Monitoring Progress In Meeting the Pesticide Risk Reduction Goals of the WWF/WPVGA Collaboration

In 1996 World Wildlife Fund (WWF) and the Wisconsin Potato and Vegetable Growers Association (WPVGA) launched a collaborative effort to achieve ambitious industry-wide goals of increased adoption of biologically based pest management systems and pesticide risk reduction. The WPVGA represents about 250 growers accounting for nearly all potato production in the state, and has played an active role for more than a decade in supporting IPM research and on-farm innovation designed to lessen the environmental effects of potato production systems.

WWF is an international environmental organization working to protect species, enhance wildlife habitat, and prevent pollution through the reward of private sector commitment to environmental stewardship. Now in its fourth decade, WWF works in more than 100 countries around the globe and has over 1.4 million members in the United States.

Major goals of the collaboration between WPVGA and WWF include developing and promoting adoption of biointensive Integrated Pest Management[1] (IPM) systems and demonstrating the linkages between IPM and pesticide use and risk reduction. A critical step in demonstrating such a linkage is developing a method to take into account the highly variable toxicity of pesticides on a pound-for-pound basis in terms of the public health and environmental consequences of changes in pesticide use. In this technical paper we summarize the pesticide toxicity adjustment methodology developed by WPVGA and WWF, with the assistance and support of scientists at the University of Wisconsin -- Madison. The toxicity adjustment index described in this paper will be used to monitor over time the progress made by WPVGA in meeting the pesticide risk reduction targets established in the collaboration between WWF/WPVGA.

The toxicity adjustment index , and the database supporting its application to potato pesticides, will continue to evolve over the life of the project. A number of researchers and organizations, both in the U.S. and abroad, are working to refine methods to quantify pesticide impacts on human health, wildlife, and the environment. We will incorporate the data and methodological improvements generated by these efforts over time and issue revised versions of the toxicity adjustment index.

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[1] Biointensive IPM in agriculture is defined as – "A systems approach to pest management that is based on an understanding of pest ecology. It relies on resistant varieties and promoting plant health, crop rotation, disrupting pest reproduction, and the management of biological processes to diversify and build populations of beneficial organisms. Reduced risk pesticides, including biopesticides, are used only as a last resort and only in ways to minimize risks." (From *Pest Management at the Crossroads*, pages 178-179, Benbrook, C., Groth, E., Hansen, M., Halloran, J., and S. Marquart, Consumers Union, 1996. See also the PMAC website, http://www.pmac.net, and the WWF-WPVGA Potato IPM Project Web-page, http://www.pmac.net/wwfwpvga/bioipm.htm).

A. The Need for a Toxicity Adjustment Methodology

Interest is growing worldwide in the potential of IPM to reduce the direct and indirect health and environmental costs associated with heavy reliance on pesticides. Both state and federal agencies have initiated or are participating in programs designed to promote adoption of IPM. Environmental and consumer groups, including the World Wildlife Fund, are also exploring ways to promote and reward IPM adoption through marketplace initiatives (for a review of WWF's involvement, see Hoppin, 1996).

Better measures of IPM adoption, linked to pesticide use and risk reduction, are needed in part because of the rapid pace of innovation in the design and practice of pest management systems. Several factors are driving change –

- Introduction of new diagnostic tools, expert systems, and phenology-based growth and pest management models;
- Discovery of promising biopesticides and other lower-risk pesticides;
- Emergence of new IPM techniques like mating disruption and augmentation of soil microbial activity;
- Marketing of seeds and production inputs enhanced through genetic engineering and other applications of biotechnology;
- Public commitment to enhance water quality and the safety of food; and
- Increased restrictions on use of potentially harmful pesticides resulting from implementation of the "Food Quality Protection Act of 1996" (FQPA) is likely to result in driving farmers toward more prevention-oriented systems.

The ability of many pest managers -- and policy-makers -- to project and manage the consequences of change in pest management systems is not keeping pace with pests or IPM systems and technology. Two traditional measures of pesticide use -- pounds of active applied per acre, and number of applications -- are increasingly inadequate when used to estimate the agronomic, environmental and public health consequences of pesticide use.[2] A review of several efforts to develop new measurement tools appears in *Pest Management at the Crossroads*[3] (*PMAC*); the PMAC website contains several documents describing and critiquing various risk index and indicator methodologies (see http://www.pmac.net/measind.htm).[4]

New and improved analytical tools are needed to address tradeoffs between environmental protection, public health, and crop production that are inherent outcomes whenever pest management systems change. Tradeoffs are unavoidable, increasingly complex, and must be better understood for farmers, researchers, and policy-makers to

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[2] Several reasons why are set forth in "Alternative Measures of Pesticide Use," Barnard, C., Daberkow, S., Padgitt, M., Smith, M.E., and N.D. Uri, *The Science of the Total Environment*, 203 (1997): 229-244.

[3] See page 82, *PMAC* (Benbrook et al., 1996).

[4] The index for the section "Recent IPM Measurement Activities" from the PMAC website lists a number of resource materials. "An Overview of Pesticide Impact Assessment Systems (a.k.a. 'Pesticide Risk Indicators') based on Indexing or Ranking Pesticides by Environmental Impact," an April 1997 paper by Dr. Lois Levitan, Cornell University, is particularly comprehensive and detailed, and is accessible at http://www.pmac.net/lois.htm.

gain a firmer sense of direction and priority in shaping pest management systems and regulatory policies. Farmers recognize that alternative approaches pose new risks and create demands for new sources and kinds of information. Finding new ways to provide such information and insight is one of the basic goals of the WWF/WPVGA potato IPM project and the focus of this paper.

1. Adjustment Methodology Attributes

Toxicity adjusted methods need to be dynamic and pliable, and offer a structured framework within which to pose and answer questions about the human health, environmental and ecological impacts of changes in pest management systems. The structure should make explicit gaps in knowledge, data sources, statistical formulations, and assumptions, while also facilitating the integration of expert judgment and new information. The necessary components within a pesticide risk index will vary as a function of the types of pesticides being used, the cropping systems they are used within, soil and climatic conditions, and the dominant risk and environmental concerns in the geographic region under study. The toxicity factors described herein, and the methods used to estimate values for application to pesticide use in central Wisconsin, are not necessarily the most relevant to assess potato production in the Pacific Northwest.

Measurement tools should support assessment of different categories of pesticide risks, singly or in combination. Adjustment factors will fit some but clearly not all situations. The broader the application, the more challenging the task of coming up with indicators that are equally applicable to different circumstances. [5]

There is no "right way" to construct and use toxicity adjustment factors. Most risk indices are too crude to distinguish reliably between two pesticides that are related and cause comparable effects at similar dose rates. Risk indices are most reliable and useful in monitoring changes in average levels of toxicity over time, and in comparing the toxicity and risks associated with groups of pesticides. Such comparisons provide insights into the magnitude of environmental and public health gains possible from progress along the IPM continuum.

B. Four Major Component Indices

The WWF-WPVGA multiattribute toxicity index is composed of four component indices: acute mammalian (AM), chronic mammalian (CM), ecological (ECO), and impacts on beneficial organisms and IPM systems (BioIPM). The sub-indices within each of the four major indices are based largely on pound-for-pound-applied comparisons of toxicity to a common set of organisms.

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[5] The design and application of multiattribute indices in evaluating pesticide risks are treated in detail in a 1995 Masters of Science thesis by D. Landy (Landy, 1995). Several toxicity ranking methods are reviewed in *Pest Management at the Crossroads* (Benbrook et al., 1996) and the extensive background paper prepared for OECD by Dr. Lois Levitan (Levitan, 1997).

The methodology does not include many important factors affecting exposure and hence risk. These include formulation differences, application methods, pre-harvest intervals, safety equipment used, and environmental fate, nor do they encompass some of the ways pesticides can harm non-target species (loss of habitat, food-chain disruption, multigeneration endocrine effects). In addition, the indices do not encompass economic impacts, although future applications are likely to include tradeoffs between reductions in toxicity units and the cost and reliability of control interventions.

An important note about terminology – in each component index, toxicology and environmental fate data on individual pesticide active ingredients are used to calculate "toxicity factors," or "toxicity factor values." When two or more component indices of such values are combined, the result is an estimate of multiattribute toxicity factors. These factors, unique to each pesticide active ingredient, are used in producing estimates of the "toxicity units" associated with the application of a given pesticide. Use of the term toxicity "values" or "factors," then, applies to estimates of toxicity comparable on a pound-for-pound basis; the term toxicity "unit" refers to an estimate of the toxicity units associated with the actual amount of a pesticide applied in a given region.

