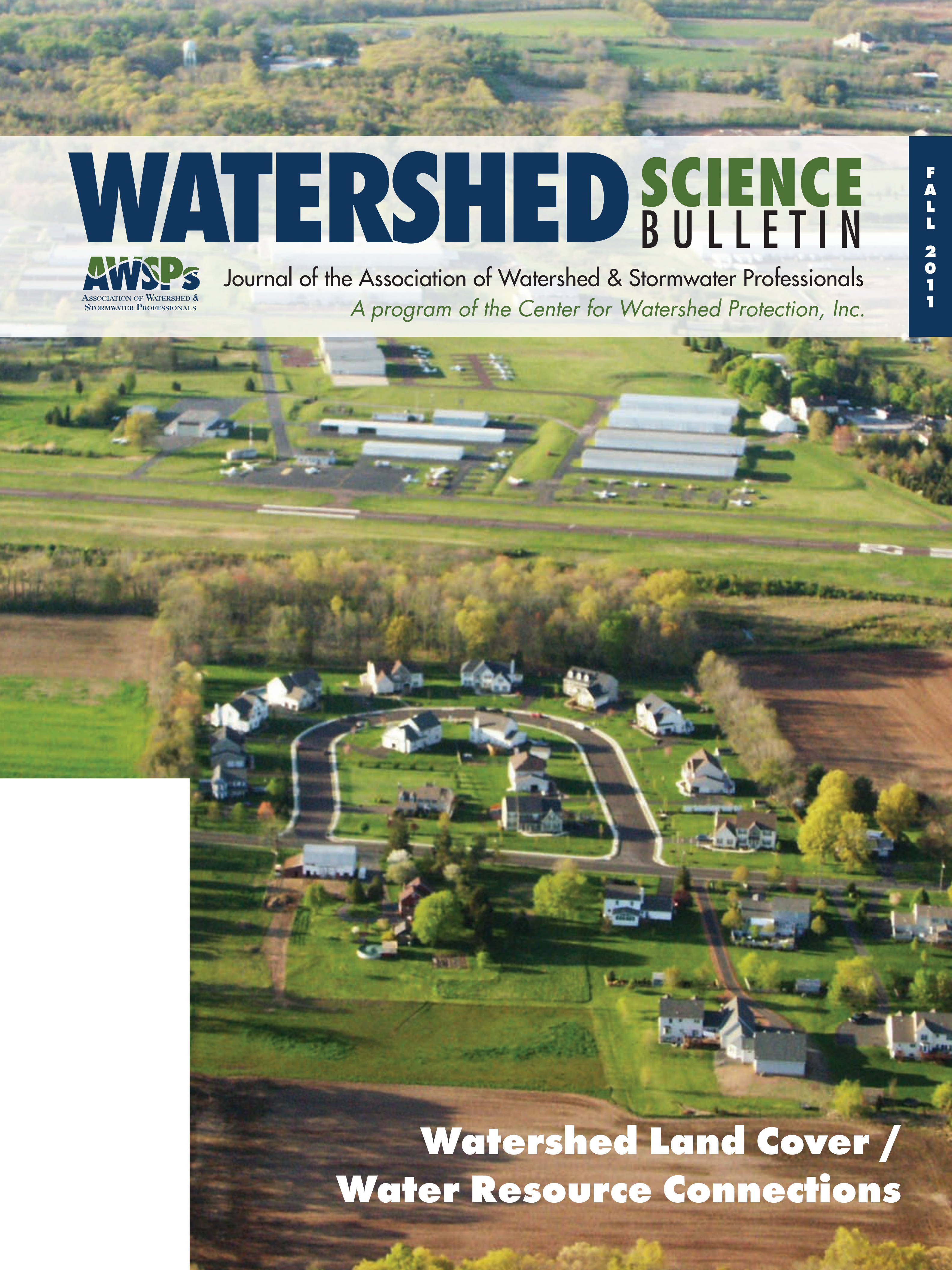
WATERSHED SCIENCE BULLETIN

AWSPs
Association of Watershed & Stormwater Professionals

Journal of the Association of Watershed & Stormwater Professionals

A program of the Center for Watershed Protection, Inc.

FALL 2011



Watershed Land Cover / Water Resource Connections

WATERSHED SCIENCE BULLETIN

Journal of the Association of Watershed & Stormwater Professionals

A program of the Center for Watershed Protection, Inc.

8390 Main St. 2nd Floor • Ellicott City, MD 21043 • 410-461-8323 (phone)
410-461-8324 (fax) • www.awsps.org • Bulletin@awsps.org

Watershed Science Bulletin (ISSN: 2156-8545) is the journal of the Association of Watershed and Stormwater Professionals (AWSPs), and is published semi-annually by the Center for Watershed Protection, Inc. (CWP).

KEY CONTACTS:

Co-Editors-in-Chief
Karen Cappiella (kc@cwp.org)
Neely Law (nll@cwp.org)

Associate Editor
Lisa Fraley-McNeal (bulletin@awsps.org)

Sponsorship Coordinator
Erin Johnson (etj@cwp.org)

AWSPs Membership
(membership@awsps.org)

MISSION: The mission of the Watershed Science Bulletin (the Bulletin) is to synthesize research and experience from the numerous disciplines that inform watershed management and transmit this valuable information to researchers, regulators, practitioners, managers, and others working to protect and restore watersheds everywhere.

POSTMASTER: Please send address changes to the Watershed Science Bulletin address provided above.

SUBSCRIPTIONS AND BACK ISSUES: Subscription is included for AWSPs members as part of member dues. The subscription rate for nonmembers is $89/year. Single copies and back issues can be purchased for $49 each. For a complete listing of back issues or to purchase a subscription, please visit www.awsps.org.

