

Nitrogen Input from Residential Lawn Care Practices in Suburban Watersheds in Baltimore County, MD

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ABSTRACT *A residential lawn care survey was conducted as part of the Baltimore Ecosystem Study, a Long-term Ecological Research project funded by the National Science Foundation and collaborating agencies, to estimate the nitrogen input to urban watersheds from lawn care practices. The variability in the fertilizer N application rates and the factors affecting the application rates were examined. Results indicated that the annual input of nitrogen from fertilizer is a major component of the urban watershed nitrogen budget and it is both spatially and temporally variable. There is a wide range in the application rate of fertilizer N to residential lawns applied by homeowners and by professional lawn care companies. Survey data estimated a mean fertilizer application rate of 97.6 kg N/ha/yr with a standard deviation of 88.3 kg N/ha/yr. Analyses suggested that the fertilizer application rate is affected by social economic factors and soil characteristics to include the market value of the house, age of development, soil bulk density and soil nitrogen content.*

Introduction

The lawn has been a fascination and pre-occupation with American homeowners for over a century and the lawn care industry in the USA has grown to be a multi-billion dollar industry (Teyssot, 1999). In the State of Maryland, lawn care companies, followed by residents of detached single-family homes, provided the greatest economic support to the turfgrass industry (Maryland Turfgrass Council, 1996). Research has shown that nitrogen application rates of fertilizer to residential lawns are comparable to fertilizer applications in agriculture and golf courses (e.g. Gold *et al.*, 1990; Liu *et al.*, 1997). However, the impact of fertilizer applications to lawns on the nitrogen cycle in urban watersheds is not well understood. Given current mandates to reduce nutrient loadings to surface

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waters such as the Chesapeake Bay, a better understanding of the sources and pathways of nitrogen is needed to achieve this water quality goal.

Run-off from residential lawns and contaminated groundwater are two types of non-point source pollution in urban watersheds that affect surface water quality. It is well documented that groundwater from agricultural land-use practices has elevated nitrate concentrations from the long-term use of fertilizers. The conversion of agriculture to urban land uses typically results in a reduction in nitrate concentrations and loads to surface water (Band *et al.*, 2002; Weller *et al.*, 2003). However, the legacies of past land-use practices, coupled with current residential fertilizer input, create a challenge to determine how best to manage non-point source pollution from urban watersheds.

Fertilizers contain two of the major nutrients, N and P that contribute to water quality impairment in the surface waters of the USA, including the Chesapeake Bay (Vitousek *et al.*, 1997; US Geological Survey, 1999). Plot-scale studies have shown that nitrate in run-off from fertilized turfgrass is not necessarily a constant source of nutrients to surface water but is temporally variable. For example, field studies have found low concentrations of nitrate in storm run-off from fertilized lawns (Petrovic, 1990; Garn, 2002), with the exception of storm events after fertilizer applications (Kelling & Peterson, 1975). For example, Line *et al.* (2002), working in suburban sites in North Carolina, measured nitrogen concentrations to be four times higher in run-off from single family residential land uses during February compared to fall or winter concentrations. Seasonal variability has also been observed for soil water nitrate concentrations from fertilized lawns. For example, Gold *et al.* (1990) measured soil-water nitrate concentrations in fertilized residential lawns in Rhode Island to be approximately seven times greater in the spring (e.g. 2.6 mg/L) compared to other seasons. Other studies in Rhode Island and Michigan found higher concentrations of nitrate-N in soil water in the fall compared to spring (Miltner *et al.*, 1996; Liu *et al.*, 1997).

As turfgrass is a dominant land cover type in urban watersheds with a majority of homeowners fertilizing their lawns (Center for Watershed Protection, 2000), there is concern regarding the impact of lawn fertilizers on water quality (Waschbusch *et al.*, 1999; Robbins *et al.*, 2001; Garn, 2002). In 1996, a survey by the Maryland Turfgrass Council estimated that 19% of the state area is covered by grass, inclusive of sod farms, golf courses, institutional land uses, parks etc. and 56% of this area is associated with single family residential land use. With the continued expansion of urban areas and residential development, fertilizer applications will represent an increasingly important source of nitrogen to the watershed (Maryland Department of Planning, 2001; Robbins *et al.*, 2001).

This paper describes the results of a residential lawn care survey which was conducted as part of the Baltimore Ecosystem Study (BES), an urban Long Term Ecological Research (LTER) project funded by the National Science Foundation and collaborating agencies. The survey was carried out to estimate the amount of nitrogen applied to urban watersheds from residential lawn care practices. The BES is one of two urban LTER sites that studies urban areas as ecological systems, where the components of the ecosystem extend to include the behaviours, relationships and interactions of people at varying scales (i.e. individuals, households and neighbourhoods) with other components of the ecosystem. The survey will contribute data to address one of the major BES research questions: 'What are the fluxes of energy and matter in urban ecosys-

tems and how do they change over the long term?’ (<http://www.beslter.org>). An initial study of nitrogen soil dynamics from various land cover types found that nitrogen cycling in lawns may be high, but losses may be low due to high soil organic matter content and active retention (Groffman *et al.*, 2002). Data generated from the survey, in addition to future modelling work, will determine the significance of specific sources of nitrogen that may contribute to non-point source pollution to surface water in urban areas. The specific objectives of the survey were to:

- Determine the temporal, spatial and socio-economic distribution of fertilizer N in urban watersheds;
- Identify the factors, both socio-economic and ecological that affect fertilizer N application rates;
- Estimate the contribution of lawn fertilization to the watershed nitrogen budget; and
- Define lawn fertilization rates as parameters for use in hydro-ecological models.

