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Urban Pesticides: From the Lawn to the Stream

The fate of pesticides applied to our lawns remains somewhat of a mystery. Indeed, it seems to depend on whom one talks too. The fact that an enormous quantity of pesticides is being applied to our nation's lawns is beyond dispute. A key question is whether pesticides reach urban streams either by leaching into groundwater or in stormwater runoff. On one hand, turf researchers generally report very little runoff or leaching of pesticides from carefully controlled lawn test plots (see article 129). On the other hand, stream researchers frequently detect a relatively wide range of herbicides and insecticides in dry weather and storm runoff from residential watersheds, at the part per billion level. While this finding seems to demonstrate a clear link between the input of lawn pesticides and their delivery to streams, it fails to tells how they were delivered, or what environmental risk they may pose. In this article, the available research on the use, fate and environmental significance of urban pesticides are reviewed.

Urban Pesticide Use

The U.S. EPA estimates that nearly 70 million pounds of active pesticide ingredients are applied to urban lawns each year. Collectively, urban lawns cover an estimated 20 to 30 million acres of our country's landscape. Homeowner surveys suggests that pesticides are regularly applied on roughly half of these acres. Thus, an average acre of maintained lawn receives an annual input of five to seven pounds of pesticides.

Who applies these pesticides to the lawn? Surveys indicate that about two-thirds of all homeowners perform their own lawn care, while professional lawn care companies service the remainder (Table 1). In some residential watersheds, the fraction of lawns treated by professionals can approach 50%, particularly when lot size and income are high.

The fraction of homes that actually apply pesticides outdoors ranges from 40 to 60% in most surveys (which includes both homeowner and professional lawn care applications). About three in 10 residents report that herbicides were applied outdoors. A similar but more variable proportion of residents—20 to 40%—report using insecticides.

The diversity of pesticides applied in urban areas is staggering. Kroll and Murphy (1994a) performed an extensive survey of pesticide use in nearly 500 homes in Baltimore and found nearly 50 herbicides, insecticides and fungicides commonly applied by residents or commercial applicators (Table 2). Immerman and Drummond (1985) report that some 338 different active ingredients are applied to lawns and gardens nationally. Each pesticide differs greatly in mobility, persistence and potential aquatic impact, and is difficult to ascertain what if any environmental risk they may pose. Marketing surveys, however, indicate that a relative handful of brand name pesticides make up the bulk of most residential pesticide applications, such as 2,4-D, MCPP, diazinon and chloropyrifos.

Table 1: Summary of Lawn Care Surveys

Lawn Care Study	Wisconsin	Virginia	Maryland	Maryland	Minnesota
References	Kroupa	Aveni	Kroll	Smith	Dindorf
Homes surveyed	204	100	484	403	136
Take care of own lawn	69%	85%	61%	68%	63%
Professional lawn care	21%	10%	39%	32%	37%
Use pesticides	—	66%*	40%	—	—
Use insecticides	17%	—	—	42%	—
Use herbicides	29%	—	—	30%	76%*

* Mail in survey technique may have led to over-reporting

As might be expected, summer is the time of year when pesticides are most commonly applied. Most residents only make one application per year, but a small minority make up to five applications. Surveys indicate that residents make their pesticide selection and application decisions based either on a recommendation from their commercial applicator, product labels or advice from neighbors (Aveni, 1994). Lastly, while residents do show an increasing awareness about the links between lawn care and water quality, their primary objective is still a sharp-looking lawn.

From the Lawn Into the Stream

Pesticides can take a number of pathways to move from the lawn to the stream. Once applied, they can leave the lawn via surface runoff, leach into groundwater, or volatize into the air (Figure 1). For the most part, most pesticides are tightly fixed on soils or thatch, where they are broken down by sunlight or microbial action (the trend in recent years has been to utilize pesticides that are relatively non-persistent, and have a half-life of days or months). For example, Branham and Weber (1985) calculated that 96% of the applied diazinon was retained in thatch and upper soil layers of lawns. Still, under the right conditions, some pesticides can migrate from the lawn (see article 133).

