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# Disproportionality as a Framework to Target Pollution Reduction from Urban Landscapes

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## Abstract

New federal water quality regulations regarding impaired waters and urban stormwater, alongside a growing need to reverse eutrophication of urban lakes, are creating demand to decrease nutrient export from urban landscapes, particularly lawns. We propose that Nowak et al.'s (2006) disproportionality framework could be used to target specific households likely to generate disproportionate levels of nutrient export. The biophysical dimension would be based on landscape vulnerability (slope, soil type, proximity to lakes); the social dimension would target "inappropriate" lawn management behaviors leading to high nutrient export on these vulnerable landscapes. Understanding of lawn nutrient cycling (biophysical dimension) and homeowner beliefs and attitudes (social dimension) would be used to develop targeted, specific messages for homeowners practicing inappropriate management. A lawn management program developed with this disproportionality framework would probably be very effective, highly economical and fair, targeting only homeowners who are creating a disproportionate impact.

## Keywords

Lawn; turf; disproportionality; hydrologic model; TMDL; MS4; urban stormwater; phosphorus; nitrogen; specificity; Theory of Planned Behavior; Theory of Reasoned Action.

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## INTRODUCTION

In urban watersheds with a high percentage of residential land, nutrient export from urban lawns can pollute lakes and streams. Runoff from experimental turf plots and functional lawns typically contains 0.5-2.0 mg P/L and 3-5 mg N/L (Barten and Jahnke 1997; Waschbusch et al. 1999; Easton and Petrovic 2004; Shuman 2004). These levels are sufficient to cause eutrophication of lakes receiving large inputs of lawn runoff.

Two major federal regulatory drivers, both outgrowths of the Clean Water Act, have fueled recent interest in the quality of urban landscape runoff. The US Environmental Protection Agency's (EPA) Total Maximum Daily Loads (TMDL) Program has compelled states to identify impaired waters, develop "total maximum daily load" (TMDL) plans to eliminate impairments, and implement these plans (US Environmental Protection Agency 2008a). The program is in a fairly early stage. In Minnesota, for example, more than 800 waters have been identified as "impaired," but only 15 TMDL plans have been written and only two waters have been "de-listed" as the result of successful implementation of these plans. The second federal program is Phase II of the Municipal Separate Storm Sewer Systems (MS4) Program, which requires municipalities to obtain National Permit Discharge Elimination System (NPDES) permits for storm sewer discharges (US Environmental Protection Agency 2008b).

In addition to federal mandates, there are compelling local needs to reduce eutrophication. Many urban water utilities store source water in local lakes or reservoirs that were once on the fringe of the urban area but are now surrounded by residential development. Even as early as the 1990s, residential land was the dominant land use in 64% of the nation's water supply reservoirs (Robbins et al. 1991). Nutrients from urban stormwater often impair municipal water supplies by causing algae-induced taste and odor problems. More than half (52%) of respondents in a national (U.S.) survey were concerned with the "smell or taste" of their drinking water (WQA 2001). High algae abundance associated with eutrophication increases the cost of treating municipal water by increasing the need for coagulation chemicals, increasing chlorine demand, shortening filter runs (hence raising energy costs for filter backwashing), and increasing sludge disposal costs. Eutrophication also impairs recreational use of urban lakes and significantly reduces property values of shoreline homes (e.g., Steinnes 1992).

To date, the main thrust of urban stormwater programs has been construction of structural "best management practices" (BMPs), such as detention ponds, constructed wetlands, and infiltration basins. Some problems with structural BMPs include high capital costs, high operations and maintenance costs, low and variable performance, and accumulation of non-degradable pollutants (Baker 2007). Though a useful part of a multiple barrier approach, it is unlikely that structural BMPs alone will be sufficient to achieve urban water quality goals. Meeting these goals will require greater emphasis on source reduction (pollution prevention). Early research (Linde and Watscke 1997; Easton and Petrovic 2004; Shuman 2004) indicates that source reduction via improved lawn management could reduce both the volume of runoff from lawns and the export of nutrients to streets and storm sewers. However, accomplishing this would require better understanding of both biophysical processes of lawns and human behaviors involved in lawn management. One daunting task for implementing source reduction from residential lawns is that it would be difficult to alter lawn management practices of all homeowners. One way to make the task tractable is to develop an approach for targeting problem lawns. The goal of this paper is to explore a conceptual framework – the disproportionality hypothesis (Nowak et al. 2006) – as a tool for targeting the intersection of vulnerable landscapes and inappropriate behaviors. The working hypothesis for this paper is that a small fraction of lawns contribute disproportional nutrient loads to storm water. If this is true, source reduction could be accomplished by changing behaviors of a small percentage of homeowners, not the entire population. In context of the proposed conceptual framework, we also propose a research strategy to test the hypothesis that a targeted lawn management program based on the disproportionality concept would be effective at reducing nutrient export from lawns.

