Assessment of Risk to Drinking Water from Turf Pesticide Runoff

Masters of Engineering Project

By

Julia Leung

Biological and Environmental Engineering

Cornell University

May 2011

Table of Contents

Executive Summary

A human health risk assessment was performed on pesticide runoff from lawns and golf courses for 9 U.S. locations using a fate and transport modeling program. Pesticide concentrations for 37 turf pesticides registered for application on golf courses were compared to drinking water standards. A maximum 24 hour lake pesticide concentration was used for an acute risk assessment and a mean daily lake concentration was used for a chronic risk assessment. Our results show that a number of the pesticides posed a potential risk as evidenced by a risk quotient (RQ; concentration divided by standard) over 0.01. For fairways, both iprodione and 24-D produced acute and chronic risk at more than 3 locations. Potential risk was only found for myclobutanil applications to greens and tees. MCPA, oxadiazon and 24-D applied to lawns posed both acute and chronic risks. The highest concentrations were seen with acephate applied to fairways with acute RQ≥0.01 in 4 locations and in oxadiazon applied to lawns in Houston with chronic RQ≥0.01. The assessment was based on simulations using TPQPond, a model developed for predicting pesticide runoff and resulting concentrations in a receiving pond, lake, or reservoir. The risk assessment followed general protocols used by USEPA in their pesticide concentration model, FIRST, but with more realistic methods of determining reservoir flow characteristics, pesticide mass balances and region specific weather data. Risk levels were found to vary with location and turf type. Pesticide concentrations were highest for fairways and lowest for greens. Greatest impacts were observed in areas of high annual precipitation rates and long growing seasons whereas lowest impacts were observed in areas of low precipitation rates. These results suggest that persons living in heavy rainfall areas may have higher exposures of turf pesticide in their drinking water than would be predicted by EPA risk assessments.

Introduction

Drinking water quality in reservoirs receiving runoff from lawns and golf courses may receive pesticide contamination. Health effects of pesticide exposure can range from dizziness and nausea to long term damage such as cancer and organ damage. A number of the pesticides used on turf grasses have been shown by the EPA to be possible carcinogens, irritants and linked to reproductive and neurological disorders *(1).*

There are over 15,000 golf courses in the US. An average golf course uses over 1,500 pounds of pesticides per year. Typical agricultural applications average less than a pound per acre per year. In some areas, pesticide applications on golf courses are more intense than on agricultural fields. In a survey of golf courses in Long Island, New York, pesticide applications averaged up to seven pounds per acre per year *(2).* Pesticides are sprayed on golf courses to maintain the greens and fairways. In addition, over 67 million pounds of pesticides are applied to lawns each year *(3).* Although golf courses often implement best management practices and integrated pest management strategies and also use specialized equipment to limit pesticide contamination, the effectiveness of these approaches is not well documented. During times of heavy precipitation, these pesticides are washed off into drinking water reservoirs.

A study on surface water quality effects from a Pacific Northwest golf course concluded that no significant impacts were found after pesticide applications *(4).* However, this study was limited to one location and a small number of pesticides. Research on the human health risk from turf grass pesticide applications is relatively limited. Haith *(5)* performed an ecological risk study using the same pesticides and weather data as this study. Of the 37 pesticides modeled, 4 posed potential risk to invertebrates or fish while 2 posed risk to plants. His study, however, was limited to acute ecological risk. This paper will explore both acute and chronic human health risk.

There is a need for a drinking water risk assessment of pesticides applied to lawns and golf courses due to the vast quantities applied to these grasses annually and the potential health hazards exposure will pose. The USEPA considers all dietary exposures when determining levels of concern for pesticide in food. Due to traces of pesticides found in ground and surface waters that are used for drinking, EPA considers drinking water a dietary pathway for exposure to pesticides. This study will take into account a full range of turf grass pesticides and weather data from different climate regions in the US. It will compare concentrations predicted by the TPQPond simulation model to individual drinking water standards to determine whether or not recommended pesticide application rates on container labels result in harmful impact on human health.

Background

The purpose of this study is to perform a human health risk assessment of pesticides applied to lawns and golf courses using the general procedures outlined by USEPA. The study is a nationwide evaluation of acute and chronic water supply health risk. Results are provided for 37 pesticides in 9 US locations on 3 different grass surfaces.

The EPA's Office of Pesticide Programs (OPP) uses a tiered approach to evaluating the human health risks of pesticides in drinking water. Pesticides that pass the first tier in EPA drinking water assessment have a low risk of adversely impacting human health. Pesticides that do not pass the first tier move on to the next tier. Each successive tier is designed to screen out pesticides by requiring more complex levels of investigation. OPP uses a 2-tiered system for evaluating human health risk. This study will focus on EPA's first tier for risk assessment.

Currently, EPA uses FQPA Index Reservoir Screening Tool (FIRST) *(6)* as their Tier 1 screening model for assessing drinking water risk. FIRST is a simulation model that calculates pesticide concentrations in drinking water based on pesticide application rates and pesticide properties. It provides conservative exposure values for acute and chronic risk assessment. FIRST takes into account adsorption of the pesticide to sediment, deposition of the pesticide due to spray drift and degradation in the field and in the reservoir. It is based on the methods used in EPA's screening model for ecological risk assessment, GENEEC2, which assumes a single, large rain event. It is linked to EPA's PRZM and EXAMS surface water models.

