Improvements to Lawn and Garden Equipment Emission Estimates for Baltimore, Maryland

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ABSTRACT

Lawn and garden equipment are a significant source of emissions of volatile organic compounds (VOC) and other pollutants in suburban and urban areas. Emission estimates for this source category are typically prepared using default equipment populations and activity data contained in emissions models such as the U.S. Environmental Protection Agency's (EPA) NONROAD model or the California Air Resources Board's (CARB) OFFROAD model. While such default data may represent national or state averages, these data are unlikely to reflect regional or local differences in equipment usage patterns due to variations in climate, lot sizes, and other variables. To assess potential errors in lawn and garden equipment emission estimates produced by the NONROAD model and to demonstrate methods that can be used to improve those emission estimates, this study employed bottom-up data collection techniques in the Baltimore metropolitan area to develop local equipment population, activity, and temporal data for lawn and garden equipment in the area.

Results of this study show that emission estimates for the Baltimore area based on local data collected through surveys of residential and commercial lawn and garden equipment users are 24% to 56% lower than estimates produced using NONROAD default data. The principal cause for the disparity is the difference in equipment populations for high-usage commercial applications. Survey-derived emission estimates of particulate matter (PM) and VOC are 24% and 26% lower than NONROAD default estimates, respectively. Similarly, survey-derived emission estimates for carbon monoxide (CO), carbon dioxide (CO_2), and nitrogen oxide (NO_x) are more than 40% lower than NONROAD default estimates. In addition, study results show that the temporal allocation factors applied to residential lawn and garden equipment in the NONROAD model underestimated weekend activity levels by 30% compared to survey-derived temporal profiles.

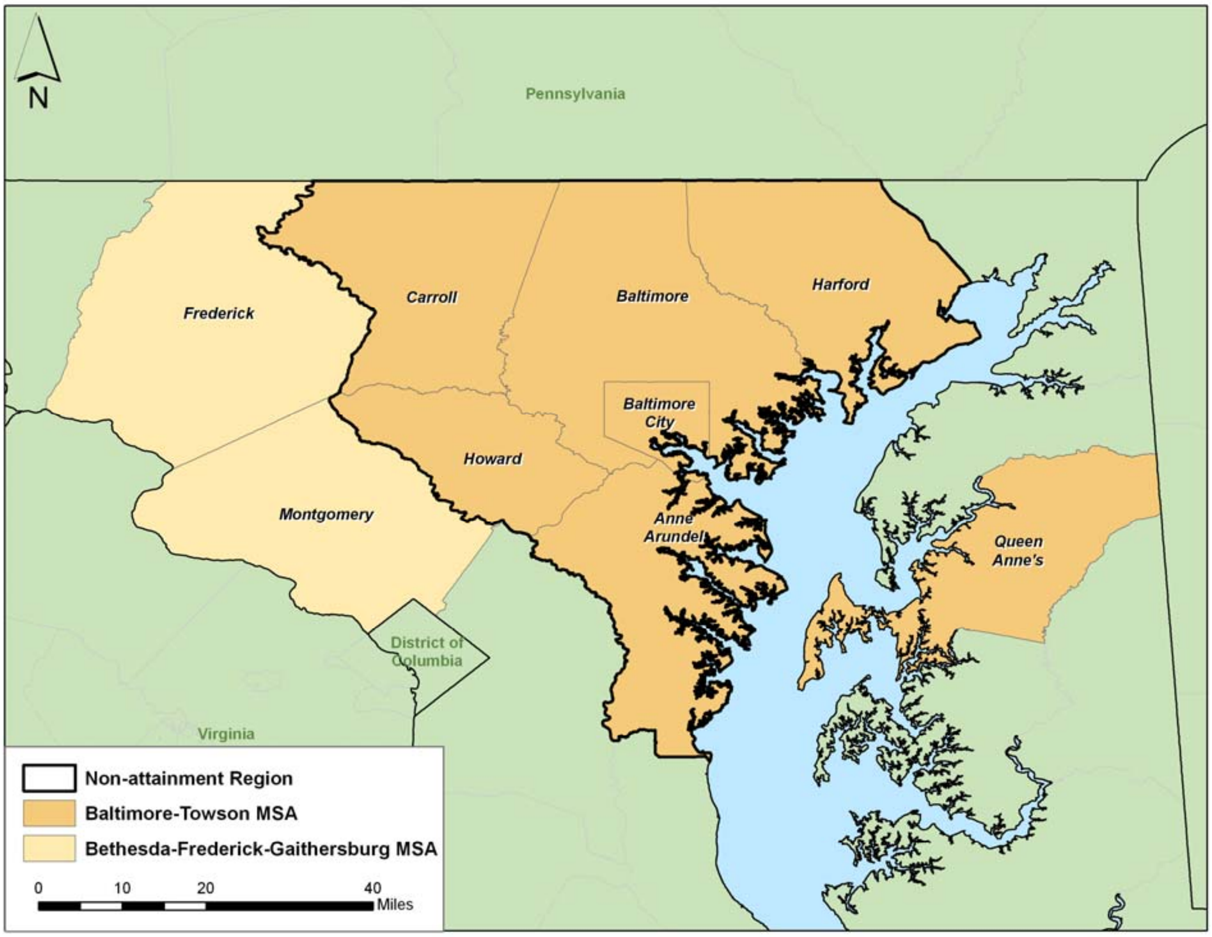
INTRODUCTION

An accurate and sufficiently detailed emission inventory is a key input for air quality simulation modeling, yet significant uncertainties exist with current emission estimates for non-road mobile sources. These estimates are typically prepared using the default activity, spatial, and temporal data contained in emissions models such as the U.S. Environmental Protection Agency's (EPA) NONROAD model or the California Air Resources Board's (CARB) OFFROAD model. The default data are based on surveys and publicly available data sources that may represent national averages but not local conditions. Because the NONROAD model was designed to use local data when available, emission estimates for non-road mobile source categories can be improved through the bottom-up collection of local data on equipment populations and usage patterns [1].

The objective of this study was to assess potential errors in lawn and garden equipment emission estimates produced by the use of the default data found in the latest version of the NONROAD model (NONROAD2008). The study was also intended to demonstrate methods that can be used to improve the estimation, spatial allocation, and temporal allocation of emissions from lawn and garden equipment in urbanized areas. Lawn and garden equipment were selected for this analysis because these machines are a significant source of volatile organic compound (VOC) emissions in suburban and urban areas, typically accounting for 40% to 50% of the non-road VOC inventory and 4% to 6% of the total anthropogenic VOC inventory in metropolitan regions [1]. In addition, NONROAD default activity data for lawn and garden equipment are unlikely to reflect regional differences in usage patterns due to variations in temperature, rainfall, lot sizes, and other variables. Therefore, this source category is a good candidate for demonstrating the impact of local activity data on emission estimates.

To meet the study objective, surveys were conducted of residential and commercial lawn and garden equipment use in the Baltimore, Maryland, metropolitan area to gather information that could be used to develop improved equipment population, activity, and temporal data for lawn and garden equipment in the region. These data were then used to estimate VOC, carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_x), and particulate matter (PM) emissions for these sources; the resulting emission estimates were compared to emissions inventories for Baltimore prepared using default NONROAD data. The Baltimore area was selected for this study based on a number of factors: nonattainment status, population, meteorology, availability of air quality data, and the contribution of lawn and garden equipment emissions to the region's overall emissions inventory. The study area consisted of the nine counties in the Baltimore-Towson and Bethesda-Frederick-Gaithersburg Metropolitan Statistical Areas, as shown in Figure 1. Based on EPA's 2005 National Emissions Inventory (NEI), lawn and garden equipment contribute 7% to total VOC emissions and 54% to non-road mobile source VOC emissions in this region. For CO, lawn and garden equipment in the region contribute 16% to total emissions and 67% to non-road mobile source emissions. Lawn and garden equipment emission estimates for the state of Maryland in the 2005 NEI were prepared using the NONROAD2005 model with default equipment population and activity data [2].

Figure 1. Map of the Baltimore area counties included in this study.



