Estimating Forest Loss with Urbanization:

An Important Step toward Using Trees and Forests To Protect and Restore Watersheds

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Abstract

Watershed forestry is a watershed-based approach for the management of trees and forests that acknowledges their importance in protecting water resources. In urban and urbanizing watersheds, this approach involves developing watershed-based goals and strategies for managing the urban forest as a whole, rather than on a site-by-site or jurisdictional basis. This paper presents a method to derive forest cover coefficients that represent the proportion of a particular area of land use that is covered by forest, using an example from Frederick County, Maryland. In an application of this method, we use the coefficients from the leaf-out analysis to evaluate changes in forest cover. We used the results in the Watershed Treatment Model to estimate pollutant loading under current conditions and under scenarios of future development for the Linganore Creek watershed, a drinking water source within the county.

Introduction

Nearly 0.4 million ha (1 million acres) of forest were converted to developed uses each year in the 1990s, with increased conversion rates through 2001 (Stein et al. 2005; Natural Resources Conservation Service 2001). Stein et al. (2005) estimate that an additional 9.3 million ha (23 million acres) of forest may be lost as a result of development by 2050. Areas experiencing the most forest loss are often suburban and urbanizing communities where municipal staff may not have the tools (or priorities) necessary to fully evaluate forest loss at the watershed scale. The projected increase in development and subsequent forest loss over the next four decades reinforces the need for better forest planning and management.

The important link between forests and the condition of streams in a watershed has been well documented. Booth (2000) found that at least 65% watershed forest cover is needed for the presence of a healthy aquatic insect community. Other researchers have determined that riparian forest cover is an important factor in maintaining stream geomorphology and various indices of biotic integrity (Moore and Palmer 2005; Goetz et al. 2003; Wang et al. 2003). And riparian forest cover can mitigate, to a certain extent, the impacts of impervious surfaces that are constructed as a watershed develops (Walsh et al. 2007; McBride and Booth 2005). Watershed forestry is a watershed-based approach for the management of trees and forests that acknowledges their importance in protecting water resources. In urban and urbanizing watersheds, this approach involves the development of watershed-based goals and strategies for managing the urban forest as a whole, rather than on a site-by-site or jurisdictional basis.

This paper presents a method to derive forest cover coefficients (FCCs) and to use them to estimate, on a watershed basis, existing forest cover and the potential forest loss likely with future development. Through a case study of the Linganore Creek watershed in Frederick County, Maryland, we illustrate an application of FCCs using the *leaf-out analysis* (Cappiella et al. 2005) to evaluate changes in forest cover under current conditions and under scenarios of future development. These methods provide planning-level estimates commensurate with commonly available data sources. Used in such a way, FCCs can play a key role in the identification of proactive measures needed to protect existing forest cover and watershed health.

Study Area

With a drainage area of 217 km^2 (83.8 square miles) and 336 km (209 miles) of streams, the Frederick County portion of the drinking water source area of the Linganore Creek watershed was the focus of this study (Figure 1). Lake Linganore, an impoundment of Linganore Creek that is classified by the State of Maryland as a recreational trout water body, provides recreational opportunities within the watershed. In addition, the County has designated the land area draining to the lake a source water protection area because the lake is a major drinking water supply serving residents in Frederick County and the City of Frederick. As the largest impoundment in the Monocacy River basin, the lake currently stores about 2.8 billion liters (729 million gallons) of water (Perot et al. 2002). Lake Linganore is also listed by the State as impaired for sediment and phosphorus, and the