Study Site Description

The survey focused on two watersheds, Glyndon and Baisman Run that are a part of the BES monitoring network within the Gwynns Falls and Gunpowder watersheds, respectively (Figures 1 and 2). The Glyndon catchment has an area of 0.8 km² and includes a portion of an historical colonial town (Reisterstown). It is a headwater catchment of the Gwynns Falls watershed. Glyndon is characterized by gentle slopes producing diffusive flow patterns in the upper part of the watershed. Soils in the catchment are largely classified as loam and silt loam that are moderate to strongly acidic (USDA, 1976). The effect of development within the catchment is physically apparent from the engineered drainage networks from past agricultural practices and the incised main channel from more recent urban development. The predominant land use is residential, served by public water supply and sanitary sewers, with a mix of other urban and open space uses (e.g. recreational field) (Table 1). Downstream of Glyndon, the Gwynns Falls River drains more intensive urban land use moving from Baltimore County into Baltimore City.

Baisman Run is part of the Gunpowder water supply catchment and is characterized by low density, large lot development on septic systems in the upper third of the watershed. Downstream, the remaining two-thirds of the watershed is completely forested and is part of the Baltimore County parks system. Similar to Glyndon, the morphology of the stream network has been altered from human-influenced land-use practices. Hillslope gradients proximal to the main branch of Baisman Run are typically steeper than hillslopes in the lower order tributaries. Slopes are convex and range from 0–5% at the ridgetops and up to 40% at the lower hillslopes. Soils within the catchment are classified as loam and silt loam and are generally acidic (USDA, 1976).

Survey Design and Methods

A household survey was designed to collect data on lawn management practices in urban-suburban watersheds to determine how much fertilizer the average homeowner uses per application and annually and how fertilizer and outdoor

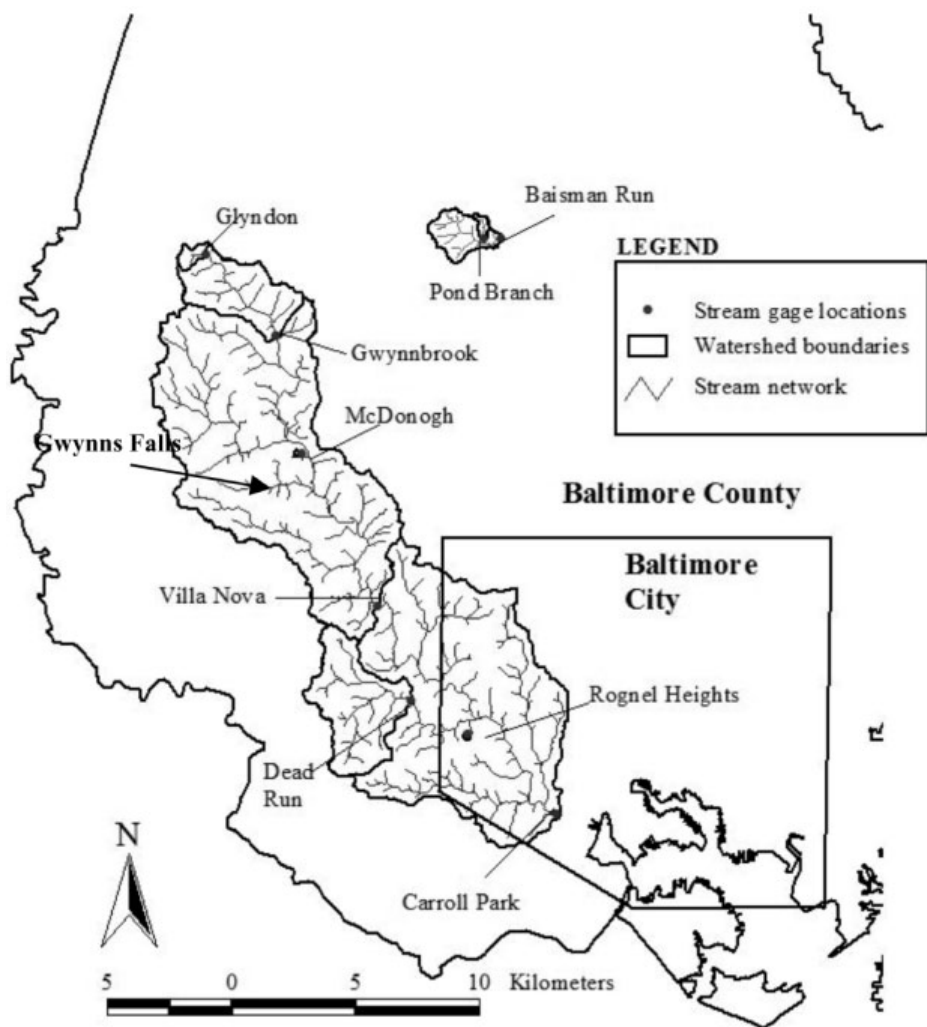


Figure 1. The Baltimore Ecosystem Study watersheds and stream network for the Gwynns Falls and its subwatersheds, Baisman Run and Pond Branch watersheds. The Glyndon watershed is located in the headwaters of the Gwynns Falls watershed.

water use practices vary within urban watersheds. Survey data were generated at this fine spatial scale (i.e. parcel) to associate lawn care practices with socio-economic and other parcel data from the Maryland Property View[®] dataset to include: the tax assessed market value of the house (land value plus improvement value), lot size, and square footage of the house.

The survey was administered door-to-door and comprised of two parts: (1) a set of 23 questions and (2) with the permission of the homeowner, soil samples from the lawn were taken to estimate soil bulk density and provide information on general soil chemistry. The survey was designed to determine fertilizer application rates and water use practices. A limited set of additional household and property characteristics were recorded to include type of grass, proportion of weeds and other landscaping features (e.g. permeable area other than turfgrass) and built structures, including driveways and sidewalks. A distance