NONROAD Model Overview

The NONROAD model uses eq 1 to calculate county-level exhaust emissions from non-road mobile sources such as lawn and garden equipment:

$$\text{Emissions} = \text{Pop} \times \text{Power} \times \text{LF} \times \text{A} \times \text{EF} \tag{1}$$

where:

Pop = equipment populations

Power = average horsepower (hp)

LF = load factor (fraction of available power)

A = activity (hours per year)

EF = emission factor in grams per horsepower-hour (g/hp-hr)

Equipment populations are based on national-level estimates developed by Power Systems Research (PSR) from engine manufacturer sales surveys, data on engine lifetimes, and surveys of equipment users. National-level sales data for lawn and garden equipment are split into residential and commercial populations using residential/commercial fractions for each type of equipment derived from a 1992 CARB study [3]. Equipment populations are then allocated to individual states and counties using county-level data from the U.S. Census Bureau. Residential lawn and garden equipment populations are geographically allocated based on one- and two-unit housing densities by county; commercial lawn and garden equipment populations are allocated based on the number of employees in landscaping services for each county [4]. This method does not take into account regional differences in lot sizes, landscaping preferences, and other factors that may determine the ownership and usage of lawn and garden equipment. Therefore, relying on these data may result in the under- or over-allocation of equipment populations to given areas.

NONROAD activity data (hours per year of operation) are based on a 1998 database of surveys of equipment owners developed by PSR. PSR used these data to determine a mean usage rate for non-road equipment by application and fuel type. Within the NONROAD model, these usage rates are assumed to be applicable to all equipment of a given type [5]. For lawn and garden equipment, this assumption means that NONROAD's annual activity data do not account for factors such as the average size of yards, growing season lengths, and annual rainfall, which vary geographically [4]. NONROAD load factors represent the average fraction of available power used by a given type of equipment and take into account operation at idle and partial-load conditions. These data are also based on PSR surveys of equipment owners and are calculated as the ratio of actual fuel consumption to estimated fuel consumption at maximum power [5]. NONROAD emission factors are based on engine tests and federal emission standards and are adjusted to account for engine deterioration with age [6].

Because the NONROAD model was designed to use local data when available [1], surveys of residential and commercial lawn and garden equipment in the Baltimore area were used in this project to develop region-specific estimates of equipment populations and activity that could be incorporated into the NONROAD model. Comparisons were then made between emission estimates produced using local data and those based on NONROAD default data.

TECHNICAL APPROACH

Survey Design

Local data on lawn and garden equipment ownership and usage were gathered using surveys that targeted residential and commercial equipment owners separately. The expectation was that these two populations would differ significantly in equipment ownership and usage patterns. Sample sizes that would yield a 95% confidence level with a confidence interval of ±5% were determined to quantify the number of completed surveys required to characterize emissions from residential and commercial lawn and garden equipment for the study area. For the residential survey, it was estimated that 350 completed surveys would be required based on the number of households in the nine-county area. For the commercial survey, it was estimated that 150 completed surveys would be required based on the number of employees in the lawn and garden services sector (Standard Industrial Classification [SIC] code 0782). To identify and contact eligible residential participants, a random sample of 7,000 residential telephone numbers in the nine-county area was purchased from a professional sample vendor. Of these 7,000 residences, 6,477 (or 93%) were single-family dwellings, the housing type judged most likely to own lawn and garden equipment (see Table 1). To represent the commercial population, more than 2,500 telephone numbers for businesses in the nine-county area were purchased. In keeping with EPA guidance [1], the commercial sample included not only businesses related to lawn and garden services (SIC 0782) but also other organizations likely to maintain large tracts of landscaped areas (e.g., golf courses, cemeteries, and college campuses). Table 2 lists SIC codes covered by the commercial survey; the commercial sample included all establishments in the nine-county area for each of these SIC codes.

Table 1. Household types included in the residential survey sample.

Dwelling Type	Number
Single-family detached	6,477
Duplex	377
Multi-family (apartment, condominium, etc.)	146
Total	**7,000**

Table 2. Business types included in the commercial survey sample.

SIC Code	Description	Sample Size
0781	Landscape counseling and planning	114
0782	Lawn and garden services	1,214
0783	Ornamental shrub and tree services	317
7261	Funeral service and crematories (for cemeteries)	198
7992	Public golf courses	75
7997	Membership sports and recreation clubs (private golf courses)	340
8221	Colleges, universities, and professional schools	202
8222	Junior colleges and technical institutes	16
9512	Land, mineral, wildlife, and forest conservation	45
Total businesses		**2,521**

Once target populations were defined, the data elements to be included in survey instruments were identified and prioritized, with a view toward keeping survey lengths within reasonable limits to maximize participation rates. The goal was to characterize the independent activity variables from eq 1, including equipment populations, equipment characteristics (e.g., type, fuel, power rating, and age), and equipment activities (e.g., engine load and time in use). In addition, other variables were identified that were judged likely to correlate with lawn and garden equipment ownership and usage, including the condition of vegetation, residential property characteristics, and business characteristics. Table 3 provides a complete list of data elements that were selected for inclusion in the survey instruments.

Table 3. Residential and commercial survey data elements.

Data Elements		
Residential Survey	**Business Survey**	**Both Surveys**
• Property characteristics – Single-, dual-, or multi-family structure – Lot size – Size of landscaped or maintained area – Condition of vegetation on maintained areas – Living space square footage – Number of bedrooms and bathrooms	• Business characteristics – Services provided – Counties of operation – Number of clients or accounts – Types of clients served – Number of employees – Annual revenue	• Number of lawn and garden equipment units owned • Equipment characteristics: make, model, type, fuel, power rating, and age • Equipment usage characteristics: engine load fuel use and time in use • Weekday and weekend day usage patterns • Seasonality of usage patterns • Anticipated plans for equipment replacement • Owner assessment of equipment condition

Survey Implementation

Survey questionnaires were prepared and implemented by Population Research Systems (PRS), a San Francisco-based survey research firm, based on the data needs identified above and PRS's experience with key aspects of survey administration (e.g., appropriate word choice, optimal question order, length of survey, and incentives for participation). For residential surveys, a pre-announcement letter was designed to inform all households in the sample data set of the purpose of the study and to prepare them to receive a subsequent telephone interview call. In addition, a monetary incentive of $20 was offered to increase response rates and produce higher data quality. For commercial surveys, initial telephone contact with each business was made to screen for eligibility and to identify the most knowledgeable person to participate in the survey. Participants were then offered the option of completing the survey over the telephone or by filling out a questionnaire provided by fax or email. An incentive of $30 was offered for participation in the business survey.

Working from the database of purchased sample telephone numbers, telephone interviews were conducted with qualified household members or business employees/owners (aged 18 and older and familiar with the operations of the household or business). Residential surveys were conducted during July and August 2009, and commercial surveys were conducted from August through early November 2009.

Data Analysis and Emission Estimation

At the conclusion of the residential and commercial surveys, survey responses were analyzed to evaluate response and refusal rates and to develop work products. The work products included local activity data sets for the Baltimore metropolitan area to replace the default data contained in the NONROAD model. For example, Baltimore-area residential equipment populations were estimated in keeping with EPA guidance on lawn and garden survey methods [1] by scaling the survey results as follows:

1. Summing the population for each equipment type addressed in the survey.
2. Dividing the equipment populations by the total number of households in the sample (including responses that documented no equipment ownership).
3. Multiplying by the total number of households in the geographic area of interest.

This same method was used to scale commercial equipment populations based on the total number of businesses in relevant SIC groupings in the Baltimore area. Survey results were also analyzed to calculate average annual usage rates, temporal usage patterns (e.g., usage on weekdays vs. weekend days), and age distributions by equipment type for both residential and commercial equipment populations. These calculations were performed for the nine-county region as a whole rather than for individual counties because the number of completed surveys was not sufficient to support county-level analyses. Finally, usage rates were correlated with other variables, such as residential lot sizes and business sizes (e.g., number of employees), to determine whether those variables could be used as surrogates for lawn and garden equipment usage.

After data analyses were complete, local activity data gathered from the survey results were converted into formats compatible with EPA's NONROAD model. NONROAD was then used to develop county-level emission estimates for lawn and garden equipment in the Baltimore metropolitan area. The resulting emission estimates were compared to emissions inventories developed using default NONROAD data for the study area, and summary tables and graphical displays of the results were prepared.

RESULTS AND DISCUSSION

Survey Response Rates

For the residential survey, pre-announcement letters were sent to all 7,000 households in the purchased sample and telephone contact was attempted for 6,934 of those households. PRS successfully contacted and invited survey participation for 1,965 households, 511 of which participated, for a response rate of 26% (7% of total attempts). The 511 completed surveys exceeded the original goal of 350 completes and yielded a 95% confidence level with a confidence interval of ±4.4%. Of the 511 participants, 371 reported ownership of lawn and garden equipment, while 140 reported no ownership (see Table 4). In addition, 94% of survey participants lived in single-family dwellings, 5% lived in duplexes, and 1% lived in multi-family housing.

Table 4. Residential survey disposition report.