SUBMISSION: To submit an article, please visit www.awsps.org.

Graphic Design by Down to Earth Design, LLC (d2edesign.com)

Copyediting by Elizabeth Stallman Brown (www.estallmanbrown.com)

Printed by the YGS Group, York, Pennsylvania (www.theygsgroup.com)

Funding support provided by the Marian Rose Foundation and Wallace Genetic Foundation.

Cover photo courtesy of Dot Cappiella
This bird's-eye view of Bucks County, Pennsylvania, taken from a hot air balloon, shows the variety of land cover types on this rural and suburban landscape. Trees, turf, pavement, cropland, and even bare soil are present in this fast-developing suburb of Philadelphia.

TABLE OF CONTENTS

FEATUREDCONTENT

BULLETINDEPARTMENTS

Lawns as a Source of Nutrient Runoff in Urban Environments

John C. Stier[a] and Douglas J. Soldat[b]*

Abstract

Many people believe that lawns and fertilizers contribute substantially to urban runoff. However, data from small-plot and watershed-scale studies indicate that runoff is primarily limited to periods of frozen ground or saturated soils. Lawn runoff research studies have typically found that less than 5% of precipitation in a given year runs off-site. Turf development over time can even overcome the effects of compaction resulting from construction or establishment practices. A small amount of soluble nutrients will always leach from any type of vegetation; this, combined with atmospheric deposition, is readily moved in runoff over the interconnected impervious surfaces found in urban environments. But properly developed and managed lawns can reduce overall runoff volume and nutrient losses. Beneficial practices may include (1) using swales in lawns, particularly near impervious surfaces; (2) avoiding runoff from irrigation; (3) forgoing the application of fertilizer to saturated or frozen sites; and (4) applying fertilizers in recommended amounts and only when turf is actively growing.

Lawns and Urbanization

Urbanization leads to increased runoff as interconnected impervious surfaces, such as rooftops, parking lots, and roads, replace pervious ground cover, such as forests and fields (Shields et al. 2008). The increased runoff results in the pollution of surface waters with sediments, nutrients, and anthropogenic compounds. Increased runoff due to the connectedness of impervious surfaces can also result in the scouring of stream and river banks, causing erosion and adding to pollutant loads entering surface waters (Wang et al. 2001).

After buildings, lawns are the most visible type of ground cover in urban environments. The United States contains nearly 70 million detached single-family homes with an average lawn size of 0.1 to 0.13 ha; this adds up to a total of between 7.1 and 9.3 million ha of ground cover (US Census Bureau 2010; Vinlove and Torla 1995). Lawns and roadsides account for the greatest and second-greatest amounts of turf area, respectively, with additional turf covering parks, corporate grounds, schools, athletic fields, airports, sod farms, and golf courses (Wisconsin Agricultural Statistics Service 2001). Estimates using satellite imagery place the total US turf area at approximately 16.3 million ± 3.9 million ha (Milesi et al. 2005), which is about the size of Wisconsin.

The high visibility of lawns keeps them, and their management, in the public eye. Some of the public believe that the contribution of lawns to urban runoff is similar to that of paved or other impervious surfaces. In Olmsted County, Minnesota, the environmental oversight committee considered an ordinance listing turf as having imperviousness similar to that of concrete (Eric Counselman, Olmsted County Environmental Commission member, pers. comm., October 23, 2009). While excessive irrigation that exceeds the soil's infiltration rate and irrigation deposited directly on sidewalks, driveways, roads, and so on certainly causes runoff, these are cases of human error, and should not be attributed to the turfgrass ecosystem. Nonetheless, the perception of lawns as a significant pollution source has led to proposals to reduce lawn inputs and lawn surface area (Marzluff and Ewing 2001; Robbins and Berkholtz 2003).

Various states and municipalities are taking steps to mitigate total suspended solids (TSS) and nutrients in urban runoff by restricting fertilization (Lehman et al. 2009), in part to comply with the US Clean Water Act. In 2005, Minnesota became the first state to ban most turf applications of phosphorus (P)–containing fertilizers (Rosen and Horgan 2005). Other states—including Michigan, North Carolina, Washington, Virginia, and Wisconsin—have enacted, or are considering, similar bans. In 2010, New Jersey enacted the most restrictive turf fertilization law in the United States, restricting both nitrogen (N) and P applications to turf (Jim Murphy, Professor, Rutgers Univ., pers. comm., January 11, 2011). Although the amount of fertilizer used for lawn care probably varies greatly across states, less than 5% of the fertilizer sold in Wisconsin is used for lawns and gardens, while the rest is used for agriculture (Michael Koran, Fertilizer Regulations, Wisconsin Department of Agriculture, Trade, and Consumer Protection pers. comm., 2004). In fact, lawns may actually

[a] *Assistant Dean, College of Agricultural Sciences and Natural Resources, University of Tennessee, Knoxville, TN, jstier1@utk.edu*

[b] *Assistant Professor, Department of Soil Science, University of Wisconsin, Madison, WI*

[*] *Corresponding author.*

be able to play a role in the reduction of urban runoff if they are properly sized, placed, and managed. This paper presents a review of the literature on lawns as a source of nutrient runoff to better inform the public understanding of lawns as both a source and a mitigator of urban runoff.

The Use of Turfgrasses as Urban Vegetation

Turfgrasses are unique plant species that evolved under grazing pressure to withstand continuous defoliation and traffic while maintaining a contiguous community that can ensure coverage of bare soil (Casler 2006). Only a couple dozen species of plants, including two broadleaf species suitable only for warm climates, have the ability to provide such cover. Turfgrasses provide an ideal vegetative cover in much of the urban environment because they require only moderate care (e.g., weekly mowing and occasional fertilization) and form a dense cover over soil at low growing heights, even under traffic. The benefits of properly managed turfgrasses—including increased property values, increased recreational opportunities, and decreased crime—have been well summarized (Beard and Green 1994; Kuo and Sullivan 2001). From a water quality standpoint, one of the most important functions of lawns may be their ability to mitigate issues associated with urban runoff, provided that they are properly designed, sited, installed, and managed.

