Article 4

Feature article from Watershed Protection Techniques. 2(1): 239-246

Nutrient Movement from the Lawn to the Stream

Are lawns a significant source of nutrients to urban streams? The answer to this frequently asked question appears to be "maybe." On the one hand, over-fertilization of home lawns has been frequently cited as an important and controllable nutrient source within urban watersheds, and has been a key element of many local outreach and pollution prevention campaigns. On the other, turfgrass researchers report that well-tended lawns produce minimal runoff and nutrient export. In this article, we explore the question of whether nutrients are moving from the lawn to the stream, by examining three areas:

- Trends in urban fertilizer use
- Research on the nutrient cycle in urban lawns
- Actual nutrient levels recorded in urban steams

The article begins with an analysis of recent trends in lawn fertilization *recommendations*, and then summarizes what we know about *actual* fertilizer applications and behavior by the homeowner and lawn care companies.

Next, the nutrient cycle of the lawn is described, including major *inputs, storage components*, and *outputs* of nitrogen and phosphorus. Potential nutrient *inputs* include fertilizer applications, atmospheric deposition, runon from impervious areas such as rooftops, irrigation water with elevated nutrient content, fixation, and decomposition of clippings left on the lawn. *Storage components* include soil, thatch, and standing turf. Potential *outputs* include volatilization, denitrification, runoff, leaching, and clippings not left on the lawn.

Lastly, the article reviews monitoring data from nearly 40 residential watersheds across the country to detect whether nutrient levels in urban streams are elevated during storm events, in relation to other land uses or nutrient sources.

Trends in Urban Lawn Fertilization

Historical Fertilizer Use

Fertilizer use mushroomed after World War II along with the chemical industry. Fertilization rates recommended by turf researchers and garden writers also grew sharply during this period. A typical recommendation prior to 1940 was 44 pounds of nitrogen* fertilizer per acre per year (Jenkins, 1994).

By the 1965 edition of the popular *America's Garden Book*, recommended fertilization rates had climbed to 283 pounds nitrogen per acre annually. Some fertilizer recommendations during the 1970s were as high as 348 pounds per acre per year (Jenkins, 1994). By 1984, EPA estimated nearly a million tons of chemical fertilizers were applied yearly across the nation's lawns—more than India applied to all its food crops in the same year (Bormann, 1993).

In recent years, the trend toward ever greater fertilization has begun to change. Part of this is due to the recognition that excess nutrients can degrade the water quality of streams, lakes, and estuaries. Also, hardier grasses such as fine fescues and native buffalograss have become more popular in response to growing water shortages. These tough grasses have lower nitrogen requirements than other grasses (Schultz, 1989). Lastly, turf research documented that lawn clippings can provide significant nutrient value and help promote dense and vigorous grass. In response to these trends, some extension agents are now recommending lower nitrogen fertilization rates. For example, according to the Northern Virginia Soil and Water Conservation District a good rule of thumb is to use half of the manufacturer's recommended application—generally less than 44 lbs/acre in any single application. Other current extension and garden literature recommendations range from 87 to 174 lbs/acre/year of nitrogen.

---

* Lawn feeding recommendations are often expressed in terms of nitrogen since this nutrient keeps grass green and soft by promoting rapid leaf growth. The vast majority of retail lawn fertilizers are "complete" fertilizers, meaning they contain nitrogen, phosphorus, and potassium. Nitrogen stimulates leaf growth; phosphorus enhances stem and root strength (as well as promoting flowering); and potassium encourages seed-ripening and stress-tolerance. Phosphorus and potassium also impart insect and disease resistance. The percentages vary, from nitrogen-heavy formulas such as 29-3-4 to more even-handed formulations such as 10-6-4, or 10% nitrogen, 6% phosphorus, and 4% potassium by weight.

Table 1: Summary of Lawn Care Surveys

Lawn care study	Wisconsin	Virginia	Maryland	Maryland	Minnesota
Reference	Kroupa & Associates, 1995	Aveni, 1994	Kroll and Murphy, 1994	Smith *et al.*, 1993	Dindorf, 1992
Homes surveyed	204	100	484	403	136
Proportion of homes that use fertilizers	54% *(69% home-owner applied)*	79% *(85% home-owner applied) less than 20% had soil tested*	38%	87%	85% *(18% had soil tested)*
Number of applications per year	2.4	no data reported	1 (37%); 2 (31%); 3-4 (16%)	no data reported	no data reported

Homeowner Fertilization Behavior

Surveys suggest that roughly 70% of all lawns are regularly fertilized, regardless of whether additional nutrients are needed (Table 1). For example, in Minnesota, 85% of respondents reported using fertilizers, but only 18% had their soil tested to confirm the need (Dindorf, 1992). Likewise, 79% of Virginia homeowners used fertilizers, but less than 20% had their soil tested (Aveni, 1994).