To ensure that the pesticides that pass these screening tiers are unlikely to pose a human health risk, EPA uses conservative measures when estimating pesticide concentrations. FIRST assumes that each surface receives the maximum number of applications at maximum application rates with minimum time between applications as indicated on the pesticide label; that there is no buffer between the reservoir and application area; that the cropped area is highly vulnerable to runoff and easily influenced by rainfall events.

FIRST uses the characteristics of an index drinking water reservoir located in Shipman City, Illinois in its simulations. The vulnerability of the reservoir in Shipman City to contamination is representative of many small, shallow reservoirs in the Midwest that are faced with pesticide contamination problems. Insufficient data for areas outside of the Midwest has prevented the EPA from developing region specific models in their risk assessment.

Model predictions of reservoir pesticide concentrations are compared to human drinking water levels of concern (DWLOC). The DWLOC is the maximum concentration of pesticide that a human can ingest before adverse health effects are observed. If the pesticide concentrations predicted by FIRST exceeds the DWLOC, the pesticide fails the first tier and moves on for further evaluation under EPA's Tier 2 screening model. If the pesticide passes the test, no further assessment is conducted and it is concluded that the pesticide poses little risk to human health. This study reports concentrations with RQ ≥0.01, since in some ecological risk assessments, pesticides with these low risk levels are of some concern.

In order to incorporate a more realistic watershed in EPA's risk analysis, pesticide concentrations are adjusted by multiplying by a percent crop area (PCA) factor. Since pesticides are usually applied only to cropped areas and not the entire area of the watershed, the PCA factor represents the maximum fraction of the watershed that the pesticide is applied to. PCA factors also vary for different types of crop since it is also unlikely that the watershed is covered with only one type of crop. For non-agricultural areas such as lawns, EPA recommends using a PCA factor of 1 *(7).*

When simulating pesticide runoff from golf courses, EPA recommends using a Golf Course Adjustment Factor (GCAF) *(8)*. Golf courses consist of several different grass surfaces classified as tees, greens, fairways and roughs. For golf course simulations, EPA assumes that the entire watershed is a golf course. The GCAF represents the decimal fraction of the watershed that is covered by a specific grass surface. This distinction is made because pesticides are not applied to entire golf courses but rather to certain playing areas. Pesticides are most intensely applied on tees and greens *(5)*. EPA recommends a GCAF of 0.29 for fairways and a GCAF of 0.05 for greens and tees *(8)*. Tees were not modeled separately because of their similarities to greens.

The risk analysis used in this study follows the general protocols of USEPA standards for drinking water assessment but uses the TPQPond simulation model rather than FIRST. The TPQPond model was developed by Haith *(9, 10)* to estimate daily pesticide concentrations in a receiving pond, lake or reservoir due to runoff from grass surfaces. Unlike FIRST, the model includes the daily water and chemical mass balances on land and in the receiving water. As a result, it is suitable for long-term simulations.

Methods and Data

This study uses the same reservoir characteristics of an index reservoir in Shipman City, Illinois as used in FIRST. Shipman City Lake is 144,000 cubic meters in capacity, 2.74 meters deep and receives runoff from a 172.8 hectare watershed *(6).* This study used the same pesticides that

Table 1: Pesticide properties and applications *(5)*

	Pesticide properties			Fairways		Greens		Lawns	
Pesticide	Koc	Soil half life	Water half life	Rate	Frequency	Rate	Frequency	Rate	Frequency
	(cm3/g)	(days)	(days)	(kg/ha)	(#/yr)	(kg/ha)	(#/yr)	(kg/ha)	(#/yr)
24-D	56	10	29	1.65	2	1.65	2	1.65	2
Benefin	10777	40	1	1.2	1			1.26	1
Bispyribac-sodium	302	13	35	0.11	3				
Carfentrazone-ethyl	866	0.5	0.4	0.06	3	0.06	3	0.06	3
Clopyralid	5	34	0	0.14	2				
Dithiopyr	801	39	0	0.43	1			0.43	1
Fluroxypyr	66	3	25	0.26	2	0.26	2	0.26	2
Isoxaben	601	105	17	0.84	1			0.84	1
MCPA	74	15	17	0.8	2			0.8	2
Mecoprop-p	31	8	50	0.23	2			0.23	2
Oryzalin	949	20	33	1.4	1	1.4	1	1.4	1
Oxadiazon	1294	135	113	3.36	1			3.36	1
Pendimethalin	15744	90	16	2.25	1	2.25	1	2.25	1
Penoxsulam	94	32		0.04	2			0.04	2
Prodiamine	12710	120		1.21	1			1.21	1
Rimsulfuron	47	24.3	6	0.03	3	0.03	3		
Sulfentrazone	43	541		0.28	3			0.28	3
Sulfosulfuron	33	24	26	0.07	2			0.07	2
Triclopyr	48	39	29	0.84	3			0.84	3
Trifluralin	8765	181	6	1.26	1			1.26	1
Chlorothalonil	850	22	0.1	11.2	3	11.2	9		
Cyazofamid	1780	10	14	0.86	4	0.86	4	0.86	2
Fluopicolide	321	271	777	0.24	2	0.24	2	0.24	2
Iprodione	373	84	30	2.17	5	2.17	5		
Mancozeb	998	0.1	76	18.3	13	18.3	13	18.3	2
Metconazole	1116	84	465	0.48	5	0.48	5	0.48	2
Myclobutanil	517	306	626	1.08	7	1.08	7	0.77	2
Propamocarb-hydCl	535	39.3	17	2.37	2	2.37	2	2.37	2
Thiophanatemethyl	207	0.6	2	1.45	4	2.9	10	2.9	2
Acephate	2	3		3.03	6	3.03	6		
Bifenthrin	236610	26	251	0.14	2	0.14	2	0.14	1
Chlorantranili-prole	328	210		0.19	3	0.19	3	0.19	1
Clothianidin	160	545	56	0.22	2	0.22	2	0.22	1
Halofenozide	250	219		1.13	2	1.13	2	1.13	1
Imidacloprid	225	191	129	0.45	1	0.45	1	0.45	1
Indoxacarb	6450	17	6	0.15	6	0.15	6	0.15	1
Permethrin	100000	13	40	0.73	3	0.73	3	0.73	1

