An Assessment of Forest Cover and Impervious Surface Area on Family Forests in the New York City Watershed

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ABSTRACT

Between 1984 and 2000, the parcelization of family forests in the New York City Watershed caused a decline in average parcel size from 19 to 16 ac. However, little is known about the timing and intensity of development on subdivided parcels, which has the potential to negatively affect water quality by increasing nonpoint source pollution associated with nutrient runoff and erosion intensified by increased impervious surface area. Using a combination of field measurements and analysis of digital orthoimagery, this study quantified forest cover and impervious surface area on new parcels resulting from subdivision and compared subdivided parcels to intact parcels. Measurements of buildings, driveways, and other features show that by 2005, parcels subdivided between 1984 and 2000 were developed to nearly the same intensity as intact parcels, with 68% of parcels classified as developed. Results indicate that residential development on subdivided parcels has added more than 640 ac of impervious surfaces on family forest since 1984, apparently without being accompanied by observable net reductions in forest cover at the landscape level. These trends have important implications for public policy intended to maintain a forested watershed and prevent the degradation of drinking water quality from nonpoint source pollution associated with development.

Keywords: parcelization, land cover, development, impervious surface, watershed management

The west-of-Hudson New York City (NYC) water supply system (the Watershed), spans 1,625 mi^2 and includes six reservoir basins and two major watersheds, the Catskill to the east and the Delaware to the west (Figure 1). Approximately 1.1 billion gallons of water per day is delivered from the six reservoirs through an extensive network of aqueducts connected to the east-of-Hudson Croton water supply system north of the city (NYC DEP 2008). The forested nature of the Watershed, combined with chemical treatment measures to control sediment loads, is responsible for producing water of sufficient quality that the system was granted a 10-year filtration avoidance determination by the US Environmental Protection Agency (EPA) in 2007, continuing its status as one of the largest unfiltered municipal water supplies in the world. In economic terms, filtering the city's water would cost taxpayers and consumers approximately $10 billion in construction costs for a new filtration facility and $400 million per year for operating costs (NYC DEP 2008). This fact has provided a strong incentive for maintaining high water quality by reducing pollution from agriculture and protecting forests in the region from development through land acquisition and conservation easements.

New York State and NYC have combined land holdings of approximately 282,000 ac, or 29% of the Watershed area, which includes the Catskill Forest Preserve. The balance of the watershed area (more than 700,000 ac) is in private holdings dominated by family forest owners. Since signing the landmark New York City Watershed Memorandum of Agreement in 1997, NYC and the Watershed Agricultural Council (WAC; a nonprofit created to administer the voluntary, incentive-based Watershed Agricultural Program), have purchased conservation easements on private holdings totaling approximately 27,000 ac. In total, about 34% of the 1 million-ac Watershed is protected permanently in public ownership and through conservation easement, with about 66% of the Watershed classified as private land in unprotected status (NYC DEP 2010, VanBrakle 2011).

Previous studies have shown that between 1984 and 2000, the average size of a private parcel in the Watershed dropped from 19 to 16 ac (LaPierre and Germain 2005, Hall et al. 2008). Tax records show that up to 6% of the aggregate area held in parcels greater than 100 ac was subdivided into smaller parcels over this period. Most notable is the increase in the total number and aggregate area of parcels in the 5–10-ac class, a lot size that is especially appealing to homeowners interested in the aesthetic values and privacy provided by a residence on a forested parcel. LaPierre and Germain (2005) reported that private forested tracts greater than 100 ac made up an estimated 43% of the land area in 2000. This figure likely declined further by 2010, despite the housing downturn late in the decade.

Development following parcelization, including the construction of new buildings and roads, has potential negative implications for water resources. Forested watersheds are associated with high water quality (Stolton and Dudley 2007), and the negative effects of forest loss due to urbanization have been well documented in many

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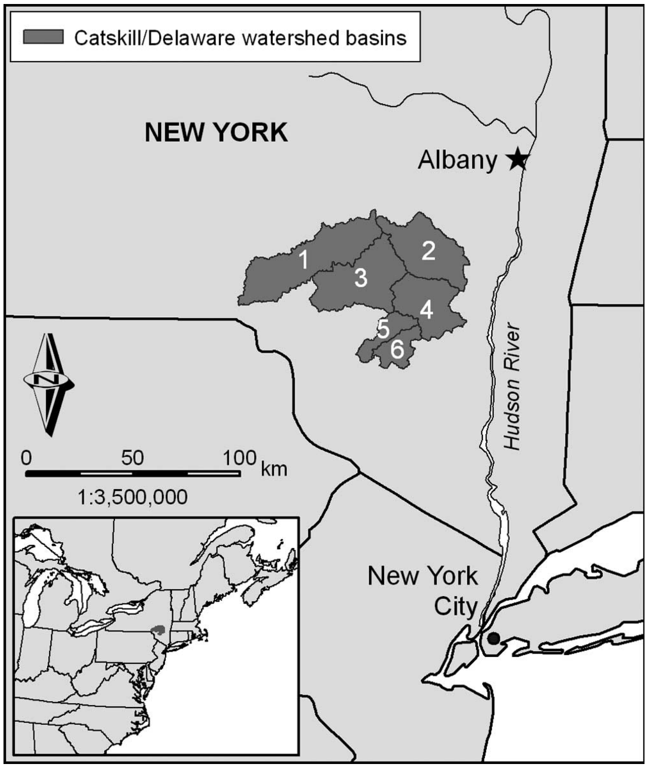

