Modeling Non-Road Agricultural Tractor Emissions in Central Texas

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ABSTRACT

The Capital Area Council of Governments (CAPCOG) represents 10 counties in Central Texas that include the Austin-Round Rock Metropolitan Statistical Area (MSA). CAPCOG has developed an approach for modeling emissions of agricultural tractors that involves a very high degree of spatial and temporal resolution and provides significant improvements over existing methods. In 2012, CAPCOG worked with Eastern Research Group (ERG) to conduct a regional survey of tractor operators in order to obtain detailed, regionally-representative data on tractor usage and engine characteristics. This survey was designed to determine if tractor usage and characteristics within the region varied significantly from data developed based on a statewide survey conducted in 2007 and from EPA NONROAD model defaults. Among the key findings from the survey were:

- Typical tractor usage in Central Texas is much lower than represented in the statewide survey or in EPA's NONROAD model;
- The typical horsepower ratings of tractors in Central Texas skew lower than the distribution and average horsepower ratings in the EPA NONROAD model;
- Annual usage varies significantly based on engine horsepower rating (higher HP tractors have higher average usage); and
- The age distributions for tractors are substantially older than the age distributions generated using the default scrappage assumptions in the NONROAD model.

CAPCOG has used this data, in conjunction with tractor population data from the Census of Agriculture, regional tractor sales data, and land usage geo-spatial data from the U.S. Department of Agriculture's CROPSCAPE tool in order to improve the representation of this non-road emissions category in regional photochemical modeling efforts.

INTRODUCTION

This project involves updating emissions estimates for agricultural tractors, a type of non-road mobile equipment included in the U.S. Environmental Protection Agency's (EPA's) NONROAD model. Agricultural operations consume significant quantities of energy, and properly modeling emissions from this sector should significantly improve the accuracy and efficacy of regional air quality planning efforts. According to the U.S. Energy Information Administration (EIA), the agricultural sector consumed about 69% more diesel than the construction sector in 2013 (EIA 2015). Tractors are the most prevalent type of non-road mobile equipment used in the agricultural sector and account for the about 85% of the diesel consumed by agricultural equipment in the NONROAD model.

As this report shows, substantial data are readily available that can be used to improve the accuracy of county-level emissions estimates and the representation of these emissions in photochemical modelling efforts. In 2013, CAPCOG completed emissions inventory research projects that developed updated 2006 ozone season day emissions estimates for agricultural tractors (CAPCOG 2013a), updated 2012 and 2018 ozone season day emissions for all non-road agricultural equipment (CAPCOG 2013b), and spatially allocated factors based on USDA CROPSCAPE land use geo-spatial data (CAPCOG 2013b). CAPCOG contracted ERG to conduct a regional survey in 2012 that was used for the previous 2006, 2012, and 2018 emissions inventory projects. This paper focuses on CAPCOG's development of updated 2012 ozone season day emissions estimates for agricultural tractors using the 2012 Census of Agriculture data, newly acquired tractor sales data, an updated version of the Texas NONROAD (TexN) model, and an improved process for performing age distribution adjustments to the TexN emissions output files. This project includes updates estimates of emissions of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_X), particulate matter (PM), sulfur dioxide (SO_2), and volatile organic compounds (VOC) for Bastrop, Blanco, Burnet, Caldwell, Fayette, Hays, Lee, Llano, Milam, Travis, and Williamson Counties for a typical 2012 summer weekday.

The agricultural tractor equipment type uses the source classification code (SCC) 22xx005015. Agricultural tractors are used for a wide variety of applications on farms, and are usually outfitted with various implements to perform different types of work. For a corn field, for instance, a tractor might use a tandem disc, chisel plow, field cultivator, liquid fertilizer rig, spray rig, and grain cart (in conjunction with a combine) over the course of a year. In most cases, modern agricultural tractors also have "power take-off" (PTO) applications that use the tractor's engine output to supply mechanical power to the implement. For example, hay balers hooked up to a tractor will use the tractor's engine output to harvest hay and form it into bales for collection at a later point.

While there are many nonroad equipment types with "tractor" in the description, such as 2-wheel tractors, off-highway tractors, terminal tractors, and lawn and garden tractors, "agricultural tractors" are specifically used in agricultural production (NAICS Code 11 – Agriculture, Forestry, Fishing, and Hunting). While other equipment types modeled in NONROAD may even include the same make and model as an agricultural tractor, only tractors used for agricultural production should be considered an "agricultural tractor."

CAPCOG DEVELOPMENT OF 2012 AGRICULTURAL TRACTOR OZONE SEASON WEEKDAY EMISSIONS ESTIMATES

Table 1 below summarizes the parameters for CAPCOG's 2012 agricultural tractor emissions modeling and the data sources used, which will be discussed in the following sections.

Table 1. Summary of parameters updated and data sources used.

Parameter	Data Sources
Equipment Populations	2012 Census of Agriculture
Fuel Type Distribution	2012 ERG Central Texas Survey (Baker and Boatman 2012), EDA Equipment Sales Data for Central Texas
Horsepower Distribution	2012 Census of Agriculture, 2012 ERG Central Texas Survey (Baker and Boatman 2012), EDA Equipment Sales Data for Central Texas
Average Horsepower	NONROAD Defaults, 2012 ERG Central Texas Survey (Baker and Boatman 2012), EDA Equipment Sales Data for Central Texas
Age Distribution	2012 ERG Central Texas Survey (Baker and Boatman 2012), 2012 Census of Agriculture, Historical Censuses of Agriculture
Annual Activity	2012 ERG Central Texas Survey
Seasonal Distribution of Activity	2007 Texas Statewide Survey by E.H. Pechan (Thesing 2009), 2012 ERG Central Texas Survey (Baker and Boatman 2012)
Weekday/Weekend Distribution of Activity	2007 Texas Statewide Survey by E.H. Pechan (Thesing 2009)
Diurnal Distribution	2007 Texas Statewide Survey by E.H. Pechan (Thesing 2009)
Meteorology	2012 Local Meteorological Data
Fuel Parameters	2011 Fuel Sampling by ERG (Baker et al. 2011)
Emissions Model	Texas NONROAD Model version 1.6.1
Spatial Allocation	2012 CROPSCAPE Data

2012 EASTERN RESEARCH GROUP (ERG) SURVEY OF CENTRAL TEXAS TRACTOR OPERATORS

CAPCOG worked with ERG to conduct a regional phone survey in August and September 2012 to better assess the annual activity, seasonal activity, horsepower profiles, age distribution, and fuel type of agricultural tractors in Central Texas (Baker and Boatman 2012). A comprehensive list of over 1,500 area farmers and ranchers was obtained for the survey from Survey Sampling International (SSI). ERG provided disaggregated survey results for agricultural tractors operating in an 11-county region (Bastrop, Blanco, Burnet, Caldwell, Fayette, Hays, Lee, Llano, Milam, Travis, and Williamson Counties) to CAPCOG. The data obtained from the phone survey was used to develop the estimates necessary for emissions modeling.

Survey and Data Collection

ERG collected data through SSI, and included farmers of all crop/livestock types, acreage, and gross farm income in order to obtain representative equipment counts, characteristics, and use profiles for agricultural equipment operating in the 11-county region. ERG obtained contact records for 1,507 farms and ranches, and 27 farm management services operating in the 11-county region. These services are likely to use their own agricultural equipment more intensively than individual farmers/ranchers, contracting with multiple clients per year. In order to encourage survey response, CAPCOG obtained support for the survey from various county-level agriculture and judicial leaders, and potential survey respondents were informed of the support from these entities upon initial contact.

The standard phone survey questions were specifically worded to elicit information regarding "typical year" operation, so as to reduce the influence of year-to-year variability (e.g., due to droughts). The phone surveys were designed to establish eligibility, collect basic establishment information as well as detailed equipment use. An e-mail version of the survey was developed for a number of respondents preferring to submit their information electronically. The complete survey questionnaire is available on CAPCOG's website as an appendix to CAPCOG's 2006 Agricultural Tractor emissions inventory.

ERG staff conducted phone surveys using the call list obtained from SSI from August 6, 2012, through September 7, 2012. Confidentiality was stressed to participants taking the study, and was maintained by eliminating names from interview records and stripping all respondent-identifying characteristics from study datasets. In addition, all project staff members were given explicit training regarding confidentiality protocols and commitments.

Phone Survey Results

ERG attempted to contact the first 832 establishments, 55% of the total included in the (randomized) SSI sample frame, at least once by phone during the one month data collection period. 108 of 832 attempted contacts resulted in a completed survey (13% response rate). In addition, excluding the "ineligible" and "no answer" calls completed, the effective response rate (i.e., the rate at which eligible individuals who were successfully contacted agreed to participate in the survey) was much higher, at 20.8%. ERG also attempted to contact all 27 farm management companies listed as operating in the 11-county area, but was not able to obtain responses from this cohort.

The relatively high effective response rate could be due to a number of factors, including efforts to enlist the support of key stakeholders, detailed research on the part of the surveyor regarding Central Texas agricultural practices, and modifications made to data collection procedures and scripts based on early respondent feedback.

Quality Assurance of Phone Survey Results

To ensure the activity, horsepower, and model year data collected in the phone surveys were reasonable, these fields in the survey had pre-defined range checks associated with them. This allowed the person conducting the survey to ask for qualifying information if the responses were not reasonable or were inconsistent. For example, the surveyor asked for confirmation if the respondents' answer regarding engine size was greater than 300 HP and/or the reported engine-on time was greater than 1,000 hours/year. The surveyor also conducted a search of equipment manufacturer websites to gap-fill any missing HP values based on available make and model information.

In addition, ERG reviewed the results of the surveys at regular intervals to check for data completeness and determine if adjustments needed to be made to the survey questions or method in order to ensure the survey was adequately collecting the data necessary for emission calculations.

Geographic Distribution of Survey Responses

Table 2 presents the county distribution for the survey respondents, along with the distribution of farms/ranches reported in the 2012 Census of Agriculture. Establishments spanning multiple counties were allocated across the counties based on the acreage split reported by the respondents. At the time the survey conducted, the most recent Census of Agriculture data available was from 2007, which ERG used as a point of comparison. Based on this analysis, ERG concluded the survey was geographically representative of the 11-county study region. The 2012 Census of Agriculture farm counts are now available, allowing for contemporaneous comparison.

Table 2. County distribution of survey respondents compared to distribution of farms in the 2012 Census of Agriculture.

County	Farms Surveyed	% of Surveys of 11-County Total	Census of Agriculture Farms	% of Census of Agriculture 11-County Total
Bastrop	10	9%	2,083	11%
Blanco	1	1%	792	4%
Burnet	4	4%	1,481	8%
Caldwell	12	11%	1,623	9%
Fayette	12	11%	2,822	15%
Hays	6	6%	1,439	8%
Lee	11	10%	1,807	10%
Llano	4	4%	740	4%
Milam	14	13%	1,909	10%
Travis	11	10%	1,132	6%
Williamson	23	21%	2,542	14%
TOTAL	**108**	**100%**	**18,370**	**100%**

Agricultural Activity Characterization

Survey respondents fell into two broad activity type categories – livestock and row crop production. ERG assigned respondents to one of these two categories based on their questioning. A total of 86 of the 108 respondents reported that 100% of their agricultural machine use was dedicated to livestock production.

Of the 13 respondents reporting that less than 50% of their equipment activity was associated with livestock production, the maximum value was 25% and the average value was 8%, with six respondents reporting 0%. These respondents generally reported cultivating a mix of various row crops, including corn, sorghum, wheat, cotton, and pecans.

According to the Census of Agriculture, livestock production/ranching establishments are far more prevalent in the 11-county study area than are farms involved in row crop production. Table 3 below presents the county-level respondent totals broken out by major activity category, as well as the corresponding establishment totals from the Census of Agriculture. While the low number of row crop respondents contributes to substantial uncertainty in the representativeness of the survey results for this activity category, the overall incidence of row crop production relative to livestock production (88%) is quite similar to that found in the 2007 Census of Agriculture (92%). As such, ERG concluded the overall survey results were representative of the target population as whole with respect to this dichotomous activity classification.

Table 3. Row crop vs. livestock operation survey results compared to the 2007 Census of Agriculture.

County	Survey County % of Regional Total of Livestock Farms	2007 Census of Agriculture County % of Regional Total of Livestock Farms	Survey County % of Regional Total of Row Crop Farms	2007 Census of Agriculture County % of Regional Total of Row Crop Farms
Bastrop	11%	12%	0%	2%
Blanco	1%	4%	0%	0%
Burnet	4%	7%	0%	0%
Caldwell	13%	8%	0%	4%
Fayette	13%	19%	0%	7%
Hays	5%	5%	0%	2%
Lee	12%	12%	0%	3%
Llano	4%	4%	0%	0%
Milam	14%	11%	8%	18%
Travis	7%	5%	31%	13%
Williamson	17%	12%	62%	50%

Of the 95 respondents falling into the livestock category, approximately one-third also reported some level of hay production, although the survey did not ask for this information explicitly. Based on this anecdotal information, we expect that hay production, either for internal use or sale, is relatively common among livestock producers in the region.

Fuel Type Distributions

Table 4 below shows the distribution of responses to ERG's survey by fuel type and horsepower range. The existence of LPG tractors is notable since the NONROAD model does not account for LPG tractors at all – this finding is also consistent with Pechan's 2009 study (Thesing 2009). There were also substantially more gasoline-powered tractors than estimated in either the NONROAD or TexN model, mostly at the lowest end of the HP ranges. The survey also demonstrated that 100% of tractors in the 100+ HP range were diesel-fueled.

Table 4. Tractor fuel type distribution by horsepower range, survey results.

HP Range	Diesel	Gasoline	LPG	Gasoline + LPG	TOTAL
<40 HP	40	17	1	18	58
40-99 HP	138	11	4	15	153
100+ HP	101	0	0	0	101
TOTAL	**279**	**28**	**5**	**23**	**312**

Given the small sample size for non-diesels, as shown in Table 4 above, ERG did not recommend separating the diesel and non-diesel tractors for determining horsepower distributions for emissions modeling.

Horsepower Distributions and Averages

Figure 1 and Table 5 below show comparisons of the HP distributions and average HP ratings for the ERG survey responses relative to the NONROAD model defaults for 2012 across all fuel types. Some of the average HP ratings were statistically significantly different at a 95% confidence level. While the distribution of survey responses by HP bin and average HP rating within several bins was statistically similar, the data in general showed that the NONROAD model population is distributed toward the lower end of the HP ranges in the NONROAD model and lower average HP ranges within the various bins.

Figure 1. Comparison of survey response and NONROAD model HP distributions.

