapolated data
			sum	**18952.0**
Fenvalerate	Oilseeds	1982	0	
Fenvalerate	Oilseeds	1983		0.0
Fenvalerate	Oilseeds	1984		948.4
Fenvalerate	Oilseeds	1985		1896.9
Fenvalerate	Oilseeds	1986		2845.3
Fenvalerate	Oilseeds	1987		3793.7
Fenvalerate	Oilseeds	1988	5477	
Fenvalerate	Oilseeds	1989		15602.0
Fenvalerate	Oilseeds	1990	25727	
Fenvalerate	Oilseeds	1991		16659.5
Fenvalerate	Oilseeds	1992	7592	
Fenvalerate	Oilseeds	1993		4177.0
Fenvalerate	Oilseeds	1994	762	
Fenvalerate	Oilseeds	1995		554.8
Fenvalerate	Oilseeds	1996	0	451.2
Fenvalerate	Oilseeds	1997		347.6
Fenvalerate	Oilseeds	1998	244	
Fenvalerate	Oilseeds	1999		0.0
Fenvalerate	Oilseeds	2000	0	0.0
			sum	**87078.4**

chemical	crop	year	Survey data	Extrapolated data
Gamma-HCH, or lindane, reported in 1942				
Gamma-HCH	Pulses	1986		0.0
Gamma-HCH	Pulses	1987		403.5
Gamma-HCH	Pulses	1988	807	
Gamma-HCH	Pulses	1989		590.5
Gamma-HCH	Pulses	1990	374	
Gamma-HCH	Pulses	1991		318.7
Gamma-HCH	Pulses	1992	0	263.3
Gamma-HCH	Pulses	1993		208.0
Gamma-HCH	Pulses	1994	0	152.7
Gamma-HCH	Pulses	1995		97.3
Gamma-HCH	Pulses	1996	42	42.0
Gamma-HCH	Pulses	1997		118.0
Gamma-HCH	Pulses	1998	194	
Gamma-HCH	Pulses	1999		97.0
Gamma-HCH	Pulses	2000	0	
			sum	**3708.0**
Oxydemeton-methyl, registered Canada 1961 PMRA database				
Oxydemeton-methyl	Oilseeds	1988	0	
Oxydemeton-methyl	Oilseeds	1989		390.0
Oxydemeton-methyl	Oilseeds	1990	780	
Oxydemeton-methyl	Oilseeds	1991		824.0

chemical	**crop**	**year**	**Survey data**	**Extrapolated data**
Oxydemeton-methyl	Oilseeds	1992	0	868.0
Oxydemeton-methyl	Oilseeds	1993		912.0
Oxydemeton-methyl	Oilseeds	1994	956	
Oxydemeton-methyl	Oilseeds	1995		478.0
Oxydemeton-methyl	Oilseeds	1996	0	
			sum	**5208.0**
Paraquat, a herbicide used from 1977-2000 in both oilseeds and pulses				
Paraquat	Oilseeds	1981		20199.2
Paraquat	Oilseeds	1982	23507	
Paraquat	Oilseeds	1983		20209.8
Paraquat	Oilseeds	1984		16912.7
Paraquat	Oilseeds	1985		13615.5
Paraquat	Oilseeds	1986		10318.3
Paraquat	Oilseeds	1987		7021.2
Paraquat	Oilseeds	1988	3724	
Paraquat	Oilseeds	1989		4903.5
Paraquat	Oilseeds	1990	6083	
Paraquat	Oilseeds	1991		5762.5
Paraquat	Oilseeds	1992	5442	
Paraquat	Oilseeds	1993		6225.5
Paraquat	Oilseeds	1994	7009	
Paraquat	Oilseeds	1995		5891.8

chemical	crop	year	Survey data	Extrapolated data
Paraquat	Oilseeds	1996	360	4774.5
Paraquat	Oilseeds	1997		3657.3
Paraquat	Oilseeds	1998	2540	
Paraquat	Oilseeds	1999		1933.5
Paraquat	Oilseeds	2000	1327	
Paraquat	Oilseeds	2001		663.5
Paraquat	Oilseeds	2002	0	

APPENDIX F: Final incident data showing extrapolated total for all years of study as well as 81-91 vs. 92-02 split.