1. General Methodological Issues

In the process of calculating component indices and combining them into a multiattribute measure of pesticide toxicity suitable for comparisons across active ingredients, several structural and statistical issues arise. Decisions have to be made regarding scaling, outlier values, dealing with missing data, and integrating data from many different, but related studies into a single value. The validity of an index rests in part on how wisely and consistently these decisions are made and then adhered to as the various component sub-indices and indices are estimated and combined.

<u>Selecting a Scalling Factor.</u> Scaling is critical in assuring that the range of numbers in component indices is roughly the same. If they are not, the index with the larger values and/or the greater variability will tend to drive the values in a multiattribute index. We applied scaling factors to remove this implicit weighting, and instead use explicit weighting factors to then alter the importance placed on individual indices.

For example, in estimating Acute Toxicity Factors in this project, a scaling factor of 500 is used. The range and maximum values of Inverse LD-50s, and other component indices, need to be adjusted through multiplication by scaling factors so that each component index varies across roughly the same range of numbers.

<u>Water Leaching Index</u> A second adjustment was made in acute and chronic mammalian toxicity index values in light of the dominance of drinking water exposure as a potential source of human health risk. The EPA model SCI-GROW was used to produce the water leaching index by active ingredient, which is then multiplied by the Scaled Inverse LD-50s (see the first column of values in Table 6).

Adjusting Outlier Values Any value in an index that is more than twice as large as the next highest value should be reviewed to determine if the difference accurately reflects actual differences in toxicity, or an artifact of the data accessible to estimate a given index value.

Deciding whether outlier values should be adjusted requires a review of other toxicological data on comparable endpoints from a set of similar studies, or from similar studies in related species. If the difference between an outlier and the next most toxic pesticide is consistently large, the value should not be adjusted. But when the data show that there are equally or more toxic pesticides, based on different studies or endpoints, an adjustment is probably warranted. In cases where an adjustment was found necessary, the mean and standard deviation of unadjusted values within the index were used as the basis for setting maximum values, following guidance from the WWF-WPVGA project advisory committee.

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2. Acute Mammalian Toxicity

The first component index reflects acute mammalian toxicity, and is based on oral LD-50s. Data on LD-50 values are derived predominantly from the "WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification 1996-1997" (International Programme on Chemical Safety, 1996). LD-50 values for recently registered active ingredients are derived from EPA tolerance documents appearing in the Federal Register. In a few cases, LD-50 values were derived from "Farm Chemicals Handbook '98" (Meister Publishing Company, 1998), company, or other sources.

The inverse of LD-50 values are calculated so that rising index values correlate with rising toxicity and a scaling factor of 500 is used. At the direction of the WWF-WPVGA project advisory committee, a second adjustment was made in acute and chronic mammalian toxicity index values in light of the dominance of drinking water exposure as a potential source of human health risk. The EPA model SCI-GROW was used to produce the water leaching index by active ingredient, which is then multiplied by the Scaled Inverse LD-50s (see the first column of values in Table 6).

Table 1 presents data on the pesticides used in Wisconsin potato production in 1995 ranked by pounds applied within each major class of pesticides. Table 2 presents pesticide use ranked by "Acute Toxicity Units." The fourth column in Table 2 reports leaching adjusted Scaled Inverse LD-50 values.

A comparison of results in these Tables 1 and 2 highlights the importance of taking toxicity into account when evaluating changes in pesticide reliance and pest management systems --

- Insecticides account for 95 percent of acute toxicity units across all herbicides, insecticides, and fungicides applied – 3.436 million units out of a total of 3,617 million;
- Four insecticides account for 89 percent of insecticide acute toxicity units;
- The average per acre toxicity units associated with herbicide use is only 0.3, and for fungicides 2.0, compared to 41 in the case of insecticides; and
- Based on current measures of acute toxicity[6], fungicides as a class are far less acutely toxic than insecticides, and variability within this class is much less than for insecticides and "Other Chemicals."

3. Chronic Mammalian Toxicity

The second component index is most relevant for assessing longer-term drinking water, occupational, and dietary risks. It encompasses chronic mammalian toxicity (CM) – the capacity of an active ingredient to cause adverse health impacts (cancer, birth defects, impaired immune system function, reproductive impacts) as a result of long-term, low-level exposures. It is based largely on a pesticide active ingredient's Reference Dose (RfD). Other factors in the algorithm include oncogenic potential and potency, and the capacity to disrupt endocrine system mediated functions.

The index is calculated using a composite variable "Mam Tox Score" that was first calculated to evaluate long-term trends in pesticide chronic toxicity as part of the analysis reported in the Consumers Union book *Pest Management at the Crossroads* (Benbrook et al., 1996). Consultations with experts and sensitivity analysis were relied upon in choosing the formula that best represented an estimate of comparative chronic mammalian risks, drawing upon readily available EPA toxicological data. The Mam Tox Score variables and formula are:

RfD: EPA reference dose (or other available estimate)
ED: Endocrine disruptor -- if yes, value=3; if no information or no evidence from appropriate assays[7], value=1
Q*: EPA cancer potency factor (or "best" estimate available)
CLASS: EPA Oncogenicity Class -- if A or B/2, value=10; if C, value=5;

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[6] Some fungicides are known to disrupt endocrine system development and functions. Very low levels of exposure for short duration (i.e. part of a day to a few weeks) during critical periods of fetal development, and as the child grows, can lead to irreversible functional deficits in the immune, neurological, or reproductive system. Since such effects can result from acute exposures, it can be argued they properly fall under the category of acute effects.

[7] In future work, data on pesticides and endocrine effects will be reviewed in order to differentiate between active ingredients that have been tested and found to produce no observable effects, in contrast to those that have just not been tested. Untested compounds will be assigned an intermediate default value.

Table 1. Pesticides Applied in Wisconsin Potato Production, 1995

(Wisconsin Acres Planted: 83,000)	Area Applied	Acres Treated	Number of Applications	Rate per Application	Rate per Crop Year	Total Applied
	(Percent)		(Number)	(#s per acre)	(#s per acre)	(Pounds)
Herbicides:						
Metribuzin	89	73,870	1.1	0.46	0.52	39,000
Pendimethalin	36	29,880	1	0.8	0.81	24,000
Metolachlor	18	14,940	1	1.44	1.44	21,000
Linuron	9	7,470	1.1	0.89	0.97	7,000
Glyphosate	8	6,640	1.0	0.62	0.62	4,000
Sethoxydim	10	8,300	1.2	0.17	0.2	2,000
Total: All Herbicides	170	141,100				97,000
Per Planted Acre						1.17
Insecticides:						
Methamidophos	65	53,950	1.4	0.88	1.26	69,000
Endosulfan	66	54,780	1.5	0.75	1.09	60,000
Azinphos-methyl	26	21,580	2.1	0.57	1.19	26,000
Carbofuran	16	13,280	1	0.89	0.93	13,000
Dimethoate	28	23,240	1.3	0.38	0.48	11,000
Oxamyl	8	6,640	1.1	0.77	0.85	5,000
Permethrin	22	18,260	1.4	0.15	0.21	4,000
Esfenvalerate	60	49,800	1.7	0.04	0.06	3,000
Piperonyl butoxide	17	14,110	1	0.2	0.21	3,000
Pyrethrins	10	8,300	1	0.02	0.02	16
Total: All Insecticides	318	263,940				194,016
Per Planted Acre						2.34
Fungicides:						
Mancozeb	86	71,380	4.7	1.24	5.76	412,000
Chlorothalonil	88	73,040	5.9	0.95	5.61	408,000
Maneb	14	11,620	5.3	1.25	6.65	76,000
Copper hydroxide	38	31,540	2.4	0.54	1.26	40,000
Basic copper sulfate	5	4,150	1.9	1.57	2.92	13,000
Copper resinate	7	5,810	1.9	1.11	2.1	12,000
Triphenyltin hydrox.	46	38,180	2.9	0.11	0.31	12,000
Propamocarb hydroch.	12	9,960	1.1	0.9	0.96	9,000
Metalaxyl	15	12,450	1.5	0.21	0.31	4,000
Total: All Fungicides	311	258,130				986,000
Per Planted Acre						11.88
Other Chemicals:						
Sulfuric acid	13	10,790	1.1	142	150.35	1,632,000
Metam-sodium	8	6,640	1	152	152	970,000
Diquat	80	66,400	1.4	0.3	0.42	28,000
Maleic hydrazide	8	6,640	1	1.91	1.91	13,000
Endothall	11	9,130	1.1	0.76	0.82	7,000
Paraquat	7	5,810	1.2	0.44	0.54	3,000
Total: Other Chemicals	127	105,410				2,653,000
Per Planted Acre						31.96
Total Herbicides, Insecticides, and Fungicides:	799	663,170				1,277,016
Per Planted Acre						15.39
Totals: All Chemicals	926	768,580				3,930,016
Per Planted Acre						47.35