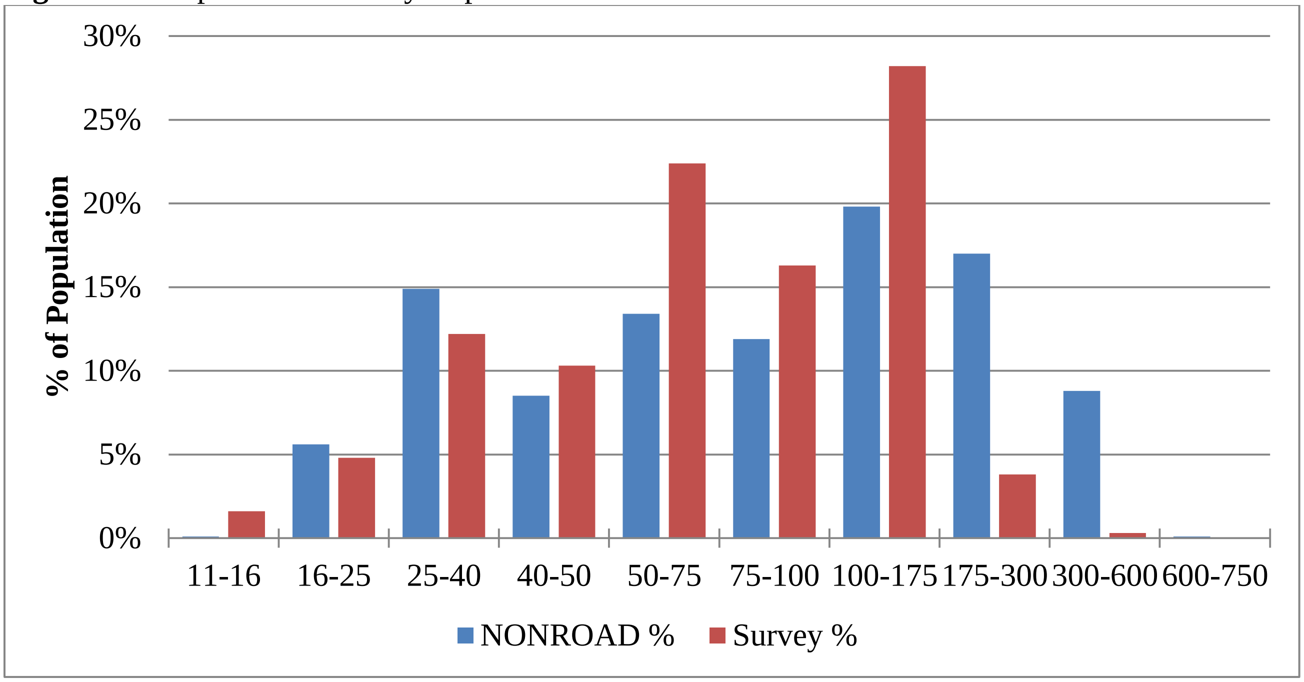


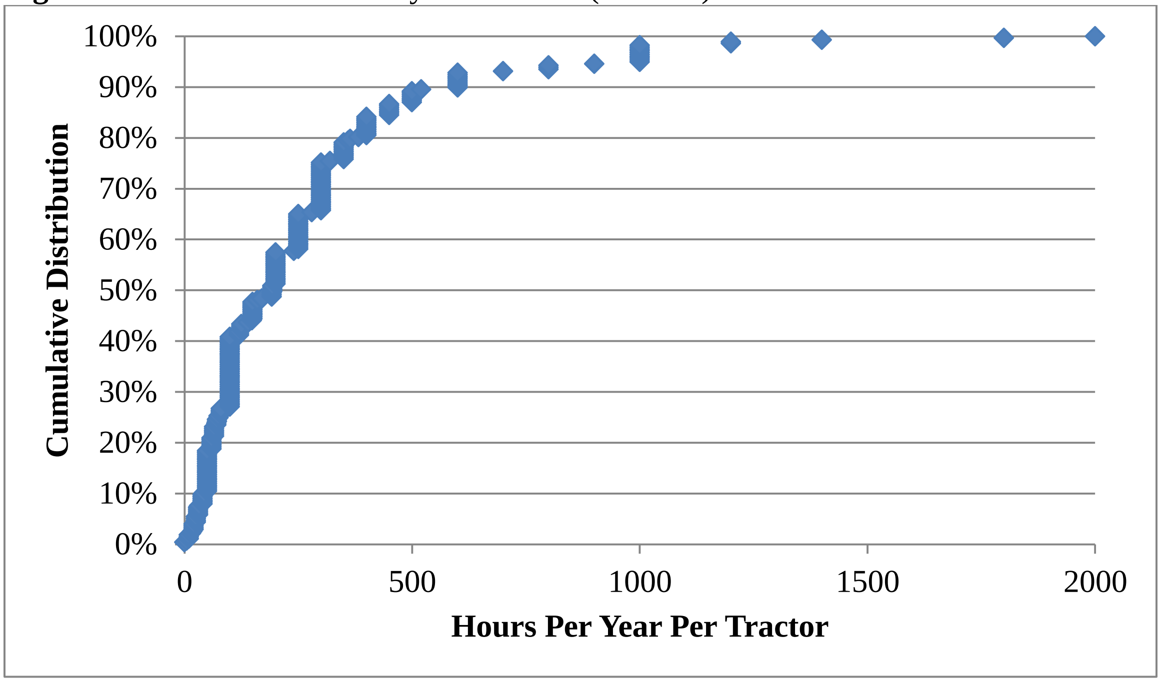
Table 5. Comparison of average horsepower ratings of survey responses by HP bin.

HP Bin	Survey HP Avg. and Range	NONROAD Avg. HP	Statistically Different @ 95% CL?
11-16	13.3 (11.6 – 15.1)	16.0	Yes
16-25	21.1 (20.1 – 22.1)	21.0	No
25-40	31.5 (29.9 – 33.0)	32.5	No
40-50	43.4 (42.3 – 44.5)	46.4	Yes
50-75	59.7 (57.8 – 61.5)	62.2	Yes
75-100	86.2 (84.3 – 88.0)	86.1	No
100-175	127.5 (123.5 – 131.6)	133.6	Yes
175-300	205.4 (187.8 – 223.0)	236.5	Yes
300-600	335.0	415.2	n/a
600-750	n/a	635.0	n/a
All	**81.9**	**131.9**	**n/a**

Annual and Seasonal Activity Profile

Reported annual hours of tractor activity ranged from a minimum of 5 hours to a maximum of 2,000 hours. Figure 2 below shows the cumulative distribution of reported activity for all tractors in the survey response data set.

Figure 2. Annual tractor activity distribution (all units).



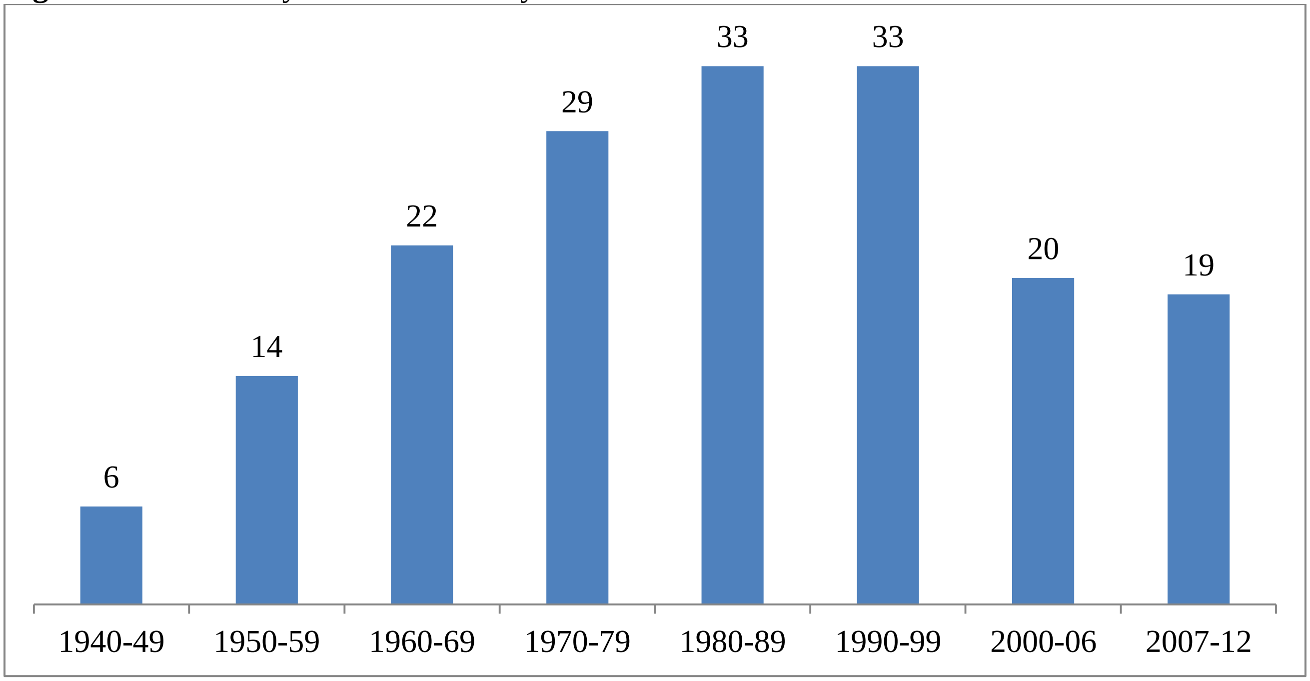
ERG evaluated the activity data from various angles to identify meaningful trends influencing tractor use, including separating ranching/hay production from row crop production, fuel types, and tractor horsepower. Differentiating activity by horsepower group showed the clearest distinction, and was chosen as the best way to characterize distinct equipment activity profiles without increasing uncertainty.

ERG assessed seasonal activity in their survey and determined that there was only a small variation in seasonal activity as a function of horsepower. Since ERG calculated essentially identical seasonal adjustment factors to those used by the TexN model, they recommended no change from the TexN parameters.

Engine Age Distribution

ERG's survey discovered that model year distribution is significantly skewed toward older tractors, with an average age of 28 years. CAPCOG's review of the data revealed, surprisingly, that the age distribution for agricultural tractors can be more accurately modeled using a scrappage curve that models no retirement until a tractor reaches its full useful life (2 times the median useful life) than NONROAD's default scrappage curve. This results in an age distribution much more heavily skewed towards newer model years than either ERG's survey or the Census of Agriculture shows. The age distribution of ERG's survey responses was consistent with the age distributions in the Census of Agriculture, showing less than 11% of tractors manufactured in the previous five years. Figure 3 shows the number of tractors surveyed by model year grouping.

Figure 3. ERG Survey – Tractor model year distribution.



EQUIPMENT DATA ASSOCIATES (EDA) TRACTOR SALES DATA

In early 2015, CAPCOG purchased a database of sales, leases, refinancings, wholesale transactions, loan terminations, and rentals of agricultural tractors in the 100+ HP range that occurred from 1992 – 2014 in the 11-county study area from EDA. CAPCOG classified each transaction according to the corresponding NONROAD HP bin and Standard Industrial Code (SIC). From this dataset, CAPCOG removed duplicate records for a specific tractor, such as a tractor that was refinanced several times or resold after initial purchase, by sorting the transactions by serial number. For some makes of tractor, the serial numbers had been truncated and reflected multiple pieces of equipment and not one specific tractor. CAPCOG filtered the data in order to obtain the earliest records associated with each unique tractor and to remove all records associated with non-agricultural SIC codes. While the Census of Agriculture only uses SIC codes 01 and 02 (farming and ranching, respectively), CAPCOG decided to also include some 07 and 08 SIC codes to reflect potential overlap with tractor populations reported in the Census of Agriculture. These correspond with the following descriptions:

- 0711: Soil preparation services;
- 0721: Crop planting and protecting;
- 0722: Crop harvesting;
- 0724: Cotton ginning;
- 0740: Veterinary services;
- 0762: Farm management services; and
- 0811: Timber tracts.

Once CAPCOG had eliminated the duplicate records and records for non-agricultural establishments, the resulting database reflected purchases or leases of new or used agricultural tractors from 1992 – 2014. First, CAPCOG confirmed that all tractors in these ranges were diesel-powered, as determined by the ERG survey. CAPCOG then examined tractors coded with “280+ HP” or “300+ HP” to determine the higher end of the HP range. These fell into 55 different make/model combinations, which CAPCOG looked up on tractordata.com to find the actual HP ratings. For this subset, none of the tractors were over 600 HP and they all fell into the 300-600 NONROAD HP bin. CAPCOG subsequently determined the actual horsepower of the rest of the EDA records for further use in calculating average horsepower ratings.

TRACTOR POPULATION UPDATES

CAPCOG used the U.S. Department of Agriculture's (USDA's) Census of Agriculture as the basis for agricultural tractor population counts. The Census of Agriculture provides county-level data on tractor populations in three horsepower (HP) groupings:

- Less than 40 HP (<40 HP);
- 40 to 99 HP (40-99 HP); and
- 100 HP or more (100+ HP).

Overview of Census of Agriculture Data on Tractors

The Census of Agriculture represents the most comprehensive dataset for agricultural tractor equipment population data at the county level for the entire nation. The Census of Agriculture is conducted by the U.S. Department of Agriculture (USDA) every five years. For this project, CAPCOG used Censuses of Agriculture for 2012, 2007, 2002, 1997, 1992, 1987, 1982, 1978, 1974, and 1969. Data on the <40 HP, 40-99 HP, and 100+ HP groupings are reported in the 2012, 2007, 2002, and 1997 Censuses of Agriculture. The 1992 and 1987 Censuses are broken down into two groupings only: <40 HP and 40 HP or greater (40+ HP). Censuses conducted in 1982 and earlier did not include a breakdown by HP range. Data on the percentage of tractors manufactured in the last five years is available for each of the Censuses.

As described in the USDA's methodology description for the Census, "The purpose of a census is to enumerate all objects with a defined characteristic. For the census of agriculture, that goal is to account for 'any place from which $1,000 or more of agricultural products were produced or sold, or normally would have been sold, during the census year."

Over the years, the terminology reported for this equipment type was reported has changed somewhat. CAPCOG counted all of the following as "agricultural tractors."

- 2012, 2007, and 2002: "Tractors;"
- 1997, 1992, 1987, 1982, 1978: "Wheel tractors;"
- 1974: "Wheel tractors" and "Crawler tractors;"
- 1969: "Tractors other than garden tractors.

As long ago as 2003, other researchers have identified the Census of Agriculture county-level equipment population data as a viable alternative to the population data in the NONROAD model (Lindhjem 2003). CAPCOG has previously used Census of Agriculture data from 2007 and earlier to estimate regional tractor emissions for 2006, 2012, and 2018 (CAPCOG 2013a, CAPCOG 2013b). For this project, CAPCOG is using 2012 and earlier data to estimate tractor emissions for 2012.