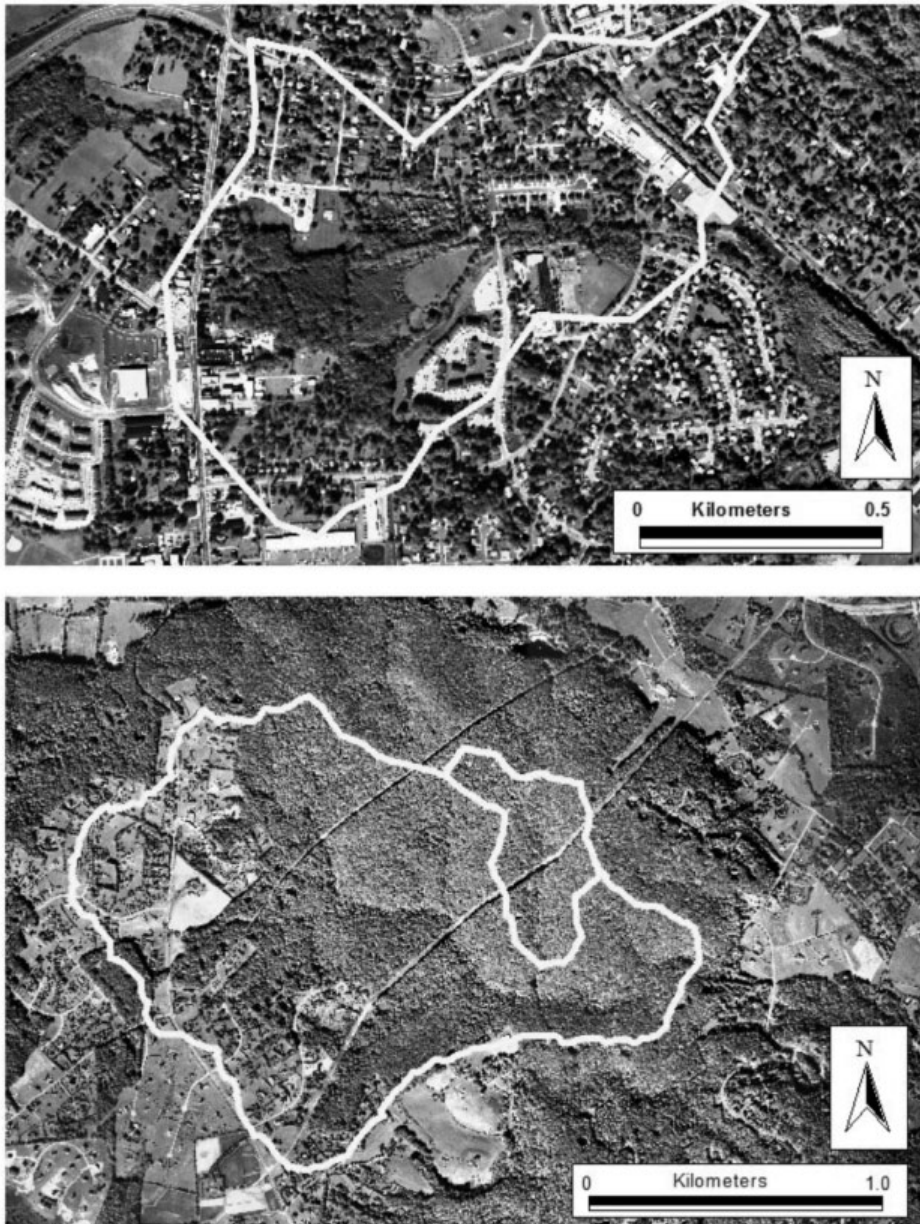


Figure 2. Land cover within the study watersheds of Glyndon and Baisman Run from high resolution digital colour infrared aerial photographs (October 1999). The outline of the watershed boundaries is indicative of vegetation land cover types to include lawns.

measuring wheel was used to estimate the lawn area for property in the Glyndon watershed. Lawn area in Baisman Run was estimated based on visual surveys that approximated the percent area of the property that was turfgrass, landscaped and had built structures, including driveways and sidewalks. These estimates were corroborated with information from the Maryland Property View[®] dataset on the lot size and building footprint, as well as high resolution

Table 1. Summary characteristics of land cover land use, population density and housing development in the study watersheds

	Glyndon	Baisman Run
Watershed area (km ²)	0.8	3.7
Residential	47%	34%
Forest	4%	66%
Open urban space	16%	0
Commercial, institutional	32%	0
Percent lawn area	15%	25.5% (75%) ¹
Population density (pers/ha)	9.4	1 (3.0)
Housing density (house/ha)	3.9	0.3 (1.0)
Average square footage of house	1534	3082
Average lot size (ha)	0.13	0.93

Note: ¹Values in parentheses refer to the residential portion of the Baisman Run watershed and not the whole watershed.

digital orthophotography. A follow-up survey to the professional lawn care companies identified in the household survey was conducted to document industry lawn care management practices.

The study watersheds were partitioned into subdivisions and households selected to participate in the survey using a GIS framework. Subdivision boundaries were defined using high resolution (1m) digital colour infrared aerial photographs, an overlay of the road network, parcel data attributed with the year the house was built from Maryland Property View© and watershed boundaries. Six subdivisions were digitized within the Glyndon watershed, and four subdivisions within Baisman Run. Only residential, homeowner-occupied households were identified to participate in the survey. Nine of the subdivisions were single family detached homes and one subdivision was a townhouse development. A random starting house was selected using GIS software AR-CView3.2a. A total of 10 households were surveyed per subdivision for a sample size of 60 in Glyndon and 40 in Baisman Run.

Composite soil chemistry was based on three to five randomly selected soil cores of equivalent depths ranging from 3 to 6 cm. The soil was dried and processed through a 0.5mm sieve prior to analysis at the University of Maryland Soil Testing Laboratory. Soil carbon, hydrogen and nitrogen (to include organic) were measured using a Leco CHN 2000 Carbon-Hydrogen-Nitrogen Analyzer. The instrument has a detection range of 0.01% to 100% for carbon and nitrogen. A soil corer was used to take samples from the top 5 cm of the soil at three randomly selected sites from the lawn to measure average bulk density. Given the purpose of the study, analyses focused on soil nitrogen as an input to residential watersheds from lawn fertilizer practices. Other BES studies provide more complete analyses of soil quality in urban watersheds (e.g. Pouyat *et al.*, 2002; Pouyat *et al.*, 2004).