Few homeowners bother to contact the local extension office for recommended fertilization rates. Instead, most rely on the local hardware store or garden center. In fact, a survey in Virginia found that product labels were the number one information source for homeowners, while Cooperative Extension Service ranked last (Aveni, 1994). Label directions vary in terms of specificity. While all labels indicate how many square feet the bag should cover, each takes a different approaches on how often the product should be applied. Some specify two or three applications per year. Others give no frequency at all and say “may be applied at any season.” Interestingly, the instructions for bagged fertilizer fail to mention soil tests.

Depending on the type of lawn care product, a homeowner might apply anywhere between 44 and 261 lbs. nitrogen/acre and from four to 26 lbs. phosphorus/acre each year. Still, this begs the question of whether or not homeowners follow package directions. There is very little actual data on homeowner application rates. A survey of homeowners in Long Island found an average application rate of 107 lb. nitrogen per acre per year (Morton, 1988.) In a Wisconsin survey, 66% of homeowners reported applying exactly the amount recommended, 31% reported using less, and only 3% reported using more than the recommended amount (Kroupa and Associates, 1995.) While that is an encouraging statistic, it must be remembered that it is a self-reported one (i.e. without verification).

What about homeowners who rely on others for their lawn care? About two-thirds of all homeowners perform their own lawn care, with lawn care companies servicing the rest. Still, in some more affluent neighborhoods, as many as 50% of lawns may be managed by a service. From the mid 1960s to the mid 1980s, the lawn care service industry grew at a rate of 25 to 30% per year (Jenkins, 1994).

Lawn care companies usually offer a variety of service plans, but the most common is a basic service plan that consists of five to eight visits per year. Most visits are dual-purpose, in that fertilizer and pesticides are both applied. Unless a customer specifically requests a soil test or a special application rate, most lawn companies give every lawn serviced by the company the same rate of fertilization. Morton (1988) reported that many commercial lawn care services apply 194 to 258 lbs/ac/yr of nitrogen.

Homeowner surveys also indicate that spring fertilization is still common in cool-season grass regions. Some homeowners even reported fertilizing in winter. In any event, homeowners and lawn care companies may not always apply fertilizer at the optimal time. Still, no matter how much fertilizer is applied to the lawn, the key question is whether enough of it finds its way to urban streams to cause water quality problems.

The Nutrient Cycle in the Urban Lawn

The nutrient cycle in an intensively managed lawn is quite complex, and consists of many interacting inputs, outputs and storage components. A better understanding of the urban lawn nutrient cycle can identify important nutrient pathways, and help estimate the potential for nutrient export. A schematic of the major elements of the nitrogen and phosphorus cycle is shown in Figure 1.

In the absence of fertilization, nitrogen is found in three major forms in the urban lawn (Figure 1a). The largest quantity of nitrogen is present in *organic* form, either in the soil, thatch or grass itself. The large reservoir of organic nitrogen, however, cannot be taken up by plant roots until it is converted into more soluble *inorganic* forms, such as nitrate and ammonium. The process is facilitated by microbes and bacteria within the soil that are continually breaking down organic nitrogen into ammonia, and ultimately, into nitrate. Most grass plants prefer to take up nitrate nitrogen, although some species (especially on acid soils) can take up ammonia-nitrogen as well. Since inorganic nitrogen is quite soluble, it moves with soil water and can leach out of the root zone. The last form is *atmospheric nitrogen gas* which is present in the pore spaces of the soil and can be converted into inorganic nitrogen by nitrogen-fixing bacteria found in leguminous plants (such as clover).

The phosphorus cycle on urban lawns is slightly less complex (Figure 1b). Phosphorus is primarily found in two forms: *phosphate* (PO_4) and other forms of soluble phosphorus (that has weathered from rocks or been released during the decomposition of organic matter), and *organic* phosphorus (that is contained in organic matter in the soils, thatch and grass itself). Phosphate is present in small quantities, and is taken up directly by grass roots, while organic phosphorus is not available for plant uptake until decomposers break it down into soluble forms.