2012 Census of Agriculture Methodology

According to the documentation of the USDA's methodology, the agency's data collection efforts for the Census of Agriculture started with the "Census Mail List." The USDA established the official Census Mail List for the 2012 Census of Agriculture on September 1, 2012. The list contained 3,009,641 records. In order to ensure high levels of participation, USDA conducted extensive outreach efforts that are fully described in the methodology appendix for the Census of Agriculture. Report forms were mailed in December 2012, due to be returned on February 4, 2013. USDA conducted follow-up mail-outs in January 2013 and February 2013, and conducted personal follow-ups using call centers in order to ensure completeness and accuracy. Overall, the response rate for the 2012 Census of Agriculture was 80.1%, compared to 85.2% in 2007 and 88.0% in 2002.

Census of Agriculture Form and Instructions

In Section 29 of the 2012 report form, farmers and ranchers were asked, "For the items listed below, report the number on this operation on December 31, 2012. Include machinery, equipment, and implements used for the farm or ranch business in 2011 or 2012, and usually kept on the operation." For each of eight equipment types, farmers and ranchers are asked to report both the number on the operation on December 31, 2012, and of these, the number that were manufactured in the last five years (from 2008-2012). The equipment types relevant for this study included were:

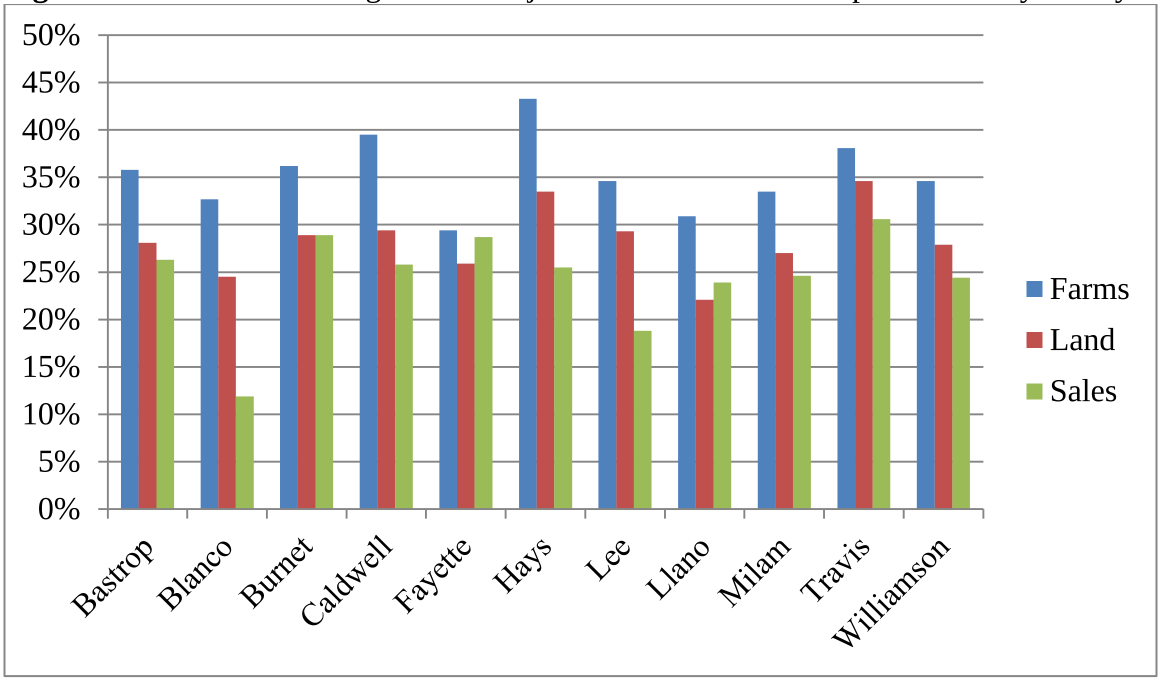
- "Tractors less than 40 horsepower (PTO) – Exclude garden tractors;"
- "Tractors 40 – 99 horsepower (PTO);" and
- "Tractors 100 horsepower (PTO) or more" (USDA, 2011a).

The instructions for this section state the following: "Report the total on this operation, or normally on this operation and normally used on this operation, in the first column. Do not report obsolete or abandoned equipment. In the second column, report only the number manufactured in the last five years" (USDA, 2011b). These instructions make it clear that the Census tractor population only includes tractors that are actively used for agricultural production.

Adjustments for Under-Coverage, Nonresponse, and Misclassification

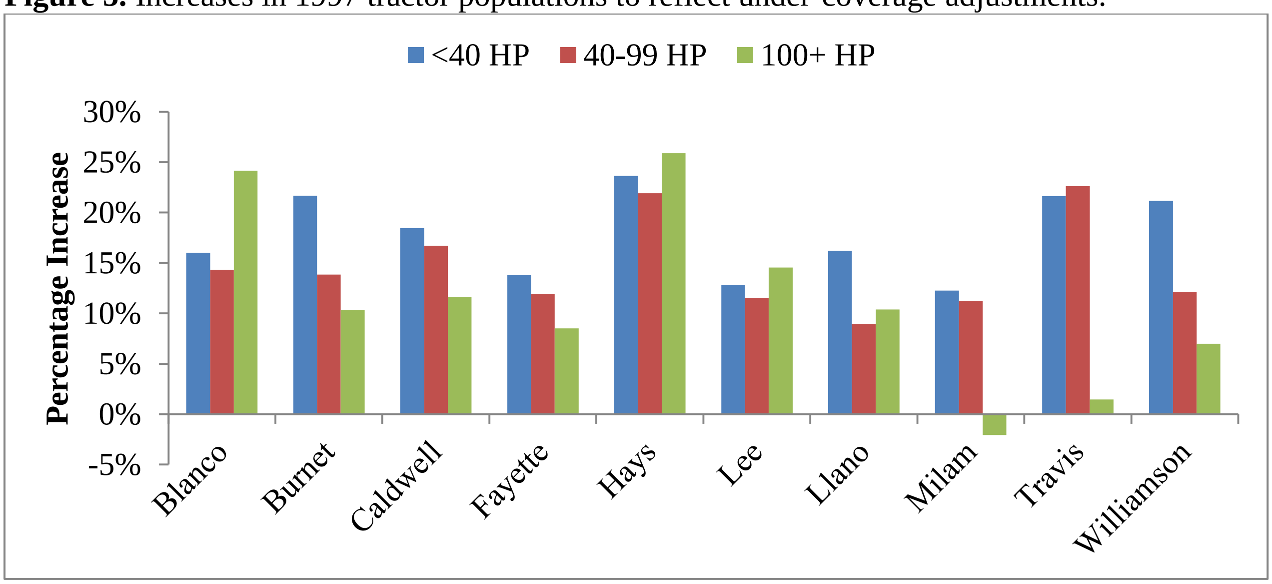
After compiling all reported data, the USDA then accounted for nonresponse, under-coverage, and misclassification errors. Nonresponse error is associated with people who have received the form but did not respond. Under-coverage error is associated with establishments not being on the original mail-out list. Misclassification error is associated with an establishment being incorrectly categorized. While the USDA does not directly provide data on the extent to which the tractor-specific data was adjusted from the data that was collected, the 2012 Census Appendix Table C does provide county-level data on these adjustments for the total number of farms, land in farms, and sales, as well as the standard error for a 95% confidence interval. In practice, this means that about 11,931 farms actually submitted responses to USDA from the 11-county study area, but 18,370 farms were reported for these 11 counties, which calculates to an adjustment of about 35%. Figure 4 below shows the contribution of each of the three adjustments to number of farms, land area, and sales estimates for each county in the region. While the adjustment factors used for tractors were not directly presented in the Census of Agriculture, CAPCOG would expect them to be within the range of values covered by these three adjustment types.

Figure 4. 2012 Census of Agriculture adjustments as % of total reported data by county.



For the 1992 and earlier Censuses, the United States Census Bureau administered the collection of the Census on behalf of the USDA. When reported, the Census Bureau adjusted any data collected only to account for non-response error. Beginning with the 1997 Census, the USDA began to directly administer the Census, and shortly thereafter, the department began applying a second adjustment to account for farms that had not been included in the survey list (the under-coverage adjustment). The data reported on the actual 1997 Census only included non-response adjustments, so in the 2002 Census of Agriculture, USDA also re-reported the 1997 data to reflect this additional under-coverage adjustment. Figure 5 below shows the % increase in tractor population counts for the 11 counties in this study area and Texas as a whole as a result of this adjustment. For reasons unknown, the adjustment for Milam County actually resulted in a decrease in the population for 1997.

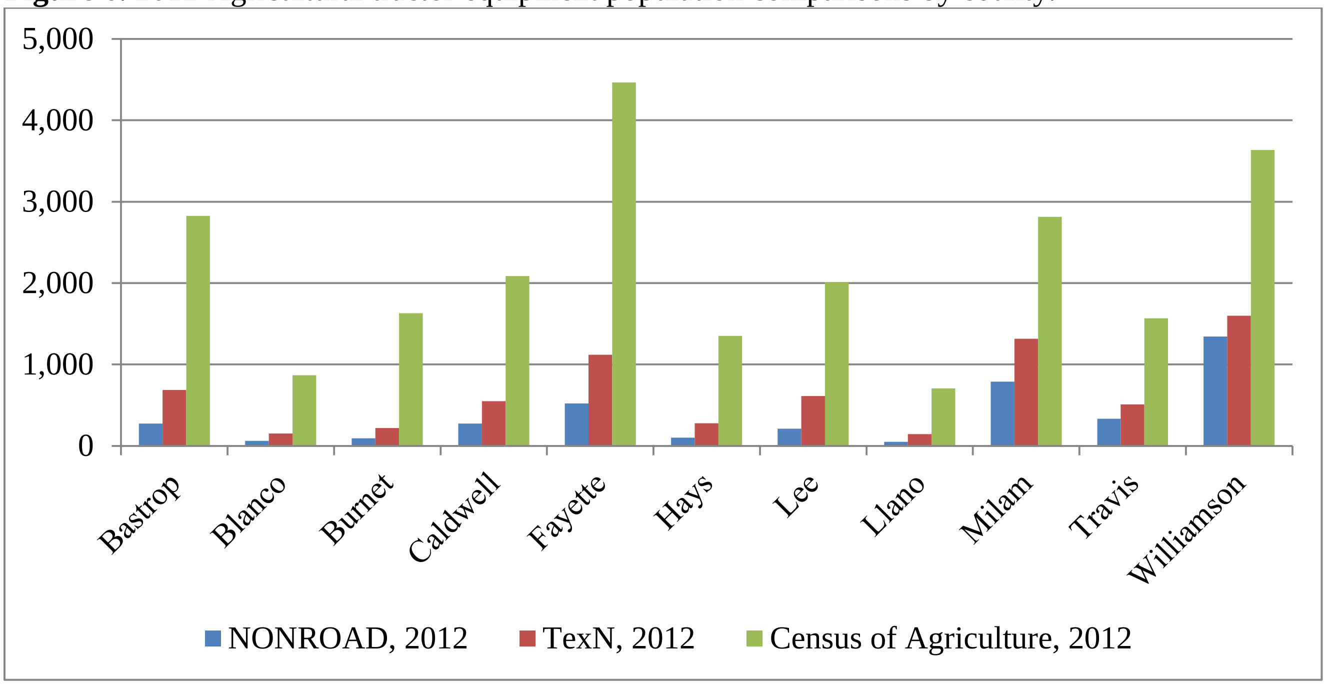
Figure 5. Increases in 1997 tractor populations to reflect under-coverage adjustments.



Comparison to Default NONROAD and TexN Populations

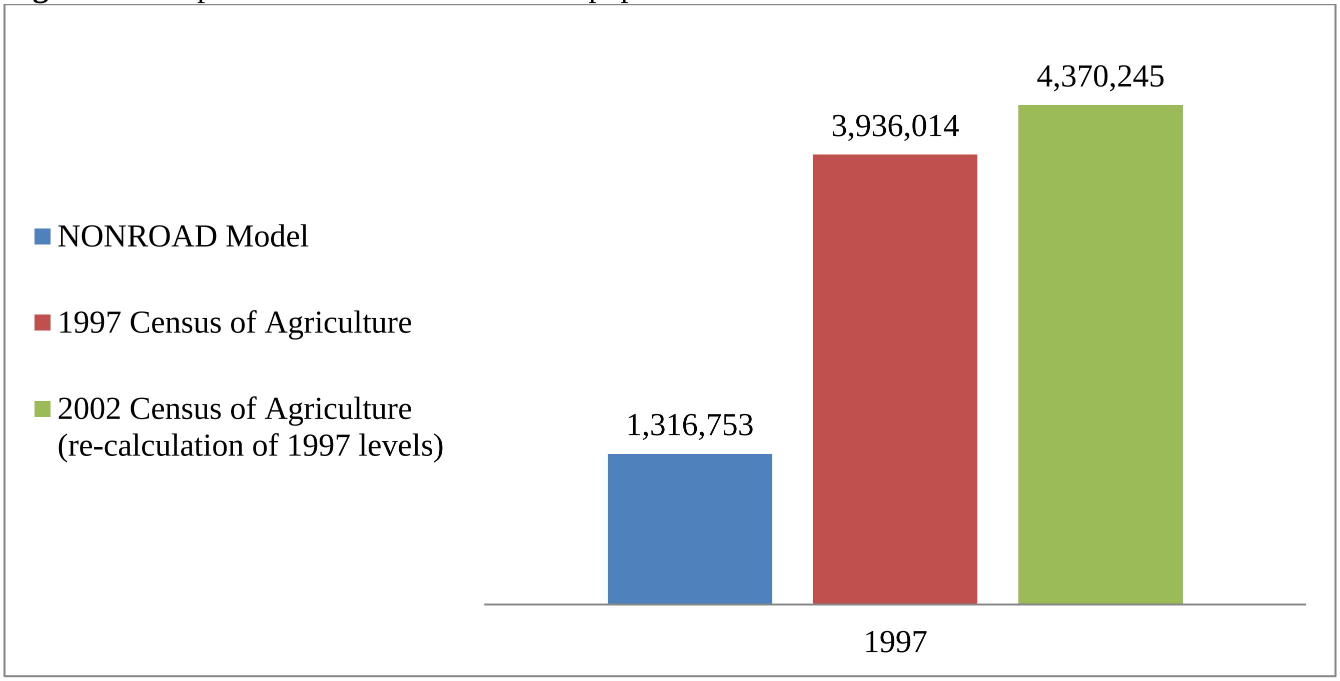
The 2012 tractor population counts obtained from the Census of Agriculture are significantly different from the tractor populations in the NONROAD model and the Texas NONROAD (TexN) model, a Texas-specific version of the NONROAD model developed by Eastern Research Group, Inc. with equipment population estimates from E.H. Pechan (Thesing 2009). Figure 6 below shows the total agricultural tractor population counts for each county based on these three estimates. The 2012 Census of Agriculture tractor populations are 2.7 – 17.4 times higher than what is estimated in the NONROAD model, and 2.1 – 7.4 times higher than the default TexN populations. These differences are significantly larger than what could be explained due to sampling uncertainty in the Census of Agriculture. The standard error for a 95% confidence interval reported for the number of farms in each county, for example, was only 1.42% - 6.39% of the farm totals reported.