## DISPROPORTIONALITY FRAMEWORK

We propose that effective, economical nutrient reduction strategies for urban landscapes could be developed with the disproportionality framework proposed by Nowak et al. (2006). Nowak et al. argued that nonpoint source (NPS) pollution is a function of both the biophysical characteristics of the landscape and human behaviors, both of which exhibit skewed distributions (Figure 1). In the biophysical dimension (y-axis in Figure 1), it is well known that small parts of the landscape contribute disproportionate runoff, sediment, and phosphorus (Schrieber et al. 2001; Benik et al. 2003). Environmental behaviors (x-axis in Figure 1) also exhibit skewed distributions. Some examples of skewed consumption and pollution generation include indoor water consumption (Mayer et al. 1999), household carbon and nitrogen fluxes (Baker et al. 2007), automobile emissions (Calvert et al. 1993), and farm fertilizer applications (Birr 2005).

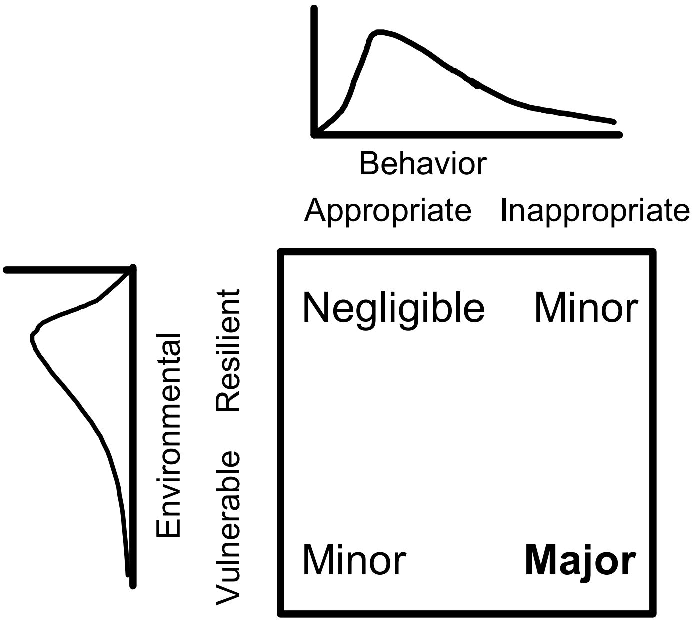

**Figure 1**. Schematic of the disproportionality framework , modified from Nowak et al. (2006). The x-axis represents environmental site vulnerability (factors such as slope and soil type) and the y-axis represents behavioral characteristics (e.g., lawn management practices). Major problems arise when inappropriate behaviors occur on vulnerable sites (the lower right quadrant).

## BIOPHYSICAL DIMENSION OF LAWNS

The y-axis of Figure 1 represents the environmental (biophysical) dimension in the Nowak et al. (2006) schema. Relevant biophysical features of residential landscapes that affect lawn nutrient export are hydrology and nutrient cycling. To date, no one has developed an ecological process model of lawns that can be used to model nutrient export as a function of lawn management practices on fine temporal scales. The next sections consider the hydrologic and nutrient cycling aspects of such a lawn model.

### Hydrology

We start with the landscape hydrology, which determines, in part, how much P and N available for export at a given moment, would be actually exported, either by runoff or leaching. Runoff depth for a given storm is the difference between the precipitation depth and losses by leaf interception and storage, surface depressional storage, and infiltration. Losses by leaf interception and storage in grasses are negligible (Branson et al. 1981). Surface depressional storage is the depth of water necessary to fill the small natural depressions that exist on lawns. Water trapped in these depressions typically infiltrates or evaporates after the precipitation event. Dominant lawn parameters influencing surface depressional storage are surface roughness and land slope (Onstad 1984). Infiltration is the process by which water moves into the soil. It is a complex process that is a function of soil characteristics (e.g., soil texture and compaction), biological factors (e.g., plant roots and worm holes), and antecedent conditions (Haan et al. 1994). The latter is represented by soil moisture at the start of a rainfall (or irrigation) event. The combined losses by leaf storage, surface depressional storage, and infiltration are frequently referred to as rainfall abstractions (Haan et al. 1994). These concepts can be represented mathematically as

$$Z = P - (DS + VI + F_1) - F_2 \approx P - I_a - F_2 \qquad \text{for } P > I_a \tag{1}$$

where Z is the runoff depth, P is the precipitation depth, VI is the vegetative interception depth, DS is the surface depressional storage depth, $F_1$ is the initial infiltration depth prior to the start of runoff, $F_2$ is the infiltration depth after the start of runoff, and $I_a = DS+VI+F_1$ is the depth of all abstractions prior to the start of runoff and is frequently called the initial abstraction. Vegetative interception and surface depressional storage are considered only as initial abstractions in the right-hand side term of equation 1. Equation 1 is only valid when the precipitation depth exceeds the initial abstractions. If the precipitation depth is less than the initial abstraction, the runoff depth is zero.