Figure 1. Location map of the west-of-Hudson New York City Watershed and component reservoir basins. The Delaware Watershed includes the Cannonsville (1) and Pepacton (3) basins. The Catskill Watershed includes the Schoharie (2), Ashokan (4), Neversink (5), and Roundout (6) basins.

regions (Hatt et al. 2004), including the east-of-Hudson water supply system (Burns et al. 2005, Heisig 2009). In general, the density of housing units is positively correlated with impervious surface area and negatively correlated with forest cover (MacDonald and Rudel 2005, Lathrop et al. 2007). In the urbanizing environment, poor water quality is closely linked to runoff from impervious surface cover, which intensifies surface water flow and the surface transport of sediments and other pollutants (Schueler 1994, Arnold and Gibbons 1996, Rogers and DeFee 2005, Xian et al. 2007). Low-density residential development in suburban, exurban, and rural environments has also been linked to significant negative water quality impacts, including nonpoint source contamination from lawn chemicals and fertilizers, septic systems, sump pumps, fecal contamination, and sediment (Bolstad and Swank 1997, EPA 2006, Schiff and Benoit 2007, Conway 2007). Furthermore, research indicates that low-density patterns of development can be associated with higher impervious surface area per housing unit (Stone 2004). These studies show that low-density patterns of development are not without risk and may be important to consider in rural watersheds.

Parcelization is widely acknowledged as a precursor to development (Best 2002). However, the timing and intensity of development on parcelized forestland has not been well documented, even in the Watershed, where parcelization trends have been quantified and watershed management by public agencies is widespread (LaPierre and Germain 2005, Hall et al. 2008). Our objectives in this study are to quantify the forest cover and impervious surface area present on private forestland and to examine the relationships between parcelization, development features, and forest cover. Using a combination of field measurements and analysis of digital ortho-

Table 1. Frequency distribution of surveyed parcels according to parcelization type and parcel size class. Stratified sampling was used to adequately represent larger parcel sizes.

	Parcel type		
Parcel size class (ac)	Intact	Subdivided	Total
5–9.9	19	29	48
10–49.9	24	20	44
50–99.9	15	6	21
≥100	16	8	24
Total	74	63	137

imagery, we compared subdivided parcels to parcels that remained intact from 1984 to 2005 to evaluate the impact of parcelization on these metrics. Patterns are discussed in light of observed trends in parcel-level and landscape-level forest cover inferred from spatial models of land cover and land use based on remote sensing and field data.

Methods

Two previous studies quantified parcelization in the Watershed using a stratified cluster sample of 4,216 parcels, 28% of which were determined to have been subdivided from a larger parcel (i.e., "parcelized") between 1984 and 2000 (LaPierre and Germain 2005, Hall et al. 2008). This study uses a stratified random subsample of parcels from the original sample of 4,216 parcels. Using parcel attribute data, we contacted 1,267 land owners by mail to request permission to complete an on-site field survey, which included a land cover assessment and measurements of impervious surface area on each parcel. This subsample was stratified by parcel size, county, and parcel type (intact or subdivided) and did not include any parcels smaller than 5 ac. The focus of this study is family forest, and parcels smaller than 5 ac were not included in the sample because they were deemed to be too small for forest management and thus are not classified as family forest. We acknowledge that some resource managers believe the threshold for forest management to be higher than 5 ac; however, we agree with DeCoster (1998) that traditional forestry practices will have to adapt to smaller parcels, especially in areas with high rates of parcelization and development, and therefore we included parcels down to 5 ac.

By definition, the boundaries of parcels classified as intact did not change between 1984 and 2000, whereas parcels classified as subdivided were newly created by division of a single, larger parcel into two or more parcels sometime during that period. Using the parcelization topology presented by Donnelly and Evans (2008), 46% of subdivided parcels were the result of the parcelization of a large "parent" parcel into a relatively large number of "child" parcels of similar area—a pattern indicative of organized subdivision for residential housing. To isolate the effects of a single occurrence of parcelization over the study period, none of the sampled parcels in either group were further parcelized between 2000 and 2005, the year of the field survey. Of the 1,267 landowners we contacted, 187 agreed to allow a field assessment. During the summer of 2005, we were able to conduct field assessments on 137 parcels, including 63 subdivided parcels and 74 intact parcels (Table 1). The relatively small sample size reflects the tradeoff between sample size and the resource demands of detailed field surveys that include intensive measurement of development features, forest cover, forest stocking, and other variables (Germain et al. 2007). Although studies using

Table 2. The most common land use and cover classifications in the study region (Anderson 1976).