Figure 6. 2012 Agricultural tractor equipment population comparisons by county.



EPA's documentation for the NONROAD model indicates that the default county-level agricultural tractor equipment counts are based on national-level agricultural equipment estimates developed by Power Systems Research (PSR), allocated to each state and county based on acreage of cropland harvested reported in the 2002 Census of Agriculture (EPA 2005c). EPA states that, while "the amount of harvested cropland does not necessarily provide as accurate a predictor of agricultural equipment population as it does for activity…Since the purpose of the NONROAD model is to estimate emissions levels, and since emissions are more directly associated with activity levels than with equipment populations, EPA believes that the amount of harvested cropland is an appropriate allocation factor for the NONROAD model." So, while the NONROAD model relies on the Census of Agriculture for geographic allocation surrogates, it did not use the Census's tractor populations, other than as a check on the nation-wide PSR data, as described elsewhere in the documentation: "PSR population data for agricultural tractors (typically in the 50-150 HP range) were also significantly higher than estimates from the Agricultural Census and sales based estimates. The differences were in the range of 50 to 150 percent" (EPA, 2010a). It is unclear exactly what this is referring to, since the Censuses of Agriculture for 1997 and 2002, the years closest to the baseline years used for the NONROAD equipment populations, have tractor populations many times higher than the PSR populations, as Figure 7 below shows.

Figure 7. Comparisons of nationwide tractor population counts for 1997.



The default equipment populations in the TexN model are based on a study completed by E.H. Pechan & Associates, Inc. (Thesing 2009) that produced ratios of equipment to production totals for five different farm types, multiplied by county-level production data from 2007. These included county-level data from the USDA's annual crop survey for the 2008 wheat acres harvested, 2007 cotton acres harvested. Data on hay production was obtained from the 2007 Census of Agriculture. Acreage harvested for other crops was based on total acres harvested by crop. For beef, Pechan used the USDA's annual livestock survey, adjusted to remove the percentage of cattle in feedlots and dairies based on district-level totals. Table 6 below shows the equipment ratios used for agricultural tractors from this study.

Table 6. Pechan agricultural tractor equipment ratios.

Farm Type	Respondents	# of Pieces in 2007	2007 Production	Equipment Ratio (Pieces per Unit of Production)
Cotton	150	571	178,719 Acres Harvested	0.003195
Hay	354	980	95,541 Acres Harvested	0.010257
Wheat	191	570	139,336 Acres Harvested	0.004091
Other	260	765	143,644 Acres Harvested	0.005326
Beef	441	1,044	335,226 Head of Cattle	0.003114

These equipment ratios were then multiplied by historical production data in order to obtain the estimated number of tractors for each county. For example, a county with 100,000 head of cattle would have:

- 100,000 head of cattle * 0.003144 tractors/head of cattle = 311.40 tractors.

The approach used by Pechan benefits from the use of a large number of responses that should be more representative of Central Texas agriculture than a national default would provide, and is much more precise accounting for variations in tractor usage by farm type. However, since the Census of Agriculture directly provides actual tractor counts, and given the scope of the data collection efforts and data analysis used for the Census of Agriculture, CAPCOG does not believe that any alternative dataset or method currently available could produce more accurate or precise county-level agricultural tractor populations than those presented in the Census of Agriculture. CAPCOG believes that one of the primary reasons that Pechan's survey results do not produce accurate estimates of Central Texas county tractor populations is that farms in Central Texas tend to be much smaller than the typical farms that responded to the Pechan survey. For a more extensive discussion of the likely sources of bias in the Pechan survey, see CAPCOG's 2006 agricultural tractor emissions inventory (CAPCOG 2013a).

TRACTOR FUEL TYPE, HORSEPOWER, AND AGE PROFILES

CAPCOG used a variety of data sources to update the fuel type, horsepower, and age profiles for agricultural tractors in Central Texas. CAPCOG assumed that the Census of Agriculture's data on the allocation of each county's tractor population into <40 HP, 40-99 HP, and 100+ HP groupings was accurate. Similarly, CAPCOG also assumed that the Census's data on the share of tractors manufactured in the past 5 years was accurate. CAPCOG made other adjustments to the fuel type and horsepower allocations of the <40 HP, 40-99 HP, and 100+ HP tractor groupings based on a survey of local farms ERG conducted for CAPCOG in the summer of 2012 and equipment sales data from 1992 – 2014, as previously described. CAPCOG also made adjustments to the average HP ratings for a number of NONROAD HP bins based on the 2012 survey data and equipment sales data.

Horsepower Distribution

CAPCOG allocated the diesel, gas, and LPG tractor populations in each of the three HP groupings to the NONROAD HP ranges (11-16, 16-25, 25-40, 40-50, 50-75, 75-100, 100-175, 175-300, 300-600, and 600-750) based on the relative share of tractors in each of these bins to the corresponding Census of Agriculture HP group in the 2012 ERG survey. For example, since tractors in the 25-40 HP bin represented 65% of the tractors surveyed in the <40 HP range, the estimated number of tractors in the 25-40 HP range for Bastrop County was:

- <40 HP Tractors, Bastrop County * % Allocation of <40 HP to 25-40 HP Range = 986 * 65% = 641

For the 100+ HP group, CAPCOG's review of the EDA equipment sales data showed a somewhat different allocation than the ERG survey showed. Since the equipment sales data included a larger number of tractors than the survey, CAPCOG decided to allocate the 100+ HP tractors based on the EDA sales data. Table 7 below shows the allocations of the tractor populations in each Census of Agriculture HP group into the appropriate NONROAD HP bins.

Table 7. Allocation of agricultural tractor populations in Census of Agriculture HP groups to NONROAD HP bins.

NONROAD HP Bin	Census of Ag. HP Group	Allocation of Census of Ag. HP Group
11-16 HP	<40 HP	7.50%
16-25 HP	<40 HP	27.50%
25-40 HP	<40 HP	65.00%

NONROAD HP Bin	Census of Ag. HP Group	Allocation of Census of Ag. HP Group
40-50 HP	40-99 HP	17.39%
50-75 HP	40-99 HP	45.65%
75-100 HP	40-99 HP	39.96%
100-175 HP	100+ HP	70.59%
175-300 HP	100+ HP	22.83%
300-600 HP	100+ HP	6.58%
600-750 HP	100+ HP	0.00%

These allocations differ significantly from the default allocations within these ranges in the NONROAD model. Table 8 shows a comparison of the allocations of the populations in these three HP groupings into the various NONROAD HP bins in a default 2012 NONROAD model run, the 2012 ERG survey data, and the 1992-2014 sales data. Most notably, higher percentages of tractors are in lower horsepower bins in the ERG survey and EDA sales data than are reflected in the default NONROAD distributions.

Table 8. Comparison of HP allocations.

NONROAD HP Bin	Census of Ag. HP Group	NONROAD Default 2012 Allocation %	2012 ERG Survey Allocation %	EDA Sales Data Allocation %
11-16 HP	<40 HP	<0.01%	7.50%	n/a
16-25 HP	<40 HP	27.35%	27.50%	n/a
25-40 HP	<40 HP	72.65%	65.00%	n/a
40-50 HP	40-99 HP	25.07%	17.39%	n/a
50-75 HP	40-99 HP	39.69%	45.65%	n/a
75-100 HP	40-99 HP	35.24%	39.96%	n/a
100-175 HP	100+ HP	43.34%	87.13%	70.59%
175-300 HP	100+ HP	37.34%	11.88%	22.83%
300-600 HP	100+ HP	19.32%	0.99%	6.58%
600-750 HP	100+ HP	<0.01%	0.00%	0.00%

Average Horsepower Ratings

For horsepower bins in which the NONROAD model's average HP rating for a given HP bin fell outside of the 95% confidence interval of the average horsepower ratings from ERG's 2012 survey, CAPCOG used survey averages. For the 100+ HP range, CAPCOG used the average values from the EDA sales data to update the average horsepower ratings. For any HP bin for which the ERG survey data was not statistically different from the NONROAD average for 2012, CAPCOG used the NONROAD average across both diesel and gasoline-powered tractors for all fuel types. This reflects CAPCOG's conclusion from the 2012 survey that there is not a statistically significant difference in HP by fuel type within the various NONROAD HP bins. Table 9 below shows the average HP inputs used, and the basis for the data.

Table 9. Average HP inputs by NONROAD HP bin and basis for average.

NONROAD HP Bin	Avg. HP	Basis
11-16 HP	13.3	2012 ERG Survey
16-25 HP	21.0	TexN Default for 2012
25-40 HP	32.5	TexN Default for 2012
40-50 HP	43.4	2012 ERG Survey
50-75 HP	59.7	2012 ERG Survey
75-100 HP	86.1	TexN Default for 2012
100-175 HP	128.6	EDA Sales Data
175-300 HP	223.4	EDA Sales Data
300-600 HP	380.1	EDA Sales Data

Fuel Type Distribution

CAPCOG allocated the tractor populations in each of the three HP groupings reported in the Census of Agriculture to different fuel types using two steps, since the tractor populations reported in the Census of Agriculture are not disaggregated by fuel type:

1) Allocate the populations to compression-ignition (diesel) and spark ignition (gasoline and LPG) engine types based on the percentage of diesel and non-diesel engines reported in each of the three HP groupings in ERG's 2012 survey; and
2) Allocate the spark ignition engines to gasoline and LPG fuel types based on the total ratio of gasoline to LPG tractors in ERG's 2012 survey.

Table 10 below shows the resultant fuel type distributions for each of the three HP groupings.

Table 10. Fuel type distribution by HP grouping.

HP Range	Diesel %	Gas %	LPG %
<40 HP	69.0%	26.3%	4.7%
40-99 HP	90.2%	8.3%	1.5%
100+ HP	100.0%	0.0%	0.0%

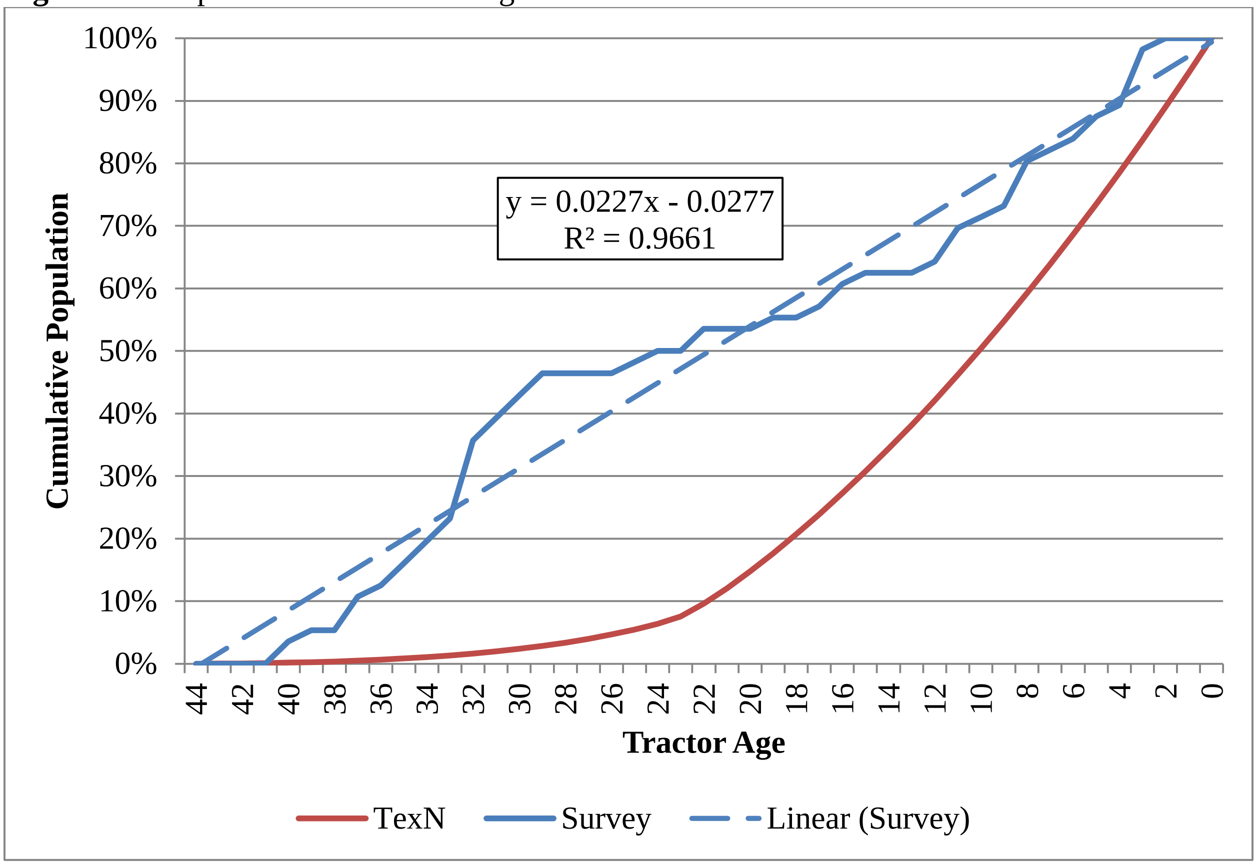
Due to the importance of the 100+ HP tractors to the total emissions estimate, CAPCOG validated the allocation of 100% of tractors in this range to the diesel fuel type by using EDA equipment sales data from 1992-2014. These data also showed that 100% of the agricultural tractors in the 100+ HP range were diesel-powered.

Age Distribution

CAPCOG made several adjustments to the TexN model and to the outputs generated from the TexN model in order to better reflect data collected in this project. The TexN model uses a database of equipment populations in conjunction with a scrappage curve in order to model the age distribution for a given equipment type. By using historical Census of Agriculture data, dating back to 1969, CAPCOG developed population data from1970-2012, extrapolating to 2050. CAPCOG interpolated equipment populations between Census data points, using the last available horsepower allocation data in the Census, and the survey-based and equipment-based HP and fuel type allocations as described above.