Disproportionality is illustrated here using a relatively simple runoff model for lawns developed for this study. The foundation of the model is the Curve Number (CN) method (Mockus 1964; Haan et al. 1994). This method is widely used to predict runoff from urban watersheds. After the start of runoff, the CN method assumes that the ratio of runoff depth to its maximum value is proportional to the ratio of the abstraction depth to its maximum value. Mathematically, this assumption can be written, using the terms in equation 1, as

$$\frac{Z}{P - I_a} = \frac{F_2}{S} \qquad \text{for } P > I_a \tag{2}$$

where S is the maximum abstraction depth. It is a landscape parameter that is related mathematically to a curve number index. Tables are widely used to estimate S as a function of soil type, land use, and soil wetness (antecedent moisture conditions), but not as a function of slope steepness. By combining equation 2 with equation 1, the runoff depth is obtained with the CN method as

$$Z = \frac{(P - I_a)^2}{P - I_a + S} \qquad \text{for } P > I_a \tag{3}$$

For a given rainfall event, P is known, and for a given landscape condition, S is known from table values. The only remaining unknown parameter in equation 2 is the initial abstraction. Standard application of the CN method estimates this parameter as $I_a = (0.2)S$, where S is the maximum abstraction depth of equation 2. Surface depressional storage is an important component of $I_{a,}$ and this storage depth is physically dependent on slope steepness. Since the estimate of S is independent of slope, the standard approach is too crude for our purpose, and an alternative approach for estimating $I_a$ is used in our study.

Our model predicts surface depressional storage depth as a function of random roughness and land slope using Onstad's (1984) relationship that is shown below.

$$DS = 0.112\, R_r + 0.031\, R_r^2 - 0.012\, R_r S_o \tag{4}$$

where DS is the surface depressional storage depth (cm), $R_r$ is the random roughness (cm) and $S_o$ is the land slope in percent.

Typical surface depressional storage depth for lawns is 0.5 cm (Haan et al., 1994). The random roughness of lawns is estimated by rearranging equation 4 to solve directly for $R_r$ using an $S_d$ of 0.5 cm and a slope of 2%. The depressional storage for other slopes is then estimated from equation 4 using this value for lawn random roughness. The other components of initial abstractions (i.e., VI and $F_1$ of equation 1) are assumed to be independent of slope. They are estimated using $(VI+F_1) = (0.2)S - DS$, where DS is determined from equation 4 and where the standard initial abstraction depth is used in the calculation.

Model predictions are shown (Table 1) for eight different types of lawns having four soil textures (sandy to clayey) and two different slopes (mild, 2% and steep, 8%) for each texture. The four groups correspond to hydrologic soil groups A, B, C and D of the original CN method (Haan et al. 1994). Grasses for all lawns are assumed to be in good condition. Antecedent moisture conditions are taken as those values typically used in hydrologic design. All results are for rainfall events of 3.8 cm (1.5 inches).

**Table 1.** Effects of soil and land slope on runoff and abstraction.

| Lawn Type | Hydrologic Soil Group | Slope | Runoff cm | Abstraction cm | Percent Runoff | Percent Abstraction |
|---|---|---|---|---|---|---|
| 1 | A (Sand) | Mild | 0 | 3.8 | 0 | 100 |
| 2 | A (Sand) | Steep | 0 | 3.8 | 0 | 100 |
| 3 | B (Fine to Sand) | Mild | 0.03 | 3.8 | 0.5 | 99.5 |
| 4 | B (Fine to Sand) | Steep | 0.03 | 3.8 | 0.9 | 99.1 |
| 5 | C (Clay to Fine) | Mild | 0.38 | 3.4 | 9.8 | 90.2 |
| 6 | C (Clay to Fine | Steep | 0.46 | 3.4 ) | 11.7 | 88.3 |
| 7 | D (Clay) | Mild | 0.74 | 3.1 | 19.0 | 81.0 |
| 8 | D (Clay) | Steep | 0.84 | 3.0 | 21.8 | 78.2 |

As shown by Table 1, differences in soil groups can have substantial impact on the runoff depths. No precipitation became runoff on lawns with sandy soils. In contrast, approximately 19- 22% of the precipitation became runoff on lawns with clayey soils. Soil texture had a greater influence on the percentage runoff than slope texture (Table 1). For example, for soil groups C and D, 3% more of precipitation became runoff on the steep slopes compared with the mild slope. A steeper slope also has more energy to transport contaminants. A slight increase in runoff may correspond to a greater increase in the loading of contaminants for these slopes. Results from Table 1 suggest that efforts to reduce surface runoff should target lawns with finer textured soils (groups C and D), particularly those on steep slopes. Conversely, changing management practices on lawns with Group A and B soils would likely have little impact on runoff.