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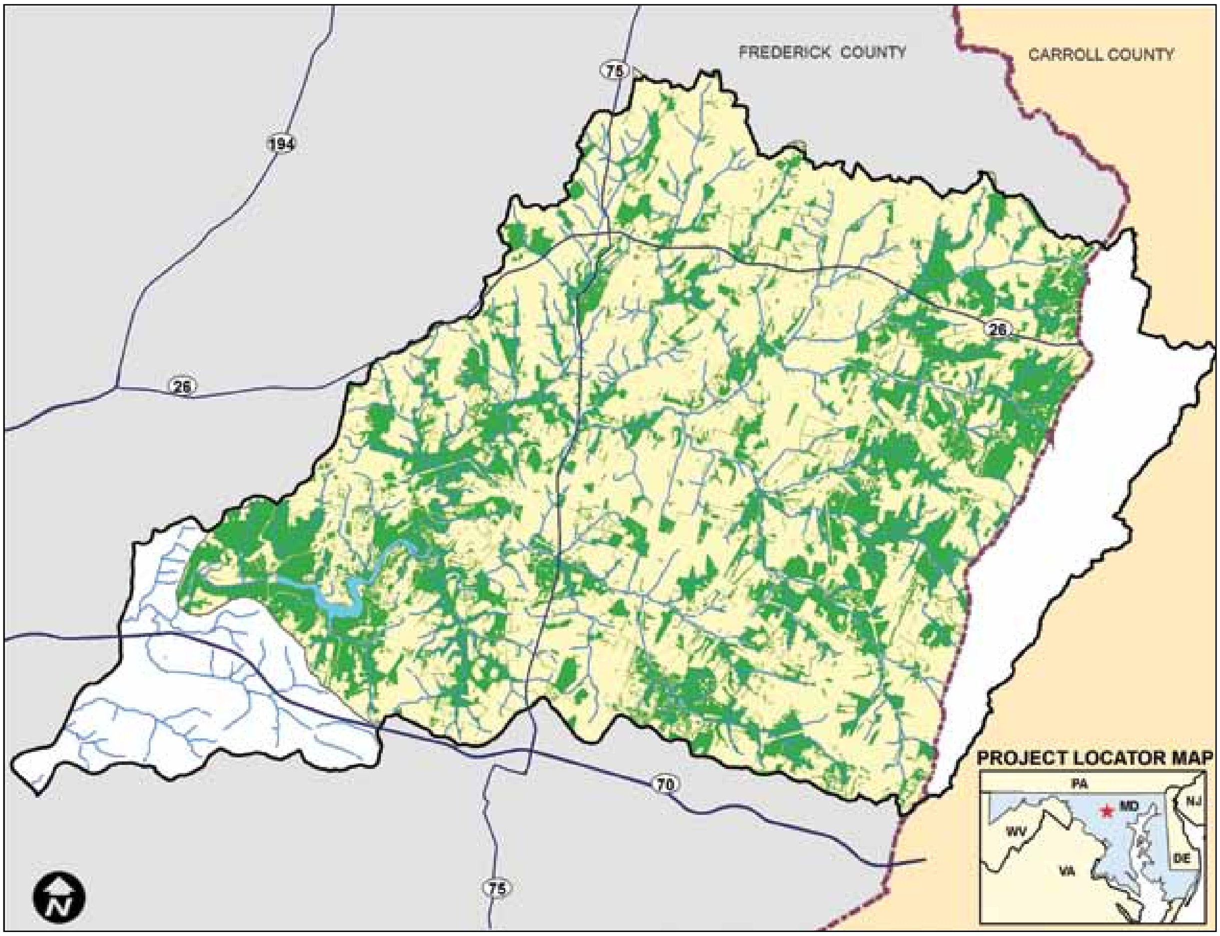

Figure 1. Forest cover (green) within the Frederick County portion of the Linganore Creek drinking water source area boundary (beige) in 2005. Approximately 90% of the Linganore source area is located within Frederick County, and the remaining 10% is within Carroll County. White areas are the portions of the Linganore Creek watershed that are either outside of the drinking water source area boundary or are in the Carroll County portion of the watershed; these areas were not analyzed in this study.

Maryland Department of the Environment (2002) has developed a total maximum daily load that will require measures to reduce sediment and phosphorus loads to the lake.

The Linganore Creek watershed had 28.2% forest cover in 2007, according to Maryland Department of Planning (MDP) land use/land cover data (Table 1). Most of the watershed's forest was cleared for agriculture by 1910. Agriculture continues to be the dominant land use within the watershed, especially in the northern and eastern portions; however, much of the land in the southern part of the watershed, along the I-70 corridor, is classified as low-, medium-, or high-density residential. Fifteen percent of the land use—primarily in areas adjacent to the lake—is urban. Although population data are not available for the watershed, the County population is expected to increase 38% by 2030 (Frederick County Government 2005, 2011), indicating considerable development pressure. This watershed has significant areas of highly erodible soils and steep slopes, exacerbating the sediment inputs to the lake any time land is disturbed. County watershed managers and environmental groups are concerned about the impact on these erodible soils of additional development that may further reduce the forest cover in the watershed and exacerbate erosion and phosphorus loadings to the creek and lake. Table 1 summarizes the land use distribution in the watershed.

Table 1. Land use/land cover distribution in the Linganore Creek watershed in 2007.

Type of Land Use/Land Cover	Percentage of Watershed
Urban/Suburban/Open Urban	15.2
Agricultural	55.7
Forest	28.2
Wetlands	0.04
Open Water	0.43
Barren/Transitional	0.52

Source: Derived from Maryland Department of Planning (forthcoming) 2007 land use/land cover data.