An average application rate of N (kg N/ha/yr) was calculated at three spatial scales from the data generated from the household and professional lawn care company surveys, in addition to land use-land cover characteristics within each watershed. The application rate estimated from survey responses on the type and amount of fertilizer product, the frequency of application and lawn area. A commonly used fertilizer formulation (29N-3P-4K) was used to estimate

Table 2. Summary of survey results aggregated to the catchment level. Values in parentheses indicate \pm one standard deviation from the mean watershed annual application rate

	Glyndon	Baisman Run
% Fertilize	68	56
% Self-apply	71	44
% Profession apply	29	56
Kg N/ha/yr	12.5 (10.2–14.4)	9.5 (7.7–11.2) 27.8 (22.6–33.0)
Soil tested (%)	19	13
Water lawn	48	9

the fertilizer N application rate for 56% of the surveys. This estimation method was reasonable as respondents provided information on the frequency and amount of fertilizer used, in addition to the product name, but the specific product type (e.g. N-P-K formulation) was not identified by the survey respondent. The percentage of homeowners who use a lawn care service or fertilize their own lawn within each watershed was used to provide a weighted average application rate. The weighted average application rate multiplied by the lawn area within each watershed provided a total mass or input of nitrogen applied to lawns. The mass of nitrogen, divided by the watershed area (mass per unit watershed area, mpw), residential land use area (mass per unit residential area, mpr) and lawn area (mass per unit lawn area, mpl) provides an application rate of fertilizer at three different spatial representations of watershed land use-land cover characteristics. The mass per unit watershed area, mpw, is a useful measure to develop nutrient mass balances at the watershed scale for ecological and hydrological studies.

The survey information, soil characteristics, and data on the socio-economic characteristics of the subdivisions were used in linear regression analyses to determine the controlling factors that may affect nitrogen input to the watersheds from lawn care practices. The average application rate (Kg N/ha/yr as mpl) for each subdivision was used as the unit of analysis and is based on the individual homeowner application rates. Individual household responses were not used given the unequal number of survey questionnaire responses and soil data for each household. Further, the methods used to estimate the application rates are well constrained by the lawn area, but there may be significant household level errors given the self-reporting method used in the survey.

Results and Discussion

Survey Results of Lawn Management Practices and Soil Analyses

Overall, the survey response rate was high with 68% and 80% of the residents in Glyndon and Baisman Run respectively, for a total sample size of 73 households. A lower percentage of homeowners permitted soil samples to be taken with 28 soil samples taken in Glyndon and 27 in Baisman Run. A summary of survey data is presented in Table 2. The survey found that a majority of homeowners in both watersheds fertilized their lawns with 68% of

the residents in Glyndon applying fertilizer to their lawns and 56% of homeowners in Baisman Run. This is consistent with survey findings by the Center for Watershed Protection (2000) that found approximately 70% of all lawns are regularly fertilized. In Baisman Run, more residents employed a professional lawn care service compared to residents in the Glyndon watershed. The frequency of application by homeowners is typically one or two times a year in spring and/or fall and up to six applications a year for residents that employ a professional lawn care service. However, the greater frequency of applications did not necessarily translate into a higher annual application rate of nitrogen given the different fertilizer products used on a seasonal basis by the professional lawn care companies. Homeowners reported using the same product throughout the year, whereas professional lawn care companies reported using less nitrogen per application during the spring and summer compared to the fall applications.

The average application rate of fertilizer on a lawn area basis reported by professional lawn care companies is higher compared to that calculated for homeowners. However, both are within the range recommended by the Maryland Cooperative Extension Service guidelines. At the scale of individual lawns, the survey of the professional lawn care companies found that the percentage of N in the product varied seasonally and that the average annual application rate ranged from 100.1 to 161.1 kg N/ha/yr of lawn (2.1 to 3.3 lbs N/1000 ft² of lawn). This application rate is based on four to six applications per year. However, some homeowners surveyed only use a professional lawn care service one to three times year, thus reducing the actual annual application rate by professional lawn care companies. The average annual application rate by homeowners who apply their own fertilizer was 106.9 kg N/ha (2.2 lbs N/1000 ft²) with a standard error of 21.8 kg N/ha and a range from 10.5 to 369.7 kg/ha (0.2 to 7.6 lb N/1000 ft²). The higher application rates were associated with the newest development of single family homes and the townhouse development. A large range in application rates was also found in a North Carolina study (Osmond & Platt, 2000). A list of fertilizer application rates reported in the literature is provided in Table 3. The values represented in the Table were used largely for experimental studies and represent an end range in application rates and are not necessarily characteristic of residential lawn care practices.

Differentiation in the application rate of fertilizer between the two watersheds is summarized at three spatial aggregations, reflecting differences in land cover, development type and household behaviour between the two watersheds (Table 4). A higher application rate was estimated within the Glyndon watershed, compared to Baisman Run. At the watershed scale, the difference in the application rate is largely a function of the area of the watershed established by the location of the stream gauge. Hence, the impact of the development in Baisman Run as measured by the gauge is reduced due to mixing with the cleaner water from the forest cover of the lower two-thirds of the catchment and in-stream processes (Law, 2003). If the residential land area is only considered, the application rate for Baisman Run and Glyndon are similar, indicative of an averaging effect between the higher application rate and smaller lawn area in Glyndon and the lower application rate and larger lawn area in Baisman Run. The greatest distinction between application rates is estimated when only the lawn area is considered within each of the watersheds. The application rate in Glyndon increased to 83.5 kg N/ha/yr, mpl compared to 37.1 kg N/ha/yr, mpl