CAPCOG also adjusted the scrappage (retirement) curve built into the TexN model to better reflect the age distribution data in ERG's survey. While CAPCOG does not believe that all tractor owners necessarily follow this pattern, modeling the age distribution using a pattern more consistent with farmers retaining their tractors for their full useful life (2 times median useful life) rather than scrapping them earlier, as is assumed by the default NONROAD and TexN models. Figure 8 below shows a comparison of the cumulative age distribution of 100-175 HP tractors by model year age in the survey to the modeled distribution in TexN that was presented in CAPCOG's 2006 agricultural tractor emissions inventory report (CAPCOG 2013a). In light of these data, CAPCOG adjusted the scrappage curve so that a tractor would only be scrapped after it had reached twice its median useful life. Again, while this may not reflect the precise scrappage pattern, it produces an age distribution that is much more consistent with the survey data – which showed that it is about as likely to see 1970s-era model tractors as it is to see 2010s-era model tractors.

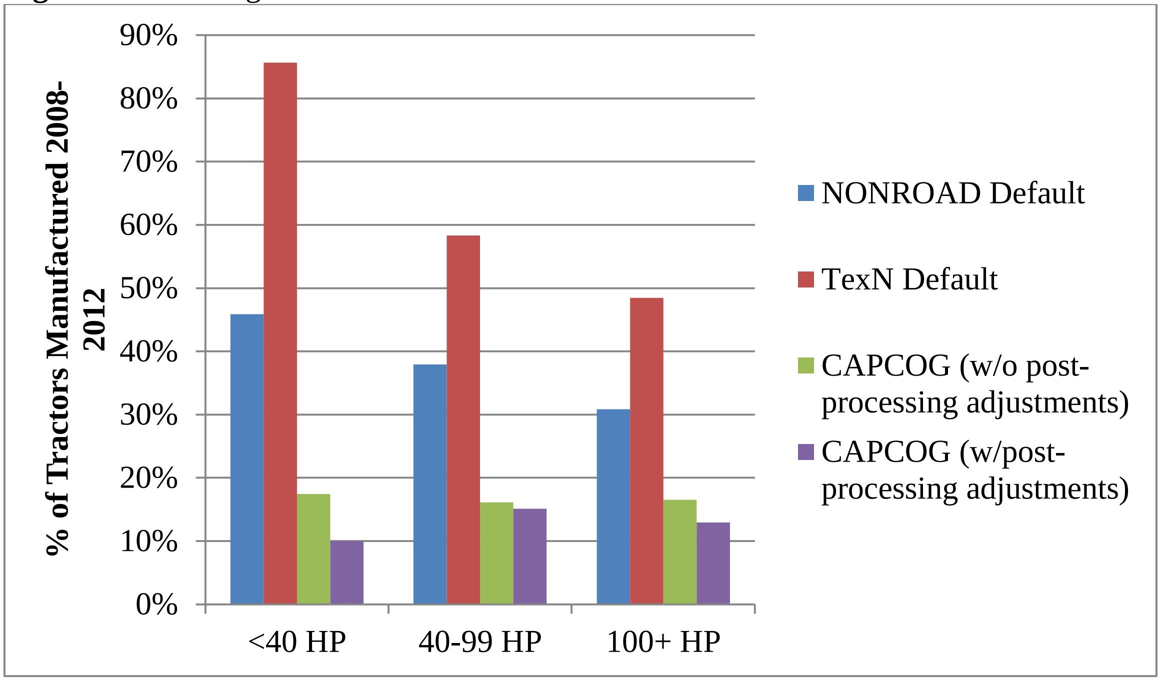
Figure 8. Comparison of cumulative age distributions of 100-175 HP tractors in TexN and ERG Survey.



After running the TexN model, CAPCOG also made one final adjustment to reflect the age distribution data reported in the Census of Agriculture – the percent of tractors manufactured in the past 5 years. CAPCOG adjusted the by-model-year output files (*nr.bmx* and *nr.bmv* files) for each county's runs to reflect that county's actual age distribution for this one parameter. Individual records were edited to account for the actual percentage of tractors manufactured 2008-2012 and prior to 2008. Once these adjustments were made, CAPCOG then re-ran the TexN post-processor in order to produce corrected emission output files.

Figure 9 shows a comparison of the percentages of tractors in the 2008-2012 model year range in the default NONROAD age distributions, default TexN age distributions, the updated modeled age distributions before post-processing adjustments, and the final post-processed adjustments.

Figure 9. Percentage of tractors manufactured 2008-2012.



ACTIVITY

Annual Activity

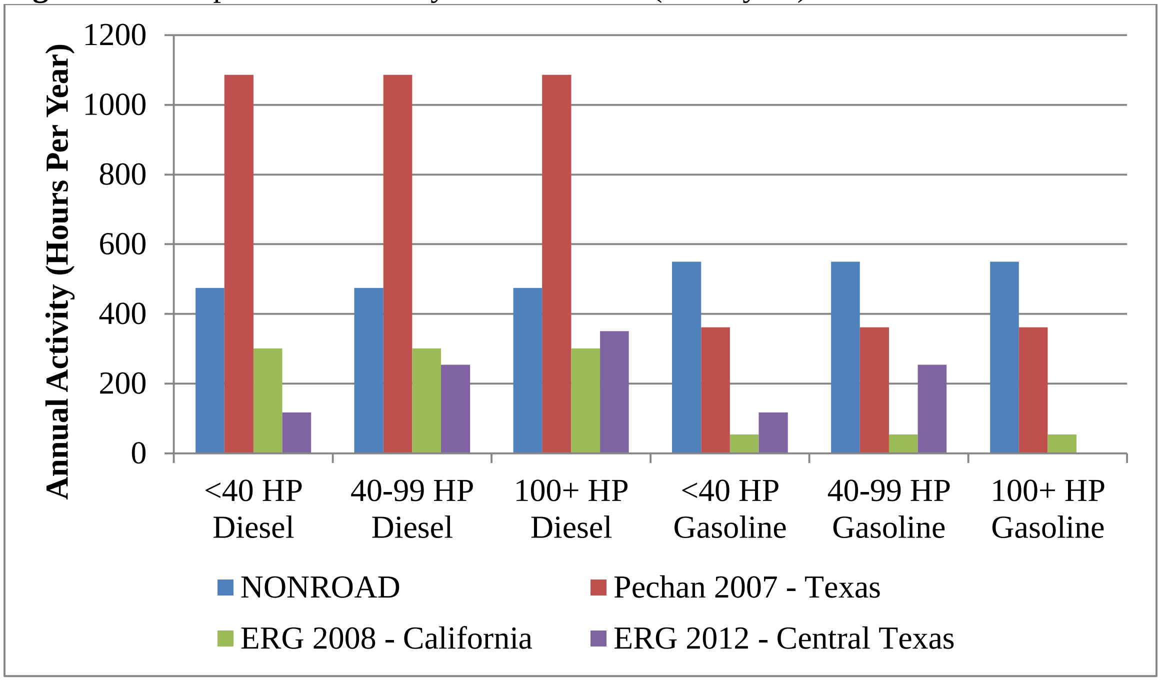
ERG's 2012 survey showed that annual activity levels vary significantly across the three Census of Agriculture HP groups, with activity increasing with the HP rating. CAPCOG used the average activity levels for the <40 HP, 40-99 HP, and 100+ HP tractors from ERG's survey as the activity inputs for emissions modeling across all fuel types. Table 11 below shows the average activity levels and confidence intervals from the 2012 ERG survey.

Table 11. Average annual activity by Census of Agriculture HP group.

HP Group	Annual Activity (hrs/yr)	95% Confidence Interval (hrs/yr)
<40 HP	117	(65 – 168)
40-99 HP	254	(202 – 306)
100+ HP	351	(292 – 410)

These average annual activity levels are significantly lower than the activity levels in the NONROAD model and Pechan's estimates based on its 2007 survey. The activity estimates from ERG's 2012 survey of Central Texas was broadly consistent with a similar California survey ERG conducted in 2008 (Baker 2008). Figure 10 shows a comparison of these activity level estimates.

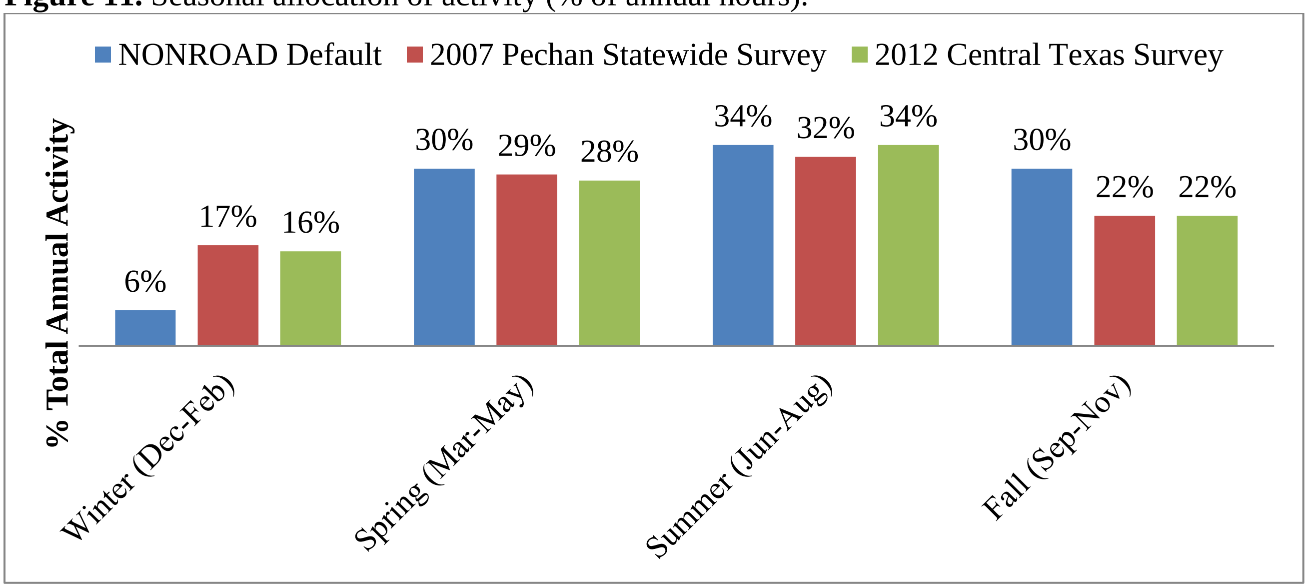
Figure 10. Comparison of activity level estimates (hours/year).



Seasonal Allocation of Activity

While ERG's 2012 survey included data on the seasonality of activity, it was not different enough from Pechan's statewide 2007 survey to warrant a change from the allocations determined in that survey. Therefore, CAPCOG used the Pechan survey's seasonal allocations, since they reflected a larger number of survey responses, and since, while the ERG and Pechan surveys were very consistent in the seasonal allocation, they were also both quite different from the NONROAD default. These differences are minor for the summer and spring allocations, but quite significant for the winter and fall periods. Figure 11 shows a comparison of the seasonal allocation of agricultural tractor activity in the NONROAD model for Texas, the 2007 Texas statewide Pechan survey, and the 2012 ERG survey of Central Texas.

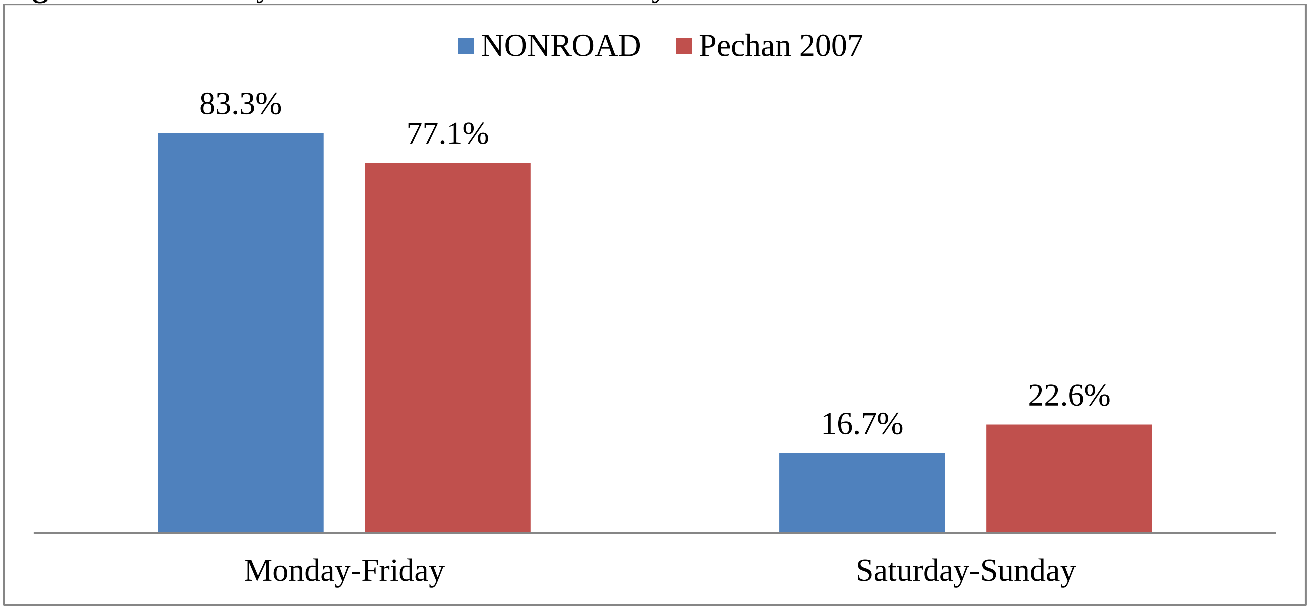
Figure 11. Seasonal allocation of activity (% of annual hours).



Weekday/Weekend Allocation of Activity

ERG's 2012 survey did not ask about weekday/weekend allocation of activity. Therefore, CAPCOG used the allocations from Pechan's 2007 statewide survey (Pechan 2009), which were substantially different from the NONROAD model. Figure 12 below shows both the default NONROAD allocation and the 2007 Pechan survey allocation.

Figure 12. Weekday/weekend allocation of activity.