were evaluated in Haith's ecological risk assessment *(5).* Chemical properties and application information are given in Table 1.

An advantage that TPQPond has over FIRST is that the former uses daily weather data to calculate runoff and flow rate through the reservoir. This enables us to run region specific simulations. FIRST uses an annual flow through the reservoir that is assumed to be enough for two turnovers or twice the reservoir volume of 144,000 cubic meters. This is equivalent to a constant flow or 33 cubic meters per hour. TPQPond uses a mass balance approach that takes into account precipitation, evapotranspiration and snow melt. This provides a more realistic model of runoff and reservoir volumes compared with FIRST, which assumes constant volume.

This study uses 100-yr generated daily weather data for 9 locations in the US with varying climate and precipitation patterns: Albany, Atlanta, Bismarck, Columbus, Fresno, Houston, Madison, Olympia, and Roswell. These are the same locations as used ecological risk assessment studies by Haith *(5).* Each location is in one of the nine climatic regions as noted by the National Climatic Data Center. Other factors in determining these locations include plant hardiness zones, annual temperature, precipitation and growing seasons. Table 2 shows the weather characteristics for these 9 locations.

Table 2: Location and climate characteristics *(11)*

Location	Mean annual temperature	Mean growing season precipitation	Growing season
	(˚C)	(mm)	
Albany, NY	9	441	May-Sept
Atlanta, GA	16	696	Apr-Oct
Bismarck, ND	5	273	May-Oct
Columbus, OH	11	554	May-Oct
Fresno, CA	17	135	Mar-Nov
Houston, TX	20	917	Mar-Nov
Madison, WI	7	443	May-Sept
Olympia, WA	10	344	May-Oct
Roswell, NM	16	264	May-Oct

A mass balance performed on the reservoir dictates daily reservoir volume. Water enters the reservoir through precipitation, snow melt and runoff. Additional water is pumped into the reservoir to maintain a minimum volume. Conversely, overflow occurs when volume levels exceed reservoir capacity. If an ice layer forms over the reservoir, snow can accumulate on top. Runoff volume is calculated using TurfPQ. Water leaves the reservoir through evaporation and overflow.

Pesticide enters the reservoir solely through runoff. TPQPond simulates daily pesticide runoff from turf grass surfaces. Four required inputs for determining runoff are biodegradation half life, organic carbon partition coefficient (Koc), runoff curve number and organic carbon content of the turf. Pesticide in both dissolved and adsorbed forms are degraded in TPQPond, whereas FIRST degrades only the dissolved component. FIRST uses results from PRZM/EXAMS simulation models to partition the pesticide into adsorbed and dissolved forms. Pesticide is partitioned into adsorbed and dissolved forms using linear partitioning in TPQPond.

Both FIRST and TPQPond assume first order biodegradation in the grass, sediment and reservoir. These degradation rates are based on water and soil half lives. FIRST also considers degradation of pesticides in the reservoir by photolysis. It assumes that photolysis rate constants are 124 times slower in the reservoir than it is in clear water. Using 1/124 the photolysis rate in our calculations offers a very minute disparity in overall pesticide degradation calculations. This study does not consider degradation by photolysis.

A pesticide mass balance on the reservoir takes into account pesticide that is already in the reservoir, pesticide entering through runoff and pesticide leaving through overflow. The reservoir is assumed to be well mixed. USEPA’s FIRST takes into account direct deposition of pesticide in the reservoir through spray drift. Spray drift occurs when spraying equipment discharge stray particles of pesticide that are carried by the wind and directly deposited into the reservoir. Application efficiency for most nozzles used in pesticide application is 99% and deposition from spray drift is minimal. This study does not consider pesticide additions from spray drift in its mass balance.

Final pesticide concentrations are adjusted by PCA factor for lawns and GCAF factor for golf courses. FIRST outputs two values: the maximum value for a single large rainstorm, used for acute risk assessment and the annual average of the peak values for 364 days, used for chronic risk assessment. For this study, TPQPond calculated 1-in-10 yr maximum daily lake concentration, used for acute risk assessment, and mean daily concentration, used for chronic risk assessment.