Level I	Level II
Forestland	41 deciduous forestland
	43 mixed forestland
	42 evergreen forestland
Agricultural land	21 cropland and pasture
	22 orchards, groves, vineyards, etc.
	24 other agricultural land
Barren land	76 transitional areas
Urban or built-up land	11 residential
	16 mixed urban or built-up land
	17 other urban or built-up land

landowner surveys and remote sensing data are common, field research of this type focused on family forest is rare and generally provides less statistical power but more detailed information.

The cover classification of each parcel was based on three sources of evidence: field data, inspection of digital orthoimagery, and the results of landowner surveys (Caron et al. in press). In the field, we systematically sampled each parcel using variable radius point samples on a rectangular sampling grid (Germain et al. 2007). The distance between sampling points on the grid was calculated to meet minimum sample targets for each parcel size class, with an average of 15.3 sampling points per parcel and 2,093 points total, representing a sampling intensity of approximately 0.35 points per acre across all cover types. Each point was categorized as forest or nonforest according to level I US Geological Survey (USGS) land use and cover classifications (Anderson et al. 1976) (Table 2). Level I classifications represent major cover types that can be relatively easily distinguished from one another, such as forest and agricultural land. For every sampling point, regardless of its land cover classification, we measured a variety of forest stocking variables, including basal area, tree diameters, and species composition (Germain et al. 2007).

The US Forest Service (2008) defines forest as "land that is at least 10% stocked by forest trees of any size, including land that formerly had tree cover and that will be naturally or artificially regenerated." The vast majority of points categorized as forest in this study occurred in closed-canopy mixed hardwood or coniferous forest. However, the forest cover designation also includes areas that had no trees present at the time of the field survey, such as clearcuts or other regeneration harvests, and some areas with very low basal area, such as abandoned fields that are transitioning back to forest. All points on abandoned agricultural lands that were classified as forest included the presence of woody stemmed species characteristic of old fields in transition from field to forest, including white ash (*Fraxinus americana*), pin cherry (*Prunus pensylvanica*), dogwood (*Cornus* spp.), eastern redcedar (*Juniperus virginiana*), hawthorn (*Crataegus* spp.), open-grown white pine (*Pinus strobes*), and a variety of woody shrub species. We assumed that old fields dominated by the successional old field forbs and grasses, but not containing the woody species, were being maintained as open field by occasional mowing. Responses to a landowner survey (Caron et al. in press) were used to help make this determination. In the study region, such areas are often kept in an old-field state to maintain a scenic view, rather than for agricultural purposes.

Beyond the level I designation, nonforest points were further classified based on USGS level II classifications, which are more detailed than level I classifications (Table 2). For example, agricultural land can be further designated as cropland or orchard. All nonforest sample points showed evidence that they are being kept clear of trees, either by site conditions or human intercession. The nonforest designation includes open water, crops, mowed fields, and actively grazed pasture. It also includes mowed lawns (even if there are shade trees present on lawns) and developed surfaces that are clear of trees, as well as old fields kept clear of woody vegetation by occasional mowing.

Analysis of land cover was carried out in ArcGIS 9.1 using digital orthoimagery from the New York State GIS Clearinghouse (2011) coupled with digital property boundaries obtained from the New York City Department of Environmental Protection (DEP). The panchromatic digital orthoimagery quarter quadrangles used in the analysis were captured in 2004 at a 24-in. resolution. For each of the 137 sampled parcels, we digitized land cover polygons within the parcel boundaries to delineate forest and nonforest cover types on the parcel at a map scale of 1:3,000. We relied most heavily on the field data and orthoimagery in the determination, using field data to identify the vegetative cover present on photos and using photos to delineate the physical extent of cover types described by the field data. Mail survey responses related to past, current, and future land use were used to help designate borderline cases, especially with regard to land that appeared to be in transition from field to forest.

The designation of parcels as developed or undeveloped was based on field measurements of development features, with all developed parcels having at least one structure at the time of the field survey. We used a measuring wheel to record the dimensions of impervious surface area, including all structures and driveways. Structures were defined as any building that has a roof, is permanently affixed to the ground, and is used for shelter of humans, animals, property, or goods. This includes homes, cabins, garages, barns, and other outbuildings, such as sheds and pavilions. These features were measured according to the area of ground they occupied, not including the overhang of the roof. In some cases, structures were located under the forest canopy and were not clearly visible on orthoimagery, which field crews referenced in hard copy during their field surveys.