## Nutrient cycles

The P cycle of lawns (Figure 2) can be used to infer where changes in lawn management might have greatest effect. The percentage of P lost by runoff or leaching immediately after application of P fertilizer is relatively small, on the order of 10-15% without watering-in and <5% with watering-in (Shuman 2004). In a worst-case scenario, in which P fertilizer was applied to saturated soils, 25% of the applied P was lost by runoff or leaching (Linde and Watschke 1997). Phosphorus loss can occur after fertilizer P is assimilated by turf or adsorbed to soil. Cutting grass results in instant mortality of the cut blades. If mowed grass is left in place or mulched, it decomposes. Depending on the stage of decomposition at the time of the next rain event, P can be exported as particulate P (pieces of partially decomposed grass or soil particles), soluble organic P, or inorganic P.

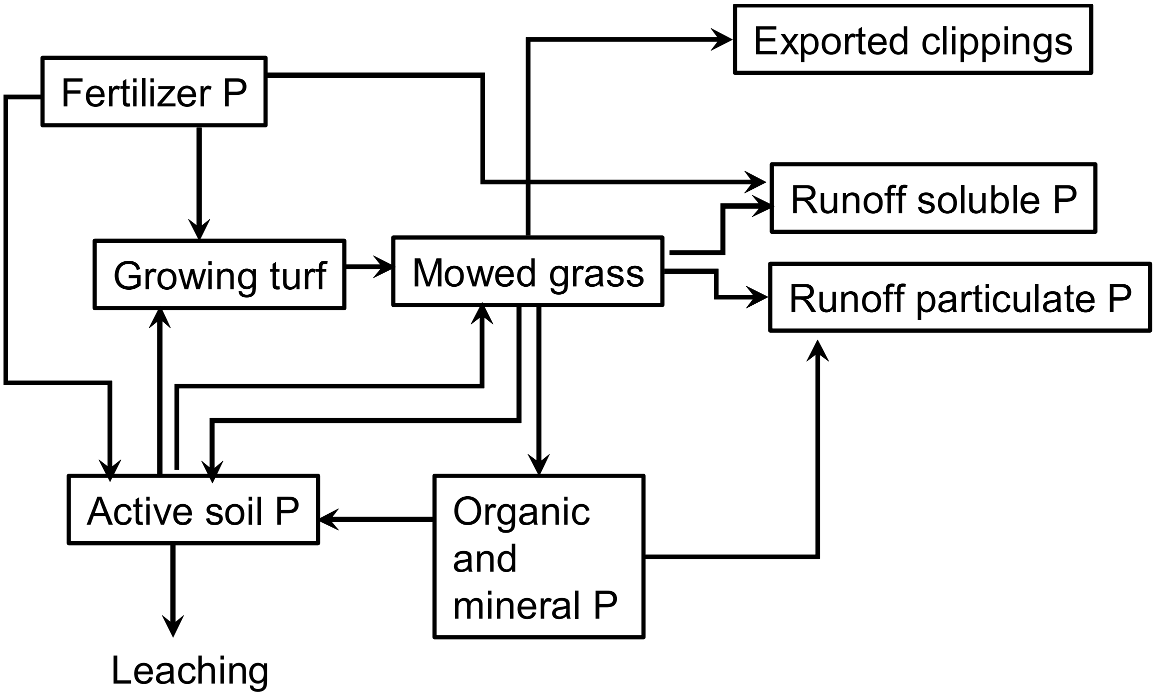

**Figure 2**. The turf P cycle.

If soil adsorption sites are not saturated, much of the orthophosphate that infiltrates downward will be adsorbed by soils. With continued P inputs, soils with high percolation rates and low P adsorption capacity, P leaching through the root zone would eventually occur. Adsorbed P (measured as "Bray" or "Olsen" P, depending upon soil pH) is a small percentage of the total soil P pool, but is readily available for plant uptake (hence is often called "available" P). Plant growth increases as adsorbed P increases from 0 to a point at which growth saturation occurs. This value is probably ~ 25 mg/kg soil test P (Hull and Martin 2004), though the exact level has not been well documented for cool-season lawn grasses. Residential lawns may have much higher soil P levels, often > 100 mg/kg, the result of years of P fertilizer applications without soil testing to determine need (Rosen and Horgan 2005; Barten and Johnson, unpublished data). Crops, and presumably lawn grass, can "mine" P for many years following cessation of P fertilizer inputs (Randall et al. 1997). The rate of depletion of available soil P after cessation would depend, in part, on lawn management. Depletion would occur faster if clippings are exported than if they are mulched, because recycling would be reduced. For lawns with high initial available P, there probably would be no noticeable decrease in turf quality for many years, and a gradual reduction of P exported in runoff. Eventually, the available P pool would become depleted, and turf quality would deteriorate. At this point, soil erosion and total P in runoff would then increase, dominated by particulate P.