Table 3. Summary of fertilizer application rates in other studies

Reference	Application rate	Comments	Study location
Kelling & Peterson (1975)	49 kg N/ha 298 kg N/ha 225 kg N/ha	Homeowner applied Fall application Considered high/ excessive	9 urban lawns (locations not given)
Flipse <i>et al.</i> (1984)	107 kg N/ha/yr		Long Island, NY
Starr & DeRoo (1980)	180–195 kg N/ha/yr	2 applications per year	Windsor, Connecticut, field plots
Liu <i>et al.</i> (1997)	149 kg N/ha/yr	Moderate application rate divided equally amongst 3 applications per year	Kingston, Rhode Island, field plots
Garn (2002)	146–171 kg N/ha/yr	Assumed residents followed manufacturers recommended rates, 4 applications per year	Lakeshore lawns in Walworth County, Wisconsin
King <i>et al.</i> (2001)	49–540.9 kg N/ha	Range of average <i>reported</i> application rates for roughs, fairways, tees and greens	Golf course in Austin, TX
Morton <i>et al.</i> (1988)	97 kg N/ha/yr	Low	Kingston, Rhode Island, field plots
Miltner <i>et al.</i> (1996)	244 kg N/ha/yr 196 kg N/ha/yr	High 5 applications of 39.2 kg N/ha	Michigan State University, field plots
Erickson <i>et al.</i> (2001)	50 kg N/ha	Moderate application rate	University of Florida, field plots
NCSU Water Quality Group (2000)	29–151 kg N/ha (average) 0–2148 kg N/ha	Based on household survey data	4 North Carolina communities
Petrovic (1990)	24–224 kg N/ha	Based on compilation of application rates in a literature review	
	49 kg N/ha/yr 267 kg N/ha/yr	Prior to 1940 1970s	
CWP (2000)	97.5–195 kg N/ha/yr	Current extension and garden literature recommended rates	

in Baisman Run. At the spatial aggregation of the lawn, the application rate is more likely to be associated with individual homeowner behaviour as residents of Glyndon have, on average, a higher fertilizer application rate compared to residents of Baisman Run.

Significance of Lawn Fertilization to Catchment N budget

Based on the data at the watershed level, Groffman *et al.* (2003) estimated that approximately 53% of the total nitrogen input for the Glyndon watershed is from the application of fertilizers with the remainder from atmospheric deposition. In Baisman Run, additional inputs of nitrogen from estimates of septic

Table 4. Application rate of fertilizers to lawns at three spatial scales

Application rate (kg N/ha/yr) Scale ¹	Glyndon	Baisman Run
Watershed (mpw)	12.5	9.5
Residential land use (mpr)	26.7	27.8
Lawn cover (mpl)	83.5	37.1

Note: ¹The spatial scale is an expression of the aerial aggregation of the watershed area, total residential land-use area within each watershed and total lawn area within each watershed. Each different scale is abbreviated as mass per unit watershed, mass per unit residential land use or mass per unit lawn area as, mpw, mpr, and mpl, respectively.

system effluent load decrease the contribution of nitrogen from fertilizer to approximately 35%. Compared to the measured output in surface water, there is considerable retention and/or loss within the watersheds. The watershed budgets do not consider leakages from sanitary sewer infrastructure in Glyndon and use conservative estimates of the total N septic tank effluent based on data presented by Swann (2001). There were no intentional discharges within each of these watersheds from commercial or industrial practices. Groffman *et al.* (2003) suggest that these budgets are an underestimation of N input and discuss the associated uncertainty of these measurements in greater detail.

Household Irrigation Patterns

Another lawn care practice surveyed was lawn watering. Overall, 32% of the survey respondents watered their lawn. The majority of lawn watering occurred in the Glyndon watershed. Only 13% of the survey participants in Baisman Run watered their lawn. This reflects the fact that Baisman Run residents use private wells for domestic water supply and at the time of the survey, summer water deficits and drought conditions existed. As a consequence, water use for exterior purposes was limited in Baisman Run.

Soil Characteristics and Testing Behaviour

The last part of the survey included soil samples to be taken from the lawn for soil bulk density and chemistry. It was found that the average soil pH of the residential lawn is within an acceptable range for healthy turfgrass as recommended by the Maryland Cooperative Extension Service, although soils in the area are generally slightly acidic (USDA, 1976). The carbon content of the soils is within the low range for the Oxisols soil order, but is generally deficient in soil N (Brady, 1990). A summary of general soil chemistry for the two watersheds is provided in Table 5. Of the survey respondents, 17% had their soil tested to determine the most appropriate N-P-K ratio in a fertilizer to apply to their lawn. This corresponds with data cited by the literature review conducted by the Center for Watershed Protection (2000), where it was found that less than 20% of residents had their soil tested prior to the application of lawn fertilizer. In the

Table 5. Summary of soil properties and chemistry from residential lawns within the study watersheds. The average values for the soil samples are provided with the standard deviation given in parentheses

Watershed	Soil type	Bulk density (g/cm ³)	pH	% Organic matter	% Carbon	% Nitrogen	% Hydrogen
Glyndon Baisman Run	Silt loam	1.3 (.21)	6.8 (0.6)	3.3 (1.0)	1.6 (0.98)	0.03 (0.01)	0.7 (0.09)
	Silt loam	1.2 (0.15)	5.9 (0.54)	4.4 (0.93)	1.7 (0.51)	0.04 (0.01)	0.8 (0.11)

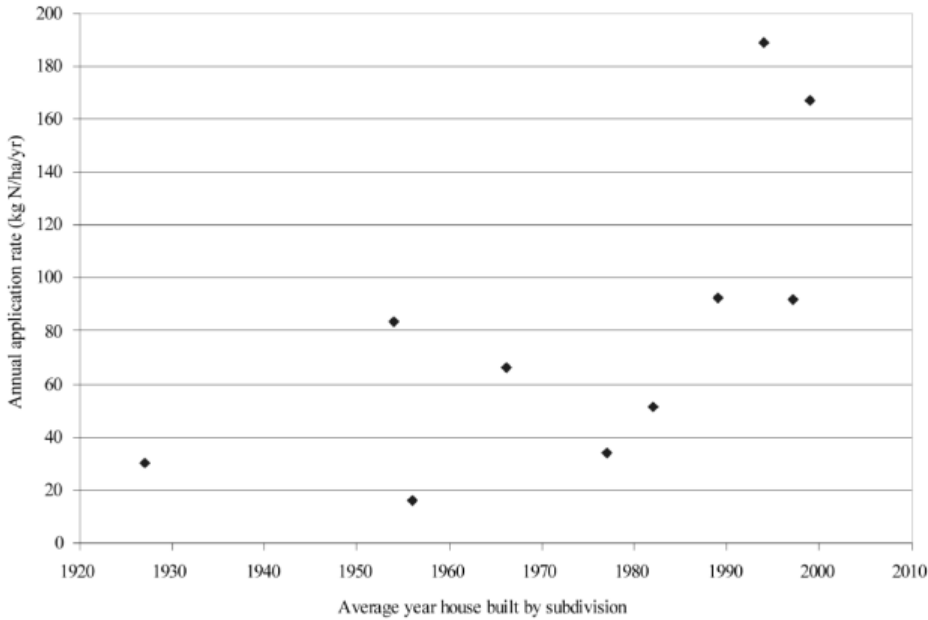


Figure 3. The mean application rate of fertilizer per unit lawn area as a function of median age of house within each subdivision.