EPA uses Drinking Water Levels of Concern (DWLOC) values as the measure for exposure and risk. In order to determine the threat of each pesticide, this study compares the model estimates of lake concentrations multiplied by PCA or GCAF with the chemical’s DWLOC value.

For an acute risk assessment, acute DWLOC values are compared to the 1-in-10 yr maximum daily lake concentrations. Chronic DWLOC values are compared to mean daily lake concentrations. Some DWLOC values can be found in individual pesticide reregistration reports *(12).* In cases where DWLOC values were unavailable, this study estimated values using chronic and acute reference dose (aRfD, cRfD, respectively) or acceptable daily intake, ADI. The reference dose is the maximum acceptable oral dose of a substance considering intake from both food and drinking water. Reference dose values can be found in USEPA pesticide registration reports, rule and registration reports or risk assessment reports. The acceptable daily intake value is used as the chronic dose when neither chronic DWLOC nor cRfD value is available. THE ADI is maximum dose of a substance that can be orally ingested over a lifetime without any health risk. Table 3 shows the list of DWLOC, RfD and ADI values used in this assessment. RfD and ADI values are converted to estimated DWLOC by assuming a 70kg male consumes 2L of water per day:

$$\text{DWLOC} = \frac{70\ (\text{RfD or ADI})}{2} \tag{1}$$

Risk quotients (RQ) are used as simple assessments that identify high or low risk situations. It is calculated by dividing exposure estimates by the drinking water standard:

$$\text{RQ} = \frac{\text{exposure}}{\text{standard}} \tag{2}$$

In human health risk assessments, pesticides resulting in RQ ≥ 1 are generally considered safe. However, in this study, we report RQ values as small as 0.01, reasoning that even these low risk levels are of some concern *(13)*.

Table 3: List of DWLOC, RfD or ADI values used in risk assessment						
Pesticide	DWLOC		RfD		ADI	Source[i]
	Acute	Chronic	Acute	Chronic	Chronic	
	(mg/L)		*(mg/kg/d)*		*(mg/kg/d)*	
24-D	1.932	1.68				RED
Benefin				0.005		RED
Bispyribac-sodium				0.1		RULE
Carfentrazone-ethyl			5	0.03		RULE
Clopyralid			0.75	0.15		RA
Dithiopyr					0.0036	PPDB
Fluroxypyr				1		RA
Isoxaben				0.05		RULE
MCPA	1.455	0.111				RED
Mecoprop-p			1.75	0.04		RED
Oryzalin			0.25*	0.14		TRED
Oxadiazon	4.2	0.126				RED
Pendimethalin				0.1		RED
Penoxsulam				0.147		RULE
Prodiamine					0.05	APVMA
Rimsulfuron				0.818		RA
Sulfentrazone			2.5	0.14		RULE
Sulfosulfuron				0.24		RULE
Triclopyr			0.3	0.05		aRfD from PPDB, cRfD from RED
Trifluralin			1*	0.024		TRED
Chlorothalonil			0.6	0.02		aRfD from PPDB, cRfD from RED
Cyazofamid			1*	0.948		RULE
Fluopicolide			0.18	0.2		aRfD from PPDB, cRfD from RA
Iprodione	0.693	.324*				RED
Mancozeb	0.123			0.05		RED
Metconazole			0.12*	0.04		RULE
Myclobutanil			0.6	0.025		RULE
Propamocarb			2	0.12		RULE
Thiophanate-methyl	5.7	0.86				RED
Acephate	0.136	0.038				RED
Bifenthrin			0.33	0.013		RA
Chlorantranilprole				1.58		RA
Clothianidin			0.25	0.098		RA
Halofenozide				0.038		NOEL
Imidacloprid			0.14	0.057		RA
Indoxacarb			0.09	0.015		RULE
Permethrin			0.25	0.25		RED

DWLOC = Drinking Water Level of Concern; RfD = Reference Dose; ADI =Acceptable Daily Intake
*Value calculated for female population, none calculated for general population

[i] RED: USEPA Reregistration Eligibility Decision Report
RULE: USEPA Rule and Registration Report
PPDB: Pesticide Property Database
RA: USEPA Risk Assessment Report
NOEL: Calculated from dog NOEL (3.8 mg/kg/d), assuming uncertainty factor = 1000
APVMA: Australia Pesticide and Vet Medicine Authority
TRED: USEPA Tolerance Reassessment Progress and Risk Management Decision Report

Simulation Results

Lake pesticide concentrations are compared with DWLOC in Tables 4-9. Results are only given for pesticide concentrations that exceeded 0.001 mg/L. A potential risk was seen on fairway, lawn and green and tee applications in Houston. A comparison of these results also shows that Houston has the highest pesticide concentrations among the other 8 locations. This is due to the long growing season and the high precipitation rate in the area. On the other hand, Fresno, with an equivalently long growing season as Houston but the lowest precipitation rate resulted in the lowest pesticide concentrations. Only myclobutanil applied on fairways posed any risk in Fresno. This demonstrates that rainfall has the highest influence on pesticide concentration.