Our consideration of lawn P cycling can be used to infer several potential "inappropriate" (sensu Nowak et al. 2006) behaviors that would contribute to high P export from lawns. A homeowner who applied high rates of P fertilizer and mulched clippings would contribute to high P export in runoff in three ways: (1) after a fertilizer application, there would be some wash-off; (2) mulched clippings would decompose in place, releasing P that is available for transport; and (3) over time, soil P adsorption sites would become saturated, increasing the potential P export by runoff and leaching. This behavior may not cause high P export via runoff on a flat lawn with sandy soils because runoff would be low, but on a steep slope with fine-textured soils, this type of management would be inappropriate. In this biophysical setting, an appropriate behavior would be to use soil P tests to determine P application rates, time fertilizer applications to avoid rain events, and remove clippings. Another inappropriate behavior for the same biophysical setting would be never adding P fertilizer, which would lead to eventual depletion of soil P to the point that turf quality is impaired, leading to increased erosion and export of particulate P.

Consideration of the N cycle of lawns (Figure 3) also leads to insights regarding inappropriate behaviors. As with P, N is released during decomposition from mulched cuttings. During decomposition, most N is initially in the form of dissolved organic N (DON), which quickly mineralizes to ammonium ($NH_4^+$) and then oxidized to nitrate ($NO_3^-$). The fate of N depends upon the age of the lawn, N fertilizer inputs, and clippings management. Young lawns tend to accumulate soil organic N (SON) until they reach equilibrium after several decades (Porter et al. 1980). Nitrate leaching also varies. In short term turf experiments, Easton and Petrovic (2004) reported that about 10% of fertilizer N was lost via $NO_3$-N leaching. Others have found concentrations from 0 to 30 mg $NO_3$-N $L^{-1}$ in leacheate from turf grass, depending on age of turf grass site, fertilizer inputs, N source, soil type, and rainfall/irrigation following fertilizer application (Petrovic 1990; Miltner et al. 1996; Guillard and Kopp 2004; Frank et al. 2006). Several studies conclude that high rates of N fertilizer application (>150 kg/ha) on mature lawns can result in high nitrate leaching rates (Frank et al. 2006; Qian et al. 2006). Finally, denitrification in soils releases NO, $N_2O$ and $N_2$. High soil temperatures, adequate supply of $NO_3$ and rainfall/irrigation can create anaerobic microsites resulting in denitrification. Under a worst case scenario (saturated soil, fertilizer applied at 49 kg $NO_3$-N $ha^{-1}$ with high soil temperatures), 15% of applied fertilizer N was denitrified as $N_2$ and 5.6% as $N_2O$ (Horgan et al. 2002).