EMISSIONS MODELING

Population Methodology and Inputs for 2012 and Historical Years

The age distributions outputs from the TexN model depend on each equipment type's annual activity level, load factor, median useful life, scrappage rates, and historical sales. For the TexN model, historical in-use population estimates form the basis of the historical sales estimates used to produce the age distribution. Therefore, in order to accurately model the age distribution of agricultural tractors in the TexN model, it is necessary to update the model not only for the year being analyzed, but also for all model historical years still present in 2012. For a fuller explanation of how the TexN model calculates age distribution, please refer to the TexN User's Guide (ERG 2008). As described earlier, data on the number of tractors in various HP ranges has changed over the years. The three groupings in the 2012 Census were included as far back as 1997, but for the 1992 and 1987 censuses, there were only two groupings reported: <40 HP and 40+ HP, and no HP breakdown existed in the 1982 and earlier censuses. CAPCOG used the newest ratios available to calculate the tractor populations in the <40 HP, 40-99 HP, and 100+ HP groupings for each census year from 1969 – 2012. Table 12 below summarizes these efforts.

Table 12. Historical Census of Agriculture tractor populations by HP range, 1969 – 2012.

Years	<40 HP Tractor Pop.	40-99 HP Tractor Pop.	100+ HP Tractor Pop.	40+ HP Tractor Pop.	Total Tractor Pop.
2012, 2007, 2002, and 1997	Reported	Reported	Reported	Calculable	Reported
1992 and 1987	Reported	Calculated: $\frac{40to99HP_{1997Pop}}{40^{+}HP_{1997Pop}} * 40^{+}HP_{CurrentPop}$	Calculated: $\frac{100^{+}HP_{1997Pop}}{40^{+}HP_{1997Pop}} * 40^{+}HP_{CurrentPop}$	Reported	Reported
1982, 1978, 1974, and 1969	Calculated: $\frac{<40HP_{1987Pop}}{Total_{1987Pop}} * Total_{CurrentPop}$	Calculated: $\frac{40to99HP_{1987Pop}}{40^{+}HP_{1987Pop}} * 40^{+}HP_{CurrentPop}$	Calculated: $\frac{100^{+}HP_{1987Pop}}{Total_{1987Pop}} * Total_{CurrentPop}$	Calculated: $\frac{40^{+}HP_{1987Pop}}{Total_{1987Pop}} * Total_{CurrentPop}$	Reported

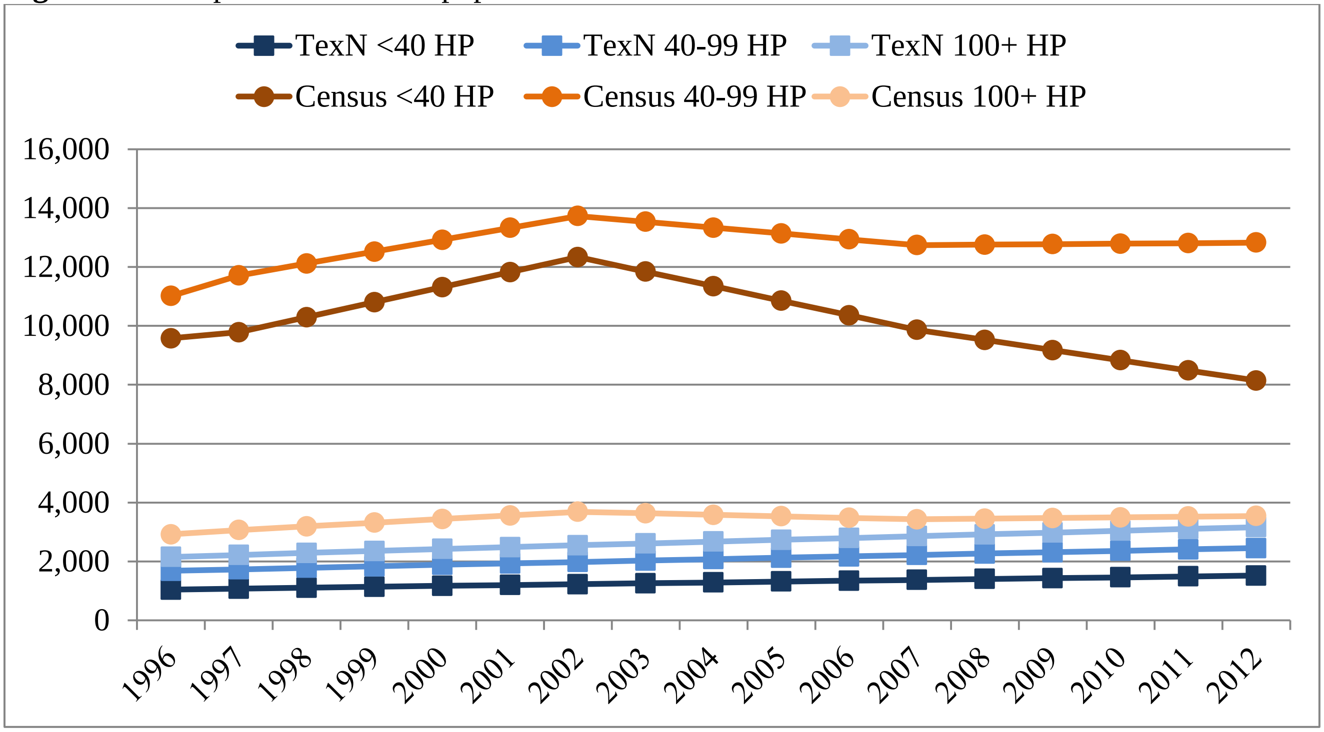
Table 13 below shows the total number of tractors in each HP grouping across all 11 counties for each census year.

Table 13. Total estimated Central Texas tractor populations in the <40 HP, 40-99 HP, and 100+ HP groupings for Census of Agriculture years.

Year	<40 HP	40-99 HP	100+ HP	TOTAL
1969	7,875.0	7,300.4	2,279.6	**17,455.0**
1974	7,301.3	6,715.3	2,049.5	**16,066.0**
1978	7,519.7	6,858.0	2,034.2	**16,412.0**
1982	8,059.7	7,256.0	2,055.2	**17,371.0**
1987	9,358.0	8,407.1	2,346.9	**20,112.0**
1992	8,742.0	8,222.7	2,318.3	**19,283.0**
1997	9,783.0	11,713.0	3,069.0	**24,565.0**
2002	12,334.0	13,731.0	3,686.0	**29,751.0**
2007	9,867.0	12,743.0	3,428.0	**26,038.0**
2012	8,143.0	12,827.0	3,543.0	**24,513.0**

CAPCOG then interpolated the equipment population for inter-census years. Figure 13 below shows that, while the default population counts for the 100+ HP range was similar between TexN and the Census of Agriculture estimates for 1996-2012, they are very different for the <40 HP and 40-99 HP ranges.

Figure 13. Comparison of tractor population estimates for Central Texas 1996-2012.



TexN Model Runs Performed

CAPCOG used the TexN model, version 1.6.1, in order to model agricultural tractor emissions. In order to account for the fact that there are no LPG tractors represented in the TexN model, CAPCOG chose another SCC equipment type to use for modeling. CAPCOG selected the LPG generators equipment type (SCC 2267006005), since this SCC contains HP bins 25-40, 40-50, 50-75, and 75-100, covering most of the ranges needed. CAPCOG adjusted the load factor for the LPG generators (default 0.68) in order to match the load factor used by spark ignition tractors (0.62). The median useful life data in TexN was also updated to match that of the gasoline-powered engines in those ranges. Additional runs were also needed to model gasoline tractors in the 11-16, 40-50, and 50-75 HP ranges, as well as LPG tractors in the 11-16 and 16-25 HP ranges, as those HP bins do not exist in TexN. A total of eight model runs were performed: Table 14 summarizes the model runs performed.

Table 14. TexN modeling runs performed.

Run Number	Diesel Tractors Modeled	Gasoline Tractors Modeled	LPG Tractors Modeled
Run 1	11-16 HP, 16-25 HP, 25-40 HP	25-40 HP	25-40 HP
Run 2	40-50 HP, 50-75 HP, 75-100 HP	75-100 HP	40-50 HP, 50-75 HP, 75-100 HP
Run 3	100+ HP	n/a	n/a
Run 4	n/a	11-16 HP	n/a
Run 5	n/a	40-50 HP	n/a
Run 6	n/a	50-75 HP	n/a
Run 7	n/a	n/a	11-16 HP
Run 8	n/a	n/a	16-25 HP

For runs 4-8, CAPCOG needed to model the emissions using another SCC "slot" and make adjustments to the activity levels and population inputs to reflect this adjustment. For 11-16 HP gasoline tractors, for instance, CAPCOG used the 16-25 HP slot in order to model the emissions. While tractors in both of these ranges are used 117 hours per year, based on the ERG survey, since the median useful life for an 11-16 HP tractor is lower than for a 16-25 HP tractor, modeling 11-16 HP tractor activity in a 16-25 HP slot would produce incorrect age distributions. For an 11-16 HP tractor, the full useful life (two times median useful life) would be 11 years [(400 hrs * 2) / (0.62 * 117 hrs/year)], compared to 21 years for a 16-25 HP tractor [(750 hrs * 2) / (0.62 * 117 hrs/year)]. Therefore, the activity level input must be multiplied by the ratio of the median useful life inputs in order to obtain the correct age distribution: 117 hrs/yr * (750 hrs/400 hrs) = 219 hrs/yr. Table 15 below shows the activity adjustments required for runs 4-8. No adjustment was needed for runs 5 and 6.

Table 15. Activity input adjustments for certain HP-fuel type combinations.

Run	Activity Level (hrs/yr)	Actual Median Useful Life (hrs)	TexN HP Slot Used	TexN HP Slot Median Useful Life (hrs)	Adjusted Activity Input (hrs/yr)
Run 4: 11-16 HP Gasoline	117	400	16-25 HP Gasoline	750	219
Run 5: 40-50 HP Gasoline	254	1,500	25-40 HP Gasoline	1,500	254
Run 6: 50-75 HP Gasoline	254	3,000	75-100 HP Gasoline	3,000	254
Run 7: 11-16 HP LPG	117	400	25-40 HP LPG	1,500	439
Run 8: 16-25 HP LPG	117	750	25-40 HP LPG	1,500	234

Next, CAPCOG needed to adjust the population inputs for these slots to account for the different average horsepower rating and the adjusted activity levels. For example, in order to model 11-16 HP gasoline tractors, CAPCOG needed to calculate the input that would be needed for the 16-25 HP gasoline tractor slot that would accurately model the 11-16 HP tractor emissions, given average HP rating of 21.0 HP for the 16-25 HP bin and the adjusted activity input of 219 hours per year, needed to obtain an accurate age distribution. The adjustment factor for modeling the 11-16 HP tractors, for example, would be: (13.3 HP * 117 hrs/year) / (21.0 HP * 219 hrs/yr) = 0.338. Therefore, for Bastrop County, for example, the population input used in the 16-25 HP slot to model the 19.47 gasoline tractors in the 11-16 HP in 2012 would be 6.57 tractors. This adjustment method effectively sets total hp-hours equal for the 11-16 and 16-25 HP bins, based on the close relationship between hp-hours and exhaust emissions. While this method does not provide the same level of accuracy for evaporative emissions, CAPCOG was primarily interested in ensuring that the exhaust emissions were accurately represented since ozone formation in Central Texas is primarily driven by NO_X exhaust emissions rather than evaporative VOC emissions.

Table 16 shows the population adjustment factors that were calculated for each run in order to develop the needed population inputs for each county.

Table 16. Tractor population input adjustments needed for certain HP-fuel combinations.

Run	Avg. HP	Activity Level (hrs/yr)	TexN Slot Used	TexN Slot HP Avg.	Adjusted Activity Input (hrs/yr)	Pop. Input Adjustment Factor
Run 4: 11-16 HP Gasoline	13.3	117	16-25 HP Gasoline	21.0	219	0.338
Run 5: 40-50 HP Gasoline	43.4	254	25-40 HP Gasoline	32.5	254	1.335
Run 6: 50-75 HP Gasoline	59.7	254	75-100 HP Gasoline	86.1	254	0.693
Run 7: 11-16 HP LPG	13.3	117	25-40 HP LPG	32.5	439	0.109
Run 8: 16-25 HP LPG	21.0	117	25-40 HP LPG	32.5	234	0.323

CAPCOG developed MySQL update scripts in order to update the TexN data tables, corresponding with runs 1-3 (one script for all three runs) and runs 4-8 (one script for each run), updating the database prior to each run in order to correspond with the updated population data. ERG quality assured each step of the data preparation and adjustment process, as well as the model outputs of each run.

Meteorology and Fuel Inputs

Meteorology was based on monthly regional weather station data for 2012. County-level fuel properties were based on ERG's 2011 summer fuel study (Baker et al. 2011). In addition to the standard fuel inputs in TexN, the low-RVP rule and the Texas Low-Emission Diesel (TxLED) rules apply to several of the counties in this region. TxLED adjustments are described later under post-processing adjustments.

Post-Processing Adjustments

As a final step in developing the emissions estimates, CAPCOG adjusted the TexN *nr.bmx* and *nr.bmv* output files that contain the exhaust and evaporative emissions, respectively, by model year for each county, in order to account for the reported age distribution data in the 2012 Census of Agriculture. The outputs were adjusted so that the age distribution modeled reflected the actual percent of tractors manufactured from 2008-2012 and the percent manufactured prior to 2008. These adjustment factors varied county-by-county and HP bin-by-HP bin. CAPCOG saved the updated versions of the *nr.bmx* and *nr.bmv* files and then re-ran the TexN postprocessor in order to produce updated output files. This ensured that the emissions estimates reflected the temperature, altitude, and TxLED adjustments made in the TexN model, while directly accounting for the age distribution data reported in the Census of Agriculture.

ERG quality assured the output files following post-processing adjustments.

EMISSION ESTIMATES

CAPCOG calculated the emissions for each fuel type and horsepower bin in each county using TexN outputs adjusted as described in the previous section. Table 17 below documents the final emissions modeled after these changes.

Table 17. Final modeled emissions by county.

	Tractor Population	NOx Exhaust (tons/day)	CO Exhaust (tons/day)	CO_2 Exhaust (tons/day)	SO_2 Exhaust (tons/day)	PM Exhaust (tons/day)	VOC Emissions (tons/day)
Bastrop	2,825	0.711	2.047	70.00	0.00071	0.119	0.180
Blanco	868	0.193	0.630	18.73	0.00020	0.032	0.054
Burnet	1,632	0.358	1.158	35.65	0.00037	0.059	0.096
Caldwell	2,088	0.505	1.459	51.41	0.00052	0.084	0.127
Fayette	4,464	1.164	3.342	111.53	0.00114	0.197	0.294
Hays	1,349	0.307	0.966	29.44	0.00031	0.050	0.080
Lee	2,565	0.685	1.923	65.35	0.00067	0.116	0.171
Llano	704	0.147	0.498	14.99	0.00016	0.024	0.041
Milam	2,812	0.930	2.026	88.07	0.00087	0.153	0.204
Travis	1,569	0.468	1.122	42.82	0.00043	0.077	0.107
Williamson	3,637	1.249	2.576	118.08	0.00116	0.205	0.266
TOTAL	**24,513**	**6.716**	**17.747**	**646.06**	**0.00654**	**1.116**	**1.620**

Table 18 shows the same emissions estimates grouped by both HP bin and fuel type.