In urban settings, atmospheric deposition can be a significant source of nutrients that readily move in runoff when deposited on impervious surfaces. A three-year study of the Baltimore, Maryland, area showed an average atmospheric deposition of 11.2 kg N ha^{-1} compared to 14.4 kg N ha^{-1} from fertilizers as potential inputs to the watershed (Groffman et al. 2004). While urbanized areas had greater N output than forested sites with the same amount of atmospheric N deposition, the authors concluded that impervious surfaces were largely responsible for the difference in N runoff. Mean annual atmospheric P deposition is approximately 0.4 kg ha^{-1} (UN Environment Programme 1999). A conventionally recommended lawn fertilization program applying 146 kg N ha^{-1} $year^{-1}$ using a 27:1.3 (N:P) fertilizer would supply 7 kg P ha^{-1} $year^{-1}$. Soldat and Petrovic (2008) found a range of 0.0 to 19.1 kg P ha^{-1} $year^{-1}$ reported in turf field plot research projects, with typical losses of approximately 0.5 kg P ha^{-1} $year^{-1}$ from established turf. These values compare to annual losses of approximately 0.2 kg P ha^{-1} from native prairie, 1.9 kg P ha^{-1} from conventionally tilled agricultural systems, and more than 13 kg P ha^{-1} from construction sites (Daniel et al. 1979; Sharpley 1995).

Effect of Vegetative Cover on Runoff

Precipitation on bare soil results in exorbitant amounts of runoff laden with sediments, dissolved nutrients, and particulate nutrients in both inorganic and organic forms. Runoff and nutrient losses dissipate as vegetative cover and other nonplant (e.g., gravel) ground cover is established; and, in turfgrasses, the newly seeded and seedling phases are most prone to runoff and nutrient loss (Easton and Petrovic 2004). Sodding costs substantially more up front than seeding but quickly and effectively reduces runoff and erosion (Krenitsky et al. 1998). Vegetative cover, mulch, rock, and other covers intercept precipitation, preventing it from disturbing the soil and impeding surface runoff with a concomitant reduction of sediment and nutrient transport (Gilbert and Clausen 2006; Gross et al. 1991; Linde et al. 1995). In many cases, the denser the turf, the less runoff occurs because the contiguousness of the turf plants creates a "tortuous pathway" that slows the water and allows greater infiltration (Linde et al. 1995; Kussow 2008). Civil engineers use roughness coefficients to determine the potential of surfaces to contribute to overland flow; higher coefficient values correspond to less runoff. In a simulated rainfall experiment, pavement had a low roughness value of approximately 0.01, short grass prairie was 0.15, and bermudagrass (*Cynodon* spp.) and bluegrass (*Poa* spp.) sod were approximately 0.4 (Engman 1986).

Sufficient fertilization is important for maintaining turf cover and reducing runoff. In a cool-season lawn mixture, runoff was reduced three-fold when infiltration increased as a result of greater shoot density in response to fertilization (Easton and Petrovic 2004). Kussow (2008) showed that applying four applications of N- and P-containing fertilizer to a Kentucky bluegrass (*Poa pratensis* L.) turf, with each application providing 49 kg N ha^{-1}, reduced runoff depth by about 25% compared to turf left unfertilized over a two-year period. Fertilized turf had P losses averaging 0.34 kg P ha^{-1} compared to 0.54 kg P ha^{-1} ($P \leq 0.05$) from nonfertilized turf, whereas no difference in N runoff was noted. Bierman et al. (2010) found similar results in Minnesota over a three-year period.

The P lost from dense vegetation is primarily soluble P, much of which leaches from the vegetation, rather than particulate P, which is derived from the soil. In general, ecosystems in which P is lost only as soluble P leaching from vegetation tend to have significantly lower P loss than those in which particulate P also results from substantial soil loss because of insufficient ground cover. Mowing at an appropriate frequency and to an appropriate height helps turfgrasses maintain maximum density. While clippings that fall back into the turf allow for nutrient recycling and reduce fertilizer needs, clippings do not appear to contribute to P runoff from turf (Bierman et al. 2010). Vegetation, turf or nonturf, that overhangs impervious surfaces may actually contribute more to nutrient losses in runoff than shorter vegetation as nutrients are leached from the leaves, particularly following freezing or drying (Bechmann et al. 2005; Kussow 2008).

Compared with turf, nonturf vegetation, such as native prairie plantings, can lose significantly more nutrients from their aboveground biomass during the winter because the prairie plants senesce during the autumn, and precipitation or snowmelt results in runoff over frozen ground (Steinke et al. 2007). Turfgrasses in the northern portions of the country are C_3 plants (cool-season grasses) that often do not die back in winter, thus retaining nutrients in their foliage. In central and southern portions of the United States, C_4 turfgrasses (warm-season grasses) are often used and may senesce with the onset of cool autumn temperatures. However, compared with unmowed native prairie or other plants, the short stature of mowed turfgrasses results in relatively little aboveground biomass and can lead to less overall nutrient losses from the foliage during winter (Steinke et al. 2007).