The management of forests in Frederick County is guided by the 1991 Maryland Forest Conservation Act (FCA). Md. Code Ann. [Nat. Res.] §5 1601–1613 (1991). The FCA requires local governments to develop forest conservation programs that must include an ordinance establishing standards for fulfilling forest conservation, reforestation, and afforestation requirements for certain land use categories and regulated activities. *Id.* § 5 1603–1612. In Frederick County, the local ordinance established under the FCA is the Forest Resource Ordinance (FRO), which was adopted in 1992. In 2007, significant and unique changes were made to the FRO that resulted in conservation requirements that are more stringent than what is mandated by the state law. Developers may choose to meet FRO requirements by purchasing forest banking credits or by paying a per-square-foot fee of required forest mitigation into a fee-in-lieu fund. In 2010, the Board of County Commissioners authorized the use of a portion of fee-in-lieu funds to purchase forest conservation easements along certain stream segments in the Linganore Creek watershed.

Methodology

To derive Frederick County FCCs that represent the proportion of a land use parcel covered by forest, we used ESRI ArcGIS© software and the basic protocol described below. Additional details are available from the Center for Watershed Protection (CWP 2011). Data used in this analysis include 1973 and 2007 (forthcoming) MDP land use/land cover data, 2005 planimetric data, 2008 parcels and tax points, 2008 subdivisions, and aerial photographs from 1988 to 2007. The County's 2005 planimetric data were the most recent and the most accurate available representation of forest cover for the study area. The data were delineated by Frederick County Department of Public Works staff from true color orthophotography with a 6-inch ground pixel resolution.

The first step in the FCC analysis was to select the targeted land use categories and the number of sampling units. The sampling units used in this study were polygons of homogeneous land use. The study used eight land use categories that corresponded to those defined by Cappiella and Brown (2001) for impervious cover coefficients. The purpose of aligning land use categories with this prior study was twofold: first, the categories are general enough to be readily transferable to other jurisdictions, and second, this approach should facilitate future land cover estimates that focus on impervious cover and forest cover using consistent land use categories and methods.

We delineated all sample polygons for those areas developed between 1973 and 2005. This time frame was based on the availability of 1973 land use/land cover data from MDP and the 2005 forest cover data derived from the County's planimetric data. It also corresponds to a period when Frederick County experienced significant urban development. From the 1970s to 1980s, the County population increased by 35.2%, from 84,927 to 114,792 (Frederick County Division of Planning 2004). The majority of the urban land created during this time period was for residential use.

Delineation of the sample polygons followed a set of criteria outlined in CWP (2011) with a brief description provided here. The polygons generally followed parcel boundaries; aerial photographs and parcel data, such as business or owner name, helped verify land use. The sample polygons included local and arterial roads where the parcels bordering each side of the road had the same land use. Local and arterial roads were included in the sample polygons if the parcels bordering each side of the road had the same land use. If a local or arterial road bordering a parcel had a different land use bordering the other side of the road, only half the road was included in the polygon. The polygons did not include interstate or state highways. For residential land uses, polygons followed the lot lines of contiguous parcels that correspond to that specific type of residential land use category (e.g., one-quarter-acre lots) and generally follow subdivision boundaries rather than individual parcels. Figure 2 shows an example of a residential polygon delineation.

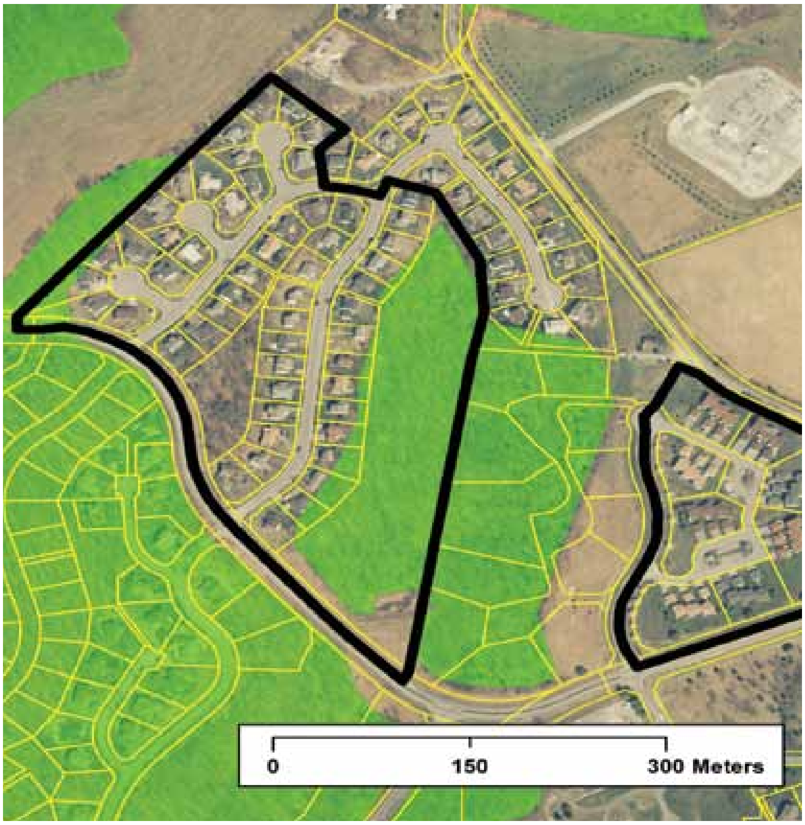

Figure 2. Example of a residential sample polygon delineation for Frederick County. Parcels are shown as yellow lines, forest cover in green, and the sample polygon delineation in black.