Table 18. Final TexN modeled emissions by HP bin and fuel type –all counties.

	Tractor Population	NOx Exhaust (tons/day)	CO Exhaust (tons/day)	CO_2 Exhaust (tons/day)	SO_2 Exhaust (tons/day)	PM Exhaust (tons/day)	VOC Emissions (tons/day)
<40 HP	8,143	0.362	5.256	44.026	0.00059	0.045	0.283
40-99 HP	12,827	3.225	10.301	328.468	0.00346	0.564	0.864
100+ HP	3,543	3.129	2.190	273.566	0.00249	0.507	0.472
Diesel	20,928	6.225	5.215	586.626	0.00535	1.111	1.074
Gasoline	3,301	0.386	12.272	53.422	0.00107	0.005	0.529
LPG	589	0.076	0.260	6.013	0.00012	0.001	0.017

COMPARISON OF EMISSIONS TOTALS TO NONROAD AND TEXN EMISSIONS ESTIMATES

The emissions from CAPCOG's enhanced modeling differ substantially from the results obtained from the default NONROAD and TexN models. The modifications that CAPCOG performed would be expected to drive the emissions in both directions. Overall tractor populations, as well as the percentage of older tractors in use were increased, both of which were expected to increase emissions. However, overall activity levels were decreased, which would have a decreasing effect on these emissions. Fuel type distributions and average horsepower modifications would also impact the total emissions profile.

Because of these changes, CAPCOG's emissions estimates were significantly higher than NONROAD estimates, and also higher than the default TexN model estimates for most pollutants. Figure 14 shows a comparison of the NONROAD, TexN, and CAPCOG emissions estimates across all 11 counties for nitrogen oxides (NO_X), particulate matter (PM), and volatile organic compounds (VOC). ERG and CAPCOG comparisons showed that estimates of other pollutants also showed an increase.

Figure 14. 2012 summer weekday emissions estimates comparison (tons per day).

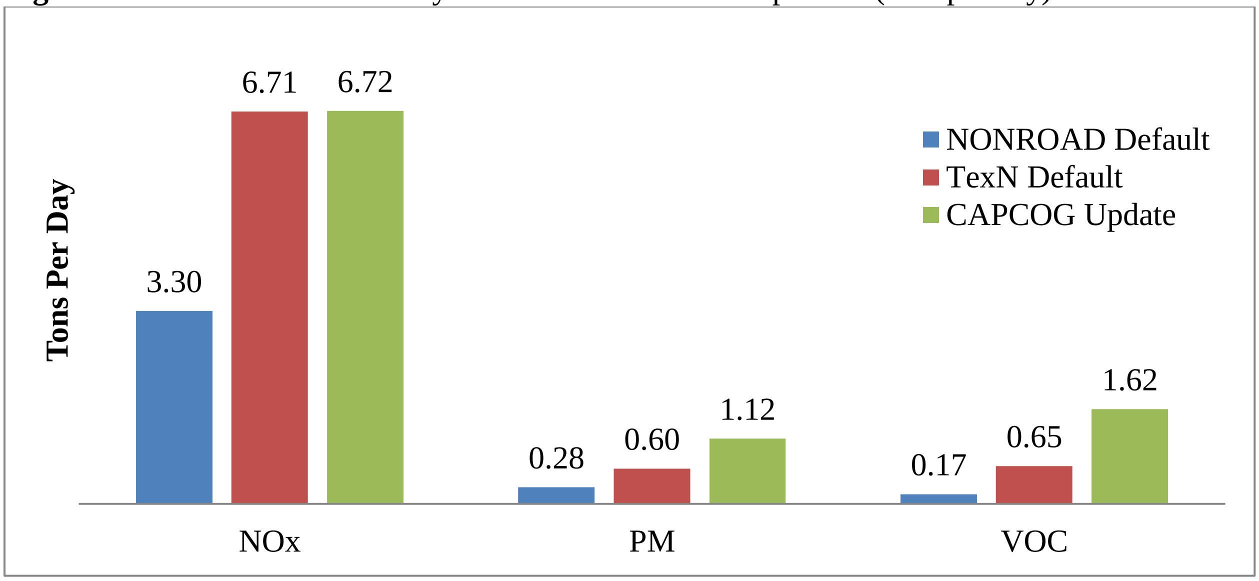
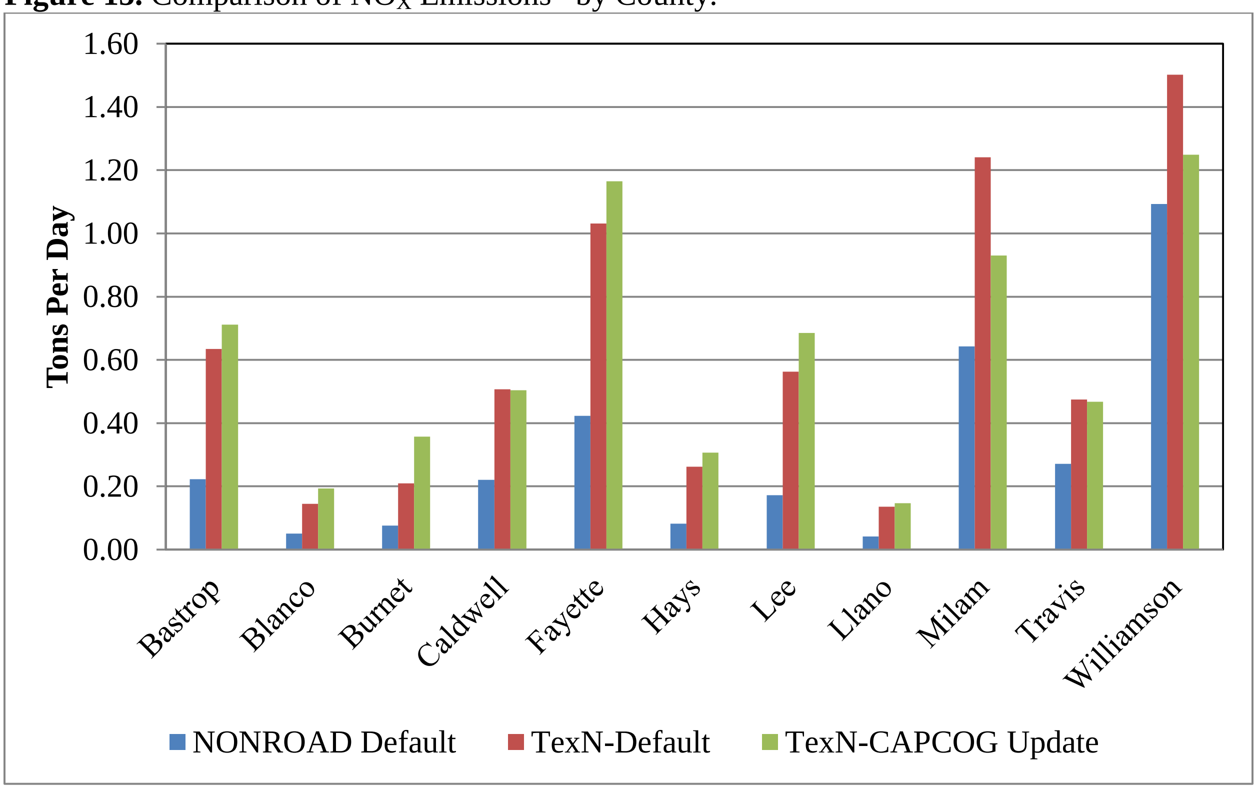


Figure 15 below shows a county-by-county comparison of NO_X emissions estimates, showing the extent to which estimates varied by county, even though the 11-county total was very similar.

Figure 15. Comparison of NO_X Emissions –by County.



For each of these pollutants, the NONROAD model underestimates pollutants across the 11-county Central Texas region. The default TexN estimates are more variable and can be explained directly through examination of the adjustments made for the CAPCOG model.

In the case of nitrogen oxides (NO_X) emissions, although the CAPCOG emissions were quite close to the TexN estimates in aggregate across the 11-county region, they varied from TexN estimates substantially county-by-county.

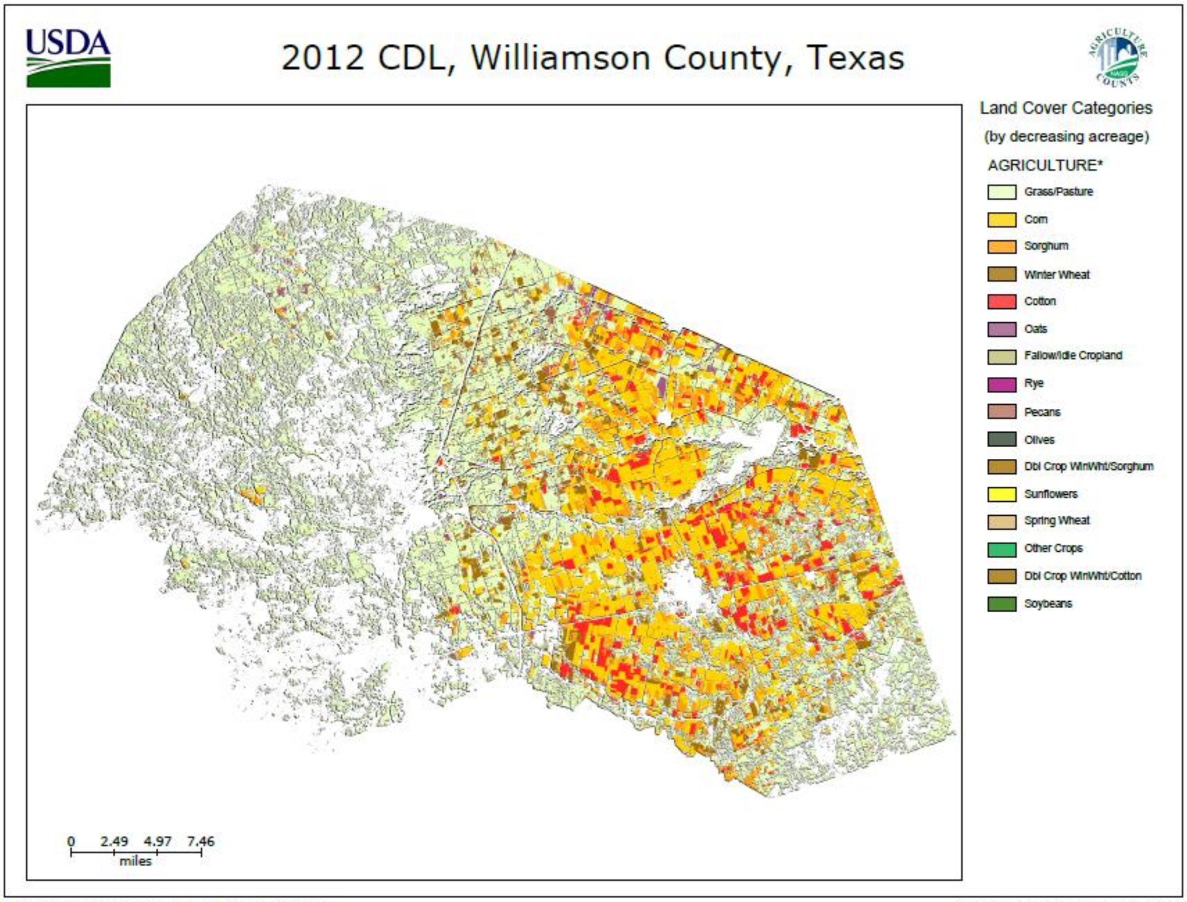
For particulate matter (PM) and volatile organic compounds (VOC) emissions, CAPCOG's estimates are uniformly higher than TexN estimates. The increase in PM emissions is due to the larger number of diesel tractors and the much smaller percentage of tractors that meet new emissions standards present in more recent model years. VOC emissions are higher due to both the larger number of tractors overall and the much higher number of gasoline-powered tractors estimated by CAPCOG based on the regional survey.

TOOLS FOR PHOTOCHEMICAL MODELING OF TRACTOR EMISSIONS

Spatial Allocation of Emissions

CAPCOG developed spatial allocation factors in order to allocate county-level tractor emissions to cells in an array of 4 km x 4 km cells covering East Texas (CAPCOG 2013b, CAPCOG 2013c). Allocation factors were based on the 2012 percentage of each county's land used for agricultural purposes contained within that grid cell. These factors were based on 2012 CROPSCAPE data. While, for projections, inclusion of fallow land with other agricultural land could be appropriate, it would be more appropriate to exclude fallow land, since by definition, it was not being used for agricultural production in that year. For Texas, these datasets exist dating back to 2008. These data represent a significant improvement over the existing spatial allocation factors in NONROAD, which are based on 1992 Landstat imagery. The default spatial surrogates used by EPA for photochemical modeling are based on "total agriculture without orchards/vineyards." According to EPA's documentation (http://www.epa.gov/ttn/chief/emch/spatial/new/surrogate_development_process_031105.pdf), this reflects the sum of the following National Land Cover Database areas: pasture/hay, grains, row crops, and fallow land from 1992 Landstat imagery. Central Texas is one of the fastest-growing regions of the country, and significant amounts of farmland have been developed since 1992. Therefore, updated surrogates based on updated distributions of agricultural land use in the region should improve the spatial representation of emissions in photochemical modeling efforts compared to EPA's default spatial allocation factors. Figure 16 shows an example of the 2012 data from CROPSCAPE for Williamson County.

Figure 16. CROPSCAPE agricultural land cover data for Williamson County, 2012.