Much of our knowledge of each pathway in the urban nutrient cycle is derived from experimental plots rather than field monitoring. In addition, most studies have focused on a single component of the lawn nutrient cycle (e.g. applied fertilizer, leaching), rather than attempting to model the full dynamics of the turfgrass cycle. Thus, we have a very dim understanding of how inputs shift nutrients from one component to another, or how rates of transport are controlled. The schematic does suggest that internal storage components such as soil, thatch and clippings are a major element of the cycle and will influence the pollution potential of a given fertilization or watering regime. This also suggests that estimates of the amount of fertilizer needed for turfgrass should credit supplemental nutrient sources such as atmospheric deposition, thatch, mulched clippings, and irrigation water.

Input 1: Fertilizer Application

As already discussed, there is some uncertainty about actual fertilization rates for home lawns. Still, it is clear that fertilization rates can approach significant levels. Table 2 offers a comparison of fertilization rates among several land uses. It shows that nitrogen amounts commonly applied by homeowners rival those applied to golf fairways and crops. Lawn care services appear to apply more nitrogen than is used on cropland or golf courses. Home lawns, however, receive less phosphorus inputs than other crops.

Input 2: Atmospheric Deposition

The contribution of airborne nutrients to the lawn has long been ignored even though studies in the Washington metropolitan area estimate 17 lbs/ac of nitrogen and 0.7 lbs/ac of phosphorus (MWCOG, 1983). Sources of airborne nutrients include power plant and vehicle emissions. Atmospheric deposition to surfaces other than the lawn may also reach the lawn through *runon*.

Input 3: Runon from Impervious Areas

Impervious surfaces collect nutrients from atmospheric deposition, pet wastes, and blown in organic matter. These nutrients are easily washed off the surfaces in stormwater runoff. When runoff from impervi-

Table 2: Comparative Chemical Application Rates in Pounds/acre/year in Maryland (Klein, 1990)

Chemical	Cropland*	Golf fairway	Greens	Home lawn (do it yourself)	Home lawn (lawn service)
Nitrogen	184	150	213	44-261	194-258
Phosphorus	80	88	44	15	no data
Pesticides	5.8	37.3	45.1	7.5	no data

* Corn/soybean rotation.