household survey, it was found that a greater percentage of residents who use a professional lawn care company had their soil tested. The practice of soil testing is likely to increase with the passage of legislation in Maryland (Code of Maryland Regulations 15.20.06) that requires professional lawn care companies to test the soil for nutrient management purposes every three years.

The Influence of Socio-economic Factors

Statistical analyses found a significant, positive linear relationship between the average application rate of nitrogen by subdivision (kg N/ha/yr, mpl) and the median year the house was built within each subdivision ($r^2 = 0.45$, p -value = 0.04) (Figure 3). The relationship suggested a set of hypotheses regarding a greater application rate for the more recently developed homes, which is a function of:

- higher socio-economic status of the newer homes; the newer homes have a higher market value; or
- more fertilizer is being applied to help establish lawns due to the poor soil quality from recent construction.

It would be expected that a higher application rate of fertilizer, (i.e. consumption of resources) would be associated with higher socio-economic status. A strong correlation existed between the market value of the house and lot size (e.g. $r^2 = 0.75$), but lot size did not significantly explain the variation in the average N fertilizer application rates between subdivisions or the likelihood of homeowners to fertilize their lawn. A mixed-effects relationship emerged between the nitrogen application rate of fertilizer and the market value of the house (Figure

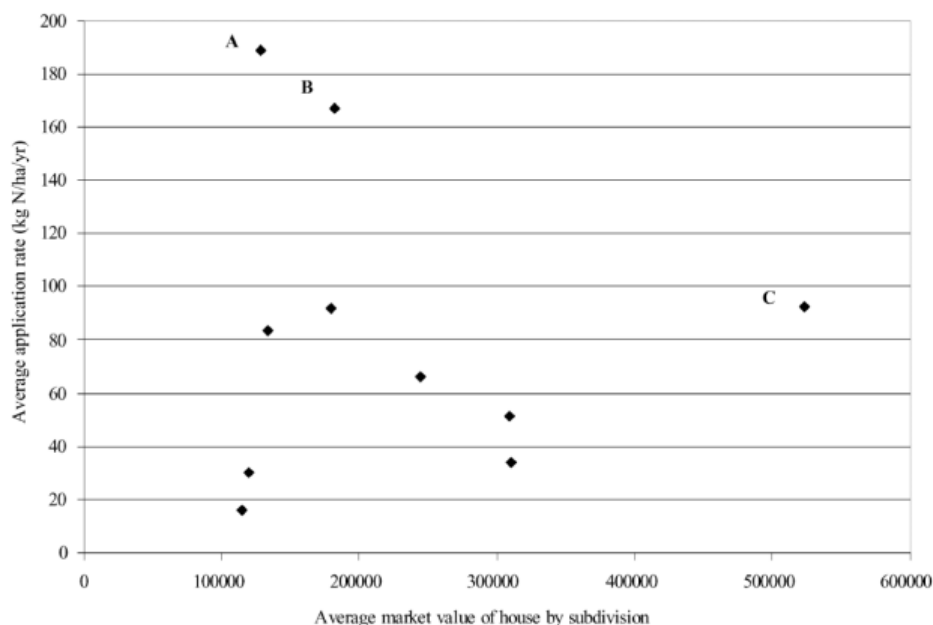


Figure 4. The mean application rate of fertilizer as a function of the average market value of houses within each subdivision. In this plot, point 'A' is a townhouse development while point 'B' represents the newest subdivision.

4). The data suggest that households with intermediate housing values, relative to the survey sample, have the highest application rate of fertilizer N and that there is similar behaviour in lawn management practices, as per fertilizer application, for the end ranges of social-economic households. This is consistent with a trend that emerged from Osmond & Platt (2000), where middle-income level households had the highest application rate of N fertilizer. The points positioned outside the trend in Figure 4 may be explained by the distinct development patterns within these subdivisions. The 'A' subdivision is a townhouse development, unlike the single family detached development in all other subdivisions surveyed and point 'B' is the more recently constructed subdivision. The point 'C' has a disproportionately high percentage of professional lawn care companies that fertilize lawns within this subdivision, relative to other subdivisions in the survey, but may also reflect an upswing in the form of the relationship as suggested in Vogel (1999) (see discussion below). Within this curve, points below and above \$200 000 are representative of the two different catchments (Figure 4). The points on the ascending limb of the curve are the Glyndon subdivisions and the points on the descending limb of the curve are the subdivisions in Baisman Run. Therefore, a misleading interpretation may be taken if data from only one watershed was surveyed.

The form of the relationship in Figure 4 reflects, in part, the properties of a Kuznet curve which is an inverted U-shaped curve that describes the effect of per capita income on environmental quality (Vogel, 1999). This theory states that pollution increases as income rises but reaches a threshold value where pollution levels begin to decline as a threshold income value is exceeded. Although the form of the relationship for the survey data is similar to the environmental

Kuznet curve, the Kuznet curve is typically based on larger spatial scales than households or subdivisions (e.g. countries). The application of such an analysis to smaller, more local scale studies may warrant further research to better understand how social and ecological drivers within the suburban landscape impact ecosystem dynamics at this fine scale. The form of this relationship, taken with the strongly linear relationship of fertilizer application rates and the median house age within each subdivision (Figure 3), suggests that household behaviour for lawn management can be influenced and changed with different socio-economic settings. Lawn management behaviour within American suburban neighbourhoods is strongly influenced by community norms and pressure, reinforced by the desire to gain acceptance within the neighbourhood and desire to reflect a particular status-level (Teyssot, 1999; Robbins *et al.*, 2001). The positive social feedback created by the community behaviour will have implications on the watershed ecology in terms of the inputs and outputs of nutrients and energy on turfgrass (Grove *et al.*, 2003). These analyses, therefore do not support Hypothesis I, that fertilizer application increases with higher socio-economic status.

