

## PESTICIDES IN SOUTHWEST FLORIDA WATERWAYS – A REPORT CARD

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**ABSTRACT:** *This paper describes a methodology for estimating pesticide hazards in surface water by Water Body ID (WBID). Southwest Florida was selected as the area of interest. The methodology considers agriculture (citrus and row crops), mosquito management, lawn maintenance, and golf course maintenance. For each pesticide, physical chemical properties are used to predict transport and fate in surface water and this is combined with acute toxicity data on fish, aquatic invertebrates, insects, and birds. This together with the quantity of each pesticide used by WBID helps to estimate the relative pesticide hazards for each WBID. Row crops contribute the greatest hazard with tomatoes and bell peppers leading the list followed by citrus, lawn maintenance, mosquito management and finally golf course maintenance. The most hazardous pesticides were: the fumigants methyl bromide and chloropicrin followed by oxadiazon (lawn herbicide), copper hydroxide (agricultural fungicide), permethrin (lawn insecticide), bromacil (lawn herbicide), mancozeb (lawn fungicide), atrazine (lawn herbicide), diuron (agricultural herbicide), chlorothalonil (agricultural and lawn fungicide), and glyphosate (agricultural herbicide). The methodology predicted that the most affected WBIDs lie in the agricultural areas of Collier and Hendry Counties.*

**Key Words:** Pesticides, surface water, WBID, hazard index, relative hazard assessment methodology, mosquito control, lawncare, golf course, agriculture, row crops, citrus

PESTICIDES have many different uses and the impacts from these applications can combine to create significant hazards to those populations that rely on surface water. Pesticides entering southwest Florida waterways predominately come from: agriculture (citrus and row crop), mosquito control, golf courses, and residential lawn maintenance.

The geographic area of interest for this project extends from Charlotte Harbor to Rookery Bay and includes the area to the west of the main Okeechobee/Everglades drainage through the “river of grass.” This drainage area is generally hydrologically separate from that for the southeastern two thirds of the state. It includes a number of distinct water drainage basins, designated by distinct water body IDs (WBIDs).

Monitoring of surface water and sediment has been done for the area of interest in the past for a limited set of pesticides. Most of these are no longer in use, though many are still present because of their long environmental half-lives. In Collier County, no surface water data were available, but sediment data for pesticides were available for a variety of locations covering the period 1991 to 1992 under two separate monitoring programs (Grabe, 1993). The bulk of the monitoring looked for aldrin, Delta-BHC, Gamma-BHC, 4,4'-DDD, dieldrin, endosulfan, endosulfan

sulfate, endrin, heptachlor and chlordane in surface sediments. While levels above the detection limit were found for all of the above at a number of locations, no levels approached the Florida soil/sediment screening levels. Of the above pesticides, only gamma-BHC (Lindane) and endosulfan are still in use, the rest having being banned.

Gardinali and co-workers (2002) reviewed the historical data on pollutants from urban and agricultural land use, including pesticides. They carried out sampling in June and December 2001 at a variety of coastal and estuarine locations. They also looked for levels of historical pesticides and found chlordanes, endosulfan and DDTs in sediment at levels above the detection limit in Rookery Bay/Henderson Creek, the Everglades/Faka Union Canal and Naples Bay. They found 4,4'-DDE in 62% of their samples, chlorpyrifos in 31% of the samples, and chlordanes in 20% of the samples. Endosulfan (including I, II and endosulfan sulfate) was not found at frequencies above 6%. Only aldrin and chlorpyrifos exceeded concentrations of 1 mg/kg. At one sampling station on the Blackwater River, the level of chlorpyrifos in sediments was well above the national average of 0.269 mg/kg and use of chlorpyrifos has been increasing.

These chlorinated pesticides tend to reside in sediments, and data for surface water concentrations of currently used pesticides have not been found. Based on the findings of the NOAA report (Clark et al., 1993) coupled with the higher percentage of pesticide detections in sediments as reported by Grabe (1993) for Collier County, Shahane (2003b) stated that Collier County is viewed as one of the "hot spots" by the state regulators.

In Charlotte County, the South Florida Water Management District undertook quarterly sampling from 1980 through the present time at three locations on the Caloosahatchee River that empties into Charlotte Harbor (Pfeuffer & Matson, 1980-present). That river receives water from Lake Okechobee as well as numerous other streams and canals. This project looked for the presence in surface water of 63 pesticides, most of which are in current use. Ametryn, atrazine and two of its breakdown products (atrazine desethyl and atrazine desisopropyl), bromacil, norflurazon, and simazine were detected above background levels. Peak concentrations tended to occur in late summer/early fall when rainfall runoff is greatest and when pumping is occurring to clear fields of standing water. Most of these pesticides are associated with sugar cane and citrus which is typical of this area.

These data, or lack thereof, point out that there is an obvious need to determine what pesticides are in use in southwest Florida, the rates at which they are being applied, and the levels to which they are present in local waters and sediments. It is also important to identify those pesticides that represent the greatest hazards to local ecosystems.

This paper describes a methodology that attempts to combine data from a number of sources in a scientific approach to determining the relative risks of various pesticides and the geographical areas (WBIDS) that are most likely to be affected. It will be in these areas that monitoring will most likely detect pesticides and the individual pesticides likely to be present can also be predicted.

*MATERIALS AND METHODS—Schema for assigning relative risk scores—*This exercise is in no way intended to be a quantitative risk assessment, predicting actual exposure levels to individual target species.

Rather, it is designed to be a relative risk estimation method to indicate which water drainage areas are most likely to be impaired due to pesticide use and which pesticides are most likely to be causing the greatest impacts on specific Southwest Florida waterways.