Table 2. Pesticides Used in Wisconsin Potato Production
Ranked by Acute Toxicity Units, 1995

(Wisconsin Acres Planted: 83,000)	Acres Treated	Total Pounds Applied	LD-50 Value	Scaled Inverse LD-50	Acute Toxicity Units	Share of Acute Toxicity Units by Type of Pesticide
Herbicides:						
Metribuzin	73,870	39,000	2,200	0.26	10,140	40.2%
Pendimethalin	29,880	24,000	1,050	0.42	10,057	39.9%
Metolachlor	14,940	21,000	2,780	0.17	3,570	14.2%
Linuron	7,470	7,000	4,000	0.11	770	3.1%
Glyphosate	6,640	4,000	4,230	0.1	400	1.6%
Sethoxydim	8,300	2,000	3,200	0.14	280	1.1%
Total: All Herbicides	141,100	97,000			25,217	
Per Planted Acre		1.17			0.3	
Insecticides:						
Methamidophos	53,950	69,000	30	14.6	1,007,400	29.3%
Carbofuran	13,280	13,000	8	68.56	891,280	25.9%
Azinphos-methyl	21,580	26,000	16	27.69	719,940	21.0%
Oxamyl	6,640	5,000	6	86.05	430,249	12.5%
Endosulfan	54,780	60,000	80	5.53	331,800	9.7%
Dimethoate	23,240	11,000	150	2.93	32,230	0.9%
Esfenvalerate	49,800	3,000	67	6.55	19,650	0.6%
Permethrin	18,260	4,000	500	0.88	3,520	0.1%
Piperonyl butoxide	14,110	3,000	5,000	0.09	270	0.0%
Pyrethrins	8,300	16	500	0.88	14	0.0%
Total: All Insecticides	263,940	194,016			3,436,353	
Per Planted Acre		2.34			41	
Fungicides:						
Mancozeb	71,380	412,000	5,000	0.09	37,080	23.8%
Chlorothalonil	73,040	408,000	5,000	0.09	36,720	23.6%
Triphenyltin hydrox.	38,180	12,000	156	2.81	33,720	21.6%
Basic copper sulfate	4,150	13,000	300	1.46	18,980	12.2%
Copper hydroxide	31,540	40,000	1,000	0.44	17,600	11.3%
Maneb	11,620	76,000	5,000	0.09	6,840	4.4%
Metalaxyl	12,450	4,000	670	0.75	3,000	1.9%
Copper resinate	5,810	12,000	5,000	0.09	1,080	0.7%
Propamocarb hydroch.	9,960	9,000	5,000	0.09	810	0.5%
Total: All Fungicides	258,130	986,000			155,830	
Per Planted Acre		12			2	
Other Chemicals:						
Metam-sodium	6,640	970,000	285	1.54	1,493,800	64.0%
Sulfuric acid	10,790	1,632,000	1,000	0.44	718,080	30.7%
Endothall	9,130	7,000	51	8.62	60,340	2.6%
Diquat	66,400	28,000	231	1.90	53,200	2.3%
Paraquat	5,810	3,000	150	2.92	8,760	0.4%
Maleic hydrazide	6,640	13,000	5,000	0.11	1,430	0.1%
Total: Other Chemicals	105,410	2,653,000			2,335,610	
Per Planted Acre		32			28	
Total Herbicides, Insecticides, and Fungicides	663,170	1,277,016			3,617,400	
Per Planted Acre		15			44	
All Chemicals:	768,580	3,930,016			5,953,010	
Per Planted Acre		47.35			72	

if D, value=2.

$$\text{Mam Tox Score Pesticide}_x = [(0.01/\text{RfD}_x) \times \text{ED}_x] + [Q^*_x \times 50 \times \text{CLASS}_x]$$

Table 3 presents data on the range and distribution of water leaching adjusted "Scaled Mam Tox Score" values for pesticides applied in potato production in Wisconsin in 1995. The unadjusted Mam Tox Score value of the fungicide triphenyltin hydroxide was clearly an outlier – 2,400 compared to the next highest values of any currently registered pesticide (metiram and ethropop at 1,000). In several chronic toxicology studies, many pesticides are more toxic than triphenyltin. Accordingly, the Scaled Mam Tox Score value of triphenyltin hydroxide was set at 286.7, one-half a standard deviation above the mean value across the pesticides included in Table 3. This value is about 60 percent greater than the next highest, dimethoate's value of 176. Triphenyltin was the only pesticide with an outlier value in this index.

In Table 3, active ingredients within each major class of pesticides are ranked by share of total chronic toxicity units. Key insights include –

- Fungicides account for 82 percent of the chronic toxicity units associated with use of herbicides, insecticides, and fungicides;
- The average chronic toxicity units per acre based on all herbicide applications was 14, compared to 153 in the case of insecticides, and 721 from fungicide use;
- A single fungicide, mancozeb, accounts for 79 percent of total fungicide chronic toxicity units, and metribuzin accounts for 90 percent of herbicide chronic toxicity units; and
- The fungicide chlorothalonil accounts for 41 percent of the total pounds of fungicides applied, yet only 5.3 percent of chronic toxicity units from all fungicides applied.

4. Ecological Toxicity and Risks

The third major index is designed to capture the relative ecological toxicity of pesticides. It integrates avian, aquatic and small invertebrate ecological risks. Impacts on organisms that can play a role in biointensive IPM (beneficial arthropods) or enhancing soil quality (worms and soil microorganisms) are included in the Biointensive IPM index, described next.

The ecological risk index (ECO) is composed of sub-indices covering toxicity to two fish species (Rainbow trout and Bluegill), several bird species, and daphnia, a small aquatic organism. The potential impacts captured in this index are important given the environmental attributes of the Central Wisconsin region and the goals of the project.

<u>Avian Toxicity</u> Substantial data confirm that the organophosphate and carbamate insecticides are by far the most toxic major groups of pesticides to birds. For this reason, organophosphate and carbamate avian toxicity values were sought from Dr. Pierre Mineau, an avian toxicologist working for the Canadian Fish and Wildlife Service. With

Table 3. Chronic Toxicity of Pesticides Used in Wisconsin Potato Production, 1995

(Wisconsin Acres Planted: 83,000)	Total Pounds Applied	Percent Pounds Applied	Scaled Mam Tox Score	Chronic Toxicity Units	Share of Chronic Toxicity Units by Type of Pesticide
Herbicides:					
Metribuzin	39,000	40%	26.77	1,044,139	89.9%
Linuron	7,000	7%	11.25	78,750	6.8%
Metolachlor	21,000	22%	0.93	19,530	1.7%
Pendimethalin	24,000	25%	0.68	16,262	1.4%
Sethoxydim	2,000	2%	1.00	1,998	0.2%
Glyphosate	4,000	4%	0.04	176	0.0%
Total: All Herbicides	97,000	100%		1,160,856	
Per Planted Acre	1.17			14	
Insecticides:					
Methamidophos	69,000	36%	88.00	6,072,000	47.8%
Endosulfan	60,000	31%	44.00	2,640,000	20.8%
Dimethoate	11,000	6%	176.00	1,936,000	15.2%
Azinphos-methyl	26,000	13%	59.36	1,543,438	12.1%
Carbofuran	13,000	7%	22.00	286,000	2.3%
Oxamyl	5,000	3%	33.52	167,600	1.3%
Permethrin	4,000	2%	9.33	37,312	0.3%
Piperonyl butoxide	3,000	2%	5.03	15,086	0.1%
Esfenvalerate	3,000	2%	4.40	13,200	0.1%
Pyrethrins	16	0%	1.38	22	0.0%
Total: All Insecticides	194,016	100%		12,710,658	
Per Planted Acre	2.34			153	
Fungicides:					
Mancozeb	412,000	42%	114.40	47,132,800	78.8%
Maneb	76,000	8%	79.20	6,019,200	10.1%
Triphenyltin hydrox.	12,000	1%	286.73	3,440,808	5.8%
Chlorothalonil	408,000	41%	7.79	3,177,504	5.3%
Copper hydroxide	40,000	4%	0.29	11,616	0.0%
Propamocarb hydroch.	9,000	1%	0.88	7,920	0.0%
Metalaxyl	4,000	0%	1.36	5,454	0.0%
Basic copper sulfate	13,000	1%	0.29	3,775	0.0%
Copper resinate	12,000	1%	0.29	3,485	0.0%
Total: All Fungicides	986,000	100%		59,802,562	
Per Planted Acre	12			721	
Other Chemicals:					
Metam-sodium	970,000	37%	95.92	93,042,400	98.2%
Diquat	28,000	1%	40.04	1,121,120	1.2%
Sulfuric acid	1,632,000	62%	0.29	473,933	0.5%
Paraquat	3,000	0%	19.54	58,608	0.1%
Endothall	7,000	0%	4.40	30,800	0.0%
Maleic hydrazide	13,000	0%	0.46	5,980	0.0%
Total: Other Chemicals	2,653,000	100%		94,732,841	
Per Planted Acre	32			1,141	
Total Herbicides, Insecticides, and Fungicides:	1,277,016			73,674,075	
Per Planted Acre	15			888	
All Chemicals:	3,930,016			168,406,916	
Per Planted Acre	47.35			2,029	