The Influence of Physical and Ecological Factors

The physical and chemical properties of the soil influence the quality of the turfgrass as the soil environment will partly control the moisture and nutrient availability for the grass. A difference of means test (*t*-test) indicated a significant difference in soil bulk densities between the two watersheds (*p*-value = < 0.01) with Glyndon having higher bulk densities compared to Baisman Run (Table 5). More recently developed subdivisions have higher bulk densities compared to the older, more established lawns (Figure 5). Additional correlation analyses as summarized in Table 3, further support Hypothesis II that the more recently developed subdivisions have poorer soil quality. For example, there is a negative relationship between the 'year built' variable with 'percent soil carbon' and 'percent soil nitrogen' that indicates more recently developed homes have lower soil N and C content compared to older development sampled.

The higher bulk densities in the more recently developed properties are attributed to the more compacted nature of the soil from recent construction traffic and fill material as suggested by Hamilton & Waddington (1999). Some of the compaction may also be attributed to lawn care practices by pedestrian and machine traffic (Kelling & Peterson, 1975). The survey data found a significant, positive relationship between bulk density and the average annual fertilizer application rate by homeowners within the subdivisions ($r^2 = 0.75$, *p*-value = 0.001).

The compacted nature of the soil in the more recently developed properties may reduce the leachate potential of nitrate-N into the soil profile and shallow groundwater, but may increase the run-off potential from the lawn. Higher bulk densities associated with the more recently developed lots is consistent with Legg *et al.* (1996), who used age of lawn, or years since development of lawn, as a surrogate for many soil properties in a study of run-off from residential lawns. Soil structure and macropores develop as a lawn age and the accumulation of organic matter and bioturbation as fauna develop decreases the bulk density of the soil and increases infiltration rates. Further, the more recently developed homes with higher bulk density from recent construction activity and fill

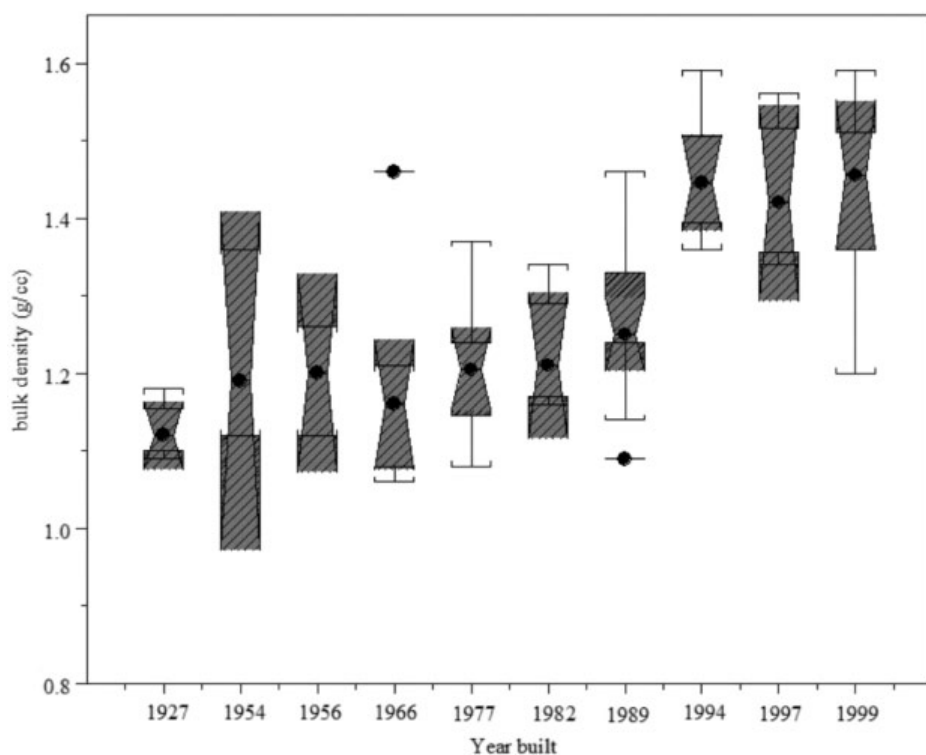


Figure 5. Average soil bulk density (g/cm^3) by the median age of house within each subdivision for the Baisman Run and Glyndon watersheds.

material apply greater amounts of fertilizer. Based on experiments by Legg *et al.* (1996), it would be expected that the run-off potential would be greater for the newly developed lawns with higher bulk density. The covariation in soil hydraulic properties such as lower infiltration rates for higher bulk density soils with higher fertilizer application rates could generate higher concentrations of nitrate and phosphate in storm run-off compared to the more established lawns.

Fertilizer application rates are correlated with soil N (p -value = 0.08, $r^2 = 0.33$) (Figure 6) and it was found that soil with higher N content had lower application rates than soil with lower N content. The soils with the lower soil N and soil C content are also associated with the more recently developed subdivisions (see Table 6). The relationship between the application rate of fertilizer and soil N content can be explained by the 'smart farmer hypothesis' as higher soil N content would promote healthier turfgrass. Given that few homeowners had their soil tested, it is suggested that homeowners are relying more upon qualitative or visual assessments of their lawn to determine the amount, or if any fertilizer is applied. Turfgrass with a sufficient nitrogen pool for shoot growth will appear healthier than lawns with lower soil N content. The higher soil carbon content in the lawns surveyed, with the greater soil N content ($r^2 = 0.86$) is supportive of the fact that soil quality may affect the amount of fertilizer that is applied to residential lawns. Further, Petrovic (1990) illustrated that total N in the surface soil layer (0–10cm) increases with the age of the turfgrass and asymptotes at 20 years and that the greatest change in soil N