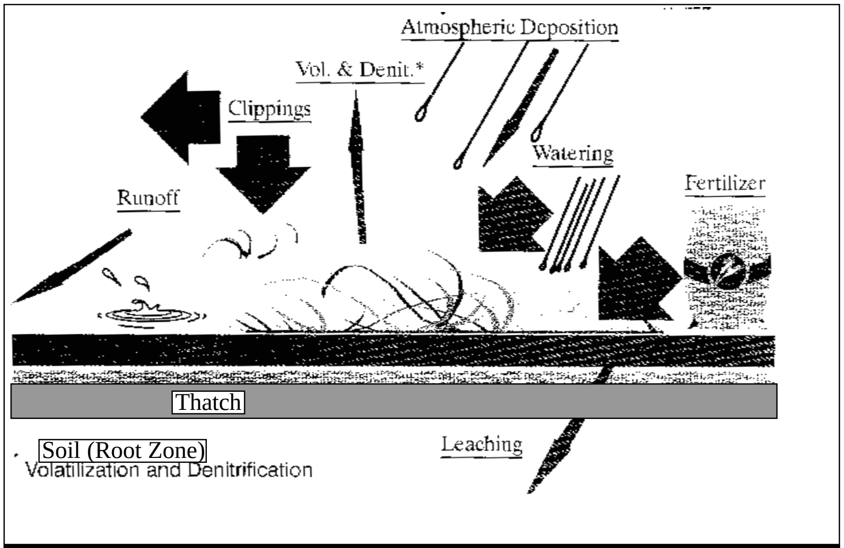

Figure 1a: Nitrogen Pathways to Urban Streams

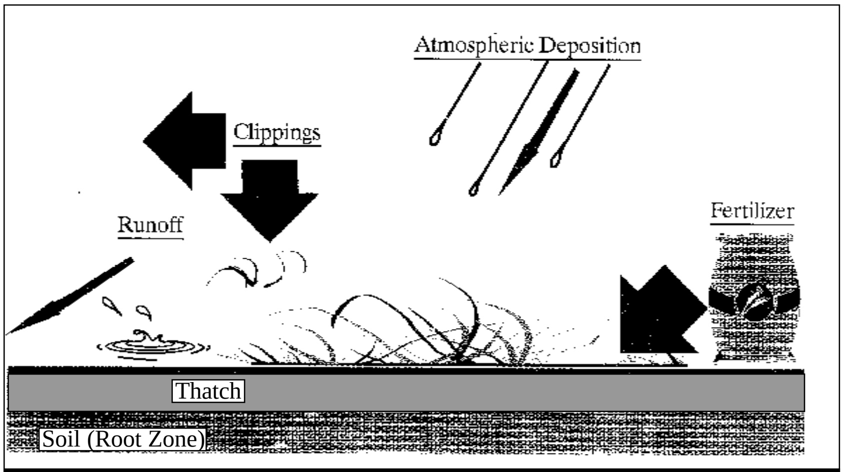

Figure 1b: Phosphorus Pathways to Urban Streams

ous areas flows onto lawns, this *runon* becomes a nutrient source. Rooftops are probably the greatest source of runon, and they can supply moderate concentrations of nitrogen and phosphorus. Bannerman (1994), for example, reported total phosphorus levels of 0.15 mg/l in residential roof runoff. Thomas and Greene (1993) reported nitrate levels of 0.1 to 0.3 mg/l in rooftop runoff.

Input 4: Nutrient Content in Irrigation Water

Many Midwestern municipalities are experiencing rising nitrate levels in public water supply wells. Exner and colleagues (1991) irrigated Nebraska turf plots with municipal water every third day regardless of rainfall from mid-May through late August. The amount of nitrogen delivered in the irrigation water was calculated to be 176 lbs/ac—more than the turfgrass required in a full year. While the irrigation level in Exner's study was designed to be excessive, the results do suggest that the nutrient content in irrigation water can be a significant input to the lawn in some regions.

Input 5: Nutrient Fixation by Plants

Atmospheric nitrogen (N_2 gas) is not usable by plants until it is *fixed*, combined with oxygen or hydrogen into compounds which plants can assimilate. Bacteria living in the soil (*Clostridium*) and on the roots of certain plants (*Rhizobium*) are able to fix nitrogen. Clover, one of the rhizobium-bearing plants, can provide up to 30% of a lawn's yearly nitrogen requirement (Olkowski, 1991).

Input 6: Decomposition of Clippings

Petrovic (1990) reviewed nitrogen recovery from clippings. *Recovery* compares the amount of nitrogen present in clippings with the amount applied through fertilization. For example, if 10 lbs of nitrogen were applied to one acre of turf, and if the resultant clippings contained 10 lbs of nitrogen, nitrogen recovery would be 100%. Petrovic reports that recovery percentages vary with grass species, rate of fertilization, and the rate at which the nitrogen contained in the fertilizer becomes available. For example, at similar fertilization rates, 99% recovery was observed in perennial ryegrass compared to 60% recovery in creeping bentgrass. As fertilization rates increase above the optimum, the percent recovery declines. For fertilizers that release most of their nitrogen within one year, recovery percentages ranged from 25 to 60%. Recovery also varies with soil type, but there is less information available. One study found a 9% recovery difference in silt loam vs. clay loam (Petrovic, 1990).

Researchers at the University of Connecticut Agricultural Station used radioactive nitrogen to track what happened to applied nutrients when grass clippings were recycled. They found that nitrogen from the clippings was incorporated into new grass growth within a week. After three years, nearly 80% of the applied nitrogen had been returned to the lawn through the clippings (Schultz, 1989). The Rodale Institute Research Center reports that an acre of clippings provides an average of 235 pounds of nitrogen, 210 pounds of potassium, and 77 pounds of phosphorus (Meyer, 1995). Thus, if all clippings are returned to the lawn, they can meet much of the nutrient requirement.

Storage Component 1: Soil Storage

Soil is the largest reservoir of nutrients in the lawn, although most nutrients are found in organic form and are not readily available for plant growth. Soil tests in New Jersey found very high phosphorus levels in the soil of 80% of residential lawns (Liptak, 1992), but runoff studies have not examined the impact of long-term phosphorus buildup. In most regions, soils generally contain enough phosphorus to grow healthy lawns without any added fertilizer (NVSWCD, 1994). However, almost all retail lawn fertilizer products do contain phosphorus. Some local soil conservation districts are now offering special no-phosphorus formula fertilizers to homeowners. In general, most experts agree that most lawn soil contains enough phosphorus to meet plant demand.

A soil's ability to store nitrogen in organic forms rises as organic matter increases. An undisturbed lawn usually adds organic matter (and thus increases nitrogen storage) until equilibrium is reached. One study showed that nitrogen accumulated rapidly in the surface layer for the first 10 years, and then was little changed after 25 years (Petrovic, 1990). This suggests that prior fertilization history or soil testing are important for determining appropriate fertilization rates and reducing the potential for nitrogen leaching.