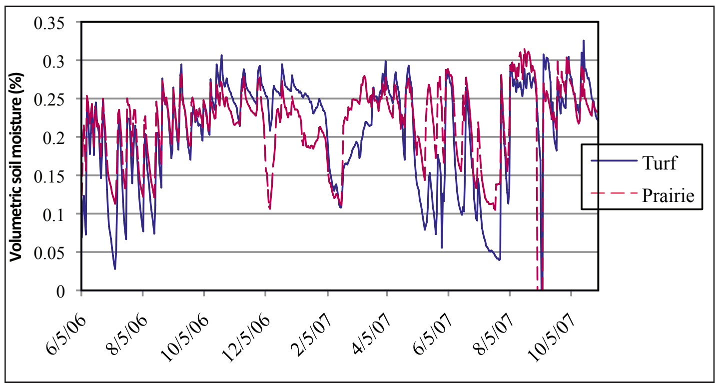


Figure 1. Soil moisture over time at a 6.4-cm depth under mowed Kentucky bluegrass turf or mixed prairie plants (primarily forbs and sedges) in silt loam soil in Madison, Wisconsin. Turf had less soil moisture in the spring and summer periods as a result of greater growth and ET rates; the reduced soil moisture provides space for precipitation to infiltrate and inhibit runoff during rain storms.

Lawns, Compaction, and Impervious Surfaces

Frozen and saturated soils negate the ability of lawns, or other vegetation on smooth ground, to stop runoff. In many cases, most or all annual runoff can occur during frozen soil conditions (Kussow 2008; Steinke et al. 2007). In nonfrozen conditions, runoff occurs when the precipitation rate exceeds the soil's infiltration rate, or when the soil becomes saturated.

Turfgrasses have an evapotranspiration (ET) rate that is similar to or higher than that of many other potential urban ground covers (Ebdon et al. 1999). Using replicated plots of forb-dominated prairie and mowed Kentucky bluegrass turf in a randomized block design, we found that the turf had less soil moisture than the prairie at a 6.4-cm depth during early spring and summer, with spring differences due to a resumption of Kentucky bluegrass growth that is earlier than that of prairie plants (Figure 1; Stier, unpublished data). Thus, the higher ET rates of the turf result in an upper layer of drier soil that allows water infiltration more effectively than would a persistently moist upper layer of soil.

Compaction of turf soils may contribute to runoff, and the extent to which it does so depends on the use of heavy construction equipment during development. A study of 15 lawns in central Pennsylvania assessed the infiltration rates of clay, silt, and loam soils (Hamilton and Waddington 1999). Based on soil characteristics alone, one would expect infiltration rates to be affected by soil type in the following order, from greatest to least infiltration: sand > loam > silt > clay. However, Hamilton and Waddington (1999) found that the soil type of lawns did not correlate with infiltration. Instead, they concluded that the soil's condition, structure, and history are likely to affect lawn infiltration rates, and that these factors are largely a function of construction practices. Preplanting tillage, as recommended for lawn establishment, and core aeration of lawns that have compacted soils can help improve infiltration rates (Partsch et al. 1993; Stier 2000). Over time, pore formation from the development of turfgrass roots, freezing and thawing, and benthic activity (e.g., from earthworms) will improve infiltration (Easton et al. 2005). Thus, in practice, when excessive compaction does occur during construction, properly tilling and establishing turf will negate compaction effects. Most states have extension services that provide guidance for establishing lawns in northern and southern climates (Stier 2000; Waltz 2010).

In some cases, the role played by compaction may be less important than might be perceived. Kussow (2008) simulated home construction site practices by intentionally compacting a silt loam soil with a 5% slope using a vibrating roller. He placed an additional 7.5 cm of the silt loam on top of the compacted area and either mixed it by tilling or left it in a layer. He chisel-plowed another section of the compacted area of each plot prior to the addition of topsoil and then seeded the entire area with Kentucky bluegrass. By year two of the study, the runoff amounts were similar for noncompacted, compacted, and compacted + chisel-plowed treatments, with an annual runoff depth of 30–39 mm from an annual 641 mm of precipitation. Bierman et al. (2010) used a bulldozer to level runoff plots to a 5% slope and then sodded them with Kentucky bluegrass. Over a three-year period, runoff averaged less than 1% of annual precipitation when the ground was not frozen.

The lack of connectedness between impervious and pervious surfaces in urban environments can prevent runoff and snowmelt from infiltrating into the soil. Urban areas are typically designed to channel storm and meltwater quickly away; this may lead to flushes of water, sediments, and pollutants (including nutrients) into surface waters. Properly placed and maintained lawn areas can alleviate runoff and nutrient losses from impervious surfaces (Mueller and Thompson 2009).

While numerous studies have shown the effectiveness of grassed buffers for reducing overland flow and pollutants from crop fields, studies evaluating the effectiveness of grass buffers in urban environments are almost nonexistent, other than perhaps studies of roadside swales. Steinke et al. (2007) studied the effects of nascent prairie and turfgrass buffer strips on runoff from concreted slopes. They developed concrete-to-vegetative buffer ratios of 1:1, 1:2, and 1:4 along a 5% slope on a silt loam soil near Madison, Wisconsin. The vast majority of runoff occurred when soils were frozen, at which times runoff from turfgrass and prairie buffers was similar. During non-frozen conditions, they measured less runoff from the managed turf areas than from than the prairie plantings ($p \leq 0.10$) the year following establishment. A vegetative buffer twice the size of the concrete area reduced annual runoff by more than 60% compared to the 1:1 concrete-to-buffer treatment, though even the 1:1 buffer allowed less than 1.5% of the precipitation to run off during nonfrozen conditions. Mueller and Thompson (2009) conducted 52 stormwater runoff tests on six lawns in Madison, Wisconsin, to determine the ability of lawns to infiltrate rooftop runoff. Using a model to estimate annual lawn runoff as a function of rooftop-to-lawn size ratios, they concluded that lawns could be useful as a stormwater management practice.