Runoff Losses

Grass turf generally produces modest runoff during most storm events (see article 133). During intense storms, however, grass can produce measurable runoff, and this runoff can carry soluble and particulate pesticides from the lawn. The greatest pesticide loss occurs when an intense storm occurs shortly after pesticides are applied. The losses of some pesticides under these conditions can be substantial. For example, Hall (1987) examined the loss of the herbicide 2,4-D in simulated runoff from sloping Kentucky bluegrass sod. Up to 90% of the 2,4-D applied was lost in runoff from a storm a few hours after initial application.

In a summary review of agricultural pesticide monitoring studies, Balogh and Walker (1992) concluded that maximum pesticide losses, under normal conditions, are on the order of:

- 1% for water-insoluble pesticides
- two to 5% for pesticides applied as wettable powders
- 0.5% for water soluble and soil incorporated pesticides.

These loss rates should be considered "worst case" numbers for most urban lawns, as they produce less runoff than row crops (where these loss rates were derived). These loss rates can be higher, of course, if an intense rain event follows application.

Table 2: Residential Pesticide Use Survey in Baltimore Watersheds (47 Different Active Ingredients Identified) (Kroll and Murphy, 1994a)

Acephate (I)	Lindane
Bendiocarb (I)	MCPA (H)
Benefin (H)	MCPP (H)
Carbaryl (I)	Maneb (F)
Chlorothalonil (F)	*Malathion* (I)
Chloropyrifos (I)	*Propoxur* (I)
Diazonin (I)	*Pyrethrum* (I)
Dicamba (H)	Temephos
Fluvalinate	Trifluralin (H)
Glyphosate (H)	2,4-D (H)
Isofenphos (I)	
Lindane (I)	(+ 27 others)

Italics indicate homeowner application only, H= herbicide, I= Insecticide, F=Fungicide

Leaching

Rainfall that doesn't run off or evapotranspire leaches through the soil to groundwater, and ultimately the stream. Some soluble pesticides can be carried with the water as it makes its slow journey to the stream. Again, turfgrass researchers have shown that only small amounts of pesticides are lost to groundwater. Gold *et al*. (1988) studied the leaching of two common herbicides (2,4-D and dicamba) through the soils of several test lawns. The sandy soils of the well irrigated lawns were thought to be ideal conditions for leaching of these mobile pesticides. After several seasons of monitoring, the herbicides were still tightly fixed in soil thatch, and significant degradation had occurred in the root zone. Pesticide concentrations in leachate were always less than 1 ppb.

Balogh and Walker (1992) came to the same conclusion after reviewing agricultural monitoring studies that examined pesticide leaching. Maximum potential loss ranged from one to 2% of the applied pesticide, which translates to groundwater pesticide concentrations on the order of 1 to 3 ppb. Watschke and Mumma (1989) examined the potential leaching of dicamba, 2,4-D and chlorpyrifos on turfgrass plots. A maximum of 2% of applied dicamba and 2,4-D were lost in leachate, with most occurring in the first few days after application.

Drift and Deposition Onto Impervious Surfaces

A third route to the stream is the movement of pesticides ingredients that volatilize or drift away as