Disposition	Description	Number
Excluded from survey	Wrong number, fax line, phone disconnected or non-working, non-English household	910
Eligibility unknown	Answering machine, busy signal, or no answer	4,059
Total non-contacts		**4,969**
Refusals	Refused to participate in survey	1,454
Participant - equipment owner	Owns lawn and garden equipment	371
Participant - no equipment	Does not own lawn and garden equipment	140
Total contacts		**1,965**
Total attempts		**6,934**

For the commercial survey, telephone contact was attempted for all 2,521 businesses and organizations in the purchased sample, which includes all establishments in the nine-county area categorized under the SIC codes listed in Table 2. A total of 1,026 businesses were successfully contacted and invited to participate in the survey, 721 of which participated, for a response rate of 70% (29% of total attempts). Of the 1,026 participants, 92 reported ownership of lawn and garden equipment, while 629 reported no ownership. The 92 completed surveys fell short of the original goal of 150 completes and yielded a 95% confidence level with a confidence interval of ±10%. The high number of businesses reporting no equipment ownership indicates that such ownership is largely limited to businesses in a small number of SIC groupings, as described in the sections that follow.

Table 5. Commercial survey disposition report.

Disposition	Description	Number
Excluded from survey	Wrong number, fax line, phone disconnected or non-working, non-English business	228
Eligibility unknown	Answering machine, busy signal, or no answer	1,267
Total non-contacts		**1,495**
Refusals	Refused to participate in survey	305
Participant - equipment owner	Owns lawn and garden equipment	92
Participant - no equipment	Does not own lawn and garden equipment	629
Total contacts		**1,026**
Total attempts		**2,521**

Equipment Populations

Residential equipment populations in the Baltimore area were based on ownership rates derived from the survey and the number of single-family dwellings in the region (sample sizes and equipment ownership rates were very low for other household types). For commercial equipment, populations were based on ownership rates derived from the survey and the number of businesses in the lawn and garden services (SIC 0782), ornamental shrub and tree services (SIC 0783), and public golf courses (SIC 7992) sectors; fewer than 2% of the establishments in the remaining SIC categories reported lawn and garden equipment ownership (see Table 6). In addition, because survey results indicated that SIC 0782 contains a fairly broad range of businesses—many of which have no lawn and garden equipment—businesses surveyed in this SIC code were further grouped by six-digit SIC code (see Table 7). Analysis of survey results indicated that ownership rates were highest for SIC sub-groupings 078204 (landscape contractors) and 078206 (lawn and grounds maintenance). Ownership rates were minimal for all other sub-groupings, so commercial equipment populations for SIC 0782 were extrapolated based on the number of businesses in these two sub-groups only.

Table 6. Commercial survey participants by SIC code.

SIC Code	Description	Owns Equipment	No Equipment
0781	Landscape counseling and planning	0	33
0782	Lawn and garden services	67	103
0783	Ornamental shrub and tree services	9	16
7261	Funeral service and crematories (for cemeteries)	4	145
7992	Public golf courses	7	9
7997	Membership sports and recreation clubs (private golf courses)	4	160
8221	Colleges, universities, and professional schools	1	118
8222	Junior colleges and technical institutes	0	8
9512	Land, mineral, wildlife, and forest conservation	0	37
–	**Total**	**92**	**629**

Table 7. Sub-groupings for the lawn and garden services sector.

SIC code	Description
078203	Sodding services
078204	Landscape contractors
078206	Lawn and grounds maintenance
078207	Topsoil
078213	Hydroseeding

The survey results indicated that overall, 2009 equipment populations in the Baltimore area totaled 2.4 million pieces of equipment. This estimate is 50% higher than the total default equipment populations in the NONROAD model (see Table 8). Also, the survey-derived populations apportioned significantly more equipment to the residential sector than does the NONROAD model. Survey-derived residential equipment populations for the Baltimore area were 75% higher than residential equipment populations in the NONROAD model, while the survey-derived commercial equipment population of 32,196 pieces of equipment was 87% lower than the NONROAD estimate of 248,859 pieces of equipment. Among residential equipment types, survey-derived populations of chainsaws and leafblowers were four times higher than NONROAD populations for these equipment types. For commercial equipment, survey-derived populations were lower than NONROAD estimates for all equipment types except rear engine riding mowers (see Table 8). In addition, survey results showed substantial residential ownership of equipment types that NONROAD assumes to be 100% commercial (e.g., chippers, front mowers, and shredders). This partly accounts for the difference in residential and commercial population splits between the survey results and NONROAD's default data.

Table 8. 2009 equipment populations by equipment type in the Baltimore area.

Equipment Type	NONROAD Default Populations			Survey-Derived Populations		
	Commercial	Residential	Total	Commercial	Residential	Total
Chainsaws	18,647	83,850	102,496	4,326	340,725	345,051
Chippers/Stump Grinders	2,708	–	2,708	679	29,929	30,608
Front Mowers	10,225	–	10,225	871	57,555	58,426
Lawn and Garden Tractors	9,674	191,311	200,985	781	92,088	92,869
Lawn Mowers	38,858	525,821	564,678	3,302	702,170	705,472
Leafblowers	27,031	118,166	145,197	5,262	421,302	426,564
Rear Engine Riding Mowers	1,189	27,995	29,185	1,505	75,972	77,477
Rotary Tillers	14,236	53,614	67,850	1,063	103,599	104,662
Shredders	7,466	–	7,466	74	18,418	18,492
Snowblowers	29,471	140,350	169,822	2,001	174,967	176,968
Trimmers/Edgers/Brush Cutters	47,526	225,018	272,544	8,636	368,351	376,987
Turf Equipment	23,984	–	23,984	1,463	–	1,463
Other Equipment	17,845	9,423	27,268	2,233	18,418	20,651
Total	**248,859**	**1,375,548**	**1,624,407**	**32,196**	**2,403,492**	**2,435,688**

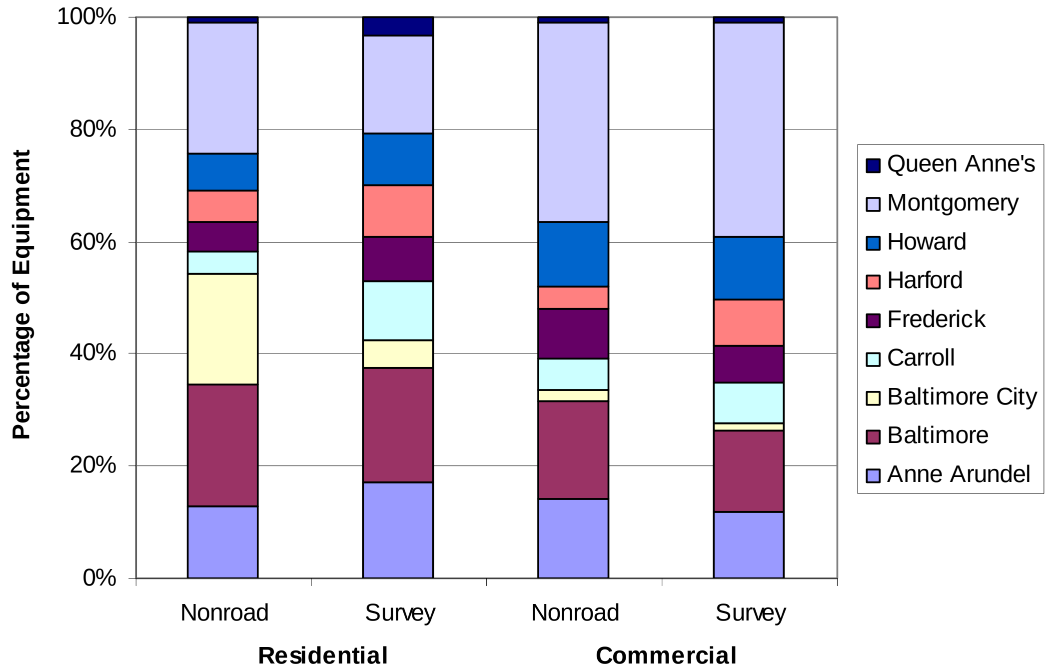
These results indicate that NONROAD's apportionment of national residential equipment populations using county-level data on one- and two-unit households may be resulting in an underestimation of equipment populations for eastern regions of the United States that, like Baltimore, have significant summer precipitation. Also, NONROAD's apportionment of national commercial equipment populations using county-level data on employment in landscaping services results in unrealistically high equipment populations for the Baltimore area. With about 11,500 employees in this sector [7], NONROAD's commercial equipment population estimate of almost 248,859 pieces of equipment results in a ratio of 22 pieces of equipment per employee (including office personnel who do not use the equipment). On the other hand, the survey-derived commercial equipment population estimate results in a ratio of 3 pieces of equipment per employee, which seems a more realistic estimate—particularly when survey results show that some businesses in this sector do not use motorized lawn and garden equipment at all.