We defined driveways as any private track used for vehicles that leads from a public thoroughfare to a structure. A driveway could be of any surface type but had to lead to a structure of some kind, including barns, cabins, and outbuildings, as well as garages and primary residences. This definition excludes forest roads from the driveway designation, and properties with forest roads were not considered developed unless structures were also present. In addition to these features, we measured the dimensions of any parking areas associated with driveways and included these measurements with driveway area in the final field tally. Driveways were characterized into four cover types: paved, gravel, soil, and other, with the "other" category represented by primarily grass or mixed grass and bare soil cover. For driveways with mixed cover types, the area of each cover type was calculated and recorded independently, and then the segments were summed to compute total driveway area for each parcel. The gravel/mixed base surfaces were included as part of the impervious surface measurement because of their low hydrologic conductivity and relative imperviousness. On well-drained soils, gravel surfaces have the second highest surface run-off index (76 of 100), after paved and building surfaces (98 of 100). Mixed-base driveway surfaces on similar soils are also relatively impervious (USDA Soil Conservation Service 1986).

Because of limitations of the parcel sampling process and variability in data quality at county tax offices at the time of sampling, we cannot say with certainty that all the development features on subdivided parcels were built after subdivision. It is possible that a portion of parcels in the subdivided group were subdivided with development features in place. Based on post hoc analysis of available data, we estimate that up to 19% of parcels in the subdivided group possibly had development features on them at the time of subdivision. This estimate is half of the maximum percentage of subdivided parent parcels that had structures built prior to 2000 based on cross-referencing parcels in our sample with tax databases that include "year built" records. However, we could not account for preexisting development directly with absolute certainty because state and local records do not share a common parcel identification scheme back to 1984. Results should be interpreted accordingly, and the implications of this sampling constraint are discussed below.

Analysis of variance (ANOVA) was used to examine differences in parcel characteristics between intact and subdivided parcels. The sample of 137 nonindustrial private forestland parcels was blocked by both watershed and parcel size, with two watershed groups (Catskill and Delaware) and four parcel size classes. Parcel size classes were chosen to be consistent with previous work (LaPierre and Germain 2005, Germain et al. 2007, Hall et al. 2008) and are based on thresholds for different forest management and property tax designations. For example, the 50-ac threshold is based on New York's 480-a forest tax law, which requires 50 ac of contiguous forest for enrollment. We compared adjusted means for the intact and subdivided groups to account for the effects of blocking factors on the within-group means. The adjusted means were calculated using the least-squares function in SAS software version 9.1 (Goodnight and Harvey 1978, SAS Institute Inc. 2004). The least-squares mean, also called the estimated population marginal mean, adjusts the group mean to account for unequal sample sizes and blocking effects, allowing a clear comparison of the means for intact and subdivided parcels. Comparisons of the number of structures between groups were evaluated using the chi-square statistic of the nonparametric Kruskal-Wallis test. SAS software, version 9.1 (SAS Institute Inc. 2004), was used for all calculations and statistical tests. A significance level of 0.10 was used for all statistical tests unless otherwise noted.

All of the parcels examined in this study are private properties and were surveyed with the written permission of the landowner. Given this fact, nonresponse bias is a possibility. To examine the possibility that the properties of respondent landowners are not representative of the sample frame as a whole, we took a stratified random sample of 76 parcels greater than 5 ac held by nonrespondent owners from the original sample of 4,216 nonindustrial private forest parcels, and used orthoimagery to delineate forest and nonforest cover types on these nonrespondent parcels. Photos were also used to count the number of structures visible on each nonrespondent parcel. Obviously, field data and mail survey responses were not available to validate cover designations for the parcels owned by nonrespondents. However, experience using field data to interpret cover types on the 137 respondent parcels generally supported photo interpretation of cover types and structure identification. ANOVA blocked by watershed and parcel size class was used to examine the difference in mean forest cover between respondent and nonrespondent groups. The Kruskal-Wallis test was used to compare the median number of structures in these groups.

Results

Mean forest cover for the sample was 83% (Table 3). Seventy-five parcels (55%) had greater than 90% forest cover, and 92 parcels

Table 3. Forest cover and impervious surface area (ISA) variables for all parcels (n = 137). These estimates include parcels with no development features present at the time of the field survey.

Variable description	Median	Mean	Standard error
Parcel area, ac	15.4	43.5	5.2
Forest area, ac	12.5	36.6	4.3
% Forest	92.1	83.1	1.8
Basal area, ft^2	107.0	105.4	2.1
Non-forest area, ac	1.5	6.9	1.4
% Non-forest	8.0	16.9	1.8
# of structures	1.0	1.8	0.2
Area of structures, ft^2	1550	1897	189
Area of driveway, ft^2	495	1320	154
% paved[a]	0.0	19.4	4.3
% gravel[a]	100	59.9	5.2
% soil[a]	0.0	7.9	2.8
% other[a]	0.0	12.8	3.3
Area of ISA, ft^2	2713	3220	300
% ISA	0.13	0.51	0.07

[a] Percentage of total driveway area for parcels with driveways (n = 75)