Applications on greens and tees yielded the lowest pesticide concentrations. Nearly none of the pesticides in the chronic risk assessment had concentrations above 0.001 mg/L. The acute risk assessment produced higher concentrations than the chronic assessment, but of the 23 pesticides applied on greens, only 1 posed a potential risk.

The pesticide with the highest acute risk was mancozeb, which also had the highest application rate among the 37 pesticides tested. Mancozeb posed acute risk on applications to fairways at 7 locations and lawns at 5 locations. Myclobutanil had the highest chronic risk with potential risk indicated at all three turf types in at least 1 location.

Although, none of the reservoir pesticide concentrations calculated by TPQPond exceeded the drinking water level of concern for humans (RQ≥1), there is still risk in a number of pesticides that exceeded RQ values of 0.01. Tables 10 -13 summarizes these results.

The pesticides with the highest risk on fairway applications were iprodione and 24-D. Both indicated potential acute and chronic risk at more than 3 locations. Acephate at Columbus, Houston, Madison, Albany and Atlanta posed the highest acute risk with a RQ≥0.1. In addition, myclobutanil posed a chronic risk at all 9 locations.

Only 1 of the 37 pesticides simulated produced any type of risk when applied to greens and tees. Myclobutanil applied in Houston produced a chronic RQ equal to 0.01.

The pesticides with the highest risk on lawn applications were 24-D and MCPA. Potential acute risk was indicated in over 4 locations and potential chronic risk was indicated in over 6 locations. Oxadiazon applied in Houston had the highest chronic risk with an RQ over 0.1.

Table 4: Comparison of 1-in-10 yr maximum daily lake concentration times GCAF with acute DWLOC for fairways [b]

Pesticide	Acute DWLOC [a]	Albany	Atlanta	Bismarck	Columbus	Fresno	Houston	Madison	Olympia	Roswell
	(mg/L)	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*
24-D	1.932	0.007	0.025	0.007	0.019		0.038	0.018		0.003
Bispyribac-sodium			0.001		0.001		0.002	0.001		
Clopyralid	26.250		0.002		0.001		0.002	0.001		
Dithiopyr		0.001	0.002		0.001		0.002	0.001		
Fluroxypyr			0.003		0.002		0.004	0.002		
Isoxaben		0.002	0.005	0.002	0.004		0.005	0.003	0.001	0.002
MCPA	1.455	0.004	0.011	0.004	0.010		0.020	0.009	0.000	0.002
Mecoprop-p	61.250	0.001	0.004	0.001	0.003		0.005	0.003		
Oryzalin	8.750	0.001	0.003		0.002		0.002	0.002		
Oxadiazon	4.200	0.008	0.014	0.006	0.014	0.001	0.018	0.012	0.007	0.006
Pendimethalin			0.001		0.001		0.001	0.001		
Penoxsulam			0.001		0.001		0.001	0.001		
Prodiamine			0.001		0.001		0.001	0.001		
Rimsulfuron			0.001				0.001			
Sulfentrazone	87.500	0.005	0.008	0.005	0.008	0.001	0.012	0.008	0.001	0.005
Sulfosulfuron			0.001		0.001		0.002	0.001		
Triclopyr	10.500	0.007	0.017	0.005	0.013		0.025	0.012	0.003	0.004
Trifluralin	35.000	0.001	0.001		0.001		0.001	0.001	0.001	
Chlorothalonil	21.000	0.031	0.051	0.022	0.051		0.081	0.050	0.002	0.031
Cyazofamid	35.000	0.001	0.002		0.001		0.004	0.001		0.001
Fluopicolide	6.300	0.004	0.005	0.004	0.006		0.009	0.007	0.002	0.004
Iprodione	0.693	0.035	0.068	0.020	0.047	0.001	0.108	0.062	0.025	0.031
Mancozeb	0.123	0.011	0.027	0.001	0.022		0.084	0.009		0.012
Metconazole	4.200	0.008	0.012	0.004	0.009		0.018	0.011	0.007	0.007
Myclobutanil	21.000	0.027	0.050	0.026	0.037	0.014	0.075	0.034	0.037	0.029
Propamocarb-hydCl	70.000	0.009	0.019	0.006	0.016		0.030	0.018	0.003	0.009
Thiophanate-methyl	5.700	0.001	0.005	0.001	0.006		0.006	0.003		0.001
Acephate	0.136	0.020	0.034	0.001	0.025		0.037	0.023		0.013
Bifenthrin	11.550									
Chlorantranilprole		0.003	0.004	0.002	0.004		0.007	0.004	0.003	0.002
Clothianidin	8.750	0.002	0.004	0.002	0.004		0.007	0.004	0.001	0.002
Halofenozide		0.013	0.023	0.013	0.022	0.001	0.042	0.026	0.007	0.013
Imidacloprid	4.900	0.002	0.005	0.002	0.005		0.008	0.005	0.001	0.002

[a]Concentrations based on acute values in Table 4, RfD and ADI values based on 70 kg male consuming 2L of water per day

[b]Maximum 24 hr concentrations calculated using TPQWS, adjusted using GCAF factor of 0.29, only values ≥ 0.001 are displayed