In addition, similar surveys of commercial and residential lawn and garden equipment users in other areas generally support the conclusion that commercial equipment populations may be overestimated in the NONROAD model, while residential equipment populations may be underestimated. Previous surveys of commercial lawn and garden equipment users have reported commercial equipment populations significantly lower than NONROAD default values [8-10], including a study in Texas that found statewide commercial equipment populations were only 31% of NONROAD's population estimates [9]. A commercial lawn and garden survey in Atlanta indicated that populations of equipment with engines rated above 25 horsepower were somewhat higher than NONROAD default populations, but the low response rate for that survey (4%) produced highly uncertain results [11]. Residential lawn and garden equipment populations in California estimated from a survey conducted by CARB are 32% higher than residential equipment populations for California in the current NONROAD model. The survey-based estimates are also higher by a factor of 2.6 than statewide residential equipment populations in CARB's OFFROAD model [12].

Populations by County

Survey-derived residential equipment populations were apportioned to the county level based on actual equipment ownership rates reported by survey respondents in each county rather than on the straight household distributions used in the NONROAD model. As a result, only 5% of regional residential equipment populations were apportioned to urbanized Baltimore City, compared to 20% in the NONROAD model (see Figure 2). For commercial lawn and garden equipment, county equipment distributions derived from survey results (e.g., equipment ownership rates and counties of operation reported by survey respondents) were very similar to county equipment distributions in the NONROAD model (see Figure 2).

Figure 2. County-level distributions of equipment populations.



Populations by Fuel Type

Equipment populations by fuel type (2-stroke gasoline, 4-stroke gasoline, and diesel) were derived from survey results and used to update NONROAD populations by fuel type, where possible. In some cases, NONROAD apportions 100% of a given equipment category to a single fuel type (e.g., 100% of chainsaws are assumed to be 2-stroke), so survey-derived fuel splits could not be used. For other equipment categories, sample sizes were insufficient to derive updated fuel splits from survey data. However, updated fuel splits were calculated for trimmers, tillers, leafblowers, and snowblowers. In general, survey-derived and NONROAD default fuel splits were similar, although survey results indicated that there is a higher proportion of 2-stroke gasoline engines for both residential and commercial rotary tillers than predicted by the NONROAD model (see Figures 3 and 4).

Figure 3. Residential equipment populations by fuel type.

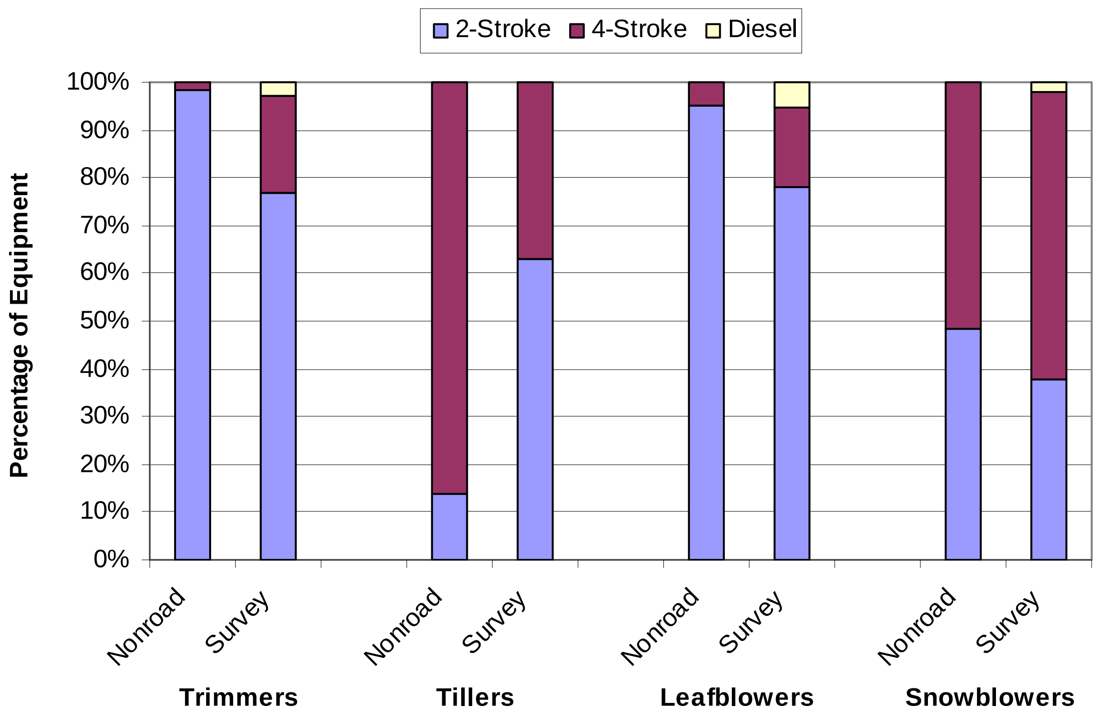
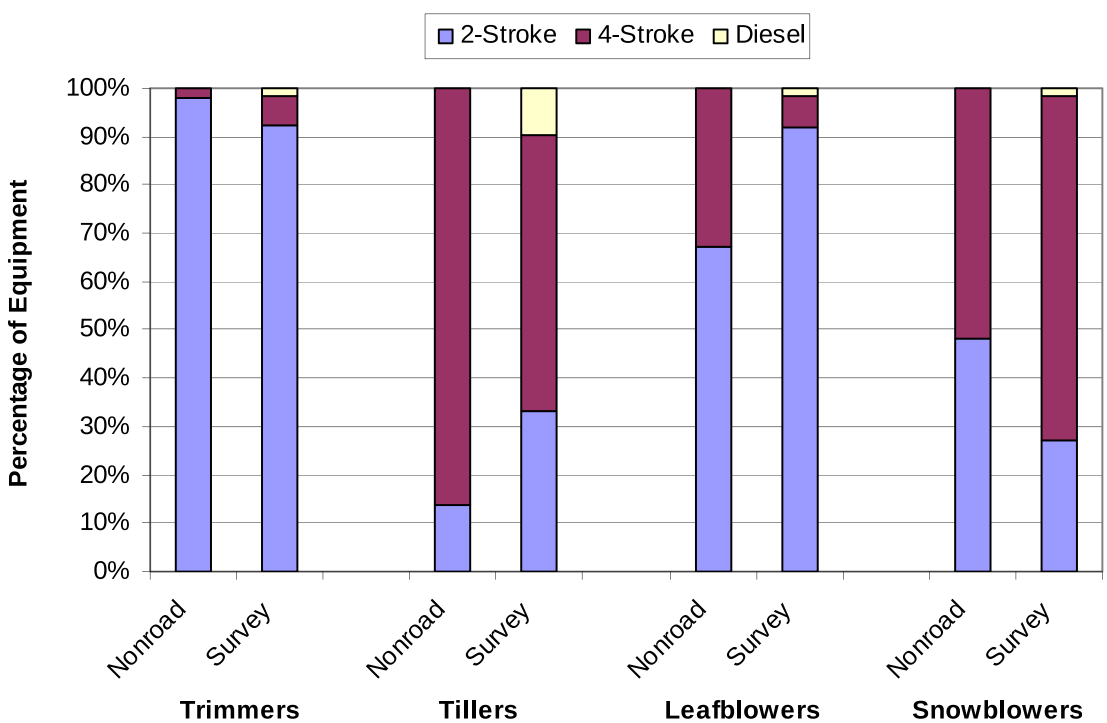


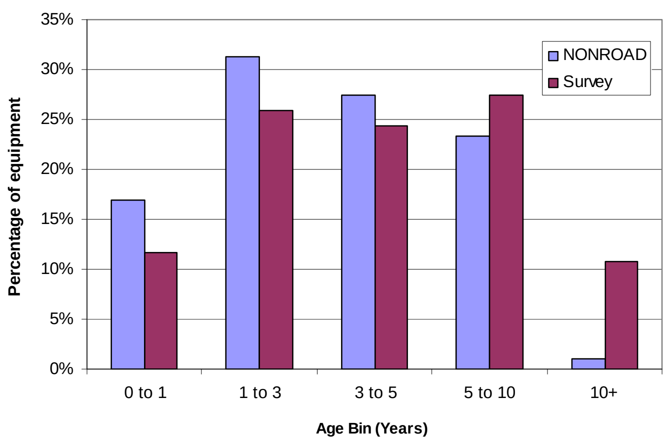
Figure 4. Commercial equipment populations by fuel type.