colleagues in Germany, Netherlands, and the United States, Dr. Mineau has developed a comprehensive avian toxicity model, drawing on a database with over 1,300 values for 146 pesticides and 61 species (Baril and Mineau, 1998).

Avian toxicity values providing by Mineau assume a 95 percent protection threshold – i.e. dosage levels that would result in 95 percent of the exposed birds surviving. Mineau values for nine OP and carbamate insecticides appear in column three, Table 4, and apply to birds weighting 20 grams (mid-size song birds). Carbofuran accounted for 7 percent of the total pounds of insecticides applied in 1995, and 44 percent of total insecticide avian toxicity units (data not shown). Endosulfan accounts for another 25 percent, methamidophos 16 percent and both azinphos-methyl and oxamyl, 7 percent. No other insecticide accounts for more than 1 percent of total avian insecticide toxicity units.

For non-OP and carbamate insecticides, herbicides, fungicides, and other chemicals applied in Wisconsin, a method was developed to calculate an approximation of acute avian toxicity levels comparable to the OP-carbamate values provided by Mineau. The method relied on Bobwhite and Mallard duck avian toxicity data provided by EPA in the "Ecotoxicology Database" (EPA-Ectox) managed by Dr. Brian Montague (Montague, 1998). For each active ingredient, avian studies were extracted from the EPA-Ecotox database.

<u>Fish Toxicity</u> No team of scientists has developed a comprehensive model to synthesize and interpret existing fish acute toxicity data comparable to the work by Mineau and colleagues on avian risks. There is, however, extensive data on pesticide impacts on several fish species available from studies in EPA files, much of it from a comprehensive 1986 report by U.S. Fish and Wildlife biologists.[8]

Through review of the fish studies in EPA databases, rainbow trout and bluegill were identified as the two most widely used test species. Valid studies were selected by active ingredient, most of which involved between 75 percent and 100 percent active ingredient in the test substance. When there were two or more studies, LC-50 values were averaged. Both the rainbow trout and bluegill data were inverted, so that rising values were associated with increasing toxicity, and a scaling factor was used so that the maximum value in each inverted index was roughly the same.

The most toxic pesticides to fish are several thousand times more toxic than the least toxic pesticides. The range in unadjusted fish toxicity values Table 4 is over 500,000-fold. Esfenvalerate, a synthetic pyrethroid insecticide, is by far the most toxic pesticide, with an unadjusted fish toxicity sub-index value of 500. Since this value was four times higher than the next most toxic pesticide to fish (endosulfan), the esfenvalerate value was adjusted 164.7, two standard deviations above the mean fish toxicity value. As in the case of avian toxicity, the majority of herbicides and fungicides are considerably less toxic than most insecticides.

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[8] *Manual of Acute Toxicity: Interpretation and Data Base for 410 Chemicals and 66 Species of Freshwater Animals*, F.L. Mayer and M.R. Ellersieck, U.S. Fish and Wildlife Service, 1986.

Small Aquatic Invertebrates Pesticides can place fish and bird species at jeopardy through impacts on aquatic food chains. In order to capture this potential in the Ecotoxicity index, a small aquatic organism sub-index was calculated, drawing on data in the EPA-Ecotox database on Daphnia, the most frequently treated crustacean species.

Using the approach previously described, comparable studies were selected out of the EPA database, and average values were calculated when there was more than one study. The values were then inverted and scaled, to produce the numbers in column 1, Table 4. Again, esfenvalerate was by far the most toxic pesticide, with an unadjusted value of 166.7, compared to a value of 13.3 for the next most toxic pesticide – another synthetic pyrethroid (permethrin). This value was adjusted downward to 52.7, two standard deviations above the mean. Not surprisingly, esfenvalerate still has the highest overall Ecotoxicity Index value – 219, about 25 percent higher than the OPs carbofuran and phorate.

Calculating Ecotoxicity Values To calculate Ecotoxicity values, the Daphnia, fish, and avian values for each pesticide active ingredient were summed. Note that the high Ecotoxicity values for esfenvalerate and endosulfan reflect largely aquatic toxicity, while the relatively high values for the carbamates carbofuran and aldicarb are largely from avian toxicity.

Significant variability is evident across classes of organisms in Table 4. For all active ingredients, the lowest value in one of the three sub-indices is 10 to 100-fold less than the value in the sub-index with the highest value. This variability complicates the selection of pesticides but also makes it possible, with good information and field knowledge, to choose pesticides less likely to harm the dominant species sharing an agricultural landscape with crop fields.

While there are substantial data on the acute toxicological effects of pesticides on several non-target organisms, there are scant data to evaluate most sub-chronic and chronic effects involving immune system development and function, or neurological integrity and behavior. Scientists are reasonably confident they have identified and studied the acute toxicological properties of most commonly used pesticides that can, and sometimes do poison fish or birds. They are much less confident in their ability to identify pesticides reducing fish and bird populations through other chronic and indirect mechanisms, such as:

- Reduction in the abundance and diversity of invertebrates, an important food source, especially during avian breeding seasons;
- Impairment of long-term reproductive success as a result of subtle, endocrine system impacts; and
- Reduction in the number of plants that serve as hosts for invertebrates, play a role in successful breeding, or which serve as food sources during parts of the season.

There is also relatively little data on ecosystem-scale and multigeneration impacts, yet growing concern about such effects as a result of the increasing homogeneity of agricultural cropping patterns and pesticide use increases.

Table 4. Ecotoxicity Index Components and Values

	Daphnia	Fish	Birds	Sum of Components
Herbicides:				
EPTC	0.003	0.008	0.34	0.35
Glyphosate	0.000	0.001	0.14	0.14
Linuron	0.125	0.030	0.21	0.36
Metolachlor	0.001	0.025	0.08	0.11
Metribuzin	0.006	0.002	0.29	0.30
Pendimethalin	0.089	0.990	0.21	1.29
Paraquat	0.021	0.002	2.08	2.11
Rimsulfuron	0.000	0.000	0.28	0.28
Sethoxydim	0.000	0.001	0.15	0.15
Trifluralin	0.042	0.000	0.30	0.34
Insecticides:				
Aldicarb	0.061	2.493	65.22	67.77
Azinphos Methyl	0.009	16.695	12.15	28.85
Bt	0.002	0.074	1.30	1.38
Carbaryl	3.676	0.028	0.61	4.31
Carbofuran	0.740	1.297	157.89	159.93
Dimethoate	10.000	0.028	5.04	15.07
Endosulfan	0.151	115.079	19.54	134.77
Esfenvalerate	52.654	164.754	1.84	219.25
Ethoprop	0.368	0.112	11.72	12.20
Fonofos	12.500	5.815	7.35	25.67
Imidachloprid	0.000	0.002	1.88	1.88
Methamidophos	0.735	0.005	10.91	11.65
Oxamyl	0.008	0.027	63.83	63.87
Permethrin	13.298	28.162	1.64	43.10
Phorate	0.676	86.458	75.00	162.13
Piperonyl butoxide	0.023	0.043	1.60	1.67
Propargite	0.275	1.172	1.94	3.39
Pymetrozine				4.00
Pyrethrin	2.155	8.859	0.90	11.91
Fungicides:				
Chlorothalonil	0.357	2.270	0.00	2.63
Copper ammonium	0.025	0.012	0.10	0.13
Copper Chloride Hy	0.025	0.092	0.47	0.58
Copper resinate	0.025	0.012	0.47	0.50
Copper sulfate, bas	0.025	0.147	0.47	0.64
Cymoxanil	0.001	0.005	0.47	0.47
Iprodione	0.010	0.037	0.27	0.31
Mancozeb	0.025	0.157	0.10	0.28
Maneb	0.007	0.708	0.06	0.77
Metalaxyl	0.000	0.002	0.07	0.07
Metiram	0.004	0.001	0.10	0.11
Propamocarb	0.000	0.000	0.16	0.16
Sulfur	0.000	0.001	0.13	0.13
Triphenyltin Hydrox	2.500	5.260	0.11	7.87
Other Chemicals:				
Dichloropropene	0.008	0.031	0.00	0.04
Diquat	0.004	0.001	0.12	0.12
Endothall	0.000	0.003	0.15	0.15
Maleic Hydrazide	0.000	0.002	1.81	1.81
Metam sodium	0.011	0.247	0.08	0.34
Sulfuric acid	0.01	0.01	0.1	0.12