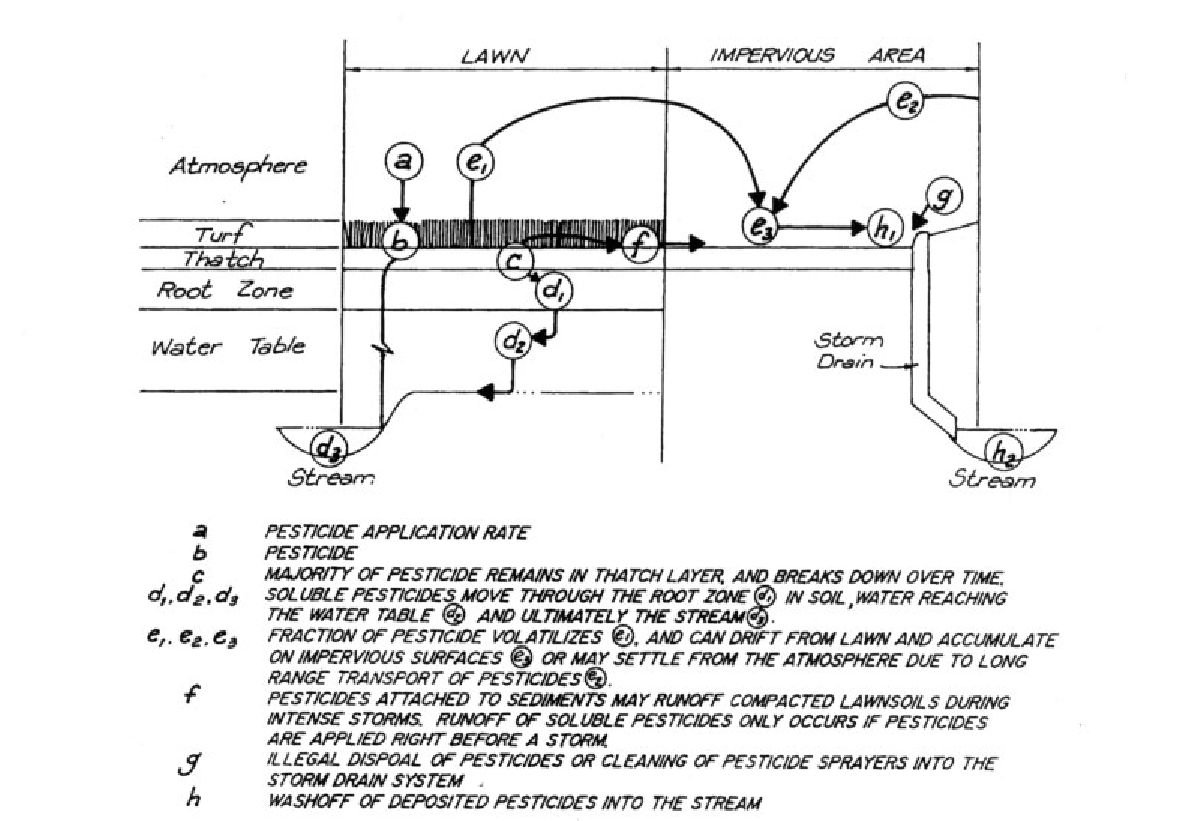

Figure 1: Urban Pesticide Pathways

they are being sprayed or applied. Depending on the nature of the pesticide and the manner that it is applied, anywhere from 2% to 25% can drift away and land on an impervious surface. During the next rainstorm, the pesticide can be quickly washed away. Pesticide drift can extend over a distance as short as a few yards or as long as several hundred miles. Glofelty *et al.* (1990) and others have studied the local and long range transport of pesticides, and have detected them in both rainfall and dustfall.

Indeed, a number of pesticides exclusively used for crops, such as Atrazine, Alachlor, Cyanazine and Metolachor, have been detected in stormwater runoff from residential watersheds located far away from agricultural sources (Wotzka *et al*., 1994; Kroll and Murphy, 1994a; Hippe *et al*., 1994). In another case, rain and fog have been found to be a chief source of diazinon in the Central Valley of California, presumably due to the drift of this pesticide from nearby orchards (Connor, 1995). The studies suggest that some pesticides can reach an urban stream simply through air deposition and subsequent washoff, even if the pesticides were never applied to residential lawns. It also opens the possibility that local drift of pesticides from lawns to streets could be a significant loss pathway.

Disposal and Sprayer Cleaning

Pesticides can also reach the stream through improper disposal or applicator cleaning. Very little is known about the significance of either pathway. The Baltimore pesticide usage survey found contradictory results (Kroll and Murphy, 1994a). On one hand, over 90% of residents claimed that they had no extra pesticides stored in their home. On the other, an even greater percentage were ignorant of how to properly dispose of excess or unused pesticides.