Table 5: Comparison of mean daily lake concentration times GCAF with chronic DWLOC for fairways [b]

Pesticide	Chronic DWLOC [a]	Albany	Atlanta	Bismarck	Columbus	Fresno	Houston	Madison	Olympia	Roswell
	(mg/L)	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*
24-D	0.168		0.001		0.001		0.001	0.001		
MCPA	0.111						0.001			
Oxadiazon	0.126	0.002	0.004	0.001	0.003		0.006	0.003	0.002	0.001
Sulfentrazone	4.900	0.002	0.002	0.002	0.002		0.003	0.003		0.001
Triclopyr	1.750		0.001		0.001		0.001	0.001		
Fluopicolide	7.000	0.002	0.002	0.002	0.003		0.004	0.003	0.001	0.002
Iprodione	0.324	0.003	0.006	0.001	0.004		0.011	0.005	0.003	0.002
Mancozeb	1.750	0.001	0.002		0.002		0.005	0.001		0.001
Metconazole	1.400	0.004	0.005	0.002	0.004		0.009	0.005	0.004	0.003
Myclobutanil	0.875	0.017	0.030	0.014	0.022	0.004	0.055	0.020	0.021	0.014
Propamocarb-hydCl	4.200		0.001		0.001		0.002	0.001		
Chlorantranilprole	55.300	0.001	0.002	0.001	0.002		0.003	0.002	0.001	0.001
Clothianidin	3.430		0.001				0.001	0.001		
Halofenozide	1.330	0.004	0.007	0.003	0.007		0.012	0.008	0.002	0.003
Imidacloprid	1.995		0.001		0.001		0.001	0.001		

[a]Concentrations based on chronic values in Table 4, RfD and ADI values based on 70kg male consuming 2L of water per day
[b]Mean lake concentrations calculated using TPQWS, adjusted using GCAF factor of 0.29, only values ≥ 0.001 are displayed

Table 6 : Comparison of 1-in-10 yr maximum daily lake concentration times GCAF with acute DWLOC for greens and tees [b]

Pesticide	Acute DWLOC [a]	Albany	Atlanta	Bismarck	Columbus	Fresno	Houston	Madison	Olympia	Roswell
	(mg/L)	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*
Chlorothalonil	21.000		0.002				0.014	0.001		
Iprodione	0.693		0.001				0.005	0.001		
Mancozeb	0.123						0.001			
Metconazole	4.200						0.001			
Myclobutanil	21.000		0.001				0.003		0.001	
Propamocarb-hydCl	70.000						0.001			
Thiophanate-methyl	5.700						0.001			
Halofenozide							0.002			

[a]Concentrations based on acute values in Table 4, RfD and ADI values based on 70 kg male consuming 2L of water per day
[b]Maximum 24hr concentrations calculated using TPQWS, adjusted using GCAF factor of 0.05, only values ≥ 0.001 are displayed

Table 7: Comparison of mean daily lake concentration times GCAF with chronic DWLOC for greens and tees [b]										
Pesticide	Chronic DWLOC [a]	Albany	Atlanta	Bismarck	Columbus	Fresno	Houston	Madison	Olympia	Roswell
	(mg/L)	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*
Myclobutanil	0.875						0.001			

[a]Concentrations based on chronic values in Table 4, RfD and ADI values based on 70 kg male consuming 2L of water per day
[b]Mean lake concentrations calculated using TPQWS, adjusted using GCAF factor of 0.05, only values ≥ 0.001 are displayed

Table 8: Comparison of 1-in-10 yr maximum daily lake concentration times PCA with acute DWLOC for lawns [b]										
Pesticide	Acute DWLOC [a]	Albany	Atlanta	Bismarck	Columbus	Fresno	Houston	Madison	Olympia	Roswell
	(mg/L)	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*
24-D	1.932	0.016	0.054	0.014	0.051		0.115	0.043		0.009
Benefin			0.001		0.001		0.001			
Dithiopyr		0.001	0.003	0.001	0.003		0.004	0.002		0.001
Fluroxypyr		0.001	0.005	0.001	0.004		0.011	0.004		
Isoxaben		0.005	0.011	0.004	0.009		0.014	0.008	0.003	0.003
MCPA	1.455	0.010	0.027	0.007	0.027		0.056	0.022		0.007
Mecoprop-p	61.250	0.002	0.009	0.002	0.007		0.015	0.006		0.001
Oryzalin	8.750	0.002	0.007	0.001	0.004		0.005	0.003		0.001
Oxadiazon	4.200	0.017	0.035	0.012	0.030	0.002	0.047	0.028	0.018	0.012
Pendimethalin		0.001	0.002	0.001	0.001		0.002	0.001	0.001	
Penoxsulam		0.001	0.002	0.001	0.002		0.003	0.001	0.000	0.001
Prodiamine		0.001	0.002		0.001		0.002	0.001	0.001	0.001
Sulfentrazone	87.500	0.017	0.023	0.015	0.021	0.003	0.039	0.023	0.005	0.013
Sulfosulfuron		0.001	0.003	0.001	0.003		0.006	0.002		0.001
Triclopyr	10.500	0.022	0.046	0.013	0.036	0.001	0.077	0.033	0.008	0.012
Trifluralin	35.000	0.001	0.002	0.001	0.002		0.003	0.002	0.001	0.001
Cyazofamid	35.000	0.001	0.002	0.001	0.002		0.005	0.002		0.001
Fluopicolide	6.300	0.011	0.016	0.010	0.016	0.001	0.027	0.019	0.009	0.011
Mancozeb	0.123	0.001	0.009		0.005		0.008	0.001		
Metconazole	4.200	0.006	0.011	0.005	0.009		0.019	0.011	0.006	0.006
Myclobutanil	21.000	0.033	0.043	0.026	0.041	0.004	0.070	0.051	0.034	0.028
Propamocarb-hydCl	70.000	0.019	0.044	0.013	0.036		0.073	0.041	0.007	0.018
Thiophanate-methyl	5.700		0.011		0.004		0.009	0.004		
Chlorantranilpro		0.002	0.004		0.010	0.006	0.003	0.002		
Clothianidin	8.750	0.002	0.005		0.014	0.008	0.003	0.003		
Halofenozide		0.015	0.027	0.001	0.065	0.039	0.017	0.017		
Imidacloprid	4.900	0.005	0.010		0.025	0.015	0.005	0.006		