Therefore, a scoring system was devised that relied on physical/chemical properties, aquatic, avian, and insect toxicity tests conducted under laboratory conditions, and information on pesticide chemical usage for the counties in Southwest Florida. This system is based on other systems used by the US Environmental Protection Agency (1992), the Florida Pesticide Review Council of the Florida Department of Agriculture (1986), and the US Department of Energy (Gillett, 1983).

The basic scoring approach involves creating a Hazard Index (HI) that serves as a measure of relative risk and represents the relationship shown in Equation 1:

$$\text{Hazard Index} = \text{Chemical Quantity} \times \text{Environmental Fate} \times \text{Toxicity} \quad (1)$$

The *Chemical Quantity* term is expressed in terms of pounds of active ingredient per acre times the number of acres to which it is applied. The quantities come from the state agricultural data for the agricultural and mosquito control pesticides, from type of land use for the lawn care pesticides, and from use statistics on a per hole basis for the golf course pesticides. Because estimated actual use data are available, it is possible to compare the relative impacts of the four categories of use.

Because it was impossible to obtain concurrent use data for all categories of use, there will be some discrepancies since use of particular products may increase or decrease over time. There are also trends in shifting land use that may affect actual outcomes. Decisions were also made to assume that all pesticide users in a particular category used the same products since there was no way to differentiate. This will lead to local variations, but overall, the methodology is useful to predict a ranked list of concerns by chemical and by WBID.

The goal of this project is to obtain scores by water drainage areas in Southwest Florida. The approach used to accomplish this varied by use pattern.

*Agriculture*—The Florida State Department of Agricultural Services publishes a survey of agricultural pesticide use every three years (Shahane, 2003a). This publication identified the major crops by county, the pesticides used on each crop, and the quantity of each pesticide used per county. This was extremely useful both in identifying the pesticides used and the differences in pesticides used by crop and region within the state of Florida. The most recent data were for 2002, and these were used for this effort.

*Mosquito control*—Shahane (2003a) also identified the quantities of various mosquito control chemicals used by county in 2002. These included both pre-emergent and larval treatments which were added together to obtain total quantities of pesticides used.

*Golf courses*—Since collective data on golf course pesticide quantities are not available. These values had to be estimated based on a survey of pesticide use by a group of typical golf course superintendents. The locations of the golf courses are known as are the counties in which they are located. There were no golf courses within the portions of Charlotte and Hendry Counties that lie within our study area (courses present in those counties lie outside the study area for this project). Collier County has 75 courses with 1539 holes, Lee County has 75 courses with 1432 holes and Glades County has two golf courses with 45 holes.

A supplier of golf course chemicals in SW Florida provided a list of chemicals and their active ingredients were identified from Material Safety Data Sheets (MSDSs) and labels. Quantities of chemicals for the 152 golf courses in our study area were estimated based on a survey of 15 golf course superintendents in Collier and Lee Counties and knowledge about the sizes and number of holes per course. The data from the 15 courses that responded to the survey were adjusted to take into account the shorter executive courses and averaged on a per hole basis. These averages were used to estimate total pesticide use at the 152 identified golf courses in the study area.

*Lawn care*—The numbers of residences within a WBID were estimated based on County data obtained from the 1999 Florida Geographic Data Library maps showing residential areas and estimating residential density within an area. The scale used was: <2 domiciles/acre are considered low density, 2–5 domiciles/acre are considered medium density, and >5 domiciles/acre are considered high density.

TABLE 1. Pesticide applicators by housing type.

	Owner Applied	Service Applied
Mobile Homes	100%	0%
Low Density (<2/ac)	50%	50%
Medium Density (2–5/ac)	30%	70%
High Density (>5/ac)	50%	50%
High Density Hi Rise	0%	100%

There are also two types of grass in Southwest Florida, St. Augustine (*Stenotaphrum secundatum*) and bahia (*Paspalum notatum*), each of which requires a unique maintenance regimen. It is assumed that 80% of the lawns are St. Augustine and 20% are bahia grass.

There are two general approaches to lawncare pesticide application: owner applied or lawn service applied. The chemicals used and concentrations in the products vary for the two approaches. The split of these two approaches shown in Table 1 was assumed.

For lawn service applied chemicals, the recommended levels of the chemicals identified by Tru-Green and the large wholesale chemical supplier were used and averaged for each grass type and then combined for a total application pattern.

For the chemicals used by homeowners, active ingredients were noted on the labels of lawncare products sold at Home Depot and Lowe's stores located in SW Florida. For residential applications, it was assumed that a series of lawncare products were used as recommended by the manufacturer as well as one container of spot weed control (herbicide), and one container for insect (aphid, scale, grub, or fire ant) control. Data for all marketed products were averaged and spread over the total number of residences. Application rates were those recommended on the label by the manufacturer.

The lawncare acreage is probably an underestimation of the current residential acreage because of the rapid rate of conversion of agricultural lands to residential lands, especially in the eastern parts of Lee, Collier and Charlotte Counties.

The *Toxicity Score* is dependent on the affected ecological populations; however scores for fish and aquatic invertebrates are averaged since they occupy the same niche. Therefore, one obtains a separate toxicity score for aquatic organisms (Ta), insects (Ti), and birds (Tb). The following is an example of the ordinal scoring schema used for toxicity. Toxicities for fish and aquatic invertebrates were based on 96 hour flow through LC<sub>50</sub>s for fish and 48 hour LC<sub>50</sub>s for the invertebrates as measured in water fleas (*Daphnia magna*). Concentrations less than 1 mg/l received an ordinal score of 7. Concentrations in the 1–10 mg/l range received a score of 3, those in the 10–100 mg/l range a score of 2, those in the 100–1000 mg/l range a score of 1, and those greater than 1000 mg/l a score of 0. Insect toxicity was based on those toxicity ranges regularly reported for honeybee bioassays with a score of 7 being assigned for honey bee toxicity <11 µg/bee, a score of 3 for 24–11 µg/bee, a score of 2 for 25–99 µg/bee and a score of 1 for >100 µg/bee. Bird toxicity was based on mallard, quail, or rat oral LD<sub>50</sub>s, in that order. A score of 7 being assigned for an LD<sub>50</sub> <5 mg/kg of body weight, a score of 3 for 5–99 mg/kg, a score of 2 for 100–999 mg/kg, a score of 1 for 1000–5000 mg/kg and a score of 0 for >5000 mg/kg.