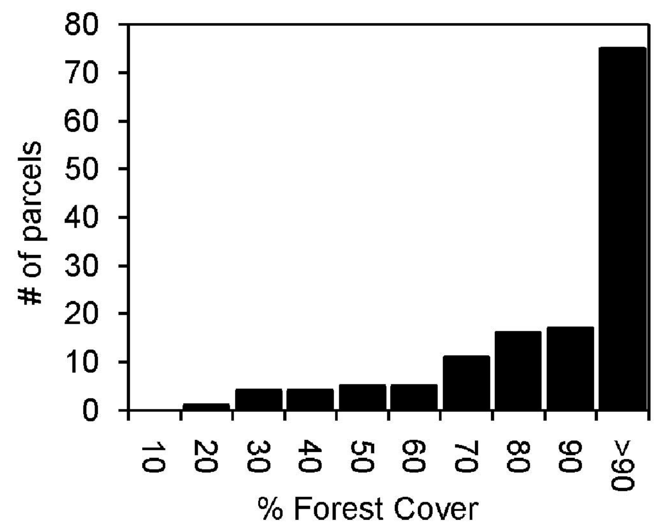

Figure 2. Distribution of parcels in the sample (n = 137) by percentage of forest cover.

(67%) had greater than 80% forest cover (Figure 2). It is important to reiterate that the mean of 83% is for family forest parcels greater than 5 ac, not for the entire area of the Watershed. For comparison, Tyrrell et al. (2004) reported all privately owned lands within the watershed as 79% forested (95% CI +3.2%/−3.5%), including shrublands, based on remote sensing data. For the blocking factors, the two watersheds were significantly different (P = 0.057), as we expected based on the higher percentage of agricultural land in the Delaware watershed, but parcel size class did not have a significant effect on percentage of forest cover (P = 0.460). The percentage of forest cover between the subdivided and intact parcels was also not significantly different (P = 0.236), with least squares means for the two treatment groups of 83 and 84% and medians of 88.9 and 94.1%, respectively. Nonresponse bias did not appear to be a concern with regard to percentage of forest cover. With a mean of 86% forest cover, the nonrespondent group was not significantly different from the respondent group (P = 0.358), which had a mean of 83% forest cover.

Overall, 75 parcels (55%) had a driveway and at least 1 structure, 18 parcels (13%) had at least 1 structure but no driveway (i.e., parking on a public road), and 44 parcels (32%) had neither. The

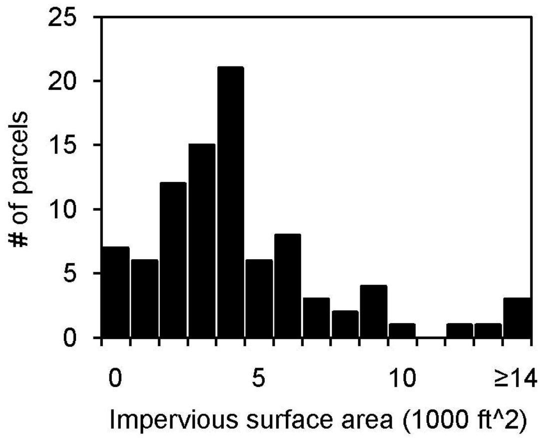

Figure 3. Distribution of parcels in the sample by impervious surface area (1,000 ft^2) for intact and subdivided developed parcels only (n = 93). Forty-four parcels (32% of the sample) had no development features present at the time of the survey.

average number of structures was 1.8 structures per parcel, and the average area of structures was 1,897 ft^2, with an average area of driveway of 1,320 ft^2 (Table 3). Among the 75 parcels that had driveways, gravel was the most common surface type (60% on average and 55.5% of total measured driveway area), followed by pavement (19% on average and 20% of total measured area). Bare soil and other driveway surfaces accounted for 24.5% of total measured area. Combining these features into a single metric, average developed surface area for the entire sample was 3,220 ft^2 per parcel, or 0.51% of total parcel area, on average, with a median of 2,713 ft^2 per parcel. The distribution of parcels by total developed surface area was right skewed (Figure 3). The outlying measurements of very high impervious surface area were taken on parcels characterized by large barns and many outbuildings with associated driveways.

With respect to the effects of parcelization on development, 76% of the intact parcels in the sample were developed at the time of the field survey, compared with 60% of subdivided parcels. As mentioned previously, based on post hoc analysis of tax databases, we estimated that up to 19% of parcels in the subdivided group may have had development features present at the time of subdivision. This has the effect of reducing the percentage of development that can be considered new development on subdivided parcels. Including all parcels in both groups, the means for impervious surface area for intact and subdivided parcels were 3,923 and 3,017 ft^2, respectively, which are not significantly different ($P = 0.216$). If we compare the effects of parcelization on the developed parcels only, treatment effects are not significant for any of the variables measured (Table 4). The two parcelization groups are very similar with regard to percentage of forest cover, number of structures, area of structures, area of driveway, and total impervious surface area. On average, intact and subdivided parcels had 5,021 and 4,483 ft^2 of impervious surface area on developed parcels, representing 0.64 and 0.58% of total parcel area, respectively. Among developed parcels, nonrespondent parcels averaged 2.2 structures per parcel, with a median of 2.0, compared with 2.7 structures per parcel and a median of 2.0 for respondent parcels, with medians that are not statistically different (chi-square = 0.635, $P = 0.425$).