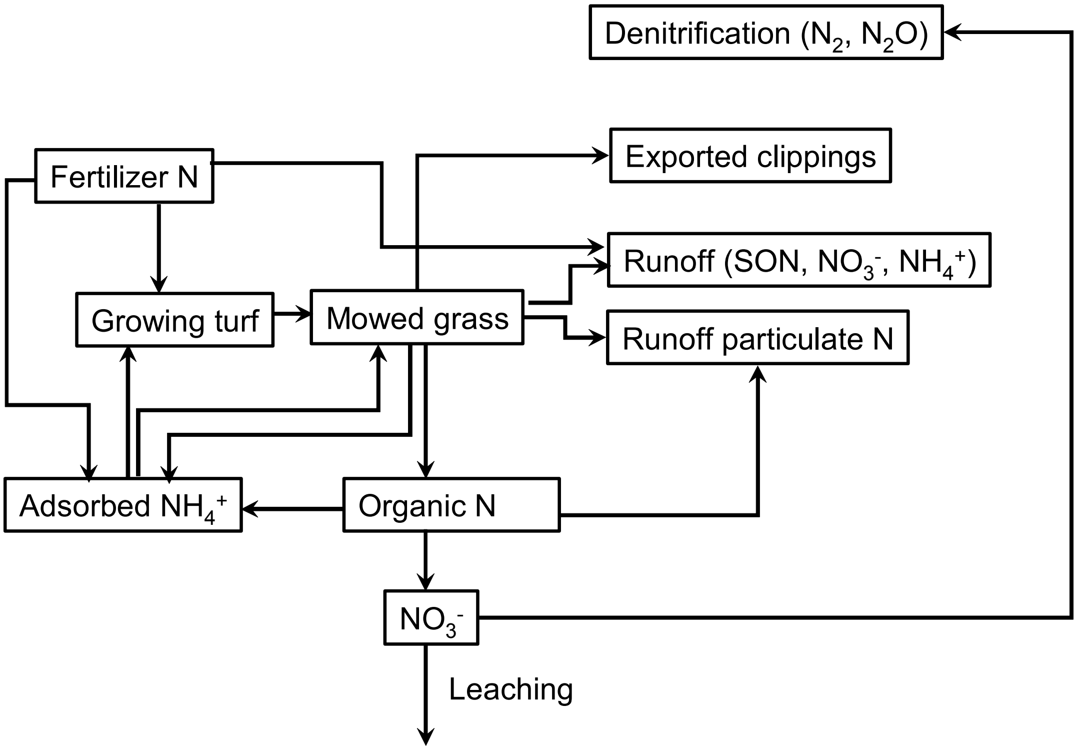

**Figure 3**. Turf N cycle

As is the case for P in runoff, an inappropriate behavior would be high N fertilization rate for a lawn on steep slopes with low soil infiltration rates. Because $NO_3^-$ is highly mobile, another inappropriate behavior would be high N fertilization on coarse-textured soils, especially when the groundwater table is very near the surface. On the other hand, N fertilization rates to support high primary productivity would be an appropriate environmental behavior for turf on flat terrain with thick loam soils. High N fertilization rates, in conjunction with clippings removal, might also be used to accelerate mining of available soil P following reduction or cessation of P fertilization.

## BEHAVIORAL DIMENSION OF LAWN MANAGEMENT

### Theoretical framework

So far, we have addressed only the biophysical aspect of disproportionality (the y-axis in Figure 1), treating management practices as controlled variables that can be switched on or off (e.g., mulching vs. removing clippings). Clearly, the real promise of disproportionality as a management framework is integrating the social dimensions (x-axis in Figure 1) with the biophysical dimensions to more effectively influence the human behaviors that have a large impact on biophysical systems (Nowak et al. 2006). The key social aspect of disproportionality is that there are specific "inappropriate" behaviors occurring within a specific, relatively small portion of the human population. Given this focus, what is the most effective approach for implementing management strategies that attend to disproportionality? We suggest an approach that is focused on altering the attitudes and behaviors of specific individuals based on social psychological theories of values, attitudes, beliefs, norms, and behavioral intention (Geller 2002; Vining and Ebreo 2002). Such an approach would integrate values-based models of environmental behavior (Fulton, et al.1996; Stern et al. 1999; Dunlap et al. 2000; Stern 2000) with the theories of reasoned action and planned behavior (Ajzen and Fishbein 2005) as well as a concerted focus on behavioral complexity (Jaccard and Blanton, 2005).

The Theories of Reasoned Action and Planned Behavior represent an enduring and well-studied theoretical basis for assessing the determinants of attitudes and behaviors (Ajzen and Fishbein 2005; Fishbein and Manfredo 1992). Generally, these theories are viewed as useful when analyzing behavior that is based on a thoughtful process of considering the personal costs and benefits of engaging in that behavior. Active management of lawns is arguably such a behavior. A key tenet of these theories is the concept of *specificity* (Fishbein and Manfredo 1992; Ajzen and Fishbein 2005). To successfully predict, and perhaps alter, human behavior rooted in values, attitudes, norms, and beliefs, requires attention to the specificity of an action directed at a target, within a specific context at a certain time. An example of this specificity is the decision to apply or not apply a high P fertilizer (action) to your lawn (target) in an area with steep slopes (context) the day before large summer thunderstorms are forecasted to occur (time). The disproportionality framework identifies an additional level of specificity that should be considered if we are interested in the biophysical outcomes of human behaviors. It asks the questions: Who are the specific actors whose specific behaviors matter? That is, whose behaviors will result in large negative or positive impacts to the biophysical system?

As noted by Nowak et al. (2006) many past programs have failed at producing meaningful behavioral change at an aggregate level because the programs failed to recognize the disproportionality of human behaviors affecting biophysical conditions. We argue that management programs designed with theoretical direction from the social psychology of values, attitudes, norms, and behaviors that attend to both the specificity (target, action, context time) of behaviors and of human actors will be much more effective than programs directed at a larger audience encouraging changes in behaviors that are also not well-specified. Just as health professionals can improve the success of behavioral modification programs by targeting specific behavioral changes in the specific clients whose family histories demonstrate they are most susceptible to specific diseases (e.g., heart disease or diabetes), we predict that resource managers could improve the effectiveness of intervention programs by targeting those homeowners whose behaviors occur on “risky” sites that will likely lead to the most severe impacts to the biophysical system.