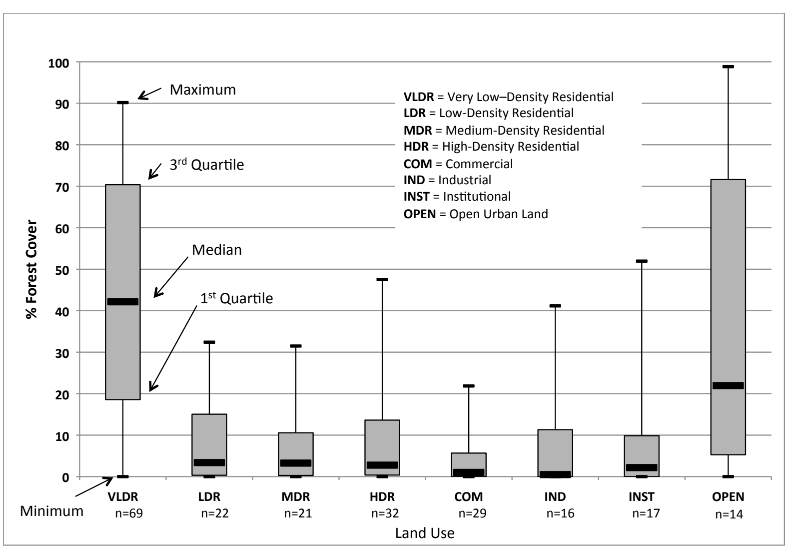

Figure 3. Box-and-whisker plot showing the percentage of 2005 forest cover across land use categories in Frederick County (n indicates the number of sample polygons delineated for each land use category).

In the final step, determining the percentage of forest cover for each delineated sample polygon involved calculating the area of each sample land use polygon and intersecting the layer with both the 2005 forest cover layer and the predevelopment forest cover layer extracted from the 1973 land use/land cover data. This allowed for calculations of the area of pre- and post-development forest cover within each land use polygon. We then divided the area of forest cover within each polygon by the sample polygon area to determine the percentage of forest cover before and after development.

Because of the high degree of variability in the data, the median proved to be a better measure of central tendencies as it discounts the importance of numbers outside the data range, whereas the mean tends to be affected by outliers. Figure 3 shows the median forest cover for all land uses. The data for the very low-density residential (VLDR) and open urban land (OPEN) land use categories have the most variability because they are influenced by the amount of predevelopment forest cover, as described further below.

For each land use category, we plotted the predevelopment and post-development forest cover data to determine whether the amount of forest cover present before development is influential in the amount that remains after development. Table 2 shows the results of a linear regression fitted to each plot, using the forest cover for the two time periods (1973 and 2005). Pre- and post-development forest cover were strongly correlated for only two land use categories, VLDR and OPEN. Low-density residential (LDR), industrial (IND), and institutional (INST) regressions were statistically significant at the 95% confidence level, but showed low correlation according to the R-squared values. Significant relationships for the remaining land use categories were not apparent. However, we found that the sample polygons for the OPEN land use category represented two distinct types of land use (i.e., recreational vs. passive) that should ideally be analyzed further to provide a more accurate estimate.

Table 2. Linear regressions comparing the percentage of forest cover before and after development.

Land Use Category	Linear Regression	R^2	Significance F
VLDR	Y = 0.0071X + 0.0397	0.86	0.00
LDR	Y = 0.0014X + 0.0043	0.24	0.02
MDR	Y = 0.0008X + 0.0048	0.09	0.20
HDR	Y = 0.0008X + 0.0066	0.06	0.17
COM	Y = 0.0003X + 0.0024	0.08	0.14
IND	Y = 0.0003X + 0.0024	0.62	0.00
INST	Y = 0.0062X + 0.0033	0.46	0.00
OPEN	Y = 0.0087X + 0.0142	0.98	0.00

Notes: Y, coefficient for post-development forest cover; X, % predevelopment forest cover. Significance F is the probability that the equation does not explain the variation in Y. If the significance F is less than 0.1, the correlation is significant.

Results

Results of the analysis show that the median percentage of 2005 forest cover best represents the post-development forest cover for the following land use categories: LDR, medium-density residential (MDR), high-density residential (HDR), commercial (COM), IND, and INST. For the VLDR and OPEN land use categories, the linear regression equation resulted in the most reliable estimate of post-development forest cover. Table 3 presents FCC recommendations for Frederick County.