4. Impacts on the Viability of Biointensive IPM Systems

The fourth major index – BioIPM -- encompasses impacts of vital significance to farmers, their neighbors, and the agricultural industry as a whole. Progress along the IPM continuum cannot be sustained without reducing adverse pesticide impacts on a range of beneficial organisms and biodiversity. As above- and below-ground biodiversity increases, new options emerge to manage species interactions in ways that disadvantage pests and strengthen a plant's ability to cope with or out-grow pest pressure. Indeed, the structured management of biodiversity and species interactions is the nuts and bolts of biointensive IPM.

The data needed to calculate BioIPM sub-indices is far from universally available. Assistance was sought from University of Wisconsin IPM experts in compiling the preliminary estimates reported here. The estimates 5 reflect pesticide use patterns, soils and agroecosystems in central Wisconsin, and should not be accepted as automatically relevant to other regions and cropping systems.

Beneficial Arthropods The first component is impacts on beneficial arthropods that play direct roles in biological control processes. In the case of insecticides, values in Table 4 are derived from the "Toxic Effect" index developed by Dr. Brian Croft and Karen Theiling at Oregon State University.[9] For insecticides, "Scaled Impacts on Beneficial" values were derived from "Toxic Effect" values using the formula:

$$\text{“Scaled Impact on Beneficials Pesticide}_x\text{”} = 100/(5\text{-Toxic Effect Pesticide}_x)$$

This formula was selected as a way to expand the relatively narrow range of values from those reported by Theiling and Croft, and to increase the maximum values comparable to other BioIPM sub-indices. "Toxic Effect" values were not available for most other pesticides, so other sources of data were sought. Values in column two, Table 4 for these other classes of pesticides are derived predominantly from the work of Dr. Joe Kovach and colleagues at Cornell University.[10]

Soil Microorganisms Many species of soil microorganisms play an important positive role by improving soil quality, enhancing nitrogen cycling and availability in the soil, promoting healthy root development, and suppressing nematodes and related plant pathogens.

"Scaled Impacts on Soil Microorganisms" values in column four were derived from estimates provided by the University of Wisconsin IPM team. As farming and IPM systems evolve in Wisconsin, it is likely that soil microbial communities will grow more diverse and important in assuring success with biointensive IPM. A major goal of

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[9] See pages 60-63 of *Pest Management at the Crossroads* for a general discussion of the "Toxic Effect Scale" and the methodology developed by Theiling and Croft. Under the direction of Dr. Paul Jepson, key work is underway in the Department of Entomology at Oregon State University. The goal is to extend and refine the database covering impacts of pesticides on arthropods, and to develop new measures of both the direct and indirect effects on communities of organisms. As new measures are developed, they will be incorporated in this methodology.

[10] "A Method to Measure the Environmental Impact of Pesticides," Kovach, J., et al., New York Food and Life Sciences Bulletin Number 139, 1992.

ongoing research at the University is to promote microbial biocontrol of soil pathogens, as an alternative to periodic fumigation with metam-sodium. As progress is made toward this goal, the team will revisit these values, since the impacts of different pesticides on soil microorganisms is bound to change as the diversity of species increases.

Resistance The emergence of resistance can undermine the efficacy of a pesticide, and hence undermine the ability of farmers to use otherwise effective pest management tools. In the case of relatively safe pesticides like *Bt* and glyphosate, the emergence of resistance is likely to lead to increased reliance and use of higher-risk products.

An estimate of each pesticide's likelihood of triggering the evolution of resistance was provided by the University of Wisconsin IPM research team. It should be noted that the very low value for *Bt* is based on foliar applications of the formulated insecticide, not the planting of *Bt*-transgenic varieties, which would have a higher likelihood of triggering resistance.

Bee Toxicity Bees play a critical role in the pollination of both agricultural crops and native species. Pesticide impacts on bees are among the most significant economic losses associated with pesticide use, and are a growing concern worldwide. In some regions, vegetable and fruit crop yield reductions of 40 percent or more have been attributed to poor pollination caused by pesticide impacts on bees.

Bee toxicity data was extracted from the EPA-Ecotox database and appears in column five, table 5. In some cases, values were extrapolated from the three acute bee toxicity ratings in "Farm Chemicals Handbook '98" – "Practically Non-toxic," "Moderately Toxic," and "Highly Toxic." For several active ingredients falling in each "Farm Chemicals" category, average bee toxicity values were calculated from data in the EPA database. These average values were then used for pesticides in the "Farm Chemicals Handbook" classes, but not in the EPA database. A scaling factor of 10 was used in producing final bee toxicity factor values.

The bee toxicity value for imidacloprid required adjustment because of the very large difference in bee toxicity between the granular and foliar formulations of this insecticide. When applied as a liquid foliar spray, imidacloprid's scaled bee toxicity value is by far the highest of any pesticide used in Wisconsin potato production. But a significant portion of imidacloprid is applied at planting time as a granular, essentially eliminated exposure to bee. Plus, there are rarely foraging bees in potato fields later in the season when foliar imidacloprid products are applied, according to University of Wisconsin entomologist Dr. Jeffrey Wyman. Accordingly, the imidacloprid scaled bee toxicity value was adjusted downward to 20.

BioIPM Values Final BioIPM values were derived by summing the values of the four sub-indices, as reported in column 7, Table 5. These values were then scaled