Rain Gardens and Lawns

Natural areas typically have a texture that is rough enough to help retain precipitation and reduce runoff. In urban environments, rain gardens have been proposed as a way to trap runoff water from impervious surfaces, such as rooftops and parking lots. Rain gardens are flat-bottomed depressions planted with trees, shrubs, or native vegetation and designed to trap and infiltrate runoff from impervious surfaces (Dietz and Clausen 2005; Wisconsin Department of Natural Resources [WDNR] 2003). While some rain gardens are highly engineered, containing sand-based root zones and drain tiles for high infiltration and exfiltration flow, they can also be carved from existing soil and surrounded by a berm, creating a miniature retention basin. Rain gardens are not usually recommended for clay soils, however, which are prevalent in many US urban areas.

Although rain gardens add texture to a landscape, and the flowering plants can add beauty during the summer, the most effective part of the rain garden for runoff control is the berm. In a two-year study, a student in our laboratory compared bermed and nonbermed rain gardens and lawns for runoff reduction from rooftops (Schneider 2007). A randomized block design with four replications was used to test Kentucky bluegrass turf maintained as lawn, rain gardens with berms, turf with a berm similar to that of a rain garden, and rain gardens without a berm (with the same surface characteristics as a lawn and lacking a depression in the ground). Berms were constructed from soil removed while excavating a 15 cm–deep basin following recommended construction methods (WDNR 2003). Rain gardens were sized to prevent 100% of the potential annual runoff from the rooftops. Given the approximately 5% ground slope and silt loam soil type, a recommended ratio of rooftop-to-rain garden of 2.8:1 was used (WDNR 2003). Transplants of species were used per a recommended design (WDNR 2003). Rooftops (7.6 m long x 2.4 m wide with a 12% slope) equipped with gutters and downspouts channeled water into the plot areas. Runoff was collected following all rainfall events using weirs and collection vessels at the downslope edge of the plots and analyzed the runoff for volume, TSS, N, and P.

In no case did the total amount of runoff exceed 5% of the annual precipitation, showing that pervious surfaces are very good at reducing potential runoff (Table 1). Even the nonbermed lawn area reduced runoff equivalent to the bermed rain garden over the two-year period. The nonbermed rain gardens, using recommended prairie-type plants, allowed significantly more runoff, sediment, P, and, in the first year, nitrate-N than the other three treatments, presumably because of low plant density and exposed soil (additional data in Schneider 2007). Adding mulch around the plants might have reduced runoff, but the study also reinforces the idea that the presence of thatch from turfgrasses

Table 1. Runoff, expressed as amounts and as percentages of precipitation, from lawn-type turf or rain garden plantings receiving rooftop runoff over a 24-month period in Madison, Wisconsin.

Situation	November 2005–October 2006		November 2006–October 2007	
	mm	% Annual precipitation	mm	% Annual precipitation
Turf, no berm	20.4	2.4	9.0	0.9
Turf, with berm	8.9	1.0	10.4	1.0
Rain garden, no berm	42.8	5.0	17.9	1.8
Rain garden, with berm	8.2	1.0	9.0	0.9
$LSD_{0.05}$	12.3		4.0	

Note: LSD, or least significant difference, is used to compare statistical differences of runoff amounts among treatments. One can add or subtract the LSD value to the runoff amount (in mm) from any treatment and compare the result to the value of another treatment. For example, in the first year, the turf with no berm (ordinary lawn) had significantly less runoff than the rain garden vegetation with no berm (20.4 + 12.3 = 32.7; 32.7 < 42.8) and a similar amount of runoff compared to the rain garden with a berm (20.4 – 12.3 = 8.1; 8.1 ≈ 8.2).

provides an ideal cover over soil that effectively reduces runoff.

Schneider (2007) concluded that the depressions and berms, not the type of vegetation, were the effective components of rain gardens. Moreover, bermed plots caused about 1% of the precipitation to run off into collection weirs because the weirs were placed adjacent to the downslope edge of the berms; installing such berms at the edges of impervious surfaces such as sidewalks or roads could actually increase runoff into storm sewers. Runoff from bermed plots would have been reduced if a sufficient buffer area, or swale, had been installed between the berm and the collection weir. In practice, berms or swales placed at some interval in lawns that slope toward impervious surfaces would reduce even the relatively small amount of runoff that occurs from turf or other vegetated areas.

Fertilizers as a Source of Nutrients in Runoff

Turfgrass areas differ greatly from agricultural areas in the manner in which N and P are applied to the vegetation and in the potential for nutrient losses. For example, P losses in agriculture are often highly correlated with soil test P and the amount of sediment loss; however, sediment losses from turfgrass areas are typically very low (Soldat and Petrovic 2008) and are unrelated to soil P levels unless P levels are unusually elevated (Soldat et al. 2009). The small but consistent level of soluble P in runoff from turf probably originates from the plant tissue itself (Soldat et al. 2009).

Although P fertilizer bans enacted in many parts of the country are expected to reduce P runoff, the impact from the bans may not be as large as anticipated. In runoff from nonfrozen ground, Bierman et al. (2010) reported a significantly greater reactive P loss (0.10 kg ha^{-1}) in only the first year of a three-year study from turf fertilized with a high P:N fertilizer (1:2), typical of garden fertilizers and natural or organic fertilizers, compared with a lower P:N fertilizer (1:27), a fertilizer without P (containing N and potassium only), or no-fertilizer treatments (0.03–0.05 kg P ha^{-1}). In the second year and third years, the nonfertilized turf exhibited greater reactive P losses than did any of the fertilizer treatments (year two: 0.11 kg P ha^{-1} for nonfertilized turf vs. 0.04–0.05 kg P ha^{-1} for fertilizer treatments, $p < 0.05$; year three: 0.03 kg P ha^{-1} for nonfertilized turf vs. 0.01–0.02 kg P ha^{-1} for fertilizer treatments; 0.05). The authors attributed the increased P runoff loads to the decreased turf density associated with the nonfertilized treatment, which exhibited higher runoff volumes than the fertilized plots. Kussow (2008) and Easton and Petrovic (2004) similarly found that increased runoff volumes from the less dense turf resulting from nonfertilization led to greater P losses. The use of native plants in lieu of mowed turf may not noticeably reduce P in runoff either, as Steinke et al. (2007) showed that P losses of fertilized turf and nonfertilized prairie plantings were similar, with the majority occurring during frozen conditions. Steinke et al. (2007) examined a relatively young (less than five-year-old) site; further study is needed to compare mature prairie vegetation with turf to develop best management practices for the control of urban runoff.