Table 3. Recommended forest cover coefficients for Frederick County.

Land Use Category	Land Use Category Description	Forest Cover Coefficient	Measure of Variance
VLDR	Single-family residential development with a density of less than 1 dwelling unit per acre	Y = 0.0071X + 0.0397	0.110
LDR	Single-family residential development with a density of 1–4 dwelling units per acre	0.034	0.147
MDR	Single-family and attached residential development with a density of 5–10 dwelling units per acre	0.033	0.103
HDR	Residential development with a density of > 10 dwelling units per acre, generally multifamily development	0.028	0.132
COM	Retail, small office, and business uses	0.010	0.057
IND	Manufacturing and industrial facilities, including associated warehouses, storage yards, and research laboratories; business, professional, and corporate office parks	0.005	0.113
INST	Schools, churches, government offices, and facilities	0.022	0.098
OPEN	Golf courses, parks, recreation areas, and game preserves (except areas associated with schools or other institutions)	Y = 0.0087X + 0.0142	0.065

Notes: Y = coefficient for post-development forest cover; X = % predevelopment forest cover. Acres were used as opposed to hectares in the land use category descriptions because that is the unit of measure used by the County. Interquartile range, a measure of statistical dispersion defined as the difference between the third and first quartiles, is used as a measure of variance for the LDR, MDR, HDR, COM, IND, and INST land use categories, for which FCCs represent the median of the sample data. Variance for the VLDR and OPEN land use categories is the standard error of the linear regressions that are used to calculate these FCCs.

Table 4. Comparison of urban forest cover for various Maryland communities and the forest cover coefficients derived for Frederick County, expressed as percentages.

Community	Agriculture	Right of Way	Commercial	Industrial	Institutional/ Government Services	Apartments /Condos	Townhomes	Single-Family Residential
Frederick County[a]	—	—	10%	0%	2%	3%[c]	3%[c]	3%[c]
Frederick County – Brunswick[b]	2%	23%	6%–8%	10%	18%	—	—	30%–34%
Frederick County – Frederick[b]	—	7%	10%–17%	7%	9%	16%	16%	14%–20%
City of Baltimore[b]	5%	37%	24%	27%	32%	29%–33%	13%	53%
Anne Arundel County – Annapolis[b]	—	25%	20%	27%	34%	37%–40%	—	54%
Allegany County – Cumberland[b]	69%	28%	38%	26%	47%	18%–33%	—	57%
Howard County[b]	39%	37%	34%	28%	44%	36%–48%	33%	56%
Montgomery County – Rockville[b]	5%	37%	24%	27%	32%	29%–33%	13%	53%
Prince George's County – Bowie[b]	—	25%	20%–31%	49%	38%	47%	47%	47%
Prince George's County – Greenbelt[b]	—	43%	17%–28%	17%–24%	24%	64%	64%	64%
Prince George's County – Hyattsville[b]	—	28%	5%–17%	12%	24%	53%	53%	53%

Notes: — = no data. Ranges exist where data from two zoning categories were included under one land use classification for purposes of comparison in the table (e.g., Bowie does not have a general commercial zoning category, but instead uses retail trade and office buildings).

[a] FCCs derived as part of this study.

[b] Forest cover data developed by the US Department of Agriculture Forest Service and the University of Vermont SAL.

[c] Apartments/condos and townhouses are assumed to correspond to County medium-density residential (MDR) and high-density residential (HDR) data. Single-family residential is assumed to correspond to low-density residential (LDR). Very low–density residential (VLDR) is not included in this table.

Table 4 compares the derived FCCs, expressed as a percentage, with forest cover data for other Maryland communities that the US Department of Agriculture (USDA) Forest Service and the University of Vermont Spatial Analysis Lab (SAL) developed using high-resolution satellite imagery following the methodology presented in Grove et al. (2006) for New York City.

Frederick County communities generally have less forest (regardless of the data source) than other communities across land use categories. As expected, the USDA Forest Service/SAL estimates are higher than the FCCs because of the difference in the resolution of forest cover data. The resolution of the data used by the USDA Forest Service/SAL is such that it captures individual trees, whereas the data used to derive FCCs was a generalization of forest cover based on a minimum mapping unit. However, even considering the difference in data resolution, Frederick County forest cover is comparatively low. Another explanatory factor for the difference between the derived FCCs and the USDA Forest Service/SAL data is that the latter analysis includes forest cover on all lands within a given zoning category, whether the land is developed or not, whereas the FCC derivation was limited to parcels of developed land within a zoning category.