The Baltimore survey also found that about one in thirteen residents was likely to spray their own pesticides with an applicator (remainder handled by commercial applicators). Two-thirds of the do-it-yourselfers indicated they rinsed out their sprayers over grass, pavement or directly into gutters or storm sewers.

Pesticides and Stormwater Practice Sediments

One possible repository for pesticides in the urban environment are the sediments of stormwater practices, such as ponds and wetlands. Only a few investigators have examined the pesticide content in pond muck (Dewberry and Davis, 1989; MWCOG, 1983). These studies have revealed the presence of several persistent and relatively insoluble pesticides, such as aldrin, dieldrin, lindane and even DDT at low levels (usually 0.2 ppb or less).

One investigator has detected the presence of 2,4-D and diazinon in pond water, and found that wet ponds were not effective in removing these more soluble and mobile compounds (Bannerman, 1994). This suggests that many urban stormwater practices may not be capable of effectively removing the current generation of soluble and mobile pesticides that are being applied.

Pesticides in Urban Streams

Finding pesticides in urban stormwater is a lot like finding a needle in a haystack. To begin with, pesticide monitoring is both complex and expensive. Researchers have only recently developed analytical techniques that can detect pesticides at the part per billion or trillion level. The search is further complicated by the diversity of pesticides applied in residential watersheds, with as many as 50 different compounds routinely applied during the growing season. Each of these compounds differs in its mobility, persistence and aquatic impact. Further, the probability that a given pesticide actually reaches the stream depends on the timing of random events—the proximity of a large storm soon after pesticide application, the decisions made by dozens of different individuals regarding pesticide selection or disposal, the occurrence of pest outbreaks and so on. Lastly, only a minute amount of pesticides is likely to ever reach the stream, even under optimal delivery conditions. Therefore, the expectation is that relatively few pesticides will be detected in urban stormwater, and then at low concentrations and frequencies

Results of pesticide monitoring of residential runoff, however, runs counter to this expectation. A review of twelve recent studies indicates that a small group of herbicides and insecticides are routinely found in urban runoff, even in different regions of the country. Not surprisingly, this group includes the most widely used and marketed pesticide compounds.

Herbicides

A small group of herbicides is frequently detected in urban stormwater, including 2,4-D, MCPA, MCPP and dicamba (Table 3). Each of these herbicides is a frequent component of many commercial weedkiller products used by homeowners and professionals alike. These weedkillers were detected in 25 to 90% of all storm samples from two different residential watersheds in Minnesota (Wotzka, 1994). 2,4-D, perhaps the most widely used pre-emergent weedkiller, has been frequently detected at many other sites in the country. The concentration and detection frequency of these weedkilling herbicides are among the highest yet reported for any urban pesticide. Other residential herbicides are detected with less frequency and lower concentration, and include Simazine, Silvex, Diruron, and Dachtal.

Insecticides and Fungicides

A wide spectrum of pesticides are applied to lawns and gardens to control insect pests and control diseases, but relatively few have been detected in urban runoff. Two notable exceptions include the insecticides, diazinon and chloropyrifos, which have been found in stormwater runoff in the low part per billion range in such diverse settings as Baltimore, Sacramento, Milwaukee and Atlanta (see Table 4). Although

Table 3: Herbicides Detected in Urban Runoff (Reported in Median Concentrations (µg/l) Parentheses Indicate Maximum Values

Study	2,4-D	Dicamba	MCPP	MCPA	Roundup	Other
Baltimore, MD (Kroll Murphy)	0.1-0.35	NA	NA	NA	0.44	Dachtal Simazine
Bloomington, MN (Dindorf)	1.5	0.7	1.4	1.3	NA	Silvex
Minneapolis,MN (Wotzka)	(6.8)	(2.6)	(1.4)	(5.6)	NA	No others
Atlanta (Thomas)	< 9.1	NA	NA	NA	NA	—
Atlanta (Hippe)	0.05 (.63)	NA	NA	0.05 (.42)	NA	Simazine 12 others
Milwaukee (Bannerman)	Detected	ND	Detected	ND	ND	—
Alameda, CA (Connor)	NA	NA	NA	NA	NA	Diuron Simazine

ND=Not Detected, NA=Not Analyzed

concentrations are relatively low, detection is very frequent. For example, weekly stormwater sampling in an Atlanta urban watershed detected diazinon and chlorpyrifos in 89% and 65% of all samples respectively. Peak concentrations were recorded in the late Spring (see Figure 2). Connor (1995) also reported frequent detection of these two insecticides in Sacramento, CA. Other studies report the occasional presence of carbaryl, malathion and aldrin in urban runoff. No fungicides have been detected.