Storage Component 2: Thatch Storage

Thatch is a brown layer of plant parts which rests on top of the soil. Thatch is composed of dead roots, stolons, and rhizomes. The amount of thatch present is highly variable, since thatch buildup can be caused by poor soil conditions and/or poor lawn management. In cases of extreme thatch buildup, a lawn may actually be rooted in the thatch layer rather than the underlying soil. Some studies provide nitrogen recovery data for stems, leaves, roots, and "debris" combined, but they do not report the amount of thatch present. In general, however, little data are available on nutrient storage in the thatch layer. One study reported a 14 to 21% recovery rate of applied nitrogen in the thatch layer (Petrovic, 1990).

Output 1: Volatilization

Some of the inorganic nutrients applied to the lawn never reach plants. Instead, they volatilize and return to the atmosphere, often during or shortly after fertilization. Petrovic (1990) reviewed literature reporting total atmospheric losses of applied nitrogen which ranged from zero to 93% of applied nitrogen. Highest rates of volatilization are associated with applications of urea fertilizers. Urea applied to turfgrass often results in more volatilization than urea applied to bare soil. Volatilization also increases with greater thatch levels and declines when turf is irrigated.

Output 2: Denitrification

Under the right conditions, some soil bacteria can denitrify, or convert nitrates to molecular nitrogen (N_2) which returns to the atmosphere. The question is how much nitrate is lost to denitrification rather than leaching or plant uptake. Limited studies of lawn denitrification indicate that if soils are saturated and temperatures are high, significant denitrification can occur. For example, Petrovic (1990) reports that 45% of applied nitrogen on silt loam and 93% on silt soil denitrified, and was lost to plants.

Output 3: Surface Runoff

Relatively little monitoring data is available to characterize loss of nutrients in surface runoff from lawns. Only one study has measured phosphorus concentrations in lawn runoff (Bannerman, 1994). This Wisconsin study found total phosphorus concentrations were as high as 2.6 mg/l in lawn runoff, ranking as the highest urban source area for that nutrient. Three studies have detected nitrate in surface runoff from turfgrass plots. Morton *et al.* (1988) detected nitrate at one to 4 mg/1 from simulated lawns in Rhode Island, but noted that runoff only occurred twice during his two year study, once during a rain on snow event and the second time during a very intense storm. Gross and his colleagues (1990, 1991) found minimal nitrate concentrations in his Maryland turfgrass test plots, except when fertilizer applications coincided with large storm events. Hipp *et al.* (1993) reported a 3% nitrate loss in test lawns in runoff from a storm two days after fertilization, but found negligible concentrations in xeriscaped plots.

The scarcity of nutrient runoff from grass reflects the fact that surface runoff is a relatively rare event in turfgrass research. Well maintained turfgrass seldom produces surface runoff, except during uncommonly intense storm events. Test plots also have ideal soil conditions. The same controlled and well-managed conditions probably do not exist at all home lawns. Many lawn soils are highly compacted, and have runoff coefficients ranging from 0.05 to 0.25 (see article 129). In addition, the travel distance for runoff between the lawn and an impervious area may also be short. Certainly, it is not hard to find home lawns with compacted soil, bare spots, steep slopes, channel flow, thin turf, and fertilized sidewalks.

Output 4: Subsurface Leaching

Turfgrass researchers have performed more studies on the possible extent of nitrate leaching from simulated urban lawns (for a summary, see article 132). Leaching occurs when excess inorganic nitrogen moves below the root zone, and travels in solution through soil water, eventfully reaching a stream or moving into deep groundwater. The experiments specifically examined some of the poor management factors thought to occur on home lawns, most notably over watering and overfertilization. In controlled studies, the average concentration of leached nitrate under home lawns that were not fertilized was about 0.5 mg/l. Leachate from lawns that were overfertilized ranged from 1 to 4 mg/l in the experiments.

The greatest leaching occurred when lawns were overfertilized and overwatered at the same time. In this situation, high nitrogen inputs are more susceptible to leaching because the overwatering sharply increases percolation through the soil. The highest rates of nitrate leaching have been recorded from golf courses that have been continuously fertilized for many decades (Cohen *et al.*, 1990). Average concentrations of 1 to 6 mg/l were recorded in test wells. In most cases, nitrate leaching is also very pronounced in sandier soils that have rapid infiltration rates. Densely populated Long Island relies on groundwater that is overlain by sandy soils, and groundwater nitrate concentrations there have risen significantly over the last 30 years. Leaching of fertilizers is thought to be a significant contributing source (Bormann *et al.*, 1993).