Application of Forest Cover Coefficients in the Linganore Creek Watershed

We estimated current forest cover (as of 2010) in the Linganore Creek watershed by subtracting the area of forest cleared between 2005 and 2009, documented by the County's FRO, from the area of forest in the 2005 forest cover layer. This application used the FCCs to estimate future forest cover in the Linganore Creek watershed via the GIS-based leaf-out analysis (Cappiella et al. 2005). Data used to complete the leaf-out analysis included: developed/undeveloped land, land use designations from the County's comprehensive plan, and protected land (e.g., conservation easements). The leaf-out analysis assumes that (1) no changes will occur in current zoning, (2) land cover on developed land will remain the same, and (3) buildable land will be developed according to the County's comprehensive plan. In addition, we assumed that all future growth within the Linganore Creek watershed would occur within the community growth areas identified in the comprehensive plan.

The leaf-out analysis for the Linganore Creek watershed included the following steps:

- identify buildable land
- calculate the area for each comprehensive plan category for buildable land
- multiply the buildable land in each comprehensive plan category by the corresponding FCCs
- calculate total forest cover on developed land
- sum future forest cover on buildable and developed land

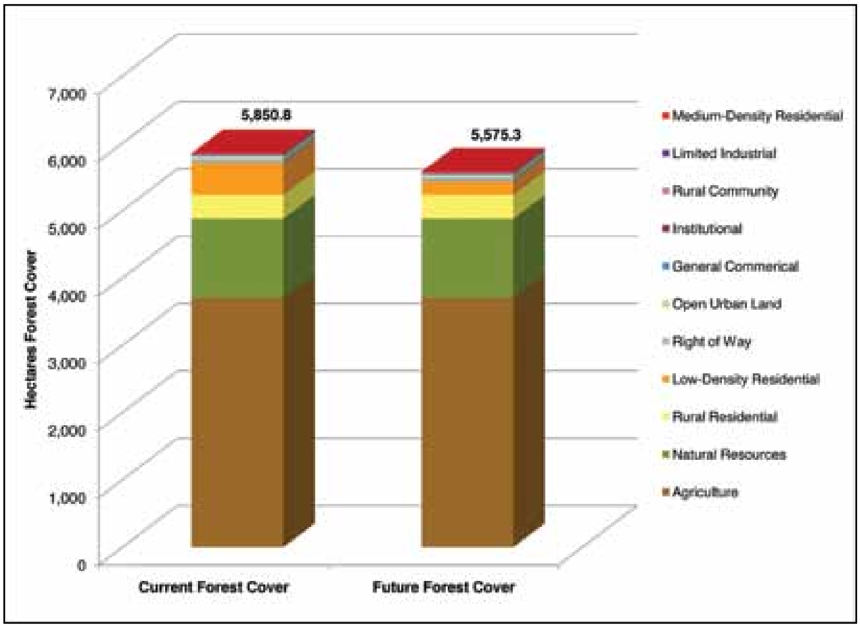

Figure 4. Current (as of 2005) and future forest cover (with watershed build-out) by comprehensive plan land use designations in the Linganore Creek watershed. Current forest cover is representative of 2005 instead of 2010 because the FRO estimates of forest loss are tallied on a watershed scale, and therefore could not be subtracted from the individual land use designations to obtain an estimate of forest cover for 2010.

The results of the leaf-out analysis (Table 5) show that, for the entire Linganore Creek watershed, the estimated 2010 forest cover is 30.0%, and forest cover is likely to decrease to 28.6% under the future build out scenario, resulting in a loss of 256.9 ha (634.8 acres) or 4.4% of 2010 forest cover. At the watershed scale, forest loss is minimal; however, this loss is more substantial within the community growth areas. Figure 4 shows the distribution of forest cover by the different comprehensive plan land use designations under current and future build out conditions for the Linganore Creek watershed. The greatest loss in forest cover will occur with the development of the LDR land use, with a loss of 270.2 ha (667.7 acres). This is followed by OPEN (2.7 ha [6.6 acres]), right-of-way (1.9 ha [4.8 acres]), and COM (0.5 ha [1.3 acres]) land uses.

Table 5. Summary of current and future forest cover for the Linganore Creek watershed.

Forest Cover	Hectares	%
2010 Forest Cover	5,832.2	30.0
Future Forest Cover	5,575.3	28.6 (potential error of −0.1% to +0.3%)[a]
Loss in Forest Cover	4.4%	

[a]The potential error was calculated using the first quartile of the sample data for the low-end estimate of error and the third quartile for the high-end estimate of error. The exception was for OPEN, for which the forest cover coefficient was calculated by a linear regression that used standard error as opposed to the quartiles to estimate error.