Banned Pesticides

Researchers still find low levels of many insecticides whose use has been severely restricted or banned for many years. These include chlordane, lindane, heptachlor, dieldrin, endrin and even DDT and its residuals (Table 5). Detections are made during both wet and dry weather flows, with detection frequencies ranging from two to 25%. Their presence in urban streams after so many years appears to reflect either the slow movement of these persistent pesticides through groundwater to the stream, or the erosion of contaminated soils. This phenomenon is typified by chlordane, an insecticide whose use has been banned for over a dozen years. It is still found in groundwater and stormwater samples in most environments where it has been tested for, albeit at low levels. Cohen et al (1990) found chlordane in 44% of test wells near a golf course in New England that had regular applications of this pesticide in the past. Thomas and McClelland (1994) have detected chlordane in urban streams in the Atlanta area in about 15% of all samples, but have never detected it in samples taken from stormwater outfall pipes. Kroll and Murphy (1994) have occasionally detected it in several Baltimore streams. D'Andrea and Maunders (1993) report lindane and dieldrin in residential, commercial and industrial runoff in Toronto, Canada. The continued presence of these persistent pesticides in urban streams so many years after they were banned is a potent reminder of the long term impact of organo-haline pesticides.

The Risks of Pesticides in Urban Streams

The mere presence of pesticides in urban runoff does not always mean that they exert a toxic effect on to downstream aquatic communities. Indeed, most of the pesticides found in urban are present in concentrations of a few parts per billion or less. Do these concentrations really pose a risk to aquatic health? In general, the concentrations of most herbicides and banned pesticides in urban runoff appears to be well below the threshold for acute toxicity for most aquatic and terrestrial organisms (Murphy, 1992). The potential for chronic or sublethal toxicity for herbicide concentrations typically found in urban runoff is not well documented. Some formulations of weedkillers have been shown to be toxic to some fish and algae species. Even low concentrations can inhibit algal photosynthesis, and can potentially harm downstream aquatic plants.

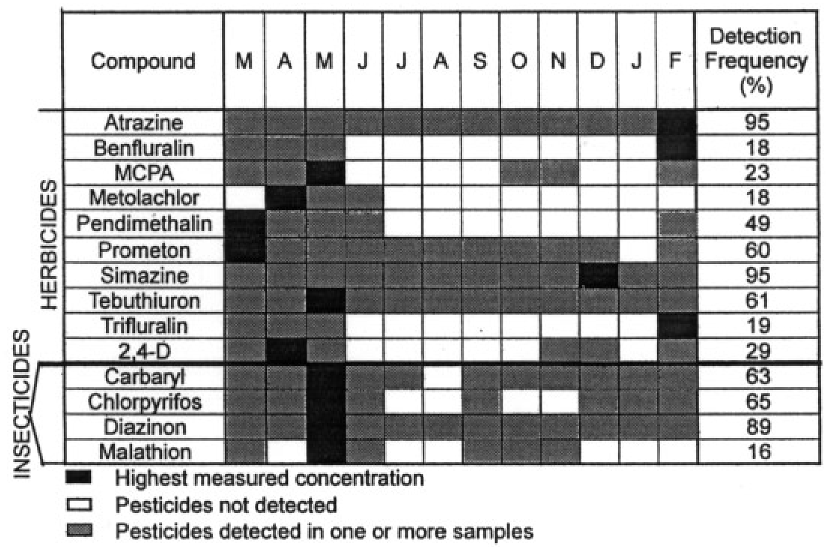

Figure 2: Seasonal Pesticide Concentration in Urban Streams in Atlanta, Ga (Hippe *et al.* 1994)