## RESEARCH TO DEVELOP A DISPROPORTIONALITY MANAGEMENT FRAMEWORK

### Biophysical component (y-axis of Figure 1)

Most studies to examine the impact of turf management on nutrient runoff or leaching have been conducted in controlled experiments over a narrow range of conditions. The alternative, direct measurements on “real” lawns are problematic and therefore infrequent. We know of only one study that compared soil fertility and fertilization practice with runoff nutrient concentrations for functional, private lawns (Barten and Jahnke 1997). One seemingly insurmountable difficulty in developing predictive relationships between homeowner fertilization rates and runoff nutrient export is that problem of measuring actual fertilization rates (most studies inquire about the number of applications and assume a fixed rate of fertilizer applied per event). Few homeowners would allow researchers to establish and maintain runoff or infiltration experiments in their yards, especially for multi-year studies. Even if they did, researchers would be confronted with the observation effect – homeowners altering their behaviors because they are being observed.

We suggest that the most practical approach to understanding nutrient export from lawns would be to link small-scale hydrologic modeling with an ecological model. As discussed above, small-scale hydrologic modeling – at the scale necessary to guide lawn management practices -- is fairly advanced, and such models can be calibrated across a range of conditions with relative ease. Developing, calibrating and verifying a turf ecological model could be done using long-term data from experimental turf plots designed to approximate functional lawns (for example, using realistic grass species, fertilization rates, and clippings management). It would then be a relatively small step to incorporate the ecological model into the hydrologic model.

A final step in model development would be verification of model predictions on functional turf. This would best be done in an institutional setting – for example, on several patches of the extensive turf maintained by most universities.

It would not be practical to run a complex runoff model for large numbers of individual lawns. Instead, the model would be used to run multiple *scenarios* across a range of conditions typical of individual lawns in a region. Model outputs would then be aggregated into simpler formats for practical use. For example, staff from local watershed districts and other agencies might utilize tables or nomographs to represent nutrient export in runoff across a range of biophysical conditions and lawn management behaviors to estimate total lawn nutrient export for a given lawn. This approach might be useful to estimate load reductions attributable to improved lawn management, information needed for effective implementation of TMDL and MS4 programs.

### Behavioral research component (x-axis of Figure 1)

As discussed above, management recommendations also need to be based on a thorough understanding of underlying attitudes and beliefs that homeowners hold concerning the outcomes of engaging in specific (i.e., action, target, context, and time) lawn management behavior. These attitudes and beliefs can be studied using social surveys designed explicitly to understand attitudes toward lawn management using the theoretical framework described above. What is important for developing tailored messages regarding lawn behavior are not the “average” behaviors or the “average” actors, but typologies of behaviors that are at real risk of causing environmental damage on vulnerable landscapes. This understanding would be used to tailor messages that reflect not only what is appropriate behavior for a specific biophysical setting, but also for specific typologies of homeowners, each of which may respond to entirely different motivations.

## Practical application

Current outreach and education programs to reduce lawn nutrient pollution typically do not clearly target specific behaviors or specific homeowners and, for that reason, are unlikely to be effective at reasonable cost. This type of program would be represented by the outer "regional" ring in Figure 4. We hypothesize that the disproportionality concept can be used to target outreach and education addressing specifically defined behaviors to a very small percentage of homeowners – those with inappropriate behaviors living in vulnerable landscapes (the lower right quadrant in Figure 1) – whose specific behaviors with their lawns actually impair surface waters.