Population Age Distributions

The NONROAD model calculates age distributions for all equipment based on a generalized scrappage curve that describes the ages at which equipment are scrapped as a function of their estimated median lifetimes, combined with application-specific information on median lifetimes, annual activity (hours of use per year), and load factor. NONROAD users have limited ability to update age distributions; however, in this study, survey-reported equipment ages were compared with age distributions generated by NONROAD for the Baltimore area. Results of these comparisons showed that NONROAD consistently allocated more equipment to recent model years than were indicated by the survey-derived age distributions. In particular, survey results showed a much higher fraction of equipment older than five years compared to NONROAD numbers (see Figures 5 through 7 for a comparison of age distributions for key equipment types). These findings indicate that lawn and garden equipment are not being retired as quickly as the NONROAD model predicts. Since older equipment have higher emission rates, this difference in age distributions could significantly impact overall emission estimations, as described in the sections that follow.

Figure 5. Comparison of NONROAD and survey-derived age distributions of residential (left) and commercial (right) walk-behind mowers.



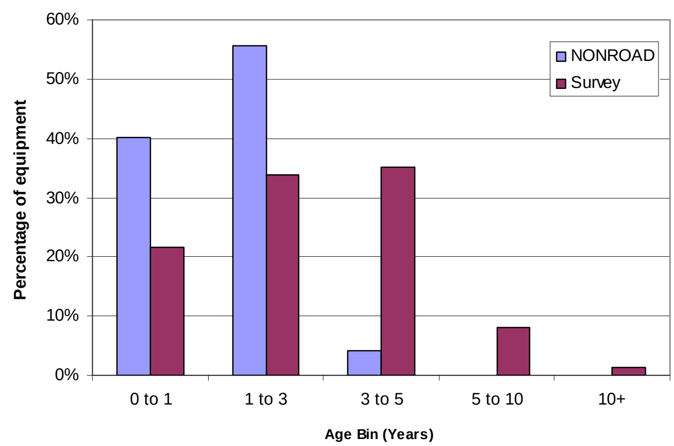


Figure 6. Comparison of NONROAD and survey-derived age distributions of residential (left) and commercial (right) trimmers, edgers, and brush cutters.

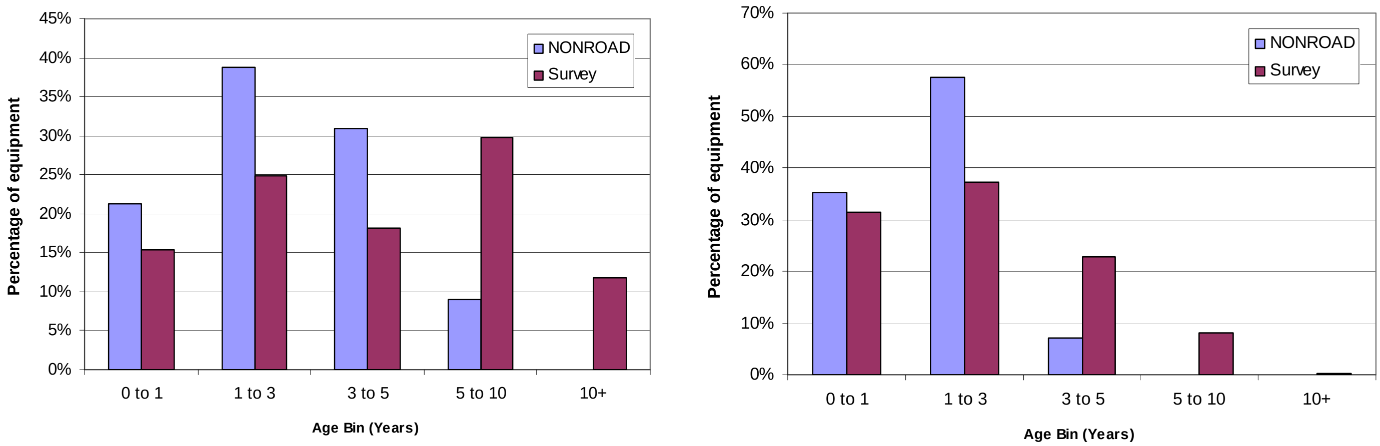
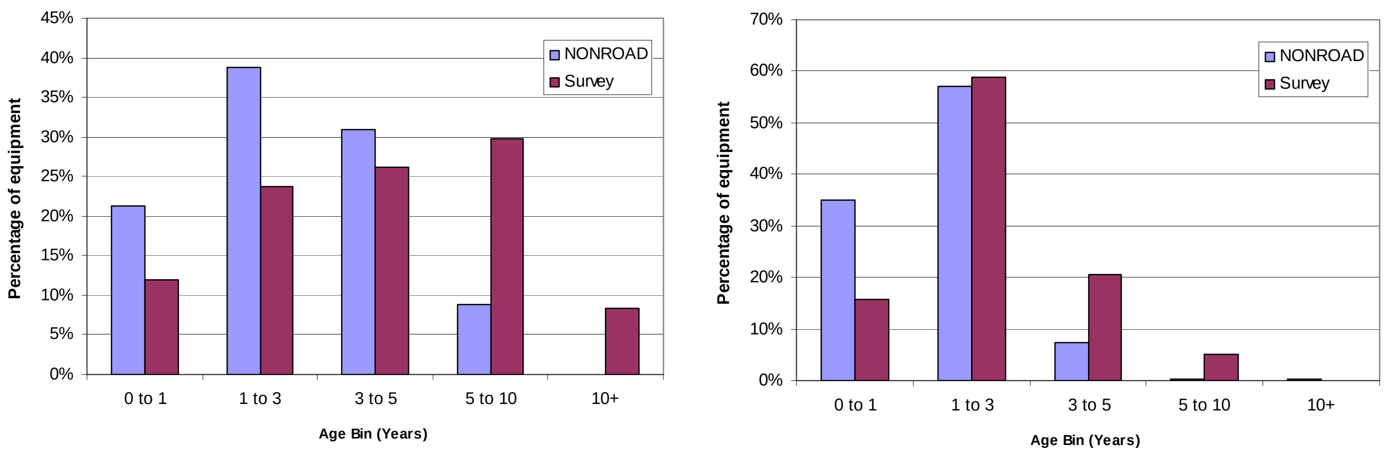


Figure 7. Comparison of NONROAD and survey-derived age distributions of residential (left) and commercial (right) leafblowers.



Equipment Activity

Annual Hours of Operation

Emission calculations in the NONROAD model are based in part on default estimates of annual hours of operation for each type of equipment covered by the model. For residential lawn and garden equipment, annual usage rates derived from survey results were generally 40% to 120% higher than usage rates in the NONROAD model; however, survey-derived usage rates for chainsaws and snowblowers were slightly lower than usage rates in the NONROAD model (see Figure 8). For commercial equipment, annual usage rates derived from survey results were generally within ±60% of usage rates in the NONROAD model; however, for equipment types with the highest equipment populations (e.g., mowers, leafblowers, trimmers, edgers, and brush cutters), survey-derived usage rates were higher than NONROAD's usage rates by 30% to 194% (see Figure 9). For both residential and commercial equipment, the relationship between equipment activity levels and other variables, such as residential lot sizes and the number of employees reported by commercial users of lawn and garden equipment, was evaluated. However, the correlation between equipment activity and each of these variables was found to be poor.

Figure 8. Annual hours of operation for residential equipment types.