The greatest risk of toxicity appears to lie with the two insecticides found commonly in urban stormwater—diazinon and chlorpyrifos. Recent studies in Sacramento have shown acute toxicity for diazinon in 100% of urban stormwater samples when *Ceriodaphnia* was used as the test organism (Connor, 1995). Diazinon concentrations were typically on the order of 0.5 to five parts per billion, which is well within the reported range in other regions of the country. Acute toxicity was not found for the same test organism in Milwaukee Pond water with diazinon concentrations that were an order of magnitude lower (Bannerman, 1994).

Connor also found chlorpyrifos to be acutely toxic for several runoff samples that had concentrations in

Table 4: Currently Used Insectides Found in Stormwater Runoff (Reported in Median or Mean Concentrations in µg/l) (Numbers in Parentheses Indicate Maximum Reported Value)

Study Site	Diazinon	Chlorpyrifos	Others
Baltimore, MD Kroll/Murphy 94a	ND	0. 021	—
Baltimore, MD Kroll/Murphy 94b	ND	0.01	—
Atlanta, GA Hippe et. al 94	0.02 (0.45)	0.008 (0.051)	Sevin (carbaryl) Malathion
Sacramento, CA Connor, 95	0.5 to 1.0	Detected	Malathion
Milwaukee, WI Bannerman,94	0.5	NA	Aldrin

Table 5: Banned or Restricted Insecticides Found in Stormwater Runoff—Concentrations in µg/l (ppb)

Study	Chlordane	Lindane	Dieldrin	Other
Baltimore Kroll/Murphy	0.52	0.18	2.44	—
Rhode Island Cohen	Detected	NA	NA	NA
Atlanta Hippe	NA	0.01 (0.048)	NA	—
Atlanta Thomas	Detected	NX	NX	heptachlor
Milwaukee Bannerman	Detected	Detected	Detected	DDT,DDE
Washington MWCOG	0.2	0.2	0.2	heptachlor
Northern VA Dewberry and Davis	ND	Trace	ND	Endrin
Toronto D'Andrea	NA	0.5 to 2	0.1 to 2	—

ND=Not Detected, NA=Not Analyzed, NX= Detection only reported if they exceeded water quality standards.

the parts per trillion level. The toxicity of these two insecticides is not surprising, as a quick look at the product label or a toxicity table will show. Indeed, the use of diazinon is no longer permitted on golf courses, although it can still be used on residential lawns. Its toxicity to terrestrial wildlife, such as geese, songbirds, amphibians is well documented (article 133).

Future toxicity testing of residential stormwater runoff should clarify whether diazinon and chloropyrifos are a problem in other parts of the country. Some recent research in the Santa Clara Valley of California suggests that residential runoff, once thought to be relatively benign, may be much more toxic than previously thought (Cooke *et al.*, 1995). Seventy percent of residential runoff samples were found to be highly or extremely toxic using *Ceriodaphnia*. The authors ruled out metals as the cause of toxicity in residential runoff, and strongly suspect that insecticides are the culprit.

Needed Research

Monitoring has demonstrated a clear link between pesticides applied to the lawn and their presence in the stream in many geographic regions of the country. The small group of herbicides and insecticides that are detected in urban runoff are also among the most widely sold lawn care products. While this link certainly justifies efforts to reduce pesticide use on home lawns, more research is needed to fully understand the biological significance of the relatively low pesticide levels found in streams.

To answer these questions, a monitoring study is needed that simultaneously measures residential pesticide use, pesticide concentrations in streams during periods of maximum application, and toxicity based on rapid bioassays. Another research priority is a monitoring assessment that compares residential pesticide concentrations from traditional lawn practices and those that employ integrated pest management (IPM) or eliminate pesticide application altogether. This research could help document whether education and community outreach efforts can produce meaningful reductions in urban stream pesticide levels. **See also articles 16, 129 and 133.**

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