Table 4. Comparison of forest cover and impervious surface area (ISA) variables for developed intact parcels (n = 56) and developed subdivided parcels (n = 37). This analysis includes only those parcels with at least one structure present.

Variable description	Group[a]		ANOVA	
	Intact	Subdivided	F	P value
% Forest	80.7 (2.7)	80.8 (3.8)	0.00	0.993
No. of structures	2.7 (0.3)	3.4 (0.4)	2.11	0.150
Area of structures, ft^2	3043 (302)	2642 (459)	0.04	0.836
Area of driveway, ft^2	1943 (258)	1843 (402)	0.53	0.469
Area of ISA, ft^2	5021 (465)	4483 (707)	0.40	0.528
% ISA	0.64 (0.10)	0.58 (0.14)	0.10	0.748

[a] Values are least-squares means (standard errors in parentheses), adjusted to account for the unbalanced design.

Discussion

The DEP and its partners have led vigorous efforts to reduce water pollution and protect long-term water quality in the Watershed. Thus far, those efforts have been focused on acquiring land in high priority areas near water bodies and on curbing pollution from agricultural and forestry operations. NYC now controls 11% of the Watershed area through fee ownership or easement. WAC has engaged farmers and forest owners throughout the Watershed in active programs that have reduced pollution through the implementation of best management practices (BMP). For example, in 2006, WAC programs were responsible for implementing 373 BMP projects on large farms, 84 BMP projects on small farms, $50,000 in forest road improvements, and 77 new forest management plans (WAC 2007). Our results indicate that as water pollution threats from agricultural and forest operations are neutralized, rural residential development may be an appropriate target for additional policies and programs.

Trends between 1984 and 2005 show that parcelization, dominated by growth in the 5–10-ac size class, is prevalent across the Watershed, with absentee landowners and second home buyers making up approximately 40% of private parcel ownership (Tyrrell et al. 2004, Hall et al. 2008). Also known as ownership fragmentation, parcelization can occur without resulting in physical effects on the landscape, at least hypothetically. For example, the ownership of land held in an estate may be divided, on paper, among surviving heirs, without being developed or otherwise physically affected. However, the results of this study indicate that as a group, subdivided parcels created as a result of parcelization of private forestland in the Watershed between 1984 and 2000 were developed to nearly the same intensity as intact parcels, within the span of 20 years or less, as measured by the number of structures, area of driveway, and area of impervious surface area.

Although results do point toward a slightly higher percentage of impervious surface area for the intact group, they suggest that the process of parcelization in the Watershed is being accompanied by development on subdivided parcels. Although statistically, the failure to detect a difference between the groups should not be interpreted as proof that there is no difference in this case, this result does appear to confirm the use of parcelization trends as a metric for assessing future development impacts. We have shown that each new subdivided parcel, including both undeveloped and developed subdivided parcels, accounts for an average of 3,200 ft^2 of impervious surface area in the Watershed. Other development indicators support these findings. For example, a review of building permits issued in Watershed towns shows an increase in the rate of permits issued, from a rate of 83 per year between 1995 and 2001 to 245 per year between 2002 and 2004 (Hall et al. 2008). Based on field measurements of impervious surface area on subdivided parcels, it is clear that parcelization is a precursor of new development, which increases impervious surfaces in the Watershed.

On average over the last few decades, 400 new parcels are created in the Watershed each year through subdivision, for a total of 6,400 new parcels created between 1984 and 2000. With an average of 4,483 ft^2 of additional impervious surface for each developed parcel in this group, the estimated 3,840 subdivided parcels that were developed over this period account for approximately 17.2 million ft^2 of impervious surface area added to the Watershed. Extrapolating to 2010, parcelization followed by development may account for an additional 10.8 million ft^2 added since 2000. Combined, this is equivalent to more than 640 ac of new impervious surfaces on private property since 1984 and does not account for impervious surface area attributable to new municipal infrastructure constructed to service new development. Furthermore, the addition of new impervious surface on intact parcels was not included in these estimates and may be a concern, depending on trends in renovation and remodeling.

When parcelization and development occur simultaneously, there are important implications for water quality, such as those documented for the NYC east-of-Hudson (Croton) watersheds, where impervious surfaces accelerate the transport of sediment and contribute to nutrient loading from septic systems, lawn fertilizers, animal wastes, road salts, and other sources (Heisig 2000, Endreny et al. 2002, Hassett et al. 2003). Not only have many studies shown the links between percentage of land in urban development and water quality (Carpenter et al. 1998, Tong and Chen 2002, Groffman et al. 2004), but the generally accepted threshold of 10% impervious surface for water quality degradation (Schueler 1994) has been challenged by a number of recent studies that have shown increased water quality impacts with impervious surface as low as 2.4% (Conway 2007, Schiff and Benoit 2007, Dietz and Clausen 2008). This poses concern for the Watershed. Although intact and subdivided family forest parcels averaged impervious surface area of 0.64 and 0.58% of total parcel area, respectively, the sample did not include parcels less than 5 ac or new municipal roads and infrastructure, which are sources of new impervious surface area that are closely linked to development of family forestland.