[a]Concentrations based on acute values in Table 4, RfD and ADI values based on 70 kg male consuming 2L of water per day
[b]Maximum 24 hr concentrations calculated using TPQWS, adjusted using PCA factor of 1, only values ≥ 0.001 are displayed

Table 9: Comparison of mean daily lake concentration times PCA with chronic DWLOC for lawns [b]

Pesticide	Chronic DWLOC [a]	Albany	Atlanta	Bismarck	Columbus	Fresno	Houston	Madison	Olympia	Roswell
	(mg/L)	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*
24-D	0.168	0.001	0.003	0.001	0.002		0.004	0.002		0.001
Isoxaben	1.750		0.001				0.001			
MCPA	0.111		0.001		0.001		0.002	0.001		
Mecoprop-p	1.400		0.001		0.001		0.001			
Oxadiazon	0.126	0.005	0.010	0.002	0.007		0.014	0.007	0.006	0.002
Prodiamine	1.750		0.001				0.001			
Sulfentrazone	4.900	0.006	0.008	0.007	0.008	0.001	0.012	0.010	0.001	0.004
Triclopyr	1.750	0.001	0.003	0.001	0.002		0.005	0.002		0.001
Fluopicolide	7.000	0.007	0.008	0.004	0.008		0.012	0.009	0.005	0.005
Mancozeb	1.750		0.001		0.001		0.002			
Metconazole	1.400	0.003	0.005	0.001	0.004		0.008	0.004	0.003	0.002
Myclobutanil	0.875	0.021	0.023	0.011	0.021	0.001	0.035	0.025	0.019	0.011
Propamocarb-hydCl	4.200	0.001	0.002		0.001		0.004	0.002		
Chlorantranilpro	55.300	0.001	0.002	0.001	0.001		0.003	0.002	0.001	0.001
Clothianidin	3.430	0.001	0.001		0.001		0.001	0.001		
Halofenozide	1.330	0.008	0.011	0.004	0.007		0.018	0.010	0.006	0.004
Imidacloprid	1.995	0.002	0.003	0.001	0.002		0.005	0.003	0.002	0.001

[a]Concentrations based on chronic values in Table 4, RfD and ADI values based on 70 kg male consuming 2L of water per day
[b]Mean lake concentrations calculated using TPQWS, adjusted using PCA factor of 1, only values ≥ 0.001 are displayed

Table 10: Pesticides with acute RQ≥0.01 for fairways

	Risk quotient								
Pesticide	Albany	Atlanta	Bismarck	Columbus	Fresno	Houston	Madison	Olympia	Roswell
24-D		0.01		0.01		0.02			
MCPA						0.01			
Iprodione	0.05	0.10	0.03	0.07		0.16	0.09	0.04	0.04
Mancozeb	0.09	0.22	0.01	0.18		0.69	0.07		0.10
Acephate	0.15	0.25	0.01	0.19		0.27	0.17		0.09

Table 11: Pesticides with chronic RQ≥0.01 for fairways

	Risk quotient								
Pesticide	Albany	Atlanta	Bismarck	Columbus	Fresno	Houston	Madison	Olympia	Roswell
24-D		0.01		0.01		0.01	0.01		
Oxadiazon	0.02	0.03	0.01	0.03		0.04	0.02	0.02	0.01
Iprodione	0.01	0.02		0.01		0.03	0.01	0.01	0.01
Myclobutanil	0.02	0.03	0.02	0.03	0.01	0.06	0.02	0.02	0.02

Table 12: Pesticides with chronic RQ≥0.01 for lawns									
	Risk quotient								
Pesticide	Albany	Atlanta	Bismarck	Columbus	Fresno	Houston	Madison	Olympia	Roswell
24-D		0.02		0.01		0.03	0.01		
MCPA		0.01		0.01		0.01	0.01		
Oxadiazon	0.04	0.08	0.01	0.05		0.11	0.05	0.04	0.01
Myclobutanil	0.02	0.03	0.01	0.02		0.04	0.03	0.02	0.01
Halofenozide	0.01	0.01		0.01		0.01	0.01		