Output 5: Clippings

Grasses rapidly take up inorganic nitrogen and phosphorus and incorporate them into biomass. When lawns are mowed, this biomass is harvested in the form of clippings. Over the course of a year, the 20 to 30 lawn "harvests" can remove a significant quantity of organic nutrients from the lawn—up to 235 pounds of nitrogen and 77 lbs of phosphorus per acre are "lost" in clippings (Meyer, 1995). If the clippings are left in place (or mulched by a composting lawn mower) the organic nutrients are returned to the soil and thatch layer, where some fraction is eventually transformed into more available inorganic forms. In this case, clippings become a nutrient storage component. If, on the other hand, clippings are bagged and exported as yard waste, the nutrients contained in clippings become an output. In addition, any clippings that are discharged from the lawn to the driveway or street also represent an output of nutrients from the system.

Nutrient Concentrations in Urban Streams

The brief review of the lawn nutrient cycle certainly indicates the potential for leaching or runoff of nutrients as a loss mechanism. The key question is whether these nutrient losses are great enough to increase nutrient levels within urban streams, either during runoff events or in dry weather flow. One indirect means of answering this question is to look at the actual nutrient concentrations in streams that drain residential watersheds that might be influenced by lawn care activity. Nutrient levels in urban streams, of course, represent a composite of many different sources and pathways, of which lawn care is but one. For example, washoff of deposited nutrients from impervious areas is thought to be a major source of nitrogen and phosphorus during storms (MWCOG, 1983). Some insights about the possible role of lawn care may have in regard to stream nutrient levels can be gained from an analysis of the runoff from residential watersheds.

Some indication of the typical concentrations of nitrate and total phosphorus in stormwater runoff are evident in Figures 2 and 3. These graphs profile the average event mean concentrations (EMCs) in storm runoff recorded at 37 residential watersheds or catchments across the United States. The sites represent a very broad geographic base, and include runoff monitoring data from 15 states (WA, SD, VA, NC, MD, IL, MI, WI, MN, KS, FL, CO, GA, TX, CA). This database includes 12 NURP and 25 post-NURP runoff monitoring studies, that collectively sampled several hundred individual storm events. Most of the residential watersheds were less than 200 acres in size.

The average nitrate EMC is remarkably consistent among the residential watersheds—with most clustered tightly around the average of 0.6 mg/l, and a range of 0.25 to 1.4 mg/l. While the nitrate concentrations during storms are high enough to be considered moderately eutrophic, the data do not suggest much of a link between lawn care and stream quality during storms. Indeed, researchers have shown that washoff of nitrate deposited on impervious surfaces from the atmosphere can account for nearly all of the observed concentrations (MWCOG, 1983). The fact that storm nitrate concentrations do not appear to be heavily influenced by lawn care activities may only reflect the fact that nitrate leaching would be expected to impact stream quality during periods of dry weather flow.

The concentration of total phosphorus during storms is also very consistent, with a mean of 0.30 mg/l, and a rather tight range of 0.10 to 0.66 mg/l (Figure 2). About 40% of the observed phosphorus was found in soluble forms that are biologically available. Phosphorus concentrations of this magnitude are generally considered to be moderately eutrophic, and are comparable to those seen in agricultural streams (Smith *et al.*, 1992). It is quite possible that the elevated phosphorus concentrations seen in residential storm runoff could be partly influenced by lawn care activities, as the only other major source, atmospheric deposition, generally can only account for about a quarter of the observed TP concentration (MWCOG, 1983). Whether the remaining phosphorus is a direct result of fertilization, or an indirect result of erosion of phosphorus-rich organic matter (clippings, pollen, leaves or soils), or some other unknown pathway is a matter of conjecture.

We know next to nothing about nutrient dynamics in urban streams during periods of dry weather. This monitoring gap prevents us from detecting whether nitrate concentrations are in fact elevated by lawn leaching during the non-growing season (when nitrate leaching is typically highest). A cursory sample of nitrate trends does indicate that levels were typically higher in baseflow (0.72 to 2.2 mg/l) than during storms, but the sample size is too small to draw any firm conclusions. Interestingly, the handful of baseflow total phosphorus observations indicate that TP levels drops sharply during dry weather periods (0.02 to 0.07 mg/l).

The USGS has recently completed a national assessment of nutrient levels at over 300 urban, agricultural, range and forest watersheds (Smith *et al.*, 1992). Most of the samples were collected during baseflow conditions, although some storm data were included in their summary statistics. Urban streams were found to have the second highest nitrate and total phosphorus levels, second only to agricultural streams. In particular, urban phosphorus levels were frequently as high as those found in many agricultural areas, except for intensive row crops.