A recent five-month watershed-scale study found reduced P export from an urban watershed in which a ban on lawn applications of manufactured fertilizers containing P had been enacted compared to a watershed without the ban (Lehman et al. 2009). One would expect that a ban on the use of manufactured fertilizers containing P would reduce dissolved P because the P forms in such turf fertilizers are highly soluble. Instead, however, Lehman et al. (2009) found that "the main effect has been [a] reduction in the particulate P load of the river," not a reduction in dissolved P. Why a P ban would result in a reduction in sediment transport without affecting dissolved P remains an open question. The researchers did not quantify differences in other activities (including construction), and they also point out that, in the watershed with the P ban, public education efforts encouraged citizens to reduce P in other ways, such as through attention to vegetated buffer strips along streams and the reduction of yard waste discharges into storm drains. More research is required to determine the most effective policies and practices for reducing P export from urban areas.

N dynamics in turfgrass systems are also substantially different from those of agricultural systems. In agricultural areas, N leaching is often the result of large applications of soluble N in fall or spring when plant cover and N uptake potential is low. Conversely, turfgrass is a permanent ground cover that has the ability to use N earlier in the spring and later in the fall than forests or agricultural crops (Pickett et al. 2008). Applications of N on turfgrass are usually no more than 45 kg ha^{-1}, often less, and contain some amount of slowly available N, which is not widely used in conventional agriculture. Bowman et al. (1989) reported that cool-season turfgrass was able to absorb 70%–80% of a 45 kg ha^{-1} application of soluble N within 24 hours, and nearly all of it within a 48-hour period. In a Florida study, Erickson et al. (2001) explored the effect of alternative vegetation to manage N export and runoff compared to turfgrass by comparing runoff from a mowed, irrigated, and fertilized St. Augustine grass lawn (*Stenotaphrum secundatum* [Walt.] Kunze) to runoff from a landscape type (containing shrubs, trees, and mulch) recommended for reducing N pollution. The plots were planted on a sandy soil with a 10% slope. Precipitation caused only one runoff event during the study, and both types of plantings had similar concentrations of inorganic N.

Best Management Practices for Turfgrass Fertilization

P is often required to maximize the establishment of turfgrass (Hamel and Heckman 2006). But once turfgrass is established, soil test P levels required to sustain adequate growth are lower than those required for many agricultural crops (Petrovic et al. 2005). Therefore, soil test results should guide the application of P fertilizer to turf, and recommendations for P should be different for established versus newly seeded or sodded turf.

In contrast to P, no soil test can accurately assess requirements for N, which readily converts among various forms and, unlike other nutrients, can convert to gaseous forms (e.g., N_2 and NH_4^+). Therefore, N fertilization should be based on appropriate research-based guidelines that are often highly specific and available from state universities or extension services. For example, recommended N rates will depend on factors like turf species, climate, microclimate (sun vs. shade), level of traffic, and clipping management (bagged vs. mulched). In general, applications should be made only when the turf is actively growing. Most commercially available fertilizers contain 0%–30% slow-release N, while lawn care companies use fertilizers containing anywhere from 0% to 100% slow-release N, depending on the company and situation. The most common types of slow-release sources of N for lawn fertilizers (which must be listed on the packaging) include sulfur-coated urea, polymer-coated urea, methylene ureas, and a generic category listed as water-insoluble N. Research has shown that both N and P nutrient losses can be mitigated by lightly "watering-in" the application (Shuman 2004). Also, avoiding the fertilization of saturated soils is a no-cost, no-effort solution to reducing potential fertilizer runoff and leaching from lawns (Morton et al. 1988; Shuman 2004).

Impacts of Homeowner Lawn Management Practices

Based on sales data, Scotts Miracle Gro estimates that approximately 50% of homeowners in the United States fertilize their lawns (Augustin 2007). Of the 50% who fertilize, the average number of annual fertilizer applications (~45 kg N ha^{-1} per application) was estimated to be 1.8, which includes an estimated 10 million homes treated by professional lawn care companies. Law et al. (2004) independently obtained a very similar estimate in Baltimore County, Maryland. These data indicate that the average homeowner who fertilizes his or her lawn is doing so only 60% as frequently as recommended by most university extension services, which typically recommend three applications per year (with wide variations, as discussed above).

A large-scale, urban watershed study of Baltimore, Maryland, concluded that lawns are useful for retaining nutrients in urban ecosystems (Groffman et al. 2004; Pickett et al. 2008). Conservation subdivisions are designed, among other purposes, to reduce stormwater runoff by ensuring sufficient vegetative cover around buildings (Arendt 2004). Baker et al. (2008) suggested that (1) a very small group of homeowners may be disproportionately skewing runoff and nutrient loading events into urban environments and (2) targeting those homeowners would more effectively reduce nutrient runoff than would general, large-scale efforts to prevent fertilization or encourage lawn replacement. WDNR applied such a philosophy to its technical standards for turf fertilization, stating, for example, that primarily water-soluble N sources should be used on slopes and should be lightly watered-in because solid, nonwater-soluble fertilizers could have a tendency to move as particulates from slopes (WDNR 2006).