The *Environmental Fate* term (EF) is computed as shown in Equation 2:

$$EF = W + S + A + BCF + Pw + (0.5 * Ps) \quad (2)$$

Where

- W = water solubility score
- S = soil mobility
- A = sediment adsorption
- BCF = bioaccumulation score
- Pw = Persistence in water
- Ps = Persistence in soil

The soil persistence score was divided in half because pesticides tilled into deeper soil layers may not reach waterways.

The following schema was used to evaluate environmental fate parameters. Soil mobility and adsorption to sediments were ranked from high to low based on Koc (soil adsorption coefficient). The tendency to bioconcentrate was based on BCF (bioconcentration factor) or log Kow (octanol/water partition coefficient) and ranges from a score of 7 for a log Kow >6 or a BCF >4000 to a score of 0 for a log Kow <3 or a BCF <300. Water solubility was obtained from literature values obtained at approximately ambient temperatures and ranged from a score of 4 for >1000 ppm to a score of 1 for a solubility of <10 ppm. The next set of scores relate to how long a chemical is likely to remain in the aquatic environment and in sandy soil. These scores range from 9 for a half life of >100 days to 0 for a persistence of less than 0.01 day.

These scales are generally logarithmic in nature and were chosen to provide a good spread of values as well as to penalize those chemicals that are particularly persistent, bioaccumulative, or toxic. Chemicals that have these attributes have been demonstrated to be those that are most likely to impact target populations.

To try to evaluate the potential for exposure to a pesticide and the effects on fish, aquatic invertebrates, insects, and birds, specific chemical information was gathered from USEPA Pesticide Fact Sheets, material safety data sheets and pesticide labels. Additional data were obtained from Hazardous Substances Data Bank, Extonet and other electronic sources available from the author upon request. These same sources generally also contain toxicity test data.

*General approach to scoring*—First EF  $\times$  Toxicity scores were obtained by group (aquatic, insect, bird). These were then normalized to a 100 point scale. Table 2 contains the scores assigned to the raw data and the calculated EF values, the raw EF  $\times$  Toxicity scores, and the normalized EF  $\times$  T scores for aquatic life, insects, and birds. These data give an indication of the relative impacts pesticide active ingredients are likely to have in the aquatic environment. Only those chemicals found to have a significant potential impact were included in Table 2, but the number of chemicals actually evaluated in this exercise was much larger.

*Computation of hazard indexes by county*—As stated previously, in EQUATION (1), the Hazard Index is the product of chemical quantity, environmental fate and toxicity. For this project, Hazard Indexes were obtained separately for agricultural, mosquito control, golf course, and residential lawncare pesticides.

For each chemical and use, the chemical quantities and the normalized EF  $\times$  T scores (aquatic, insect and bird) were multiplied together. These results show the major impacting chemicals by activity and by county for the region of Southwest Florida. These results are shown in Table 3 for agricultural crops; similar tables are available from the author for mosquito control, lawn care and golf course maintenance.

Table 4 contains the percentages of the total pesticide loading across the whole study area represented by each pesticide use category in each of the counties studied. It can be seen that the quantities vary greatly by use.

It is obvious that agriculture dominates the pesticide use with over 84% of the total. This also results in elevated county totals for Collier and Hendry, where most of the agricultural activities occur. Collier has the highest overall county scores because it has both agriculture and a significant residential population. Lee County, which has much less agriculture, has the highest residential lawncare-related pesticide use because its residential area is the greatest.

*DISCUSSION—Pesticides representing the greatest impacts*—Throughout this evaluation, pesticides have been grouped into use categories as fungicides (F), herbicides (H) and insecticides (I). The fact that a pesticide shown in Table 2 may have a particularly high EF  $\times$  T score does not necessarily mean that it is causing a problem within the study area. This is because potential impacts are caused by a combination of EF  $\times$  T and the amount used. Sometimes, a lower scoring EF  $\times$  T pesticide that is used in higher volumes will actually cause greater harm than one with a high EF  $\times$  T score but with lower use. Many active ingredients in pesticides are included in a wide range of products that are approved by USEPA for a variety

TABLE 2. Pesticide data table including environmental fate and toxicity scores.