Table 5. BioIPM Index Components and Values

	Toxic Effect Scale	Scaled Impacts on Beneficials	Scaled Resis-tance	Scaled Impacts on Soil Micro-organisms	Bee Toxicity	Scaled Bee Toxicity	Sum of Compon-ents	Scaled BioIPM Index
Herbicides:								
EPTC	2.95	17	75	100	12.1 ugb	0.83	192.83	77.1
Glyphosate	2.95	41.3	6	80	>100 ugb	0.10	127.40	51.0
Linuron	2.95	51	6	40	>120.9 ugb	0.08	97.08	38.8
Metolachlor	2.95	17	9	50	>100 ugb	0.10	76.10	30.4
Metribuzin	2.95	51	60	50	60.4 ugb	0.17	161.17	64.5
Pendimethalin	2.95	17	18	60	49.8 ugb	0.20	95.20	38.1
Rimsulfuron	2.95	51	120	70	>100 ugb	0.10	241.10	96.4
Paraquat	2.95	65	6	60	6 ugb	1.67	132.67	53.1
Sethoxydim	2.95	15	45	60	>10 ugb	1.00	121.00	48.4
Trifluralin	2.95	6	18	60	24.17 ugb	0.41	84.41	33.8
Insecticides:								
Aldicarb	3.28	58.14	30	100	.285 ugb	35.09	223.23	89.3
Azinphos-methyl	3.58	70.42	75	40	.82 ugb	12.20	197.62	79.0
Bacillus thuringiensis	2.06	34.01	6	10	>100 ugb	0.10	50.11	20.0
Carbaryl	3.83	85.47	45	40	1.3 ugb	7.69	178.16	71.3
Carbofuran	3.6	71.43	45	100	.16 ugb	62.50	278.93	111.6
Dimethoate	3.6	71.43	15	40	.13 ugb	76.92	203.35	81.3
Endosulfan	3.37	61.35	75	40	6.2 ugb	1.61	177.96	71.2
Esfenvalerate	3.5	66.67	120	30	.1 ugb	100.00	316.67	126.7
Ethoprop	3.5	66.67	15	80	4.1 ugb	2.44	164.11	65.6
Fonofos	3.2	55.56	15	80	6.8 ugb	1.47	152.03	60.8
Imidachloprid	2.5	40.00	75	50	0.041 ugb	20.00	185.00	74.0
Methamidophos	3.7	76.92	21	50	1.37 ugb	7.30	155.22	62.1
Oxamyl	4.28	138.89	45	50	5.21 ugb	1.92	235.81	94.3
Permethrin	4.03	103.09	120	30	.1 ugb	100.00	353.09	141.2
Phorate	4	100.00	30	80	3.61 ugb	2.77	212.77	85.1
Piperonyl butoxide	2.5	40.00	9	20	>10 ugb	1.00	70.00	28.0
Propargite	2	33.33	12	30	>10 ugb	1.00	76.33	30.5
Pymetrozine	2.4	30	10	20	>200 ugb	0.05	60.05	24.0
Pyrethrins	4	100.00	120	30	>10 ugb	1.00	251.00	100.4
Fungicides:								
Chlorothalonil	2.59	50	6	20	181 ugb	0.06	76.06	30.4
Copper ammonium	2.59	38	6	30	>10 ugb	1.00	75.00	30.0
Copper hydroxide	2.59	38.3	6	30	>10 ugb	1.00	75.30	30.1
Copper resinate	2.59	38.3	6	30	>10 ugb	1.00	75.30	30.1
Copper sulfate	2.59	10.9	6	40	>10 ugb	1.00	57.90	23.2
Cymoxanil	2.59	35	30	20	>25 ugb	0.40	85.40	34.2
Iprodione	2.59	38.3	60	20	>10 ugb	1.00	119.30	47.7
Mancozeb	2.3	78	6	20	178 ugb	0.06	104.06	41.6
Maneb	2.3	83.3	6	20	12 ugb	0.83	110.13	44.1
Metalaxyl	2.59	52.5	150	80	100 ugb	0.10	282.60	113.0
Metiram	2.3	54.8	6	20	>10 ugb	1.00	81.80	32.7
Propamocarb hydroch.	2.59	30	30	20	>10 ugb	1.00	81.00	32.4
Sulfur	2.59	87	6	20	>100 ugb	0.10	113.10	45.2
Triphenyltin hydrox.	2.59	70	6	20	114.8 ugb	0.09	96.09	38.4
Other Chemicals:								
Dichloropropene		50.00	6	60	>10 ugb	1.00	117.00	46.8
Diquat		40.00	6	20	>1 ugb	10.00	76.00	30.4
Endothall		40.00	6	20	>10 ugb	1.00	67.00	26.8
Maleic hydrazide		40.00	6	20	36.3 ugb	0.28	66.28	26.5
Metam-sodium		60.00	6	80	36.2 ugb	0.28	146.28	58.5
Sulfuric acid		20.00	6	20	>10 ugb	1.00	47.00	18.8

using a factor of 0.4 to produce a maximum value and range comparable to the other major indices. As expected, the average value of insecticides is substantially higher than the average value for other classes of pesticides. But like other indices, there is large variability within and across categories of pesticides.

C. Integrating the Component Indices into a Single Index

Index values and toxicity-adjustment factors are intended to more accurately characterize the tradeoffs inherent in the selection of pesticides and pest management systems. While researchers are often interested primarily in a single dimension of risk, farmers and society as a whole have to live with all risk, efficacy, and economic impacts, both positive and negative. Hence, the complexity of the challenge inherent in identifying the least disruptive and dangerous product across all categories of risk and impacts from those products available to address a given problem pest.

The general functional form of the equation used to calculate multiattribute index values is:

$$\text{Value for Pesticide}_x = (a)AM_x + (b)CM_x + (c)ECO_x + (d)BioIPM_x$$

Where, (a), (b), (c), and (d) are weights assigned to each component index.

1. Assigning Weights: An Example Involving Potato Production in Wisconsin

Decisions regarding the importance to place on the four component indices must be made and incorporated in the equation through the weighting factors (a), (b), (c), and (d). Guidance was sought from the WWF-WPVGA Advisory Committee and technical consultants regarding what weights to use for the purpose of establishing baseline multiattribute toxicity units subject to project risk reduction goals. The committee recommended that four different formulas be calculated, reflecting different environmental and public health concerns. The formulas are –

Wisconsin Project Risk Index = $(0.5)*AM_x + CM_x + ECO_x + (1.5)*BioIPM_x$
Equal Weight Index = $AM_x + CM_x + ECO_x + BioIPM_x$
Human Health Focus Index = $(1.5)*AM_x + (2.0)*CM_x + (0.5)*ECO_x + BioIPM_x$
Environment Focus Index = $(0.3)*AM_x) + (0.5)*CM_x + (2.0)*ECO_x) + (2)*BioIPM_x$

After reviewing the results, the “Wisconsin Project Risk Index” was chosen for use in setting the toxicity unit baseline (pounds applied of pesticide$_x$ times the toxicity factor value of pesticide$_x$). It will also be used in monitoring risk reduction progress because, in the judgement of the advisory committee, it best reflects the balance of concerns associated with pesticide use on central Wisconsin potato farms.

The weight assigned the acute mammalian toxicity component is set at (0.5), reducing its significance relative to other component indices. This adjustment reflects the relative lack of circumstances leading to worker and applicator exposure and the low frequency of residues of acutely toxic pesticides in harvested potatoes, especially after washing, peeling, cooking and/or processing. The adjustment was not applied to the chronic mammalian toxicity index because low-level exposures are more widespread in the region from pesticides in drinking water, the air, and as a result of occupational exposure. To the limited extent the general public faces risks from pesticide residues in potatoes, they are likely to be chronic in nature.

A (1.5) weight has been assigned to the BioIPM component because BioIPM index impacts, especially resistance management and impacts on soil microorganisms and beneficial arthropods, are particularly important as Wisconsin potato producers progress along the IPM continuum toward more biologically based methods to manage pests. In recent years, secondary pests have been a recurrent concern and pest managers have invested considerable effort in devising and implementing resistance management plans. Efforts are also underway to build soil quality by raising organic matter content. Progress in enhancing soil quality is seen by many growers as critical in their efforts to improve nitrogen management efficiency, a key goal in reducing production costs.

Results using these four formulas are presented in columns 7, 8, 9, and 10 in Table 6 for pesticides used in potato production in 1995 in all states according to National Agricultural Statistics Survey (NASS) data. There are about 15 pesticides in Tables 4, 5, and 6 that were not used in Wisconsin in 1995, and hence these active ingredients do not appear in Tables 1, 2, 3, and 7. They are included in Table 6 to allow comparison with the pesticides used in other states by potato farmers.

Note the significant differences in the rankings of pesticides across the four formulas. Under the “Environmental Effects Focus Index,” pesticides that score high on “Scaled Ecotoxicity” top the list – esfenvalerate at 695, carbofuran at 566, and phorate, 560. But under the “Health Effects Focus Index,” esfenvalerate drops to 11th out of 18 insecticides, aldicarb rises to number one, and carbofuran drops to number 14. Under an environmental focus, carbaryl scores almost five times higher than in the health focus index. The botanical pyrethrins score about seven times higher.

Some fungicides, on the other hand, score significantly higher in the human health focus index than the environmental effects index. The differential is greatest in the case of metiram, which has a human health focus value of 439 (driven by its maximum value under chronic effects) and an environmental focus value of only 139. Among herbicides, all environmental focus index values are higher than health focus values mostly because of their relatively high “Scaled BioIPM Index” values. The environmental index value for the herbicide pendimethalin exceeds its human health focus value by 6.5 fold. While these indices are not accurate enough to express such differences to two significant digits, they are generally reliable in highlighting the often significant differences that exist in the relative hazards posed by different pesticides.