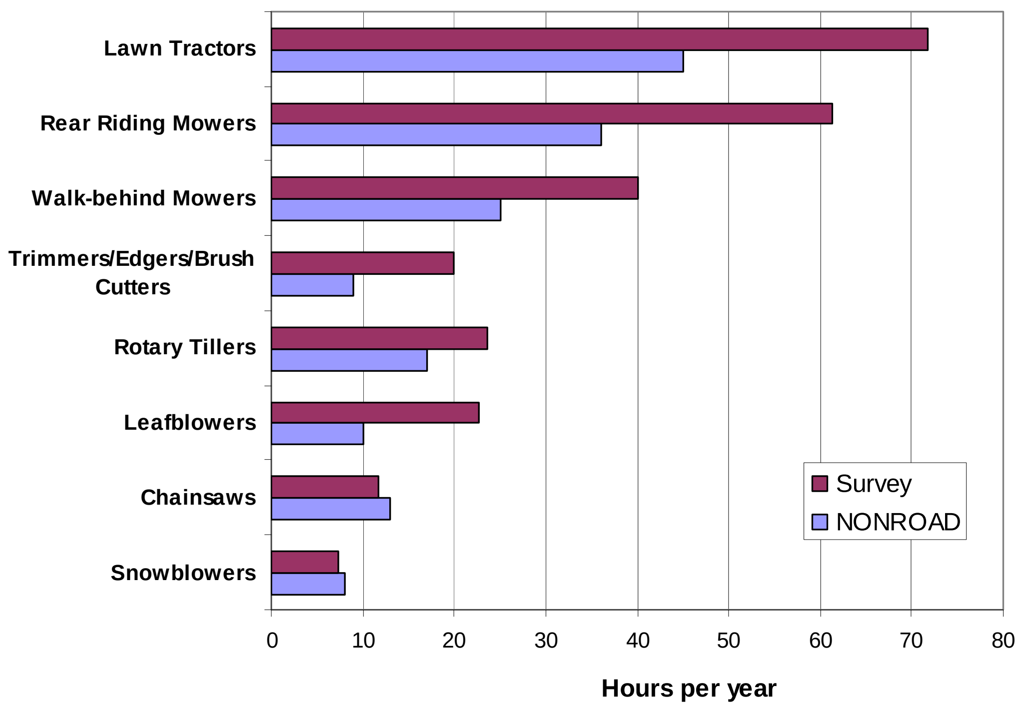
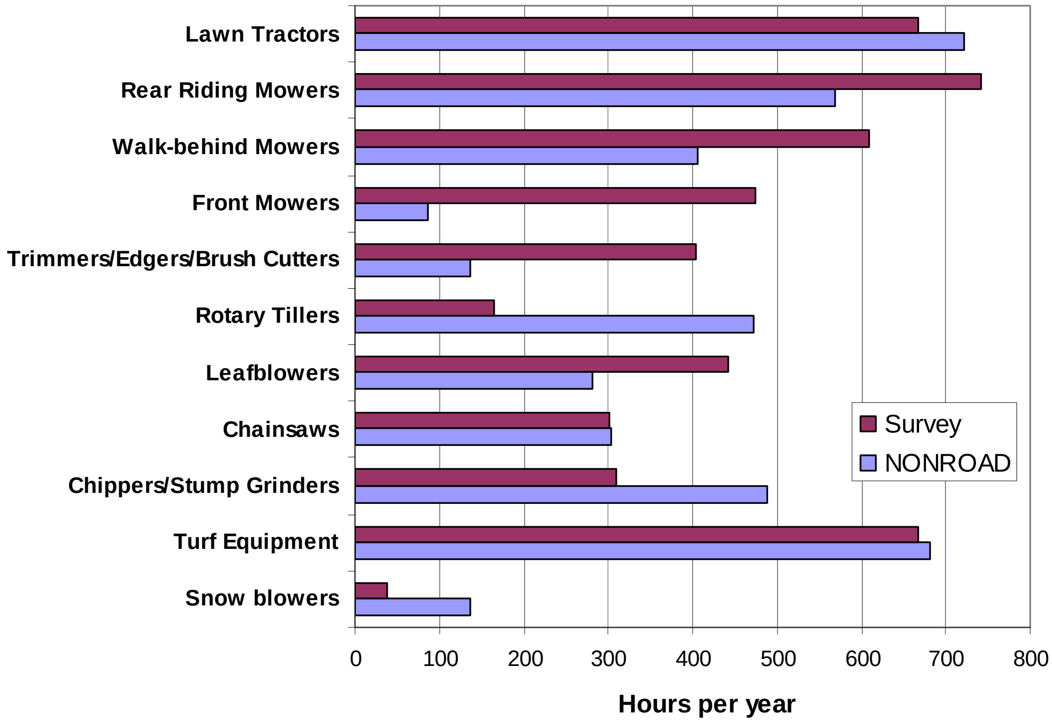


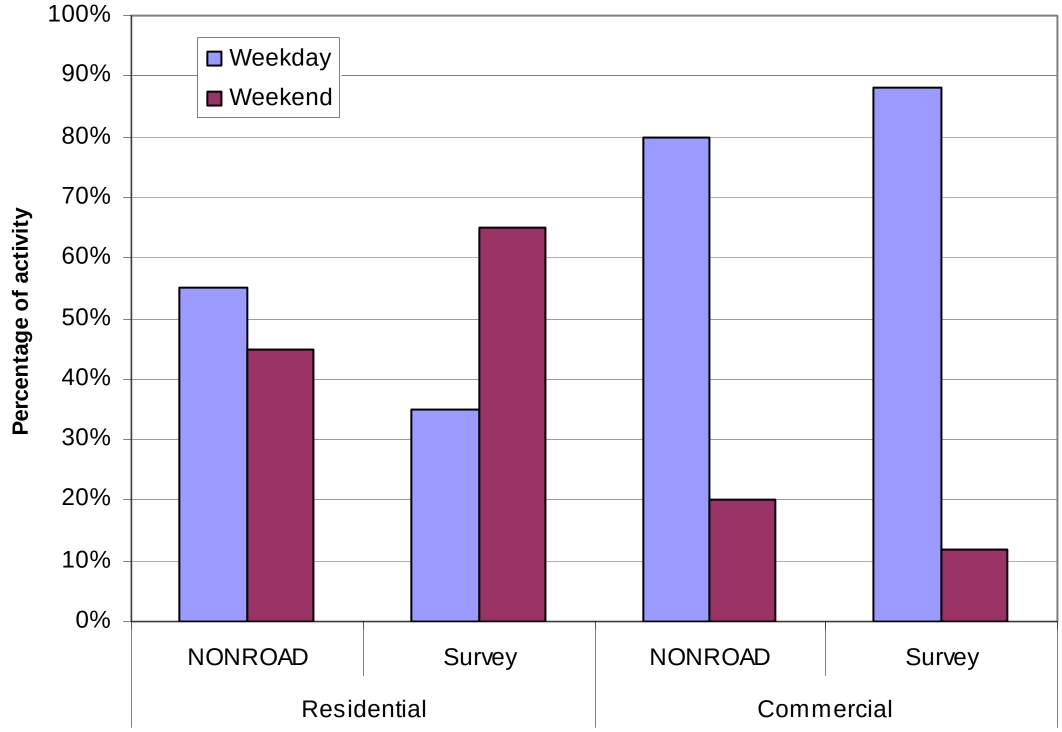
Figure 9. Annual hours of operation for commercial equipment types.



Temporal Patterns of Activity

The NONROAD model uses temporal allocation factors to assign equipment activity to months of the year and to weekdays or weekend days. To simplify the survey, respondents were asked to report equipment usage by season rather than by individual months; therefore, NONROAD monthly temporal profiles were aggregated to the seasonal level for comparison with survey results. In general, seasonal lawn and garden equipment usage patterns derived from survey results were very similar to seasonal usage patterns derived from NONROAD's monthly profiles. However, significant differences were found between survey-derived and NONROAD weekday/weekend allocation factors, particularly for residential equipment. Survey results indicated that about two-thirds (65%) of residential lawn and garden equipment usage occurred on weekend days, while the NONROAD model apportions less than half (45%) of residential equipment usage to weekend days (see Figure 10). For commercial lawn and garden equipment, survey results indicated that 88% of equipment usage occurred on weekdays, while the NONROAD model apportions 80% of equipment usage to weekdays (see Figure 10). Commercial survey results were consistent with similar studies performed in Los Angeles [13] and Texas [10], where business surveys indicated that over 90% of lawn and garden equipment activity occurred on weekdays.

Figure 10. Weekday vs. weekend allocation factors for residential and commercial lawn and garden equipment.