In addition to the leaf-out analysis, we assessed runoff volume and pollutant loadings using the Watershed Treatment Model (WTM; Caraco 2010) for three scenarios—Predevelopment (99.7% forest), Existing Development (30.0% forest), and Future Build Out (28.6% forest) of the watershed based on comprehensive land use plan designations. For each scenario, we calculated annual loading rates for total nitrogen (TN), total phosphorus (TP), and total suspended sediment (TSS). This analysis used GIS and 2007 land use/land cover data for Frederick County (MDP forthcoming). While the runoff and pollutant estimates for the existing and future scenarios do not reflect absolute values—because they do not account for secondary sources of pollution (i.e., non–land use factors such as road sand, septic systems, and channel erosion) or the presence of management practices to treat runoff—the results of this analysis show the relative change in runoff and pollutants associated with land use changes in the watershed.

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The WTM calculates annual runoff and pollutant loading rates based on annual rainfall, pollutant concentrations, and land cover coefficients for forest, impervious cover, and turf using the modified simple method equation described by the Virginia Department of Conservation and Recreation (2011). This analysis used event mean concentrations, derived from a watershed assessment of Lower Linganore Creek (Perot et al. 2002), for TN, TP, and TSS instead of the default values provided with the WTM. For the Existing Development scenario, we determined land cover distribution across urban land uses by multiplying the total acreage of each land use by the FCCs and a Frederick County–specific impervious cover coefficient for each of the eight land use categories, with the exception of VLDR and OPEN. For VLDR and OPEN, we derived land cover distributions directly from the GIS. The analysis assumed that land cover not classified as forested or impervious was turf. For the Future Build Out scenario, we also used land cover coefficients to determine the distribution of forest, impervious cover, and turf across urban land use types. To solve the linear regression formula for VLDR and OPEN in the Future Build Out scenario, we used the 2005 forest cover layer to calculate predevelopment forest cover as an input to the equation. One could derive a more accurate estimate of urban land cover for the Existing Development scenario by directly deriving impervious and forest cover from the GIS. However, use of the land cover coefficients allowed for consistency with the Future Build Out scenario since the primary goal of this exercise was to evaluate relative changes in pollutant loads under different land use scenarios; in addition, the use of land cover coefficients provides a reasonable approximation of land cover distribution.

The results, presented in Table 6, show that pollution loading increases as forest cover is replaced with agriculture and urban uses. Comparing Predevelopment to Existing Development reveals that TN increased 82%, TP increased 289%, and TSS increased 30%. Comparing Existing Development to Future Build Out reveals that TN may increase an additional 3%, TP may increase by 5%, and TSS may increase another 3%.

Discussion

A number of data limitations were apparent in the Frederick County study. For example, the 1973 forest cover derived from MDP data are mapped at a lower spatial resolution

Table 6. Estimated annual land use–based pollutant loadings for the Linganore Creek watershed.

Land Cover Scenario	Annual Runoff (m^3/year)	TN (kg/year)	TP (kg/year)	TSS (kg/year)
Predevelopment (99.5% forest cover)	4,019,918 (3,259 acre-feet/year)	55,560 (122,487 lbs/year)	4,392 (9,683 lbs/year)	2,186,447 (4,820,210 lbs/year)
Existing Development (30.0% forest cover)	15,166,894 (12,296 acre-feet/year)	101,001 (222,665 lbs/year)	17,106 (37,712 lbs/year)	2,846,646 (6,275,675 lbs/year)
Future Build Out (28.6% forest cover)	16,589,099 (13,449 acre-feet/year)	103,706 (228,628 lbs/year)	17,939 (39,549 lbs/year)	2,934,435 (6,469,212 lbs/year)

(i.e., a 4-ha [10-acre] minimum mapping unit) than the 2005 forest cover derived from the planimetric data; therefore, the predevelopment forest cover is typically over- or underestimated (e.g., forest tracts less than 4 ha [10 acres] are not mapped). Further, many areas reforested as part of the FCA are not reflected in the 2005 forest cover data because they had not yet matured enough for mapping methods to classify these areas as forest. New plantings typically take an estimated 5–10 years to become established and 15 years until they are identifiable using moderate-resolution remote-sensing imagery. However, the ability to identify and map individual tree canopy is also dependent on the spatial resolution of the remote-sensing imagery (e.g., 30-m Landsat compared to digital aerial imagery at a resolution of less than 0.3 m).

Many variations on the methods described here to derive FCCs are possible, depending on the available data, the scale at which the coefficients will be applied, and the representative land use categories chosen. The methods chosen to delineate sample polygons may also affect the derivation of FCCs. For example, delineation of sample polygons for determining FCCs can be done by (1) using individual parcels, (2) lumping parcels in the same land use category (as we did for Frederick County), or (3) on a broader scale, analyzing all areas of the same land use together. Delineation based on individual parcels is a good way to evaluate land cover for a large number of parcels within each land use type. However, the ability to account for the land cover changes associated with urbanization taking place outside of individual parcels (e.g., road networks created to sustain urban development) is limited under this approach. Lumping of parcels in the same land use category can be used to capture these changes, but is a more time-intensive process because it requires the development of criteria for delineating land use polygons, which then need to be hand-delineated. A subdivision is an example of a case in which aggregation of individual parcels into one land use polygon is applicable.