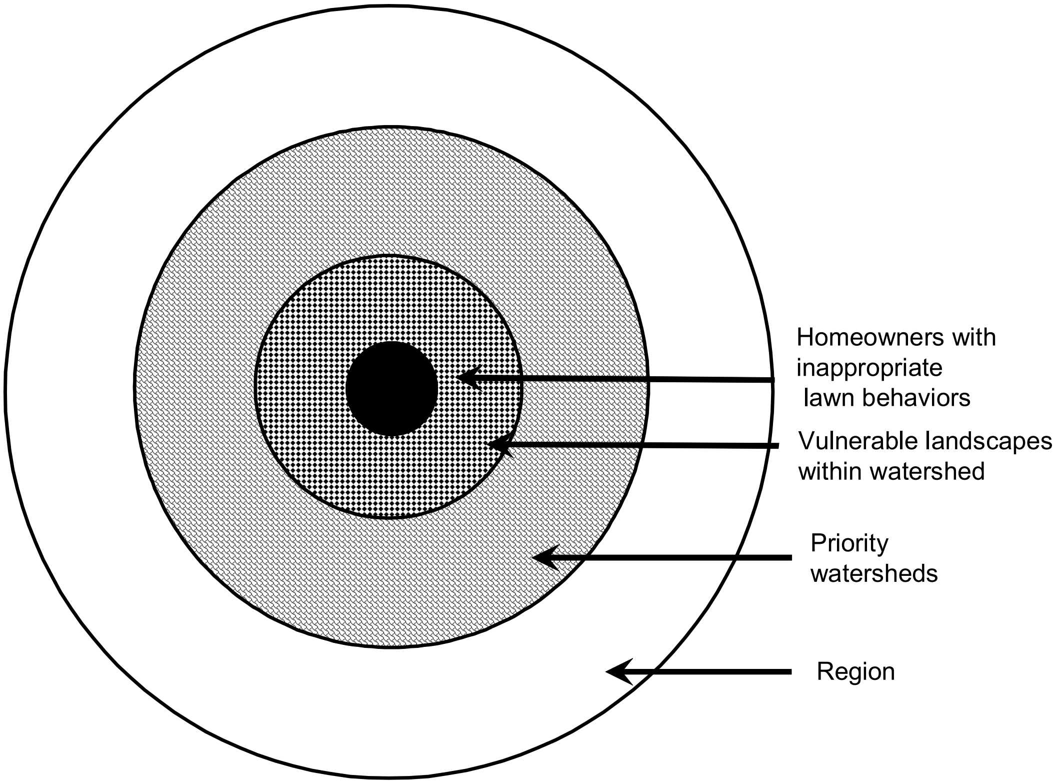

**Figure 4.** Illustration of targeting homeowners with greatest potential for causing nutrient impacts. Within a broad urban region, there will be a fraction of high priority watersheds (e.g., those with recreationally important lakes). Within these watersheds, only a portion of the watershed surface is vulnerable to potentially high nutrient export from inappropriate lawn management. The bull's eye represents those homeowners within vulnerable landscapes who actually practice these inappropriate behaviors.

In practice, a more focused program to reduce nutrients in lawn runoff would start by targeting priority watersheds (Figure 4). In Minnesota, for example, this might include watersheds of important recreational lakes within the urban region. Within priority watersheds, areas of biophysical vulnerability could readily be identified using simple GIS overlay tools. An overlay of slope, soil type, and land use, used in conjunction, could quickly identify areas with vulnerable lawns. Within these vulnerable areas, a relatively short screening survey of lawn management practices among homeowners would identify homeowners likely to engage in inappropriate behaviors (the "bull's eye" in Figure 4). We predict that this target population would be a few percent of the total regional population. Based on subsequent detailed studies guided by social psychological theory, the attitudes, norms, and beliefs that influence these homeowners specifically defined behaviors could be identified and used to tailor outreach programs. Because this would be a small group, education and outreach efforts could be fairly intensive. It might, for example, include subsidized soil testing, followed by a home visit to explain results and deliver a tailored message regarding suggested changes in lawn management, and perhaps follow-up phone calls to answer questions regarding recommended practices.

Outcomes from the research might also be used to develop web-supported guidance to homeowners. For example, an interactive web page could guide homeowners, using visual and text prompts to enter approximate conditions of their lawn (e.g., based on the photos at left, is your lawn flat, slightly sloped, steep, or very steep?), to yield approximate outputs (e.g. "high" potential for runoff phosphorus). Further questioning would be used to identify their lawn management typology, which would then direct them to tailored educational information.

## CONCLUSIONS

New regulations for stormwater management and restoration of impaired waters, combined with the practical concern for urban water supply and lake-based recreation has placed new focus on the need to reduce nutrient sources in urban stormwater. Lawn runoff contains varying levels of N and P and is a source of nutrients to stormwater in many residential watersheds. We hypothesize that skewed distributions of both biophysical characteristics and lawn management behaviors interact to cause disproportionate patterns of nutrient export from lawns.

Consideration of hydrologic and nutrient cycles of lawns points to types of lawn management behaviors that would create disproportional nutrient export. Social psychology offers a theoretical framework, the Theory of Planned Behavior, by which to evaluate barriers to behavioral change. A fine-scale (i.e., lawn scale) model of nutrient export could be used to predict N and P export under varying biophysical and management conditions. Outputs from this model could be combined with behavioral studies to identify barriers to "appropriate" behaviors, which in turn, could be used to develop management recommendations and education tailored to specific typologies of homeowners. A lawn management program developed for targeted locations with this disproportionality framework would probably be very effective, highly economical, and fair.

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