Table 13: Pesticides with acute RQ≥0.01 for lawns									
	Risk quotient								
Pesticide	Albany	Atlanta	Bismarck	Columbus	Fresno	Houston	Madison	Olympia	Roswell
24-D	0.01	0.03	0.01	0.03		0.06	0.02		
MCPA	0.01	0.02	0.01	0.02		0.04	0.02		
Oxadiazon						0.01			
Mancozeb	0.01	0.08		0.04		0.07	0.01		

Conclusions

The assessment presented here shows that pesticide concentrations vary with location and turf type. Applications on fairways and high precipitation areas like Houston produced the highest pesticide concentrations. Dry areas such as Fresno and greens and tees turf types yielded the lowest model estimates. Risk quotients exceeded 0.01 for only 1 pesticide in Fresno and only 1 pesticide applied on greens and tees had RQ ≥ 0.01 at any location. Only 8 of the 37 pesticides indicated potential acute or chronic risk with RQ≥0.01. Five of these 8 pesticides had greater chance of risk with RQ≥0.1 in at least one location.

Mancozeb posed highest acute risk, RQ ≥ 0.01, on applications to lawns and fairways. This is probably due to the large applications - 18.3 kg/ha up to 13 times a year. The average application rate for turf pesticides is 1.6 kg/ha, applied 3 times a year. Myclobutanil posed the highest chronic risk, RQ ≥ 0.01, on applications to all three turf types. Myclobutanil was the only pesticide to indicate chronic risk in Fresno and the only pesticide to indicate chronic risk on green and tee turf types.

Acephate, 24-D, iprodione and mancozeb are all pesticides eligible for reregistration by the EPA. However, according to this study, these same pesticides posed some potential acute and chronic risk. 24-D had a RQ≥0.01 on fairways and lawns in over 3 locations, including Houston. These results suggest that persons living in heavy rainfall areas may have higher exposures of turf pesticide in their drinking water than would be predicted by EPA risk assessments. Discrepancies between the two models may be due to differences in model calculations and procedures. TPQPond takes into account regional weather data that may account for these variations. Consequently, evaluations as crucial as drinking water risk assessments should be conducted using several approaches to determine the most conclusive results.

References

(1) Commonly asked questions about chemical lawn care. Washington DC. <http://www.beyondpesticides.org/lawn/factsheets/faq.htm>

(2) Cox, C. *Pesticides on golf courses: Mixing toxins with play*. Journal of Pesticide Reform. Volume 11, Number 3 (available online at http://www.pesticide.org/get-the-facts/ncap-publications-and-reports/general-reports-and-publications/journal-of-pesticide-reform/journal-of-pesticide-reform-articles/golfcourses.pdf)

(3) USGAO. Lawn care pesticides: Risks remain uncertain while prohibited safety claims continue. **1990** <http://www.getipm.com/government/fifra-laws/gao-rpt.htm>

(4) Hindahl, M.S. et al. *Surface water quality impacts from golf course fertilizer and pesticide applications*. International Turfgrass Society Research Journal Volume 11. **2009**. (available online at http://www.nwturfgrass.net/enewsletter/newsletters-09/sept/sept-09-linked-documents/GC%20Surface%20Water%20Q%20ITSRJ.pdf)

(5) Haith, D.A. 2010a *Ecological risk assessment of pesticide runoff from grass surfaces*. In Environmental Science & Technology (available online as es101636y, July 28,**2010**)

(6) USEPA. FIRST: A screening model to estimate pesticide concentrations in drinking water, **2008.** <www.epa.gov/oppefed1/models/water/first_v1_1_1_description.doc>

(7) Jones, D.R. et al. *Development and use of percent cropped area adjustment factors in drinking water exposure assessments.* **2010.** Office of Pesticide Programs, Environmental Protection Agency <http://www.epa.gov/oppefed1/models/water/pca_adjustment_dwa.html>

(8) USEPA. *Golf course adjustment factors for modifying estimated drinking water concentrations and estimated environmental concentrations generated by Tier I (FIRST) and Tier II (PRZM/EXAMS) models.* **2011.** <http://www.epa.gov/oppefed1/models/water/golf_course_adjustment_factors.htm>

(9) Haith, D.A.2010b. *A PC program for estimating pesticide concentration in a receiving pond due to runoff from turfgrass.* Biological and Environmental Engineering, Cornell University, Ithaca, NY.

(10) Haith, D.A. **2002**. *A PC program for estimating pesticide runoff from turfgrass*. Biological and Environmental Engineering, Cornell University, Ithaca, NY.
(11) Haith, D.A.; Duffany, M.W. *Pesticide runoff loads from lawns and golf courses*. J. Environ. Eng. **2007**, 133 (4), 435-446
(12) USEPA. Pesticide Reregistration Status. <http://www.epa.gov/oppsrrd1/reregistration/status.htm>
(13) USEPA. Appendix D. Risk quotient (RQ) methods and levels of concern (LOC). <http://www.epa.gov/espp/litstatus/effects/redleg-frog/permethrin/appendix-d.pdf>