Conclusion

Runoff from lawns is typically limited to 5% or less of precipitation. The greatest amount of runoff in northern climates typically occurs during winter when the ground is frozen. At other times of the year, and in nonfreezing climates, runoff occurs when soils become saturated or when sprinkler systems overspray and leak onto impervious surfaces. Lawns with dense turf cover release relatively little TSS. Some fertilization, primarily N, is usually needed to maintain sufficient turf density, which is important to minimize runoff volume and nutrient losses. Research has indicated that fertilizer use per se will not contribute significantly to nutrient losses if applied based on agronomic needs and to actively growing turf with nonsaturated soils. Small amounts of nutrients leach from plant tissues—even nonfertilized, nonturf vegetation—particularly when vegetation is senescent. Nutrient runoff loads tend to be directly related to runoff volume, which can be mitigated by maintaining dense turf and possibly by incorporating swales between vegetated sites and paved areas that concentrate and funnel runoff to storm sewers or surface waters. Based on data and the desirability to have turfgrasses as vegetative ground cover in urban areas for recreation and other activities, the development of practices and regulations that promote the best use of lawns to reduce urban runoff will be beneficial.

REFERENCES

Arendt, R. 2004. Linked landscapes: Creating greenway corridors through conservation subdivision design strategies in the northeastern and central United States. Landscape Urban Planning 68:241–269.

Augustin, B. 2007. Perception vs. reality: How much nitrogen do homeowners put on their lawn? Paper presented at the annual meeting of the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, New Orleans, Louisiana, November 4–8.

Baker, L. A., B. Wilson, D. Fulton, and B. Horgan. 2008. Disproportionality as a framework to target pollution reduction from urban landscapes. Cities and the Environment 1(2): article 7. http://digitalcommons.lmu.edu/cate/vol1/iss2/7/.

Beard, J. B., and R. L. Green. 1994. The role of turfgrasses in environmental protection and their benefits to humans. Journal of Environmental Quality 23:452–460.

Bechmann, M. E., P. J. A. Kleinman, A. S. Sharpley, and L. S. Saporito. 2005. Freeze–thaw effects on phosphorus loss in runoff from manured and catch-cropped soils. Journal of Environmental Quality 34:2301–2309.

Bierman, P. M., B. P. Horgan, C. J. Rosen, A. B. Hollman, and P. H. Pagliari. 2010. Phosphorus runoff from turfgrass as affected by phosphorus fertilization and clipping management. Journal of Environmental Quality 39:282–292.

Bowman, D. C., J. L. Paul, and W. B. Davis. 1989. Nitrate and ammonium uptake by nitrogen-deficient perennial ryegrass and Kentucky bluegrass turf. Journal of the American Society for Horticultural Science 114:421–426.

Casler, M. D. 2006. Perennial grasses for turf, sport and amenity uses: Evolution of form, function and fitness for human benefit. Journal of Agricultural Science 144:189–203.

Daniel, T. C., P. E. McGuire, D. Stoffel, and B. Miller. 1979. Sediment and nutrient yield from residential construction sites. Journal of Environmental Quality 8:304–308.

Dietz, M. E., and J. C. Clausen. 2005. A field evaluation of rain garden flow and pollutant treatment. Water, Air, and Soil Pollution 167:123–138.

Easton, Z. M., and A. M. Petrovic. 2004. Fertilizer source effect on ground and surface water quality in drainage from turfgrass. Journal of Environmental Quality 33:645–655.

Easton, Z. M., A. M. Petrovic, D. J. Lisk, and I.-M. Larsson-Kovach. 2005. Hillslope position effect on nutrient and pesticide runoff from turfgrass. International Turfgrass Society Research Journal 10:121–129.

Ebdon, J. S., A. M. Petrovic, and R. A. White. 1999. Interaction of nitrogen, phosphorus, and potassium on evapotranspiration rate and growth of Kentucky bluegrass. Crop Science 39:209–218.

Engman, E. T. 1986. Roughness coefficients for routing surface runoff. Journal of Irrigation and Drainage Engineering 112:39–53.

Erickson, J. E., J. L. Cisar, J. C. Volin, and G. H. Snyder. 2001. Comparing nitrogen runoff and leaching between newly established St. Augustine grass turf and an alternative residential landscape. Crop Science 41:1889–1895.

Gilbert, J. K., and J. C. Clausen. 2006. Stormwater runoff quality and quantity from asphalt, paver, and crushed stone driveways in Connecticut. Water Research 40:826–832.

Groffman, P. M., N. L. Law, K. T. Belt, L. E. Band, and G. T. Fisher. 2004. Nitrogen fluxes and retention in urban watershed ecosystems. Ecosystems 7:393–403.

Gross, C. M., J. S. Angle, R. L. Hill, and M. S. Welterlen. 1991. Runoff and sediment losses from tall fescue under simulated rainfall. Journal of Environmental Quality 20:663–668.

Hamel, S. C., and J. R. Heckman. 2006. Predicting need for phosphorus fertilizer by soil testing during seeding of cool season grasses. HortScience 41:1690–1697.

Hamilton, G. W., and D. V. Waddington. 1999. Infiltration rates on residential lawns in central Pennsylvania. Journal of Soil and Water Conservation 54:564–568.

Krenitsky, E. C., M. J. Carroll, R. L. Hill, and J. M. Krouse. 1998. Runoff and sediment losses from natural and man-made erosion control materials. Crop Science 38:1042–1046.