	Soil Mob	Sed Adsorb	BCF	H2O sol	Fish Tox	Inv Tox	Ins Tox	Bird Tox	Ps	Pw	Env Fate
1,3-dichloropropene	3	3	0	4	3	3	7	0	6	3	17.5
2,4-D	3	3	0	3	2	3	3	1	6	3	16.5
acephate	3	3	0	4	7	7	7	2	3	6	16
aldicarb	3	3	0	3	3	2	7	7	6	6	18
atrazine	3	2	0	2	2	3	1	1	6	9	17.5
basic copper sulfate	1	1	3	4	7	7	1	1	6	6	18
bifenthrin	1	1	7	1	7	7	7	1	6	6	19
bromacil	3	3	0	3	3	1	1	0	9	6	21
carbaryl	3	3	0	3	7	7	7	2	6	3	16.5
chloropicrin	3	3	0	3	7	7	1	3	3	3	13.5
copper hydroxide	3	3	1	1	7	7	1	1	6	6	17
diazinon	1	1	1	1	7	7	7	7	6	3	11.5
dicofol	1	1	2	1	7	7	1	1	6	9	15.5
diuron	2	1	0	2	7	7	1	0	9	9	18.5
endosulfan	1	1	1	1	7	7	3	2	9	3	14.5
ethion	1	1	3	1	3	7	3	0	9	9	19.5
glyphosate	1	1	0	4	2	2	1	1	6	6	15
lambda-cyhalothrin	1	1	7	1	7	7	3	0	6	3	17.5
malathion	3	3	0	3	7	7	7	1	3	6	15
mancozeb/maneb	2	2	0	1	3	7	1	0	3	3	9.5
methomyl	3	3	0	3	3	2	7	1	6	9	19.5
methyl bromide	3	3	0	2	3	3	7	3	6	6	17
monosodium methane arsenate (MSMA)	1	1	7	2	7	7	7	1	9	9	24.5
naled	3	3	0	4	7	7	3	1	3	6	16
norflurazon	1	1	0	2	3	2	1	1	6	6	13
oxadiazon	1	1	7	1	7	3	1	1	9	6	22
pentachloronitrobenzene	1	1	7	1	7	7	0	1	9	3	20.5
permethrin	1	1	7	1	7	7	7	0	6	6	19
simazine	3	2	0	1	1	3	1	0	6	3	13.5
sulfur	1	1	0	1	1	0	1	0	6	6	12
thiophanate-methyl	3	3	0	2	3	3	1	0	6	3	15.5

of uses. Therefore, it is also important to sum the use of each pesticide active ingredient across uses to estimate its potential impact.

Table 5 contains the data on potential pesticide impacts across uses by pesticide for those with the highest risks. Table 5 is coded to show increasing levels of risk. There are only two chemicals with extremely high risk and these are chloropicrin and methyl bromide, both which are only used as fumigants on agricultural crops. These highly toxic fumigants are applied to the soil prior to planting to sterilize it against nematodes, bacteria, fungi, and insects such as grubs, cutworms and wireworms. The fumigated area is immediately covered with a tarpaulin to avoid evaporation and drift. The high usage volumes also affect the HI score and elevate it further. These two pesticides alone account for 63.35% of the total calculated risk (see last column on Table 5). There is international legislation under the Montreal Protocol to reduce levels of methyl bromide released to the atmosphere where it is

TABLE 3. Hazard indexes by county for highest impact agricultural pesticides.

Chemical	Use	Charlotte HI Total	Collier HI Total	Glades HI Total	Hendry HI Total	Lee HI Total
basic copper sulfate	F	0	605,250	0	807,000	0
chloropicrin	O	0	2,189,734	0	2,919,645	0
chlorothalonil	F	0	122,105	0	162,806	0
copper hydroxide	F	0	77,089	0	102,785	0
methyl bromide	O	0	3,246,847	0	4,329,129	0
Total Cucumber		0	6,384,443	11	8,512,591	0
chlorpyrifos	I	258,047	95,993	17,191	463,472	76,096
copper hydroxide	F	1,675,054	623,118	111,595	3,008,525	493,962
diuron	H	272,465	101,286	18,139	488,944	80,292
ethion	I	377,855	140,562	25,173	678,657	111,427
fenbutatin-oxide	I	60,165	22,381	4,008	108,062	17,742
glyphosate	H	273,500	101,742	18,221	491,227	80,653
norflurazon	H	65,056	24,201	4,334	116,845	19,185
sulfur	F	516,770	192,238	34,428	928,159	152,392
Total Grapefruit		3,852,519	1,433,061	257,227	6,918,998	1,136,027
aldicarb	I	1,036,348	1,909,946	566,807	5,201,139	566,807
basic copper sulfate	F	192,673	355,088	105,378	966,971	105,378
bromacil	H	219,590	404,696	120,100	1,102,062	120,100
carbaryl	I	735,295	1,355,117	402,152	3,690,237	402,152
chlorpyrifos	I	239,992	442,295	131,258	1,204,452	131,258
copper hydroxide	F	2,464,191	4,541,399	1,347,732	12,367,078	1,347,732
dicofol	I	227,908	420,025	124,649	1,143,806	124,649
diuron	H	1,670,433	3,078,537	913,605	8,383,430	913,605
ethion	I	183,041	337,336	100,110	918,630	100,110
glyphosate	H	1,209,074	2,228,272	661,275	6,068,000	661,275
iprodione	F	24,507	45,165	13,403	122,992	13,403
mefenoxam	F	24,645	45,420	13,479	123,688	13,479
norflurazon	H	178,717	329,369	97,745	896,933	97,745
paraquat	H	48,521	89,421	26,537	243,511	26,537
pyridaben	I	32,578	60,040	17,818	163,500	17,818
simazine	H	298,147	549,473	163,065	1,496,318	163,065
sulfosate	H	56,268	103,700	30,775	282,396	30,775
sulfur	F	257,262	474,123	140,703	1,291,124	140,703
Total Oranges		9,268,587	17,081,613	5,069,347	46,516,421	5,069,239
chloropicrin	O	0	12,884,460	0	23,621,509	0
copper hydroxide	F	0	1,130,546	0	2,072,667	0
mancozeb/maneb	F	0	623,947	0	606,278	0
methomyl	I	0	258,166	0	473,304	0
methyl bromide	O	0	38,876,181	0	71,272,999	0
Total Peppers		0	54,008,016	500	98,476,950	0
methyl bromide	O	0	2,206,466	0	1,427,713	778,753
Total Squash		0	2,206,699	0	1,427,960	778,835
chloropicrin	O	0	71,474,984	0	28,244,147	8,069,756
chlorothalonil	F	0	3,762,502	0	1,486,795	424,799
copper hydroxide	F	0	7,486,655	0	2,958,436	845,267
diquat	H	0	128,565	0	50,804	14,515
endosulfan	I	0	1,038,213	0	410,262	117,218
imidacloprid	I	0	205,351	0	81,147	23,185

TABLE 3. Continued.