The results of this case study quantify the known links between parcelization, development, and impervious surface area on family forests. Furthermore, in this case there does not appear to be a corresponding net decline in forest cover over the study period. In fact, based on the most current land cover assessments, forests have been regenerating on former agricultural land in the Watershed over the last 30 years (Mehaffey et al. 2005, Hall et al. 2008). Field measurements in this study support inferences from remote sensing data, with transitional areas accounting for the third largest area behind forest and agricultural lands. Given the large area of land in transition from field to forest, we should expect continued net gains in forest cover in many areas, especially in the western part of the Watershed, where agricultural land use is more common. Our results also indicate that, on average, the percentage of forest cover on subdivided, developed parcels is not lower than on intact parcels. In this case, there may be a perception that conditions in the Watershed are more pristine than they truly are because residential lots in this region retain high forest cover and because development is being accompanied by the transition of fields to forest. On the ground, what was once undeveloped working forestland held in relatively large ownerships is slowly being transformed into low-density rural residential land use, without net losses to forest cover. Although both land covers may be classified as forest, their potential for nonpoint source water pollution is not the same.

At this point, the implications for water quality remain unclear. Additional studies are required to document the direct impact of expanding rural residential land use on water quality in general, and specifically for the NYC watershed. The key question remains: at what point does spatially diffuse development overwhelm the forest sponge and begin to negatively affect water quality? In the case of the NYC watershed, a clear tipping point exists where the cumulative effect of thousands of individual land use decisions could cost billions of dollars if the 2007 EPA filtration avoidance determination is lost. Although the transition of agricultural lands to forest has been a positive development in terms of maintaining long-term water quality, high forest cover may not be an appropriate predictor of future trends in water quality. As the tipping point approaches, reducing the negative effects of low-density, rural residential development in a forested landscape is likely to require a creative mix of policies to maintain long-term water quality.

Literature Cited

Anderson, J., E. Hardy, J. Roach, and R. Witmer. 1976. *A land use and land cover classification system for use with remote sensor data*. Geological Survey Professional Paper 964. United States Government Printing Office, Washington, DC. 41 p.

Arnold, C. Jr., and C. Gibbons. 1996. Impervious surface coverage: The emergence of a key environmental indicator. *J. Am. Planning Assn.* 62(2): 243–258.

Best, C. 2002. America's private forests: Challenges for conservation. *J. For.* 100(3):14–17.

Bolstad, P., and W. Swank. 1997. Cumulative impacts of landuse on water quality in a southern Appalachian watershed. *J. Am. Water Res. Assn.* 33(3):519–533.

Burns, D., T. Vitvar, J. McDonnell, J. Hassett, J. Duncan, and C. Kendall. 2005. Effects of suburban development on runoff generation in the Croton River basin, New York, USA. *J. Hydrol.* 311:266–281.

Caron, J.A., R. Germain, and N.M. Anderson. 2012. Parcelization and land use: A case study in the New York City Watershed. *North. J. Appl. For.* 29(2):74–80.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint source pollution of surface waters with phosphorus and nitrogen. *Ecol. Appl.* 8(3):559–568.

Conway, T.M. 2007. Impervious surface as an indicator of pH and specific conductance in the urbanizing coastal zone of New Jersey, USA. *J. Environ. Manag.* 85:308–316.

DeCoster, L. 1998. *Adapting programs to fragmented forests*. Forest fragmentation: Roundtable discussion. Society of American Foresters Headquarters, Bethesda, MD.

Dietz, M.E., and J.C. Clausen. 2008. Stormwater runoff and export changes with development in a traditional and a low impact subdivision. *J. Environ. Manag.* 87:560–566.

Donnelly, S., and T. Evans. 2008. Characterizing spatial patterns of land ownership at the parcel level in south-central Indiana, 1928–1997. *Landscape Urban Plan.* 84:230–340.

Endreny, T., J. Hassett, M. Mitchell, D. Siegel, D. Burns, and P. Heisig. 2002. Runoff timing and quality as a function of suburbanization. Am. Water Res. Assn. Annual Conference, Philadelphia.

US Environmental Protection Agency (EPA). 2006. *Protecting water resources with higher density development*. EPA 231-R-06-001. Development, Community, and Environment Division, US EPA, Washington, DC. 46 p.

Germain, R., N. Anderson, and E. Bevilacqua. 2007. The effects of forestland parcelization and ownership transfers on nonindustrial private forestland forest stocking in New York. *J. For.* 105(8):403–408.

Goodnight, J., and W. Harvey. 1978. *Least squares means in the fixed-effect general linear model*. Tech. Rep. R-103. SAS Institute, Cary, NC. 13 p.