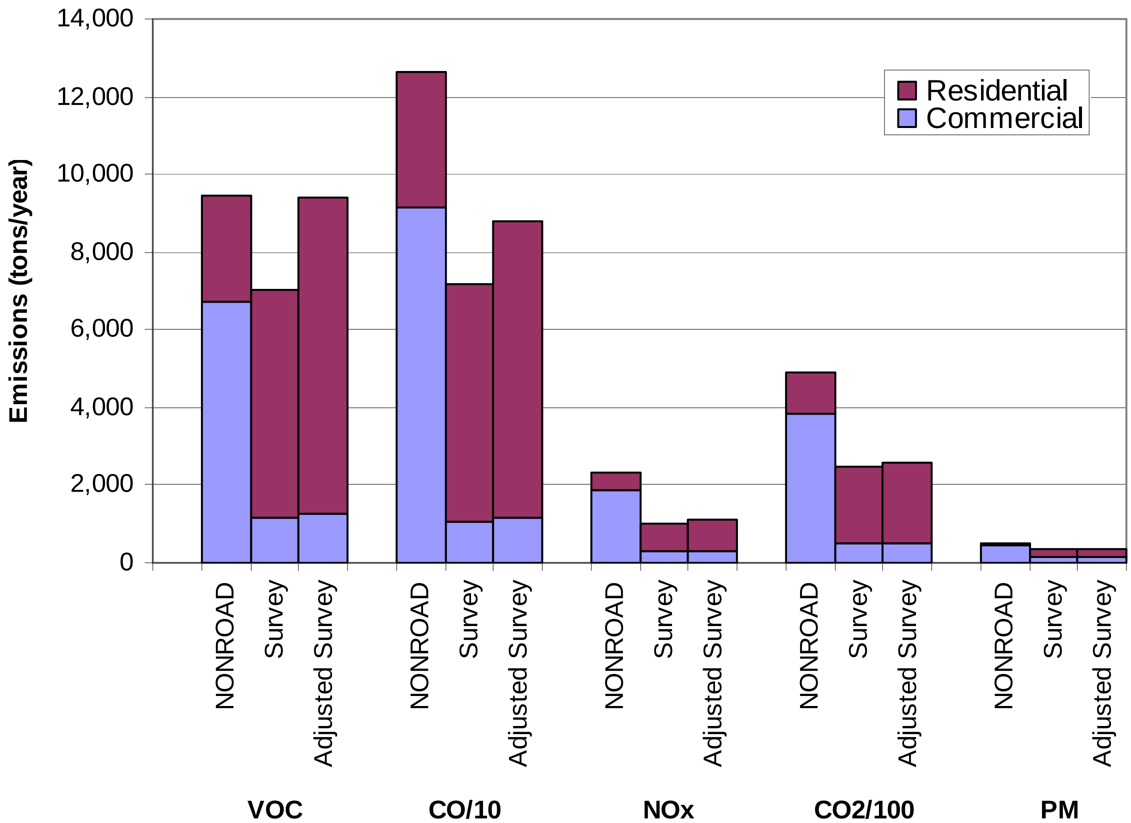


Emission Estimates

The NONROAD model was run for the Baltimore area for 2009 using default input data and updated input data (e.g., county-level equipment populations, hours of activity, and temporal allocation factors) derived from survey results. Overall, survey-derived emission estimates were 24% to 56% lower than emission estimates produced by NONROAD default data (see Figure 11); survey-derived VOC and NO_x emission estimates were 26% and 56% lower than NONROAD default emission estimates, respectively. These lower emission estimates occurred despite higher overall equipment populations in the survey-derived data. They resulted from the fact that commercial equipment populations produced by the survey results were much lower than those contained in the NONROAD default data. Because commercial equipment is used much more heavily than residential equipment, this decrease in commercial equipment populations results in emissions reductions that are not completely offset by the increase in residential equipment populations. If these emission reductions were applied to the 2005 NEI data discussed in the Introduction, the contribution of lawn and garden equipment to total VOC emissions in the Baltimore area would fall from 7% to 5%, while the contribution of lawn and garden equipment to non-road mobile VOC emissions in the Baltimore area would fall from 54% to 47%. For CO, the contribution of lawn and garden equipment to total emissions would decline from 16% to 9%, while the contribution of lawn and garden emissions to non-road mobile source emissions would fall from 67% to 54%.

In addition, because NONROAD's default age distributions allocate a higher percentage of equipment to recent model years than the survey results indicate, NONROAD outputs were examined by model year to estimate the impact of these differences in equipment ages. When adjustments were made to survey-derived emission estimates to account for the presence of older equipment in the surveyed populations, survey-derived VOC emissions increased by 34% and were virtually identical to VOC estimates produced by NONROAD default data (albeit for the wrong reasons). However, emission estimates for other pollutants increased by a smaller percentage and remained significantly lower (from 24% to 52% less) than emission estimates produced by NONROAD default data (see Figure 11). Note that no age adjustment was incorporated into the analyses of emissions by equipment type, county, and day-of-week described below.

Figure 11. Comparison of 2009 lawn and garden equipment emission estimates from NONROAD default data and survey-derived data. ("Adjusted Survey" values represent the estimated impact of using survey-derived equipment age distributions. For scaling purposes, CO emissions have been divided by 10 and CO_2 emissions have been divided by 100.)



In addition to an overall decrease in the magnitude of lawn and garden emissions for the Baltimore area and a shift in emissions from commercial to residential applications, there were differences in the distribution of emissions among equipment types as well. Among residential equipment types, walk-behind mowers accounted for over 30% of VOC emissions in both the NONROAD default and survey-derived inventories. However, the survey-derived emission estimates showed a greater contribution to VOC emissions from leafblowers and trimmers/edgers/brush cutters than VOC emissions produced by NONROAD default data (see Figure 12). For commercial equipment, walk-behind mowers, leafblowers, and chainsaws combined to account for over 40% of VOC emissions in both the NONROAD default and survey-derived inventories. However, survey-derived emission estimates showed a smaller contribution to VOC emissions from turf equipment, snowblowers, and rotary tillers and a higher contribution to VOC emissions from trimmers/edgers/brush cutters than VOC emissions produced by NONROAD default data (see Figure 12). County-level emission distributions are similar for both NONROAD default and survey-derived emission inventories, although updates to residential equipment populations in the survey-derived inventory shifted emissions from Baltimore City and Montgomery County to the northern counties of Carroll and Harford (see Figure 13).

Figure 12. Comparison of 2009 lawn and garden equipment VOC emission estimates from NONROAD default data and survey-derived data.