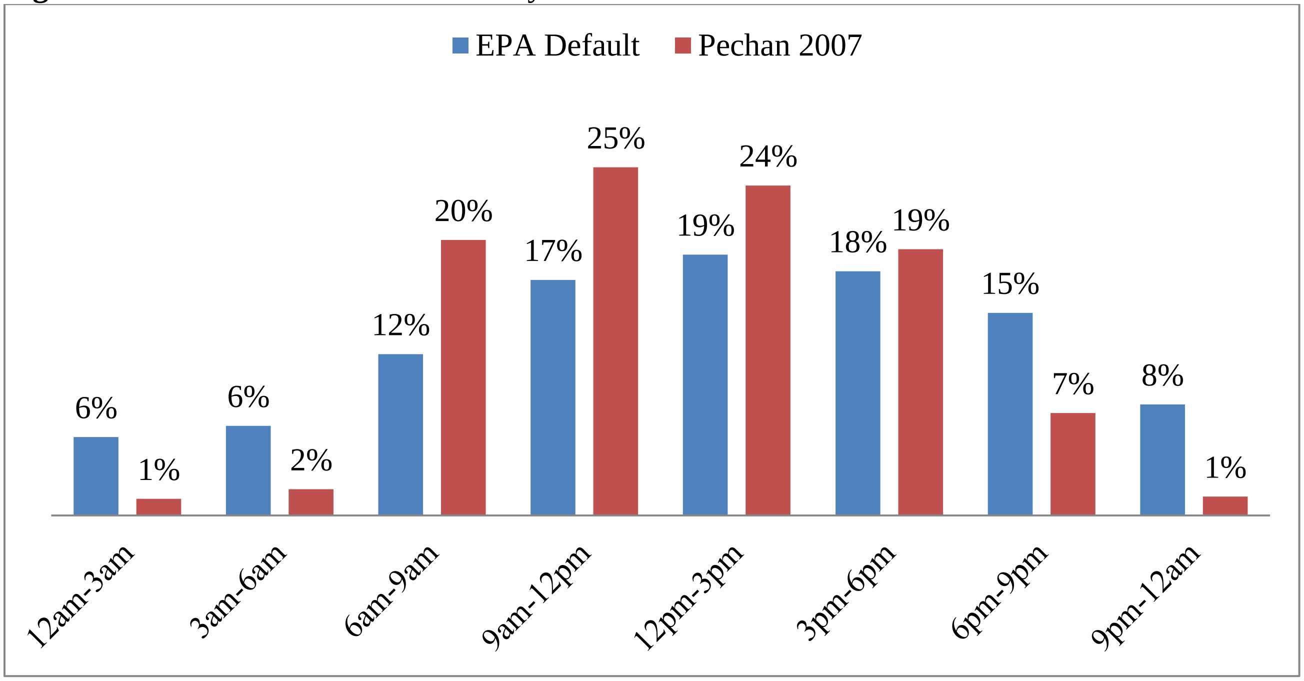
Produced by CropScape - http://nassgeodata.gmu.edu/CropScape

* Only top 16 agriculture categories are listed.

Diurnal Allocation of Emissions

ERG's 2012 survey did not collect data on the diurnal distribution of activity. Since Pechan's 2007 statewide survey (Thesing 2009) showed a significantly different diurnal distribution than EPA's default distribution, Pechan's allocations should be more representative of agricultural production patterns in Central Texas. Importantly, the survey results indicate a much higher percentage of activity occurs during the key hours of 6 am – 12 pm, indicating that a higher percentage of agricultural equipment emissions have the opportunity to contribute to peak 8-hour ozone concentrations that usually measured between 10 am and 6 pm at the regulatory ozone monitoring stations in Austin. Figure 17 shows a comparison of the default and updated diurnal activity distributions.

Figure 17. Diurnal distribution of activity.



CONCLUSIONS

This paper describes CAPCOG's approach to modeling agricultural tractor emissions using bottom-up techniques, including surveys conducted by the USDA as part of the Census of Agriculture, a regional survey of tractor operators conducted by ERG, a statewide survey conducted by Pechan, regional equipment sales data, and highly refined and up-to-date geospatial data. These methods provide an extremely accurate representation of agricultural tractor emissions for Central Texas. CAPCOG's 2012 emissions inventory data differ substantially from default emissions inventories developed using EPA's NONROAD model and the TCEQ's TexN model. While, in aggregate, CAPCOG's NO_X emissions estimates for the 11-county region covered by this study is remarkably close to the aggregate estimate produced by the TexN model, the county-by-county estimates differ substantially, and both the TCEQ and CAPCOG estimates are significantly higher across the board compared to NONROAD defaults. CAPCOG's emissions estimates for PM and VOC are more uniformly higher for all counties. This is due to the sensitivity of PM estimates to the percentage of Tier 3 and 4 engines, which is related to the age distribution, and the sensitivity of VOC estimates to the number of gasoline-powered engines.

The techniques and methods used by CAPCOG in this study and can be adapted by the EPA, state agencies, and regional agencies to improve the modeling of this category of non-road emissions. The most easily incorporated method that can be widely adopted would be the use of Census of Agriculture data for tractor populations. The Census of Agriculture represents a uniquely comprehensive dataset for modeling agricultural tractors. It covers every year included in the NONROAD model up through 2012 and provides highly accurate and precise estimates of tractor populations, stratification by horsepower ranges, and information on age distribution.

However, even with the Census of Agriculture data, adapting it to fit the NONROAD model is not as straightforward as it might seem. The NONROAD model relies on static allocation ratios of national-level populations to states and counties and a static horsepower distribution across time. The TexN model, which uses a MySQL database, represents a significant improvement over the NONROAD model's functionality in this regard. The unique age distribution characteristics of agricultural tractors and the existence of tractors in fuel type/HP combinations not included in the NONROAD model create significant hurdles to incorporating new information about this equipment category into emissions modeling efforts that are not solely focused on this category. Additional research on tractor age distributions and scrappage patterns would be very useful to developing a more sophisticated scrappage curve for agricultural tractors.

One important piece of information from this study for future NONROAD efforts is the variation seen in activity levels by HP shown in ERG's 2012 survey. This makes common sense – a farmer would need to use a larger tractor more often than a smaller tractor in order to justify the higher level of capital investment. This finding is unlikely to be unique to agricultural tractors. However, this information cannot be easily incorporated into the NONROAD or TexN models. Averaging activity levels across HP bins will tend to result in modeling small engines being used more often than they actually are, and result in modeling larger engines being used less often than they actually are. This will, in turn, skew age distributions for smaller equipment towards the newer end of the spectrum and larger equipment towards the older end of the spectrum. For control strategy programs directed at replacing, repowering, or retrofitting non-road equipment, it is particularly important to account for these variations by HP bin. For future non-road model development efforts, CAPCOG recommends similar surveys of other equipment types whose emissions represent a large share of total non-road emissions in order to evaluate the extent to which this activity pattern is seen in other equipment types as well. CAPCOG also recommends model functionality that allows for different activity levels to be assigned to various HP ranges for a given SCC. At a minimum, this study shows that tractors in the <40 HP, 40-99 HP, and 100+ HP ranges should be modeled separately. They have distinct activity levels and growth rates, and the normal functionality of the NONROAD model does not readily accommodate these properties.

This project also demonstrates the value of bottom-up research for emissions modeling for this equipment category specifically, but also for any non-road equipment category more generally. Agricultural activity varies significantly by location, even within a county. Having high-quality data that are representative at the county level is important to accurately estimating agricultural equipment emissions. CAPCOG's emissions modeling efforts for agricultural tractors used multiple sources of regionally representative data to characterize this important source of emissions. The final inventory estimates for the region showed that this equipment category represents an even more significant source of emissions for the region than the already-significant levels that would be modeled using default data in the NONROAD model. Accurately estimating and characterizing these emissions using the techniques identified in this paper should lead to improvements in regional, state, and national air quality planning efforts.

REFERENCES

Baker, R. (Baker 2008), "Characterization of the Off-Road Equipment Population"; Prepared for the California Air Resources Board and the California Environmental Protection Agency by Eastern Research Group, Inc., Austin, TX, December 2008, http://www.arb.ca.gov/research/apr/past/04-315.pdf.

Baker, R. Preusse, D., and Ratford, M., (Baker et al. 2011), "Sampling and Laboratory Analysis of Retail Gasoline and Diesel Fuel for Selected Texas Cities – Summer 2011"; Prepared by Rick Baker and Diane Preusse of Eastern Research Group, Inc., and Michelle Ratford of the Southwest Research Institute for Morris Brown, Technical Analysis Division, Texas Commission on Environmental Quality, Austin, TX, August 31, 2011, revised March 2015; ERG No. 0292.00.003.

https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/mob/5821199776FY1103-20110831-ergi-summer_2011_fuels.pdf.

Baker, R. and Boatman, L. (Baker and Boatman 2012), "Agricultural Equipment Emission Inventory Survey"; Prepared for Andrew Hoekzema, Capital Area Council of Governments, by Eastern Research Group, Inc., Austin, TX, December 14, 2012.

Capital Area Council of Governments (CAPCOG 2013a), *Agricultural Tractor 2006 Ozone Season Weekday Emission Inventory for the CAPCOG Program Area*, Austin, TX, August 2013. http://www.capcog.org/documents/airquality/reports/2013/CAPCOG_Agricultural_Tractor_Emissions_2006_Merged.pdf.

Capital Area Council of Governments (CAPCOG 2013b), *Spatial Allocation Surrogate Updates for Selected Area and Non-Road Sources in the Austin-Round Rock Metropolitan Statistical Area*, Austin, TX August 2013. http://www.capcog.org/documents/airquality/reports/2013/Task_3.3_-_Development_of_Updated_Spatial_Surrogates_for_Selected_Area_and_Non-Road_Sources_Final.pdf

Capital Area Council of Governments (CAPCOG 2013c),*2012 and 2018 Emissions Updates for the CAPCOG Region and Milam Counties*; Austin, TX, November 2013. http://www.capcog.org/documents/airquality/reports/2013/Task_3.1-2012_and_2018_Emissions_Modeling_for_CAPCOG_Region_and_Milam_Counties_2013-12-02.pdf

Eastern Research Group, Inc. (ERG 2008), "Texas NONROAD (TexN) Model Version 1.0 User's Guide", Prepared for the Air Quality Division, Texas Commission on Environmental Quality, Austin, TX, August 2008; ERG No. 0227.01.009.00. ftp://amdaftp.tceq.texas.gov/pub/Nonroad_EI/TexN/TexN_Users_Guide.pdf

Lindhjem, C. (Lindhjem 2003), "Revised Agricultural Emissions Estimates for the Houston-Galveston Nonattainment Area"; Prepared for the Houston Advanced Research Center (HARC) by ENVIRON International Corporation, Novato, CA, June 2003, http://files.harc.edu/Projects/AirQuality/Projects/H008C.2003/AGR/H8C-AGRProjectSummary.pdf.

Thesing, K. (Thesing 2009), "Development of Emissions Inventory of Agricultural Equipment in All Texas Counties Part Two", Prepared for Mr. Peter A. Ogbeide, Air Quality Division, Texas Commission on Environmental Quality, by E.H. Pechan & Associates, Inc., Durham, NC, August 15, 2009; Contract No. 582-7-84008, Work Order No. 582-7-84008-FY09-02, Tracking No. 2009-47. https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784008FY0902-20090815-ehpa-tx_agr_equipment_ei_taks6.pdf

U.S. Department of Agriculture (USDA 2011a), *United States 2012 Census of Agriculture Form*, Form Number 12-A103, December 13, 2011. "http://www.agcensus.usda.gov/Help/Report_Form_and_Instructions/2012_Report_Form/Region3_12a103_121311.pdf. Last accessed March 30, 2015.

U.S. Department of Agriculture (USDA 2011b), *Instruction Sheet for the United States 2012 Census of Agriculture*, Form 12-A01(I). December 13, 2011. http://www.agcensus.usda.gov/Help/Report_Form_and_Instructions/2012_Report_Form/12-A01%28i%29.pdf.

U.S. Department of Agriculture (USDA 2014a), *2012 Census of Agriculture*, Volume 1, Chapter 2: County Level Data: Texas, Appendix A: Census of Agriculture Methodology, Table C. May 2, 2014. http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_2_County_Level/Texas/txappxa.pdf.

U.S. Energy Information Administration (EIA 2015). *Adjusted Distillate Fuel Oil and Kerosene Sales by End Use*, http://www.eia.gov/dnav/pet/pet_cons_821usea_dcu_nus_a.htm. Last accessed March 23, 2015.

U.S. Environmental Protection Agency (EPA 2004a). *Nonroad Engine Growth Estimates,* NR-008c. Assessment and Standards Division, Office of Transportation and Air Quality, Ann Arbor, MI, April 2004; EPA420-P-04-008. http://www.epa.gov/otaq/models/nonrdmdl/nonrdmdl2004/420p04008.pdf

U.S. Environmental Protection Agency (EPA 2004b). *Weekday and Weekend Day Temporal Allocation of Activity in the Draft NONROAD2004 Model*, NR-015a. Assessment and Standards Division, Office of Transportation and Air Quality, Ann Arbor, MI, April 2004, EPA420-P-04-015. http://www.epa.gov/otaq/models/nonrdmdl/nonrdmdl2004/420p04015.pdf

U.S. Environmental Protection Agency (EPA 2005a). *Seasonal and Monthly Activity Allocation Fractions for NONROAD Engine Emissions Modeling*, NR-004c. Assessment and Standards Division, Office of Transportation and Air Quality, December 2005; EPA420-R-05-017. http://www.epa.gov/otaq/models/nonrdmdl/nonrdmdl2005/420r05017.pdf.

U.S. Environmental Protection Agency (EPA 2005b). *Calculation of Age Distributions in the Nonroad Model: Growth and Scrappage*, NR-007c. Assessment and Standards Division, Office of Transportation and Air Quality, Ann Arbor, MI, December 2005; EPA420-R-05-018. http://www.epa.gov/otaq/models/nonrdmdl/nonrdmdl2005/420r05018.pdf

U.S. Environmental Protection Agency (EPA 2005c). *Geographic Allocation of Nonroad Engine Population Data to the State and County Level*, NR-014d. Assessment and Standards Division, Office of Transportation and Air Quality, Ann Arbor, MIDecember 2005; EPA420-R-05-021. http://www.epa.gov/otaq/models/nonrdmdl/nonrdmdl2005/420r05021.pdf

U.S. Environmental Protection Agency (EPA 2010a). *Conversion Factors for Hydrocarbon Emission Components*, NR-002d. Assessment and Standards Division, Office of Transportation and Air Quality; Ann Arbor, MI, July 2010; EPA-420-R-10-015. http://www.epa.gov/oms/models/nonrdmdl/nonrdmdl2010/420r10015.pdf

U.S. Environmental Protection Agency (EPA 2010b). *Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling*, NR-005d. Assessment and Standards Division, Office of Transportation and Air Quality, Ann Arbor, MI, July 2010; . EPA-420-R-10-016. http://www.epa.gov/otaq/models/nonrdmdl/nonrdmdl2010/420r10016.pdf

U.S. Environmental Protection Agency (EPA 2010c). *Nonroad Engine Population Estimates*, NR-006e. Assessment and Standards Division, Office of Transportation and Air Quality, Ann Arbor, MI, July 2010; EPA-420-R-10-017. http://www.epa.gov/otaq/models/nonrdmdl/nonrdmdl2010/420r10016.pdf

KEY WORDS

Emission Inventories
Mobile Sources
Non-Road
Agricultural Tractors