Chemical	Use	Charlotte HI Total	Collier HI Total	Glades HI Total	Hendry HI Total	Lee HI Total
mancozeb/maneb	F	0	3,810,423	0	1,505,732	430,209
methamidophos	I	0	235,865	0	93,205	26,630
methomyl	I	0	542,183	0	214,250	61,214
methyl bromide	O	0	233,047,662	0	92,091,415	26,311,833
Total Tomatoes		0	322,495,708	406	127,437,873	36,410,821
1,3-dichloropropene	O	392,873	622,672	0	1,015,939	327,722
Total Watermelon		406,615	640,649	0	1,045,269	337,184

considered an ozone depleting substance. This has the potential to reduce the use on agricultural fields in southwest Florida and to reduce the overall potential risk from pesticide exposure significantly.

The agricultural pesticides of greatest concern, following methyl bromide and chloropicrin are: copper hydroxide, diuron, glyphosate, aldicarb, mancozeb, captan, chlorothalonil, and sulfur. For mosquito control, no chemicals reach the levels of risk posed by the agricultural pesticides, but naled, malathion and permethrin are still of concern. The lawncare chemicals representing the greatest risk are: oxadiazon, pentachloronitrobenzene, bifenthrin, atrazine and mancozeb. The golf course chemical use is so greatly reduced due to integrated pest management techniques that only monosodium methane arsenate, and acephate are of potential concern. The use categories (herbicide, insecticide, fungicide and fumigant for the above listed chemicals of potential concern are included in Table 5.

Many of these high use pesticides are designated by the USEPA (2003) as Restricted Use Products or RUPs. This means that they must only be applied by trained operators and records of exposure must be maintained as required by 40 CFR 152 Subpart I. Generally only those pesticides felt to represent a risk to applicators or the environment are designated as RUP. The pesticides that have been designated as RUP are indicated with an asterisk in the second column of Table 5.

Only those pesticides indicated as High, Medium-High or Medium Risk should be considered for inclusion in the follow-on monitoring program since they represent the greatest potential risks to the environment. It should be pointed out that copper hydroxide and sulfur may represent more significant hazards than this method identifies because they contain elements that are not further degraded in the environment and which will be cumulative and persistent.

TABLE 4. Percent of total pesticide use across study area by activity.

County	Agriculture	Lawncare	Mosquito Control	Golf Course Maintenance	County Totals
Charlotte	1.58	0.29	0.26	0.00	2.13
Collier	44.80	1.34	0.96	0.48	47.58
Glades	0.59	1.30	0.00	0.01	1.91
Hendry	32.37	0.08	0.00	0.00	32.44
Lee	4.91	9.76	0.83	0.43	15.94
Use Totals	84.24	12.78	2.05	0.93	100

TABLE 5. Total HIs by pesticide by activity.

Chemical	RUP	Golf				Total	%
		Agriculture	Mosquito	Lawncare	Course		
1,3-dichloropropene		M				M	0.24
2,4-D		P		M	LM	M	0.12
acephate		P		M	M	M	0.55
aldicarb	*	M				M	0.94
atrazine	*	P		MH	P	MH	1.89
basic copper sulfate		M				M	0.32
bifenthrin	*	LM		MH	P	MH	2.17
bromacil		M				M	0.21
carbaryl		M		LM	LM	M	0.79
chloropicrin	*	H				H	15.35
chlorothalonil	*	M		M	LM	MH	1.33
chlorpyrifos	*	M			LM	M	0.34
copper hydroxide		MH				MH	4.32
diazinon	*	LM		M		M	0.92
dicofol		M				M	0.22
diuron		MH				MH	1.61
endosulfan		M				M	0.17
ethion	*	M				M	0.30
glyphosate		MH		LM	LM	MH	1.29
lambda-cyhalothrin	*	P		M	P	M	0.16
malathion		P	M	LM		M	0.35
mancozeb/maneb		M		MH	P	MH	2.12
methomyl	*	M				M	0.17
methyl bromide	*	H				H	48.00
MSMA		LM			M	M	0.19
naled		P	M			M	0.90
norflurazon		M				M	0.19
oxadiazon				MH	LM	MH	8.03
PCNB				MH		MH	3.91
permethrin	*	LM	M			M	0.19
simazine	*	M				M	0.29
sulfur		M				M	0.42
thiophanate-methyl				M	LM	M	0.37

H = High Hazard, MH = Med-High Hazard, M = Medium Hazard, LM = Low-Med Hazard, P = Present.

*Determination of potential impacts by water drainage area*—The distribution of pesticide use within each Southwest Florida county was obtained separately for each type of application, but was then divided into water drainage areas using the ArcView™ Geographic Information System (GIS). Southwest Florida had Water drainage area delineations are available from several sources. For this project, the water drainage maps from the Florida State Department of Environmental Protection were used. These maps were merged and boundary discrepancies minimized for use on this project so they would cover the 5-county Southwest Florida water drainage area. It should be pointed out that a number of the WBIDs span county borders which is logical since the boundary lines are generally straight and do not follow waterways in this part of the state.