Our historical approach to monitoring, however, has never allowed us to really test the hypothesis that urban lawn fertilization directly contributes to elevated nutrient levels in streams. Systematic monitoring of dry weather nitrate concentrations of urban streams, coupled with detailed watershed surveys of residential fertilizer use would permit a test whether these links exist. Similarly, a more experimental sampling program might detect the source of total phosphorus in urban storm runoff. The sampling approach could involve test plots of fertilized and unfertilized lawns adjacent to streets, with an experimental device that allows the investigator to allow or block lateral movement of organic matter from the lawns to the street. More targeted monitoring programs are clearly needed to define the lawn/stream nutrient interactions.

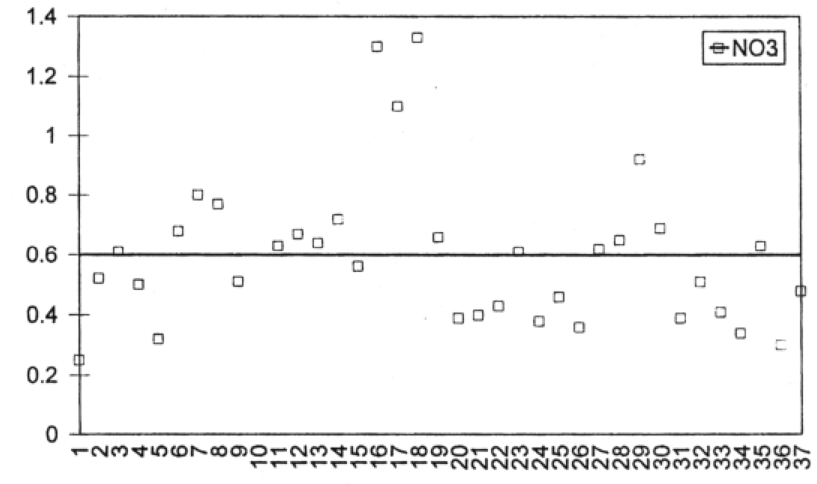

Figure 2: Nitrate-Nitrogen Concentration in Stormwater Runoff (Mean EMCs) (37 Residential Watersheds Across U.S.)

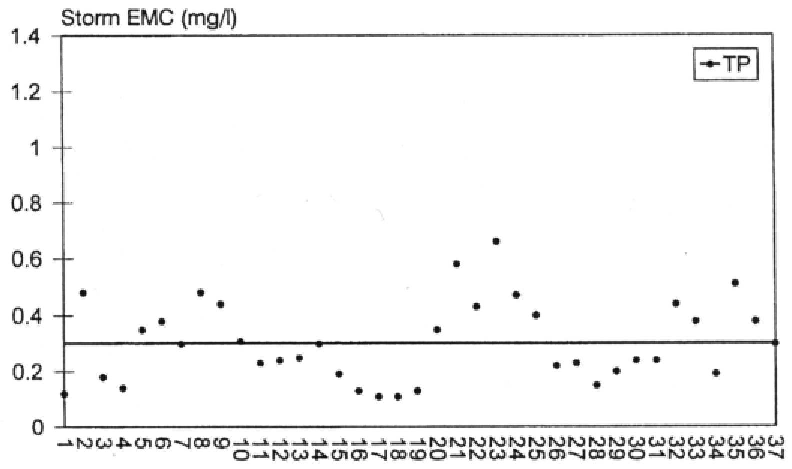

Figure 3: Total Phosphorus Concentration in Stormwater Runoff (37 Residential Watersheds Across U.S.)

Nutrient Impacts

Although the role of urban lawn care remains somewhat of a mystery, a number of conclusions can be made about nutrient concentrations in urban streams. On one hand, monitoring has never shown a single exceedance of the 10 mg/l nitrate criteria for drinking water, and therefore, urban runoff is not much of a risk to potable water supplies. On the other hand, concentrations of total nitrogen and phosphorus in urban runoff are certainly high enough to trigger eutrophication (or over-enrichment) in nutrient sensitive surface waters. In this respect, urban watersheds that drain to oligotrophic or mesotrophic lakes (where phosphorus is the limiting nutrient) or poorly flushed coastal waters and estuaries (where nitrogen is limiting) appear to be most vulnerable to eutrophication. The impact of elevated nutrient levels on small streams and their substrates have not been extensively explored, but several researches have reported changes in periphyton growth in urban streams.

Needed Research

For all the runoff research done on experimental turfgrass plots, we know very little about actual lawns. There are more real world data on complex natural ecosystems such as forests and wetlands than on the comparatively simple lawn. Experimental results are extended to home lawns without benefit of basic information on the differences between homeowner-managed lawns and professionally-managed test plots. Simple small watershed studies in different regions could provide valuable information on important characteristics such as soil condition, turf density, thatch levels, slopes, and plant diversity. Ideally, such studies would also take place in communities of varying economic characteristics. Even without actual runoff data, a better characterization of lawns would aid interpretation of the existing body of experimental results.