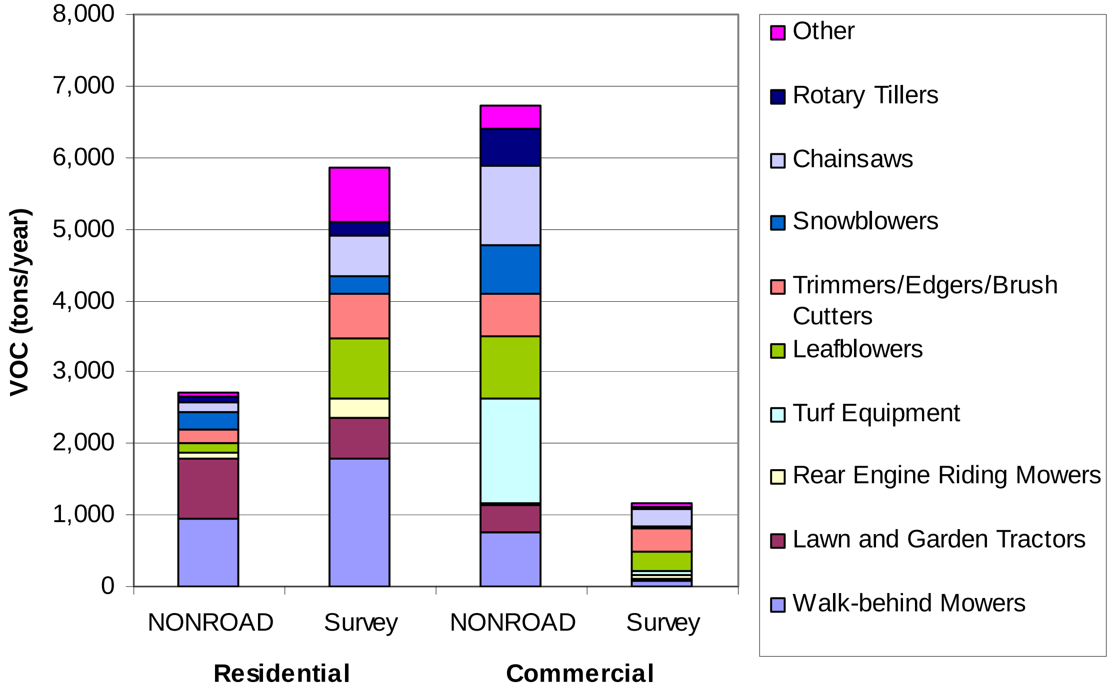
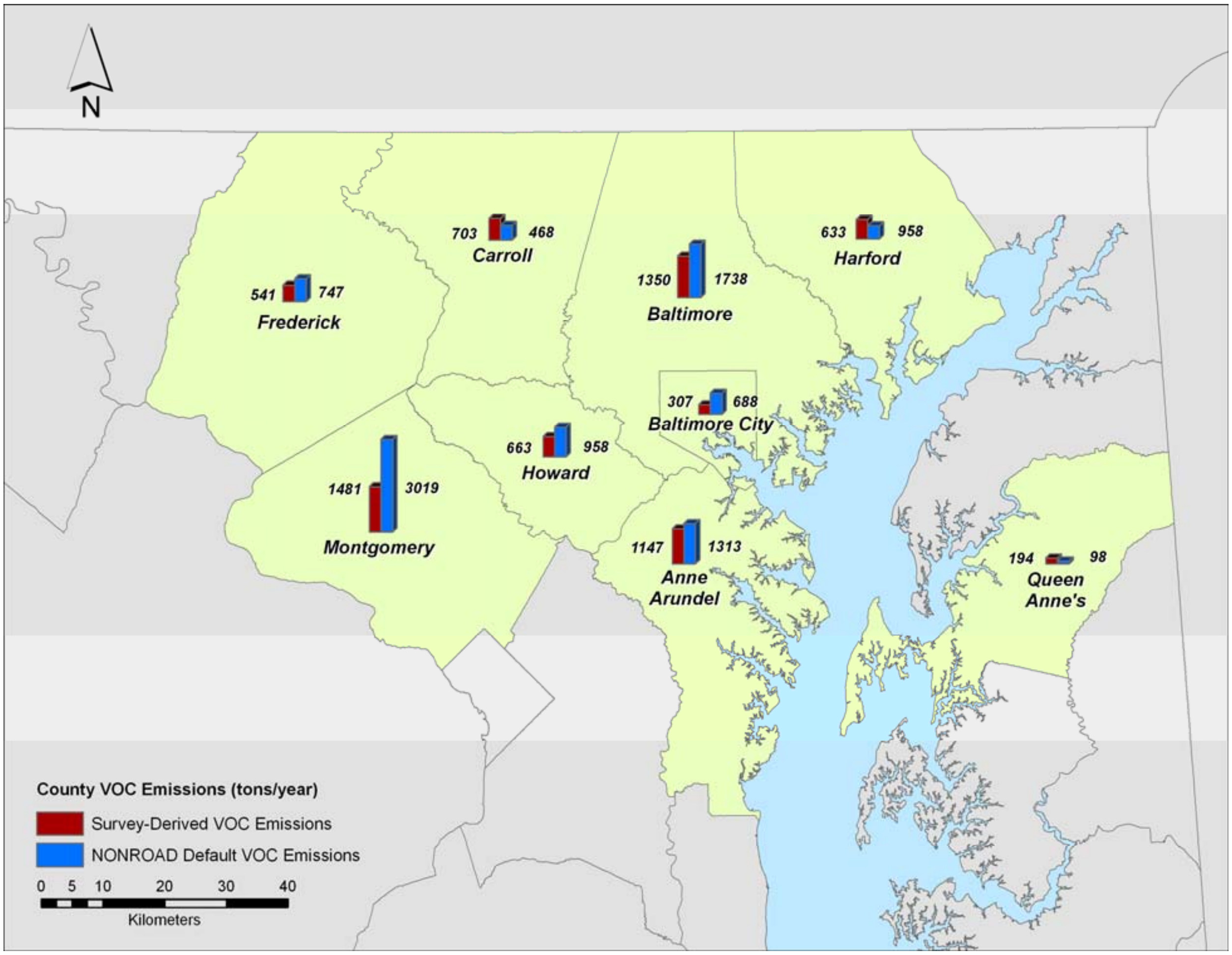
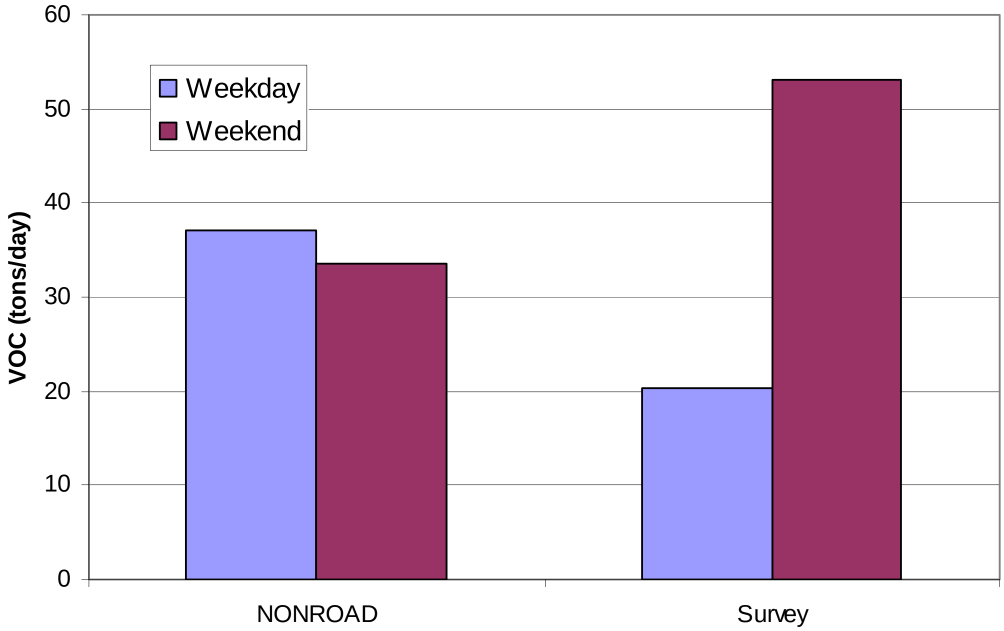


Figure 13. Comparison of 2009 county-level lawn and garden equipment VOC emission estimates from NONROAD default data and survey-derived data.



In addition to generating annual average emission estimates for lawn and garden equipment, the study also derived average weekday and weekend day emission estimates for the month of July in order to evaluate the impact of updating NONROAD temporal profiles for this source category. As discussed above, survey results showed significantly higher weekend activity levels for residential equipment than NONROAD's temporal allocation factors, while weekend activity levels for commercial equipment were slightly lower than NONROAD's temporal data. As a result, survey-derived average weekend day emission estimates for VOC were 60% higher than weekend VOC emission estimates produced with NONROAD default data (see Figure 14). In addition, survey-derived average weekend day VOC emission estimates were 2.6 times higher than survey-derived average weekday emission estimates, while VOC emission estimates produced with NONROAD default data showed a 10% decrease in average emissions on weekend days relative to weekdays.

Figure 14. Average July weekday and weekend day emission estimates produced by NONROAD default data and survey-derived data.



CONCLUSIONS

Results of this project show that default lawn and garden equipment population and activity data in EPA's NONROAD model are not representative of local conditions in the Baltimore area, and that urban-scale emission estimates for this source category can be improved through the bottom-up collection of local data on equipment populations and usage patterns. For the Baltimore metropolitan area, it was determined that across all pollutants, emission estimates based on surveys of residential and commercial users of lawn and garden equipment are 24% to 56% lower than estimates produced using NONROAD default data, largely due to a shift in equipment populations from high-usage commercial applications to relatively low-usage residential applications. For PM and VOC, survey-derived emission estimates are 24% and 26% lower than NONROAD default estimates, respectively, while survey-derived emission estimates for CO, CO_2, and NO_x are more than 40% lower than NONROAD default estimates. Also, the temporal allocation factors applied to residential lawn and garden equipment in the NONROAD model resulted in significantly underestimated weekend activity levels compared to survey-derived temporal profiles. Thus, survey-derived average weekend emission estimates for VOC were 2.6 times higher than average weekday emission estimates, while VOC emission estimates produced with NONROAD default data showed a 10% decrease in average emissions on weekend days relative to weekdays.

These findings indicate that potential errors in VOC emission estimates for lawn and garden equipment in metropolitan areas may be as large as emission reductions achievable with control measures such as the use of reformulated gasoline [14]. It should also be noted that when emission estimates were adjusted to account for the presence of older equipment in survey-derived equipment populations (as compared to NONROAD's default age distributions), survey-derived VOC emission estimates increased by 34% and were virtually identical to VOC estimates produced by NONROAD data—which points to possible "compensating errors" in the NONROAD model. (Emission estimates for other pollutants increased by a smaller percentage following age adjustments and remained 24% to 52% lower than emission estimates produced by NONROAD default data.) In addition, potential errors in the temporal data the NONROAD model uses to apportion lawn and garden emissions to weekdays and weekend days may result in the underestimation of weekend VOC emissions.

Similar surveys of commercial and residential lawn and garden equipment users elsewhere generally support the conclusion that commercial equipment populations may be overestimated in the NONROAD model, while residential equipment populations may be underestimated. Previous surveys of commercial lawn and garden equipment users have indicated commercial equipment populations that were significantly lower than NONROAD default values [8-10], including a study in Texas that resulted in statewide commercial equipment populations that were only 31% of NONROAD's equipment population estimates [9]. Residential lawn and garden equipment populations in California developed from a survey conducted by CARB are 32% higher than residential equipment populations for California in the current NONROAD model and higher than statewide residential equipment populations in CARB's OFFROAD model by a factor of 2.6 [12]. Taken together, these results point to a potential bias in the methods used in the NONROAD model to apportion lawn and garden equipment to residential and commercial applications. The results also highlight an important area of focus for future efforts undertaken at the local or national level to improve estimates of emissions from lawn and garden equipment.

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