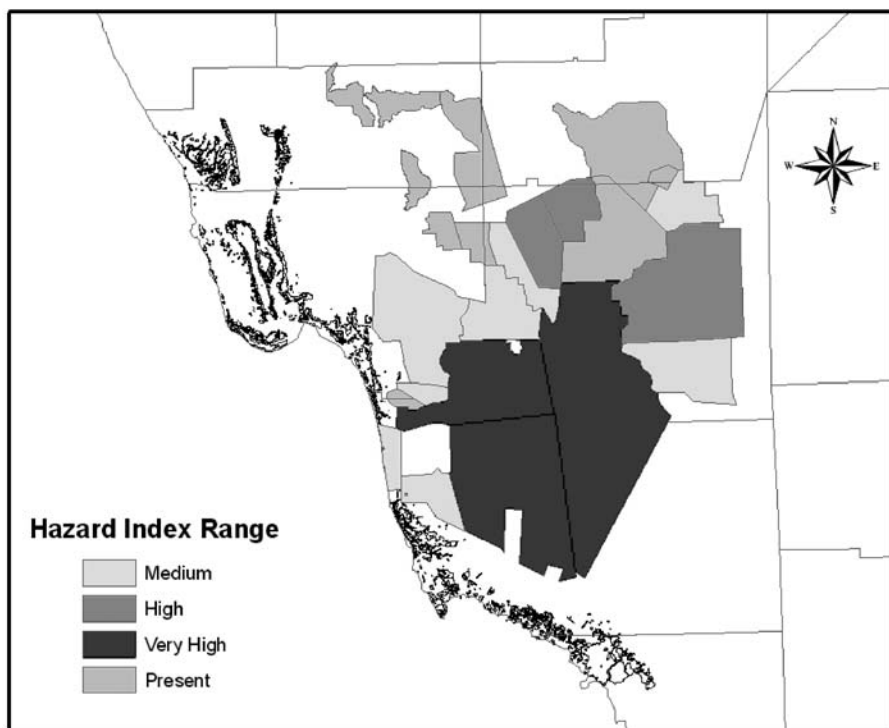


FIG. 1. Drainage areas of greatest concern for pesticides used in row crop agriculture.

GIS technology was also used to locate the various pesticide usage areas and to estimate the usage by water drainage area for each type of application on a county basis.

*Agriculture*—The US Department of Agriculture’s Regional Agricultural Agent had significant experience covering the region in question and knew all of the farms, where they were located, the crops grown, and acreages by crop (McAvoy, 2004). The percentage of the total area for each crop was estimated for each water drainage area by overlaying the farm location and drainage area maps. The quantity of each major agricultural pesticide was calculated by water drainage area by County and is available from the author. The Agricultural Agent was also asked to review the State data on pesticides used by crop to see whether these data appeared consistent with his experience; and they were.

In addition, digitized county maps provided by Florida Geographic Data Library (1999) with layers showing farm locations for citrus and other row crops were used. Agricultural areas were split into two separate subcategories: citrus (oranges & grapefruit) and row crops (tomatoes, peppers, squash, cucumbers, watermelon). These two agricultural crop types have very different pesticide use patterns and so splitting them is logical. Figure 1 demonstrates the potential impacts of agricultural pesticide use on row crops by WBID. For citrus, there is one WBID

of high concern (3261C which straddles Collier and Hendry Counties) and three WBIDs of moderate concern (2041 (Charlotte County), 3259B (Collier County) and 3259X (Collier, Lee, and Hendry Counties)).

*Mosquito control*—Areas of mosquito control were obtained from for the Collier Mosquito Control District (2004) from their web site. Similarly, Charlotte data were available at their website. Data for Lee County were obtained from their mosquito control department and application areas and rates were said to approximate the population distribution so that was used as a surrogate. No spraying is done in Hendry or Glades counties. These data were then added as a GIS layer and used to estimate the percentage the total spraying, and therefore of chemical use, could be allocated to each drainage area.

Table 6 contains the mosquito pesticide use relative risks by WBID and Figure 2 shows the WBIDs potentially affected. Most of the treated areas in Charlotte County were outside our study area. Only four WBIDs were identified as being of low potential concern: 3258C (Lee County), and 3259B, 3259I and 8064 (Collier County).

*Golf courses*—Each of the 152 golf courses identified during our survey was located on a base map using its address as a locator. Based on the data obtained for the 15 courses that participated in our survey, a typical per hole average application of chemicals was obtained. This was then multiplied by the total number of holes within each water drainage area. Amounts of chemicals were reduced by 15% for executive courses. Table 6 contains the golf course pesticide use relative risks by WBID. The greatest impacts are in Collier and Lee Counties which have the highest concentration of courses. Only two WBIDs (3259B & 3259C in Collier County) were indicated as potentially affected, and these are of low-measurable concern.

*Lawncare*—The GIS was used to estimate the total lawncare use by pesticide by water discharge area. This is shown in Table 6. The WBIDs potentially affected by residential lawncare use are all only of low potential concern and include: 3235J (Lee & Hendry Counties), 3235M (Glades & Hendry Counties), 3240A,B,C & E (Lee County), 3240I & J (Lee County), 3235J (Lee & Hendry Counties), 3235M (Glades & Hendry Counties), 3255 (Hendry County), 3258 C & E (Lee County), 3259 B, C, D, E, F, H & I (Collier County), and 8064 (Collier County).

*Combined impacts from all sources by WBID*—Because the HI scores for all activities are computed on the basis of pounds of active ingredient per acre, and are based on the same normalized  $EF \times T$  scores, they can be summed across different uses within the same water drainage area. Table 6 contains the total relative risk data from all sources by WBID and the summed results are displayed in Figure 3. Several WBIDs that were below concern for any particular use pattern became of low concern when all patterns were combined: 2092 (Lee County), 3235D (Lee, Charlotte, Glades & Hendry Counties), 3235I (Lee & Hendry Counties), 3240L (Lee & Charlotte Counties), 3258F (Lee & Collier Counties), 3258G & H (Lee County), and 3259A (Lee & Collier Counties).