Summary

We are presently unable to accurately quantify the impact lawns have on stream water quality. Nonetheless, techniques are available to minimize the *potential* for nutrient and pesticide exports from turf areas. Requiring no construction or engineering, these techniques can in fact save homeowners time and money. The prudent course, therefore, is to help homeowners adopt this new approach to lawn care. **See also articles 126, 130, 131 and 132.**

References

Aveni, M. 1994. "Homeowner Survey Reveals Lawn Management Practices in Virginia." *Watershed Protection Techniques* 1(2): 85-86.

Bannerman, R. 1994. "Sources of Urban Stormwater Pollutants Defined in Wisconsin." *Watershed Protection Techniques.* 1(1): 30-32.

Bormann, F., D. Balmori, and Gordon T. Geballe. 1993. *Redesigning the American Lawn— A Search for Environmental Harmony.* Yale University Press. Binghampton, New York. 166 pp.

Cohen, S., S Nickerson, R. Maxey, A. Dupuy and J. Senita. 1990. "A Groundwater Monitoring Study of Pesticides and Nitrates Associated With Golf Courses on Cape Cod." *Groundwater Monitoring Review.* 1990. 160-173.

Dindorf, C. 1992. *Toxic and Hazardous Substances in Urban Runoff.* Hennepin Conservation District. Minnetonka, MN 98 pp.

Exner, M, M. Burbach, D. Watts, R. Shearman and R. Spalding. 1991. "Deep Nitrate Movement in the Unsaturated Zone of a Simulated Urban Lawn." *J. Environ Quality* 20: 658-662.

Gross, C., J. Angle, and M. Welterlen 1991. "Runoff and Sediment Losses from Tall Fescue." *J. Environ. Quality.* 20:3 604-607

Gross, C., J. Angle, and M. Wetherlin. 1990. "Nutrient and Sediment Losses From Turfgrass." *J. Environ Quality* 19(4): 663-668.

Hipp, B. S. Alexander and T. Knowles. 1993. "Use of Resource Efficient Plants to Reduce Nitrogen, Phosphorus and Pesticide Runoff in Residential and Commercial Landscapes." *Water Science and Technology.* 28(5): 205-213.

Jenkins, V.S. 1994. *The Lawn — A History of an American Obsession.* Smithsonian Institution Press. Washington, DC 246 pp.

Klein, R.D. 1990. *Protecting the Aquatic Environment From the Effects of Golf Courses.* Community and Environmental Defense Assoc. Maryland Line, MD 54pp. (410) 329-8194.

Kroupa and Associates. 1995. *Westmoreland Lawn Care Survey*. 11pp.

Liptak, C. 1992. *Lawn Management Options to Improve Water Quality*. Somerset County, NJ. 6pp.

Metropolitan Washington Council of Governments. 1983. *Urban Runoff in the Washington Metropolitan Area.* Final NURP Report. Dept. of Environmental Programs. Washington, DC. 212 pp

Meyer, S. 1995. "What Do You Feed a Hungry Lawn?" *Organic Gardening.* May-June 1995:46-48

Morton, T, A. Gold and W. Sullivan. 1988. "Influence of Overwatering and Fertilization of Nitrogen Losses From Home Lawns." *J. Environ Quality.* 17: 124-130

Northern Virginia Soil Water Conservation District. 1994. "Please Don't Feed Our Streams." *How to Feed Your Lawn Without Overloading the Bay*. Northern Virginia Soil and Water Conservation District. 4pp.

Olkowski, W., S. Daar, and H. Olkowski 1991. *Common-Sense Pest Control.* Taunton Press. Taunton, CT. 715 pp.

Petrovic, A. 1990. "The Fate of Nitrogenous Fertilizers Applied to Turfgrass." *J. Environ. Quality* 19:1 1-14

Schultz, W. 1989. *The Chemical-Free Lawn— The Newest Varieties and Techniques to Grow Lush, Hardy Grass.* Rodale Press. Emmaus, PA. 194 pp.

Smith, R, R. Alexander and K. Lanfear. 1992. "National Water Summary 1990-1991: Stream Water Quality." pp 111-140 in *USGS Water Supply Paper* 2400. Reston, VA.

Thomas, R. and G. Greene. 1993. "Rainwater Quality From Different Roof Catchments." *Water Science Technology.* 28(3-5) 291-299.