Table 6. Preliminary Toxicity Adjustment Factors: Pesticides Used in Potato Production, 1995

	Scaled Leaching Index	LD-50	Scaled Inverse LD-50	Scaled Chronic Toxicity	Scaled Ecotox-icity	Scaled BioIPM Index	WWF-WPVGA Project Index	Equal Weight Index	Human Health Focus Index	Environment Effects Focus Index
Herbicides:										
2,4-D	0.89	375	1.17	30.00	8	45	106	84	61	114
EPTC	0.91	1,652	0.28	3.64	3.5	45.1	75	53	19	98
Glyphosate	0.88	4,230	0.10	0.04	1.4	51.0	78	53	14	105
Linuron	0.90	4,000	0.11	11.21	3.6	38.8	73	54	28	88
Metolachlor	0.93	2,780	0.17	0.93	1.1	30.4	48	33	10	63
Metribuzin	1.16	2,200	0.26	26.76	3.0	64.5	127	94	58	142
Paraquat	0.88	150	2.92	19.47	12.9	38.1	91	73	48	108
Pendimethalin	0.88	1,050	0.42	0.67	21.1	96.4	167	119	36	235
Rimsulfuron	1.14	5,000	0.11	7.12	2.8	53.1	90	63	25	114
Sethoxydim	0.90	3,200	0.14	1.00	1.5	38.8	61	41	12	81
Trifluralin	0.88	5,000	0.09	12.65	3.4	68.6	119	85	38	147
Insecticides:										
Aldicarb	1.05	1	86.05	286.73	67.8	89.3	531	530	572	407
Azinphos-methyl	0.89	16	27.69	59.07	28.8	79.0	220	195	150	237
Bacillus thuringiensis	0.88	5,000	0.09	0.01	1.4	20.0	31	22	6	43
Carbaryl	0.89	300	1.48	6.92	4.3	71.3	119	84	32	153
Carbofuran	1.10	8	68.56	21.94	159.9	111.6	384	362	209	566
Cryolite	0.88	5,000	0.09	0.88	20.0	20.0	51	41	16	80
Dimethoate	0.88	150	2.93	175.81	15.1	81.3	314	275	295	238
Endosulfan	0.88	80	5.53	44.22	134.8	71.2	289	256	157	424
Disulfoton	0.88	3	86.05	286.73	200.0	130.0	725	1560	1341	833
Esfenvalerate	0.88	67	6.55	4.39	219.3	126.7	417	357	154	695
Ethoprop	1.01	26	19.35	286.73	12.2	65.6	407	384	472	232
Fonofos	0.88	8	55.06	44.05	25.7	60.8	188	186	149	198
Imidachloprid	0.88	450	0.97	1.54	1.9	74.0	115	78	23	152
Methamidophos	0.88	30	14.60	87.62	11.6	62.1	200	176	167	173
Methyl parathion	0.88	14	31.32	286.73	100.0	90.0	537	508	534	460
Oxamyl	8.38	6	86.05	33.53	63.9	94.3	282	278	192	346
Permethrin	0.88	500	0.88	9.29	43.1	141.2	265	194	72	371
Phorate	0.88	2	86.05	176.26	162.1	85.1	509	510	453	560
Phosmet	0.88	230	1.91	33.30	20.0	30.0	99	85	69	109
Piperonyl butoxide	0.88	5,000	0.09	5.00	1.7	28.0	49	35	15	61
Propargite	0.88	2,200	0.20	9.69	3.4	30.5	59	44	24	70
Pymetrozine	0.88	5,280	0.08	15.44	4.0	24.0	55	44	31	60
Pyrethrins	0.88	500	0.88	1.37	11.9	100.4	164	115	34	225
Fungicides:										
Chlorothalonil	0.88	5,000	0.09	7.81	26.3	30.4	80	65	33	115
Copper ammonium	0.88	650	0.67	0.29	1.3	30.0	47	32	9	63
Copper hydroxide	0.88	1,000	0.44	0.29	5.8	30.1	52	37	11	72
Copper resinate	0.88	5,000	0.09	0.29	5.0	30.1	51	36	11	70
Copper sulfate	0.88	300	1.46	0.29	6.4	23.2	42	31	11	60
Cymoxanil	0.88	960	0.46	5.48	4.8	34.2	62	45	20	79
Dimethomorph	0.88	3,900	0.11	10.00	5.0	20.0	45	35	23	53
Iprodione	0.88	3,500	0.13	20.78	3.1	47.7	96	72	45	107
Mancozeb	0.88	5,000	0.09	114.72	2.8	41.6	180	159	184	118
Maneb	0.89	5,000	0.09	80.07	7.7	44.1	154	132	135	124
Metalaxyl	1.01	670	0.75	1.36	0.7	113.0	172	116	31	228
Metiram	0.88	5,000	0.09	286.73	1.1	32.7	337	321	439	139
Propamocarb hydroch.	0.88	5,000	0.09	0.88	1.6	32.4	51	35	10	68
Sulfur	0.88	3,000	0.15	0.09	1.3	45.2	69	47	12	93
Triphenyltin hydrox.	0.88	156	2.81	286.73	78.7	38.4	424	407	482	307
Other Chemicals:										
Chloropicrin	0.88	250	1.75	100	10.0	30.0	156	142	164	105
Dichloropropene	0.90	224	2.00	287	0.4	46.8	358	336	444	167
Diquat	0.88	231	1.90	39.83	1.2	30.4	88	73	70	74
Endothall	0.88	51	8.62	4.39	1.5	26.8	50	41	23	60
Maleic hydrazide	1.15	5,000	0.11	0.46	18.1	26.5	58	45	16	89
Metam-sodium	0.88	285	1.54	95.49	3.4	58.5	187	159	161	148
Sulfuric acid	0.88	1,000	0.44	0.29	1.2	18.8	30	21	6	40

1. Attainment of WWF-WPVGA Project Risk Reduction Goals

WWF-WPVGA risk reduction goals apply to high-risk pesticides that trigger an acute or chronic toxicity trigger, as shown in Table 7. In the case of acute risk, any active ingredient appearing in the WHO categories Class Ia, “Extremely Hazardous” and Class Ib, “Highly Hazardous” is subject to the 25 percent reduction goal between crop years 1995 and 1997. Four pesticides used in Wisconsin potato production in 1995 meet this criterion: azinphos-methyl, carbofuran, oxamyl, and methamidophos (see the fourth column in Table 7).

Another seven active ingredients fall under the chronic toxicity reduction goal, for a total of 11 pesticides out of a total of 31 applied in 1995. Any pesticide that is a known endocrine disruptor or a B2 carcinogen is subject to the 15 percent chronic toxicity reduction goal between 1995 and 1997.

The goal of the WWF-WPVGA project is to promote adoption of biointensive IPM as a means to reduce reliance on pesticides posing risk to humans, wildlife and IPM systems. To assure that risks are reduced comprehensively, the pounds applied of the 11active ingredients subject to the reduction targets are converted to Wisconsin Project Toxicity Units by multiplying pounds applied by multiattribute toxicity index values (shown in the third column in Table 7). Toxicity units are then summed across the four active ingredients in the case of acute risks, and seven active ingredients in the case of chronic risks. These totals are then divided by the acres planted – 83,000 – to produce an estimate of per acre planted toxicity units. The 25 percent acute and 15 percent chronic reduction goals are then applied to these estimates, as shown in the bottom portion of Table 7.

In 1995, there were about 25.9 million toxicity units associated with the four pesticides triggering the acute risk reduction criterion, or 312 per planted acre. To meet the reduction goal in crop season 1997, the toxicity units associated with active ingredients meeting the acute risk trigger must not exceed 234 per planted acre.

There were on average 1,769 chronic toxicity units per acre associated with pesticide use in 1995. In order to reach the 15 percent reduction target, the average number of toxicity units per acre associated with the application of pesticides meeting the chronic toxicity trigger must be reduced by 265, to 1,504 per acre in 1997.

It is important to note that the reduction goals apply to any and all pesticides applied in 1997 that meet one or both toxicity criteria, possibly including active ingredients not applied in 1995, and hence not contributing to the baseline of toxicity units.