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

Hall, M., R.H. Germain, M. Tyrell, and N. Sampson. 2008. *Predicting future water quality from land use change projections in the Catskill-Delaware watersheds*. Prepared for the New York State Department of Environmental Conservation, Albany, NY. 269 p. Available online at www.esf.edu/es/hall/water.pdf; last accessed Dec. 5, 2011.

Hassett, J., T. Endreny, S. Wolosoff, M. Adam, and M. Mitchell. 2003. Effect of suburban development and landscape position on water quality in three small watersheds within the Croton System, New York. *Eos Trans. American Geophysical Union*, 84(46, Fall Meet. Suppl.):Abstract H51C-1066.

Hatt, B., T. Fletcher, J. Walsh, and S. Taylor. 2004. The influence of urban density and drainage infrastructure on the concentrations and loads of pollutants in small streams. *Environ. Manag.* 34(1):112–124.

Heisig, H. 2000. *Effects of residential and agricultural land uses on the chemical quality of baseflow of small streams in the Croton Watershed, Southeastern New York*. US Geological Survey WRIR 99-4173. 16 p.

Heisig, P.M. 2009. *Nutrients, dissolved organic carbon, color, and disinfection byproducts in base flow and stormflow in streams of the Croton watershed, Westchester and Putnam Counties, New York, 2000–02*. US Geological Survey Open-File Rep. 2009–1054. 105 p.

LaPierre, S., and R. Germain. 2005. Forestland parcelization in the New York City watershed. *J. For.* 103(3):139–145.

Lathrop, R., D. Tulloch, and C. Hatfield. 2007. Consequences of land use change in the New York-New Jersey Highlands, USA: Landscape indicators of forest and watershed integrity. *Landscape Urban Plan.* 79:150–159.

MacDonald, K., and T. Rudel. 2005. Sprawl and forest cover: What is the relationship? *Appl. Geogr.* 25:67–79.

Mehaffey, M., M. Nash, T. Wade, D. Ebert, K. Jones, and A. Rager. 2005. Linking land cover and water quality in New York City's water supply watersheds. *Environ. Monit. Assess.* 107:29–44.

New York City Department of Environmental Protection (NYC DEP). 2008. *Drinking water supply and quality report*. New York City Department of Environmental Protection, New York. Available online at www.nyc.gov/html/dep/html/drinking_water/wsstate.shtml; last accessed Dec. 5, 2011.

New York City Department of Environmental Protection (NYC DEP). 2010. *Final environmental impact statement (EIS): The extended New York City Watershed land acquisition program.* CEQR No. 10DEP046U. New York City Department of Environmental Protection, New York. Available online at www.nyc.gov/html/dep/pdf/reviews/land_aquisition_program/extended_lap_feis.pdf; last accessed Dec. 5, 2011.

New York State GIS Clearinghouse. 2011. *New York State GIS clearinghouse*. NYS Office of Cyber Security, Albany, NY. Available online at www.nysgis.state.ny.us; last accessed Dec. 5, 2011.

Rogers, G., and B. DeFee. 2005. Long-term impact of development on a watershed: early indicators of future problems. *Landscape Urban Plan.* 73:215–233.

SAS Institute Inc. 2004. *Base SAS 9.1 procedures guide*. SAS Institute Inc., Cary, NC. 1,861 p.

Schiff, R., and G. Benoit. 2007. Effects of impervious cover at multiple spatial scales on coastal watershed streams. *J. Am. Water Res. Assoc.* 43(3):712–730.

Schueler, T. 1994. The importance of imperviousness. *Watershed Protection Techniques* 1:100–111.

Stolton, S., and N. Dudley. 2007. Managing forests for cleaner water for urban populations. *Unasylva* 58(229):39–43.

Stone, B. 2004. Paving over paradise: How land use regulations promote residential imperviousness. *Landscape Urban Plan.* 69:101–113.

Tong, S., and W. Chen. 2002. Modeling the relation between land use and surface water quality. *J. Environ. Manag.* 66:377–393.

Tyrrell, M., M. Hall, and R. Sampson. 2004. *Dynamic models of land use change in the northeastern USA: Developing tools, techniques and talents for effective conservation action*. Global Institute of Sustainable Forestry, Yale University, New Haven, CT. 79 p.

US Forest Service. 2008. Forest Inventory and Analysis national program. Available online at fia.fs.fed.us; last accessed Dec. 5, 2011.

USDA Soil Conservation Service. 1986. *National engineering handbook: Hydrology section*. U.S. Government Printing Office, Washington, DC.

Watershed Agricultural Council (WAC). 2007. *Watershed farm and forest: 2006 annual report edition*. Watershed Agricultural Council, Walton, NY. Available online at www.nycwatershed.org/pdfs/WFF%20AnnRept%202006%20Final%20.pdf; last accessed Dec. 5, 2011.

VanBrakle, J. 2011. *Watershed land statistics*. Internal WAC report. Watershed Agricultural Council, Walton, NY. 1 p.

Xian, G., M. Crane, and S. Junshan. 2007. An analysis of urban development and its environmental impact on the Tampa Bay watershed. *J. Env. Manag.* 85: 965–976.