Kuo, F. E., and W. C. Sullivan. 2001. Environment and crime in the inner-city: Does vegetation reduce crime? Environment and Behavior 33:343–367.

Kussow, W. R. 2008. Management practices affecting nitrogen and soluble phosphorus losses from an Upper Midwest lawn. In: The fate of nutrients and pesticides in the urban environment, vol. 997, ed. M. Nett, M. J. Carroll, B. P. Horgan, and A. M. Petrovic, 1–18. Washington, DC: American Chemical Society.

Law, N. L., L. E. Band, and J. M. Grove. 2004. Nitrogen input from residential lawn care practices in suburban watersheds in Baltimore County, MD. Journal of Environmental Planning and Management 47:737–755.

Lehman, J. T., D. W. Bell, and K. E. McDonald. 2009. Reduced river phosphorus following implementation of a lawn fertilizer ordinance. Lake and Reservoir Management 25:307–312.

Linde, D. T., T. L. Watschke, A. R. Jarrett, and J. A. Borger. 1995. Surface runoff assessment from creeping bentgrass and perennial ryegrass turf. Agronomy Journal 87:176–182.

Marzluff, J. M., and K. Ewing. 2001. Restoration of fragmented landscapes for the conservation of birds: A general framework and specific recommendations for urbanizing landscapes. Restoration Ecology 9:280–292.

Milesi, C., S. W. Running, C. D. Elvidge, J. B. Dietz, B. T. Tuttle, and R. R. Nemani. 2005. Mapping and modeling the biogeochemical cycling of turf grasses in the United States. Environmental Management 36:426–438.

Morton, T. G., A. J. Gold, and W. M. Sullivan. 1988. Influence of overwatering and fertilization on nitrogen losses from home lawns. Journal of Environmental Quality 17:124–130.

Mueller, G. D., and A. M. Thompson. 2009. The ability of urban residential lawns to disconnect impervious area from municipal sewer systems. Journal of the American Water Resources Association 45:1116–1126.

Partsch, C. M., A. R. Jarrett, and T. L. Watschke. 1993. Infiltration characteristics of residential lawns. Transactions of the American Society of Agricultural and Biological Engineers 36:1695–1701.

Petrovic, A. M., D. Soldat, J. Gruttadaurio, and J. Barlow. 2005. Turfgrass growth and quality related to soil and tissue nutrient content. International Turfgrass Society Research Journal 10:989–997.

Pickett, S. T. A., M. L. Cadensasso, J. M. Grove, P. M. Groffman, L. E. Band, C. G. Boone, W. R. Burch, Jr, et al. 2008. Beyond urban legends: An emerging framework of urban ecology, as illustrated by the Baltimore ecosystem study. BioScience 58:139–150.

Robbins, P., and T. Berkholtz. 2003. Turfgrass revolution: Measuring the expansion of the American lawn. Land Use Policy 20:181–194.

Rosen, C. J., and B. P. Horgan. 2005. Regulation of phosphorus fertilizer application to turf in Minnesota: Historical perspective and opportunities for research and education. International Turfgrass Society Research Journal 10:130–135.

Schneider, J. 2007. Urban rain gardens for controlling stormwater runoff and increasing groundwater recharge. MS thesis, University of Wisconsin–Madison.

Sharpley, A. 1995. Identifying sites vulnerable to phosphorus loss in agricultural runoff. Journal of Environmental Quality 24:947–951.

Shields, C. A., L. E. Band, N. Law, P. M. Groffman, S. S. Kaushal, K. Savva, G. T. Fisher, and K. T. Belt. 2008. Streamflow distribution of non-point nitrogen export from urban–rural catchments in the Chesapeake Bay watershed. Water Resources Research 44:W09416, doi:10.1029/2007WR006360.

Shuman, L. M. 2004. Runoff of nitrate nitrogen and phosphorus from turfgrass after watering-in. Communications in Soil Science and Plant Analysis 35:9–24.

Soldat, D. J., and A. M. Petrovic. 2008. The fate and transport of phosphorus in turfgrass ecosystems. Crop Science 48:2051–2065.

Soldat, D. J., A. M. Petrovic, and Q. Ketterings. 2009. Effect of soil phosphorus levels on phosphorus runoff concentrations from turfgrass. Journal of Water, Air and Soil Pollution 199:33–44.

Steinke, K., J. C. Stier, W. R. Kussow, and A. Thompson. 2007. Prairie and turf buffer strips for controlling runoff from paved surfaces. Journal of Environmental Quality 36:426–439.

Stier, J. C. 2000. Lawn establishment and renovation. Extension Bulletin A3434. Madison, WI: University of Wisconsin.

UN Environment Programme. 1999. Planning and management of lakes and reservoirs: An integrated approach to eutrophication. International Environmental Technology Centre Technical Publication 11. Paris, France: UN Environment Programme.

US Census Bureau. 2010. US population. Washington, DC: US Census Bureau.

Vinlove, F. K., and R. F. Torla. 1995. Comparative estimations of US home lawn area. Journal of Turfgrass Management 1:83–97.

Waltz, C. 2010. Lawns in Georgia. Extension Bulletin 773. Athens, GA: University of Georgia.

Wang, L., J. Lyons, P. Kanehl, and R. Bannerman. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. Environmental Management 28:255–266.

Wisconsin Agricultural Statistics Service. 2001. 1999 Wisconsin turfgrass survey. Madison, WI: Wisconsin Agricultural Statistics Service.

Wisconsin Department of Natural Resources. 2003. Rain gardens: A how-to manual for homeowners. WDNR publication PUB-WT-776 2003. Madison, WI: Wisconsin Department of Natural Resources.

———. 2006. Interim turf nutrient management. Technical Standard 1100. Madison, WI: Wisconsin Department of Natural Resources.