TABLE 6. Continued.

WBID	Counties	ethion	glyphosate	lambda-cyhalothrin	malathion	mancozeb	methomyl	methylbromide	MSMA	naled	norflurazon	oxadiazon	pentachloronitrobenzene	permethrin	simazine	sulfur	thiophanate methyl
2041	Charlotte	M	MH								M						
3235B	Glades		MH	M	M	MH	M	H				MH	MH	M		M	M
3235J	Lee/Hendry		MH	M	M	MH	M					MH	MH				M
3235L	Hendry	M	MH	M	M	MH	M	H			M			M		M	
3235M	Glades/Hendry	M	MH								M			M		M	
3235N	Hendry	M	MH	M	M	MH	M	H			M			M		M	
3237A	Glades	M	MH								M			M		M	
3237B	Glad/Hend	M	MH								M			M		M	
3237D	Glad/Hend		MH	M	M	MH	M	H									
3240A	Lee		MH	M	M	MH	M					MH	MH				M
3240B	Lee/Char		MH	M	M	MH	M					MH	MH				M
3240C	Lee		MH	M	M	MH	M					MH	MH				M
3240E	Lee		MH	M	M	MH	M					MH	MH				M
3240I	Lee		MH	M	M	MH	M					MH	MH				M
3240K	Lee		MH	M	M	MH	M					MH	MH				M
3255	Hendry		MH	M	M	MH	M					MH	MH				M
3258B	Lee		MH	M	M	MH	M	H				MH	MH	M			M
3258C	Lee		MH	M	M	MH	M					MH	MH				M
3258E	Lee		MH	M	M	MH	M					MH	MH				M
3259B	Collier	M	MH	M	M	MH	M	H		M		MH	MH	M			M
3259C	Collier	M	MH	M	M	MH	M	H		M		MH	MH	M			M
3259D	Collier	M	MH	M	M	MH	M			M		MH	MH	M			M
3259E	Collier		MH	M	M	MH	M					MH	MH				M
3259F	Collier		MH	M	M	MH	M					MH	MH				M
3259H	Collier		MH	M	M	MH	M	H				MH	MH	M			M
3259I	Collier		MH	M	M	MH	M					MH	MH				M
3259L	Collier	M	MH								M						
3259M	Collier	M	MH								M						
3259X	Col/Lee/Hend	M	MH	M	M	MH	M	H				MH	MH	M			M
3261C	Collier/Hend	M	MH	M	M	MH	M	H				MH	MH	M			M
3267	Hendry	M	MH					H				MH	MH	M			M
8064	Collier		MH	M	M	MH	M			M		MH	MH				M

H = High Hazard, MH = Med-High Hazard, M = Medium Hazard.

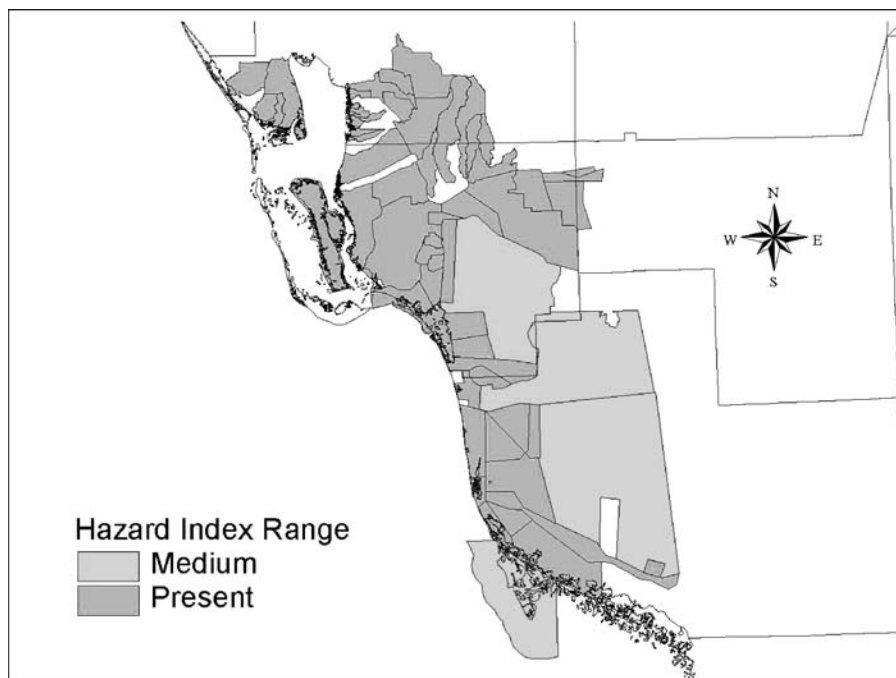


FIG. 2. Drainage areas of greatest concern for pesticides used in mosquito control.

**CONCLUSIONS**—The impacts of the evaluated activities appear to have the potential to impact the aquatic environment in the following order:

Agriculture >>> Lawncare >> Mosquito Control > Golf Course Management

This pattern was shown in Figure 4. Within the Agriculture category, row crops have a greater potential impact than citrus crops on a chemical use per acre basis. When the potential impacts of the individual row crops are evaluated, the following order emerges:

Tomatoes > Green peppers >> Watermelons > Cucumbers > Squash

Collier and Hendry Counties have the greatest concentrations of agricultural areas and hence the greatest potentials for impacts. Collier County also has the added concern of large residential areas adding in the lawncare, golf course maintenance and mosquito prevention activities.