Table 7. Potato Production in Wisconsin: Year 1995 Baseline and 1997 Pesticide Toxicity Unit Reduction Goals

	Acres Treated	Total Pounds Applied	WWF-WPVGA Toxicity Unit Values	WWF-WPVGA Toxicity Units Subject to Acute Toxicity Reduction Goal	WWF-WPVGA Toxicity Units Subject to Chronic Toxicity Reduction Goal
Herbicides:					
Glyphosate	6,640	4,000	78.0		
Linuron	7,470	7,000	73.1		
Metolachlor	14,940	21,000	47.8		
Metribuzin	73,870	39,000	126.6		4,937,400
Pendimethalin	29,880	24,000	166.6		
Sethoxydim	8,300	2,000	60.8		
Total: All Herbicides	141,100	97,000			
Per Planted Acre		1.17			
Insecticides:					
Azinphos-methyl	21,580	26,000	220.3	5,727,800	
Carbofuran	13,280	13,000	383.5	4,985,500	
Dimethoate	23,240	11,000	314.4		
Endosulfan	54,780	60,000	288.5		17,310,000
Esfenvalerate	49,800	3,000	417.0		
Methamidophos	53,950	69,000	199.7	13,779,300	
Oxamyl	6,640	5,000	282.0	1,410,000	
Permethrin	18,260	4,000	264.7		1,058,800
Piperonyl butoxide	14,110	3,000	48.7		
Pyrethrins	8,300	830	164.3		
Total: All Insecticides	263,940	194,830			
Per Planted Acre		2.30			
Fungicides:					
Basic copper sulfate	4,150	13,000	42.1		
Chlorothalonil	73,040	408,000	79.8		32,558,400
Copper hydroxide	31,540	40,000	51.5		
Copper resinate	5,810	12,000	50.5		
Mancozeb	71,380	412,000	180.0		74,160,000
Maneb	11,620	76,000	153.9		11,696,400
Metalaxyl	12,450	4,000	172.0		
Propamocarb hydroch.	9,960	9,000	51.1		
Triphenyltin hydrox.	38,180	12,000	424.0		5,088,000
Total: All Fungicides	258,130	986,000			
Per Planted Acre		12			
Other Chemicals:					
Diquat	66,400	28,000	87.6		
Endothall	9,130	7,000	50.4		
Maleic hydrazide	6,640	13,000	58.4		
Metam-sodium	6,640	970,000	187.4		
Paraquat	5,810	3,000	91.0		
Sulfuric acid	10,790	1,632,000	29.9		
Total: Other Chemicals	105,410	2,653,000			
Per Planted Acre		32			
Total Herbicides, Insecticides, and Fungicides:	663,170	1,277,830		25,902,600	146,809,000
Per Planted Acre		15		312	1,769
Acute Tox Reduction Goals for 1997:					
25% Toxicity Units				6,475,650	
Ave. Reduction Per Acre				78	
Chronic Tox Reduction Goals for 1997:					
15% Toxicity Units					22,021,350

2. Challenges and Next Steps

A number of activities are underway to collect better data and incorporate more sophisticated concepts and methods into the methodology used to calculate toxicity factor values. Some of the major areas in need of further work are –

- Incorporating Synergism into the Model
- Adjustments for Exposure
- Building Economic Impacts into the System
- Calibrating Model Predictions to Field Monitoring Data
- Projecting the Impacts of Genetically Engineered Production Inputs

Future Applications With the benefit of these and other refinements, the system described herein will provide a solid basis to monitor progress toward biointensive IPM and pesticide risk reduction goals set as part of the WWF-WPVGA potato IPM project. Other partnerships involving farm groups and consumer and environmental organizations are likely to use or build on the system. Government agencies evaluating the impacts and accomplishments of IPM programs are also likely to make use of pesticide toxicity indices.

Current and future applications will provide valuable insights into long-term trends in pesticide toxicity levels, as well as the benefits of progress along the IPM continuum in reducing the average toxicity units associated with the production of major crops. One longer-term goal is establishment of an information base useful in forging consensus on future regulatory policies and research and education priorities. Crisper recognition of problems, constraints, and opportunities should help the nation take the steps needed to provide farmers with progressively safer and more effective IPM tools, and the public with safer and higher quality foods grown with fewer adverse impacts on the environment.

Bibliography and Further Information

Baril, A., and P. Mineau. 1998. “A Distribution-Based Approach to Improving Avian Risk Assessment,” Canadian Wildlife Service (in press).

Baril, A., Jobin, B., Mineau, P., and B.T. Collins. 1994. “A Consideration of Inter-Species Variability in the Use of Lethal Dose (LD-50) in Avian Risk Assessment,” Technical Series Report No. 216, Canadian Wildlife Service, Ottawa, Ontario.

Barnard, C., Daberkow, S., Padgitt, M., Smith, M.E., and N.D. Uri. 1997. "Alternative Measures of Pesticide Use," The Science of the Total Environment,” Vol. 203: 229-244.

Benbrook, C. 1996a. “Adoption of Integrated Weed Management Systems by Corn and Soybean Farmers in 1994: An Application of a New Methodology to Measure Adoption of IPM and Pesticide Use and Reliance," Paper presented at the Weed Science Society of America Annual Meeting, February, 1996, Norfolk, Virginia. Available on the Internet at <http://www.pmac.net> Go to the World Wildlife Fund section in "Measuring IPM Adoption."

Benbrook, C. 1996b. “Primer on Pesticides Known to Disrupt the Endocrine System,” Campaign for Pesticide Policy Reform, Washington, D.C..

Benbrook, C., Groth, E., Halloran, J., Hansen, M., and S. Marquardt. 1996. *Pest Management at the Crossroads*, Consumers Union, Yonkers, New York. See also *PMAC* website at http://www.pmac.net

Burnet, M.W.M., Hart, Q., Holtum, J.A.M., and S.B. Powles. 1994. "Resistance to Nine Herbicide Classes in a Population of Rigid Ryegrass (*Lolium rigidium*)," *Weed Science*, Volume 42, Number 3: 369-377.

Colborn, T., vom Saal, F.S., and A.M. Soto. 1993. "Developmental Effects of Endocrine-Disrupting Chemicals in Wildlife and Humans," *Environmental Health Perspectives*, Volume 101, Number 5: 378-384.

Croft, B.A. & K. Theiling. 1990. “Pesticide effects on arthropod natural enemies: a database summary,” Chap. 2. p. 17-46. In *Arthropod Biological Control Agents & Pesticides*. Ed. B. A. Croft. J. Wiley, N.Y. 723 pp.

Gressel, J. 1997. Review of Glyphosate Resistance in *Resistant Pest Management*, Volume 8, Number 2, Winter 1996.

Hager, A.G. 1996. "Weed Resistance to Herbicides: Understanding How Resistance Develops in Weeds is the First Line of Defense," *Weed Control Manual: Volume 30*. Meister Publishing Company, Willoughby, Ohio.

Hoppin, P. 1996. “Reducing Pesticide Reliance and Risk Through Adoption of IPM: An Environmental and Agricultural Win-Win,” Presentation February 27, 1996 before the Third National IPM Symposium/Workshop.

International Programme on Chemical Safety, “The WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification 1996-1997,” World health Organization, Geneva, Switzerland, 1996).

Kovach, J., Petzoldt, C., Degnil, J. and J. Tette. 1992. "A Method to Measure the Environmental Impacts of pesticides," *New York's Food and Life Sciences Bulletin*, Volume 139:1-4.

Landy, D. 1995. “Multiattribute Ranking Systems for Pesticides,” Masters of Science Thesis, Energy and Resources Department, University of California, Berkeley.

Leivtan, L. 1997. "An Overview of Pesticide Impact Assessment Systems (a.k.a. 'Pesticide Risk Indicators') based on Indexing or Ranking Pesticides by Environmental Impact," Background Paper, OECD, Paris, France, accessible on the Internet at <http://www.pmac.net/lois.htm>.

Lewis, W.J., van Lenteren, J.C., Phatak, S.C., and J.H. Tumlinson. 1997. "A Total System Approach to Sustainable Pest Management,” *Proc. Nat. Acad. of Sci*., Vol. 94, pp. 12243-12248, November 1997. (Accessible via the PNAS website at http://www.pnas.org, search for article by lead author's name).

Meister Publishing Company. 1998. “Farm Chemicals Handbook ’98,” Willoughby, Ohio.

Mineau, P., Jobin, B., and A. Baril. 1994. “A Critique of the Avian 5-Day Dietary Test (LC-50) as the Basis of Avian Risk Assessment,” Technical Report Series No. 215, Canadian Wildlife Service, Ottawa, Ontario.

Montague, B. 1998. “EPA Ecotoxicological Database,” available from EPA headquarters.

Palling, E.D. 1992. “Evidence for Pesticide Synergism in the Honeybee (*Apis mellifera*),” Aspects of Applied Biology Vol. 31, pages 43-47.

Theiling, K.M., Croft, B. 1988. "Pesticide Side-Effects on Arthropod Natural Enemies: A Database Summary." Unpublished Manuscript, Oregon State University Department of Entomology.

Theiling K. & B.A. Croft. 1988. “Pesticide Effects on Arthropod Natural Enemies: A Database Summary,” *Agric., Ecosys. & Environ*. 21:191-218.

Vandeman, A., Fernanedez-Cornejo, J., Jans, S. and B.H. Lin. 1994 *Adoption of Integrated Pest Management in U.S. Agriculture*. Agriculture Information Bulletin No. 707, Economic Research Service, Washington, D.C.