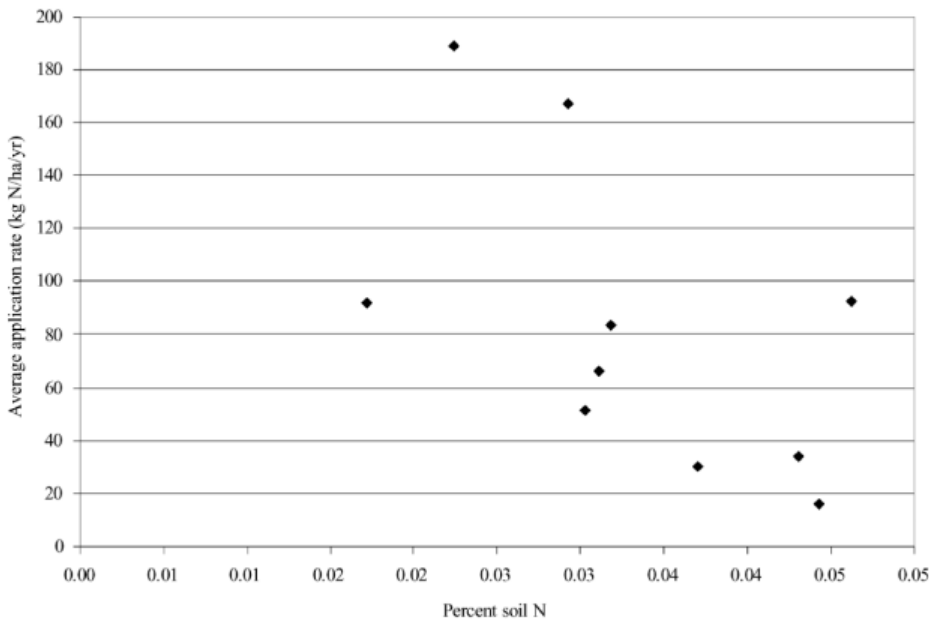


Figure 6. Fertilizer application rate as a function soil N content.

Table 6. Correlation coefficients between subdivision age and tax value, with soil characteristics averaged for the Glyndon and Baisman Run watersheds

	Year built	Market value
Soil bulk density	0.83	− 0.1
Percent organic matter	− 0.23	0.62
pH	0.28	− 0.64
Percent soil carbon	− 0.59	0.02
Percent soil nitrogen	− 0.41	0.45

occurs within the first 10 years of turfgrass establishment. The age of development within the subdivisions with the lower soil N content and higher application rates of fertilizer were less than 10 years old at the time of this survey. The health of the lawn is also contingent upon other factors, such as soil moisture or disease stress. Thus, an incorrect assessment of the factors leading to the unhealthy appearance of turfgrass may lead to inappropriate decisions on lawn care management practices. Therefore, the analyses do support Hypothesis II, that more fertilizer is being applied to lawns due to poor soil quality from recent construction.

Conclusions

The residential lawn care survey is one of a few studies that attempted to determine the input of nitrogen from fertilizers within an urban watershed. It was found that approximately 53% of the total nitrogen budget in Glyndon is

from lawn fertilization. Although the input of fertilizer N accounted for a large component of N input to the watershed, survey results found that the application rates of fertilizer to individual lawns are comparable to findings in other studies and recommendations by the Maryland Cooperative Extension Service on lawn care (e.g. 97.7–195.3 kg N/ha of lawn or 2–4 lbs of N per 1000 ft²), depending upon grass species. However, the spatial scale at which the application rates are estimated can yield large variation in the results. Given varying spatial representations of land use-land cover within the watershed, a distinction between the two watersheds emerged.

Within a single land use type, residential, the watershed-based survey indicated that there is a spatial and temporal pattern to nitrogen input from residential lawn care practices that is influenced by socio-economic and soil characteristics. The application rate of fertilizer varied spatially, by subdivision where greater rates of application were associated with the age and type of development. The temporal distribution of fertilizer input, however, was similar across subdivisions that generally occurred in the spring and fall but varied in the frequency of applications. The form of the relationships and statistical significance suggested that a subdivision's socio-economic status will influence the input of N fertilizer to residential lawns, in a non-monotonic function, rather than linear, as initially hypothesized. A higher application rate of fertilizer is not linearly associated with higher socio-economic status. A more linear relationship was found to exist, however, between variables indicative of soil quality and fertilizer N application rates, where more fertilizer was being applied to lawns with poorer soil quality.

The potential consequence of the variable management practices within the same residential land use type is the generation of hot spots for nutrient run-off. Based on the statistical analyses, it is suggested that sites with the greatest potential for nitrate export in run-off are properties trying to establish a healthy green lawn within suburban watersheds (i.e. recent development). To minimize this impact, soil testing of lawns may need to go beyond soil chemistry and include physical characteristics such as bulk density or other measures or indices that indicate the run-off potential from lawns.

Future applications and extensions of the household survey will be used to explore how behavioural patterns affect nutrient input to watersheds from fertilizer use. This information would be used to further define the potential feedback system that was suggested by the initial study where a change in fertilizer practices may result given a change in socio-economic setting. For example, data are needed on a wider distribution of development types and socio-economic characteristics. More detailed information on social demographic characteristics (e.g. income) and attitudes/perceptions of lawn care management would provide greater insight toward behavioural patterns associated with fertilizer N input within urban watersheds. Additional survey questions would address the attitude of homeowners towards the importance of the characteristics of neighbours' lawns, the perceived impact the quality of lawn has on property value, and environmental impact of fertilizer on water quality. Future work will also include the use of a hydro-ecological simulation model to determine the impact that lawn fertilization has on nitrogen cycling and output within urban, residential watersheds. Model simulations will be used to explore how a change in the amount of fertilizer applied, when and where it is applied within the watershed affects surface water quality. A coupled understanding of

the sources of nitrogen and the hydrologic flowpaths within residential watersheds would provide an improved understanding of non-point source pollution dynamics and lead to more focused efforts to reduce its impact on water quality.

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