Whichever method is chosen to delineate sample polygons, the number of sampling units chosen for each land use category should be based on the frequency and variability of land uses or zoning categories. For example, a larger sample size would be needed with greater variability of land cover within a given land use. For this analysis, we initially targeted 10 sample polygons for each land use. Statistical analysis showed that the data did not follow a normal distribution; therefore, it was not possible to accurately predict the sample size needed to provide a statistically significant result. As an alternative, all possible sample polygons that were developed between 1973 and 2005 were delineated; this provided the maximum possible sample size.

Comparing Predevelopment to Existing Development reveals that TN increased 82%, TP increased 289%, and TSS increased 30%.

One option for improving the FCC methodology in Frederick County is to delineate a larger number of sample polygons built after establishment of the FRO. Originally, we attempted this as part of the FCC derivation for Frederick County, but not enough sample polygons were delineated for areas developed after establishment of the FRO to yield reliable results. This expanded analysis would help determine forest cover impacts that can be attributed to the FRO. In addition, one could incorporate the age of the development into sample polygon delineation to determine how age affects the FCCs. One would expect that older developments should have greater percentages of forest cover because trees in such developments have been growing for a longer duration. Last, one could obtain a more accurate FCC estimate for OPEN by analyzing the different types of land use within this category, such as parks, golf courses, and playgrounds.

Results of the FCC derivation in Frederick County show that post-development forest cover for all land uses except VLDR and OPEN is less than 5%, suggesting that forest loss in response to development is substantial, despite pre-existing land use conditions and the requirements of the County's FRO and the Maryland FCA. One potential explanation is that many areas reforested on-site as part of the FRO are not reflected in the 2005 forest cover data because they had not yet matured enough for mapping methods to classify these areas as forest, or reforestation to meet FRO requirements occurred off-site and was therefore not captured in the land use polygon analysis. In addition, in many areas within the County, the predevelopment land use is agriculture, which experienced forest clearing prior to development. Unless on-site reforestation were to occur as part of the development process, these areas would continue to have low percentages of forest cover. Note that the County updated the FRO in 2007 to encourage greater forest conservation on-site. All of the land use polygons delineated for determining the FCCs were built prior to 2007; therefore, the FCCs may not be representative of expected forest conservation on future development sites in Frederick County.

One of the assumptions of the leaf-out analysis was that land outside of the community growth areas would not be rezoned. However, rezoning is a real possibility, especially considering the population increase projected for the watershed. In fact, future forest loss may actually be greater than predicted. In addition, even with the concentration of growth caused by the community growth areas, development within the watershed continues to place added stress on the drinking water supply reservoir in terms of water quality. While the WTM-estimated increase in pollutants and runoff in the Future Build Out scenario relative to the Predevelopment scenario cannot be ascribed solely to the loss of forest cover (since forest loss is always associated with the addition of a new land cover), the results imply that forest conservation and reforestation measures have great potential in helping the County meet regulatory requirements for pollution reduction in the watershed.

The leaf-out analysis results presented in this study will aid the development of (1) a forest cover goal for the Linganore Creek watershed and (2) recommendations to achieve this goal and to analyze the impacts of these actions. Recommended actions may include reforestation, the protection of forests with high value for water quality and habitat protection, and the implementation of outreach or incentive programs to encourage tree planting on private land. The GIS data derived for input to the leaf-out analysis can be used to target actions to specific land use types. For example, if most of the forest loss will occur on LDR lands, forest tracts on these lands can be evaluated, prioritized, and targeted for conservation. Similarly, one could use the land use distribution and associated land use coefficients in the watershed to identify the land use types with the greatest reforestation potential and target outreach programs accordingly. Once identified, these actions can be incorporated into the leaf-out analysis to determine how their implementation will impact future forest land use in the watershed.

Summary

Urban watershed forestry acknowledges the importance of trees and forests in protecting water resources. The development of FCCs facilitates the ability of local governments to anticipate and manage the forest loss that accompanies urban growth. The FCCs and leaf-out analysis can be useful tools for estimating future changes in forest land use, defining watershed forestry goals, and informing local government strategies on forest conservation and afforestation. The FCCs presented in this analysis can be used in similar Maryland communities (i.e., watersheds with a mix of urban, suburban, and rural land with development pressure), but have limited application outside of the state because of variations in forest management regulations and watershed conditions. When applying the methodology presented in this study to derive FCCs and conduct the leaf-out analysis in other communities, the methods should be adjusted based on available data and local conditions.

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