From Figure 4 it becomes apparent that the impacts on the aquatic environment are greatest followed by those on insects and birds. Many pesticides target insects, but when runoff to aquatic habitats occurs, the fish and invertebrates are adversely affected. Birds are less affected because their diet does not tend to come all from one water body and they also tend to eat a variety of biota.

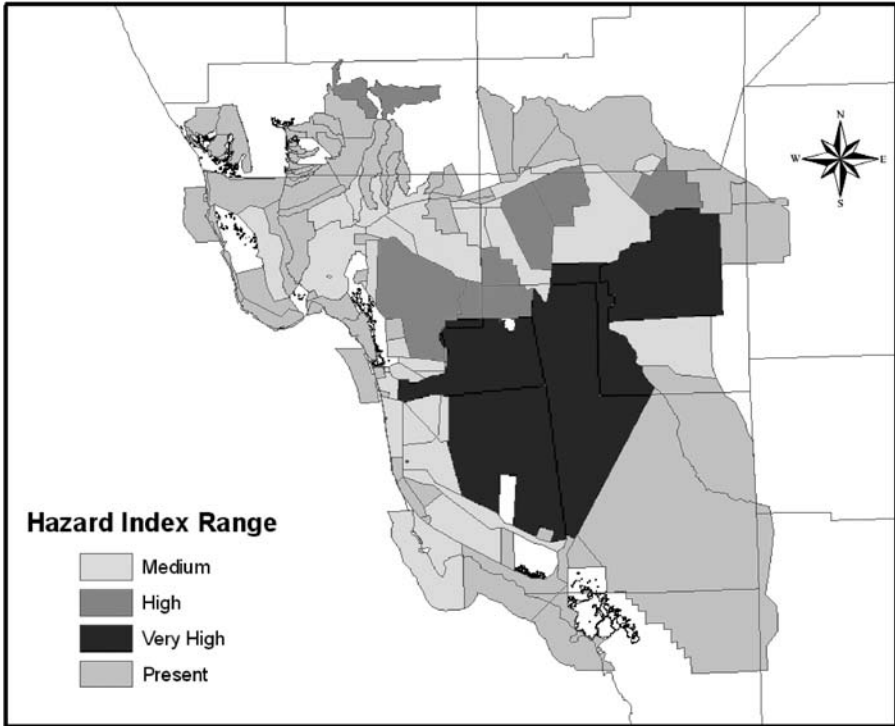


FIG. 3. Drainage areas of greatest concern for pesticides for all uses combined.

*What next?*—This exercise has been purely predictive based on literature values and reported and estimated application rates for a wide variety of pesticides used in agriculture, mosquito control, golf course maintenance, and residential lawn care. However, it has indicated the need for confirmatory monitoring of pesticides likely to represent the greatest threats and the water drainage areas most likely to be affected in Southwest Florida.

To confirm these predictions, sampling of surface water and sediment is required. Because the greatest runoff of pesticides occurs during the rainy season (in August–September), this is the optimal sampling time. The second best time is shortly after the first heavy rain following the dry season (April). Table 6 contains a matrix of the pesticides of potential concern by WBID where high levels of potential impacts are predicted and can be used to establish priorities for monitoring. The WBIDs indicated with a High or Medium-High Risk are the first priority. This prioritization can be used to select chemicals for inclusion in a monitoring program depending on the available funding level.

Ideally confirmatory sampling should include both water column and sediment samples at the same location at several points along the waterway within the selected WBID. Sampling points should be located downstream of identified stormwater outfalls. If high levels are identified at a sampling point, follow-up sampling to more

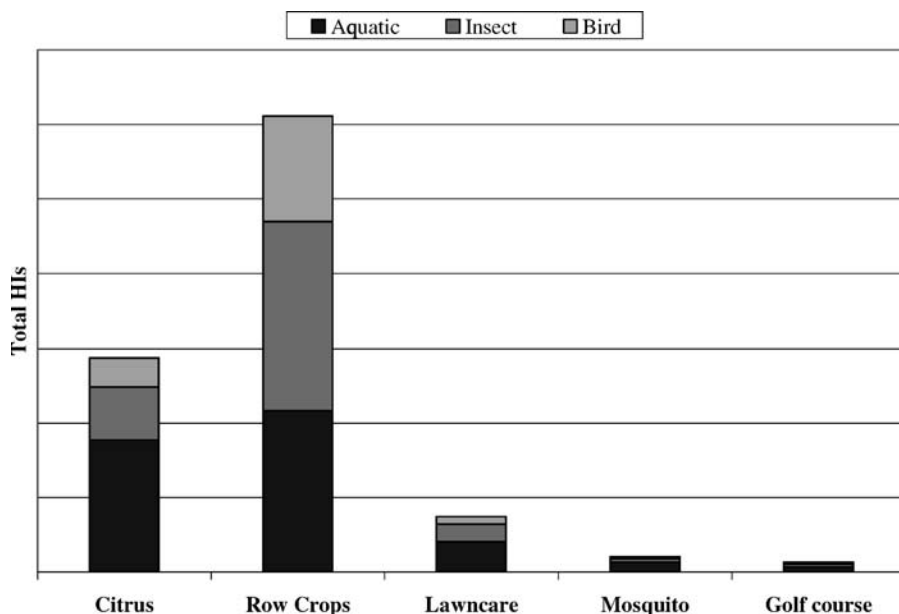


FIG. 4. Hazard impacts on ecological populations by type of use.

closely define the local situation may be required. It may also be desirable to sample some of the same points in the spring as well as in the fall.

If the sampling activities confirm the presence of levels of pesticides that raise environmental concerns, ways of reducing these potential impacts should be sought.

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