chemicals	crop	area treated all years	mortality all years	Area 1981-91	mortality 81-91	Area 1992-02	mortality 92-02
Alpha-cypermethrin	Oilseeds	1748947.3	4	502514.8	2	1246432.5	2
Alpha-cypermethrin	Pulses	83344.1	0	10186.1	0	73158.0	0
Azinphos-methyl/demeton-S-methyl sulphone	Oilseeds	3642.0	2	3642.0	2		0
Bifenthrin	Oilseeds	23650.8	0	6977.3	0	16673.5	0
Bifenthrin	Pulses	3786.0	0		0	3786.0	0
Chlorpyrifos	Oilseeds	10656.0	0	2487.5	0	8168.5	0
Chlorpyrifos	Pulses	10305.5	0	1039.5	0	9266.0	0
Cyfluthrin	Oilseeds	7449.0	0	6159.0	0	1290.0	0
Cyfluthrin	Pulses	5107.0	0	5107.0	0		0
Cypermethrin	Oilseeds	3861418.9	2	704192.9	0	3157226.0	2
Cypermethrin	Pulses	1561382.9	0	404103.4	0	1157279.5	0
Deltamethrin	Oilseeds	792749.8	2	465455.3	2	327294.5	0
Deltamethrin	Pulses	326720.8	1	83955.3	0	242765.5	1
Demeton-S-methyl	Oilseeds	48224.2	0	46078.2	0	2146.0	0
Demeton-S-methyl	Pulses	89590.2	4	66234.7	4	23355.5	0
Dimethoate	Oilseeds	37497.4	3	21836.1	0	14531.5	3
Dimethoate	Pulses	424996.3	26	209157.3	25	215839.0	1
Diquat	Oilseeds	1463877.0	0	730356.5	0	733520.5	0
Diquat	Pulses	545392.2	0	305074.2	0	240318.0	0

chemicals	crop	area treated all years	mortality all years	Area 1981-91	mortality 81-91	Area 1992-02	mortality 92-02
Esfenvalerate	Oilseeds	55587.4	0	3401.4	0	52186.0	0
Esfenvalerate	Pulses	31831.5	0	1519.3	0	30200.5	0
Fenitrothion	Pulses	18952.0	0	6744.3	0	12207.7	0
Fenvalerate	Oilseeds	87078.4	0	72949.8	0	14561.4	0
Fenvalerate	Pulses	87925.0	0	68184.5	0	19740.5	0
Gamma-HCH	Oilseeds	422362.4	7	323389.4	7	98973.0	0
Gamma-HCH	Pulses	3666.0	0	2519.0	0	1527.0	0
Lambda-cyhalothrin	Oilseeds	894398.1	1	70373.5	0	823678.0	1
Lambda-cyhalothrin	Pulses	539127.0	0	13729.5	0	525397.5	0
Oxydemeton-methyl	Oilseeds	5208.0	0	1994.0	0	3214.0	0
Oxydemeton-methyl	Pulses	18712.0	0	18601.0	0	111.0	0
Paraquat	Oilseeds	171720.7	8	132256.7	0	39464.0	8
Paraquat	Pulses	97120.6	0	43089.1	0	54031.5	0
Permethrin	Oilseeds	9196.0	1	3344.0	0	5852.0	1
Permethrin	Pulses	13685.4	0	13685.4	0		0
Phosalone	Oilseeds	114733.8	0	28423	0		0
Pirimicarb	Oilseeds	78369.5	0	17212.0	0	61157.5	0
Pirimicarb	Pulses	994850.5	0	293156.0	0	701694.5	0
pirimicarb/Lambda-cyhalothrin	Pulses	48522.8	0		0	48522.8	0
Triazophos	Oilseeds	557798.0	115	524846.5	115	32951.5	0
Triazophos	Pulses	213772.0	5	171628.5	4	42143.5	1

chemicals	crop	area treated all years	mortality all years	Area 1981-91	mortality 81-91	Area 1992-02	mortality 92-02
Zeta-cypermethrin	Oilseeds	153993.5	0		0	153993.5	0
Zeta-cypermethrin	Pulses	32734.5	0		0	32734.5	0