Using Aerial Photography and GIS Data to Improve Quarry Equipment Emissions Inventories

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ABSTRACT

In the past, off-road emission inventories of quarries were frequently incomplete or contained inaccuracies. The NONROAD model default values were inappropriate for quarry emission calculations in the San Antonio region due to the larger construction equipment in use and almost constant usage rates at these sites. The accuracy of these calculations increases with the use of local data acquired through surveys and aerial photography. Local quarry equipment activity was requested in a two-stage survey to determine equipment population, usage rates, and equipment characteristics at quarries in the San Antonio region for the year 2005. Because of a low response rate to the initial survey and large variations in quarry sizes and production rates, further analysis was necessary to improve the results of the equipment inventory and increase accuracy of the emissions calculations. Aerial photography was used to determine equipment populations of all quarries in the San Antonio area. The equipment for each quarry was identified, marked, and counted using 6-inch resolution imagery with Geographic Information Systems (GIS) software. Once emissions were calculated using survey data, aerial counts, and the NONROAD 2004 model, the emissions were geo-coded to each quarry site. The GIS software was then used to allocate emissions to the grid systems used by photochemical models to improve the accuracy of predicting ozone formation and the effectiveness of control strategies.

INTRODUCTION

Most emission inventories of quarries contain point sources such as cement kilns and hot asphalt plants. However, quarry equipment is a major source of emissions that is often overlooked or not accurately estimated. A variety of minerals are mined in the San Antonio region: limestone, aggregate, granite, sand and gravel, and lignite. Current methodologies, including the use of NONROAD model factors, have proven unreliable in developing an accurate emissions inventory for the San Antonio region. Since quarry equipment emits 3.2 tons of nitrogen oxides (NOx) a day in the San Antonio area, it is important to have a methodology that produces accurate emissions estimations.

In the San Antonio region, there are 29 large quarries that contain a wide assortment of equipment in use nearly 24-hours a day, every day of the week. However, getting access to equipment population and usage rates is difficult; quarry companies are reluctant to release this data. Many of the companies are wary that competitors will have access to data that would give competitors a market advantage. Because of the reluctance to release information, other methods of obtaining this data, such as the utilization of aerial photography and GIS software, are necessary to increase the accuracy of an emission inventory. These tools can be used to determine equipment populations at each quarry.

Emission estimates for volatile organic compounds (VOC), nitrogen oxides (NOx), and carbon monoxide (CO) for the San Antonio region were calculated for diesel vehicles in the following categories of quarry equipment:

- 2270002018 Scrapers
- 2270002036 Excavators
- 2270002048 Graders

- 2270002051 Off-highway Trucks (rock trucks)
- 2270002060 Rubber Tire Loaders
- 2270002066 Tractors/Loaders/Backhoes
- 2270002069 Crawler Tractor/Dozers

METHODOLOGY

The methodology used in producing quarry equipment emission estimates for the San Antonio region is based on local data produced from surveys and aerial photographs, or on national data used in the EPA NONROAD 2004 Emission Inventory Model, in the absence of reliable local data. The methodology involves:

1) Conducting a survey to request equipment population, usage rates, and equipment characteristics from local quarries
2) Analyzing aerial photographs to identify equipment in use and equipment populations
3) Determining equipment populations for quarry sites without survey data
4) Conducting a second survey with pre-filled data obtained from the first survey or data estimated with the use of aerial photography of quarry equipment activity at each quarry
5) Estimating VOC, NOx, and CO annual emissions for a typical ozone season weekday (tons/day) using survey responses and NONROAD model defaults
6) Spatially allocating emissions to 4km photochemical modeling grids with TransCAD 4.7 GIS software

Equipment emissions were calculated for quarries with more than 9 employees, only. Smaller quarries do not have a significant amount of equipment usage. There are 29 quarries in the San Antonio region that have more then 9 employees (Table 1). The steps used to calculate emissions are outlined following table 1.

Table 1. Allocation of quarries in the San Antonio region, 2005

County	FIPS code	Number of Large Quarries*
Atascosa	48013	1.5
Bexar	48029	15.0
Comal	48091	8.0
Gillespie	48171	2.0
Kerr	48265	1.0
Medina	48325	1.5
Total		29.0

Note: Two quarries cross county boarders. For these two quarries, 50 % of the emissions were allocated to each county.

Step 1: Conduct a Survey of Local Quarry Equipment Activity

The preferred method of calculating quarry equipment emissions involves conducting a survey of equipment use within the San Antonio region (Appendix A). The survey form requested the following information:

- Activity Rates (HRS) – total annual hours of use by type of equipment
- Temporal Profiles – equipment use on weekdays and equipment use on weekend days for all types of equipment
- Engine Characteristics:
  1) Engine Type –diesel

2) Engine Horsepower – rated power of the engine

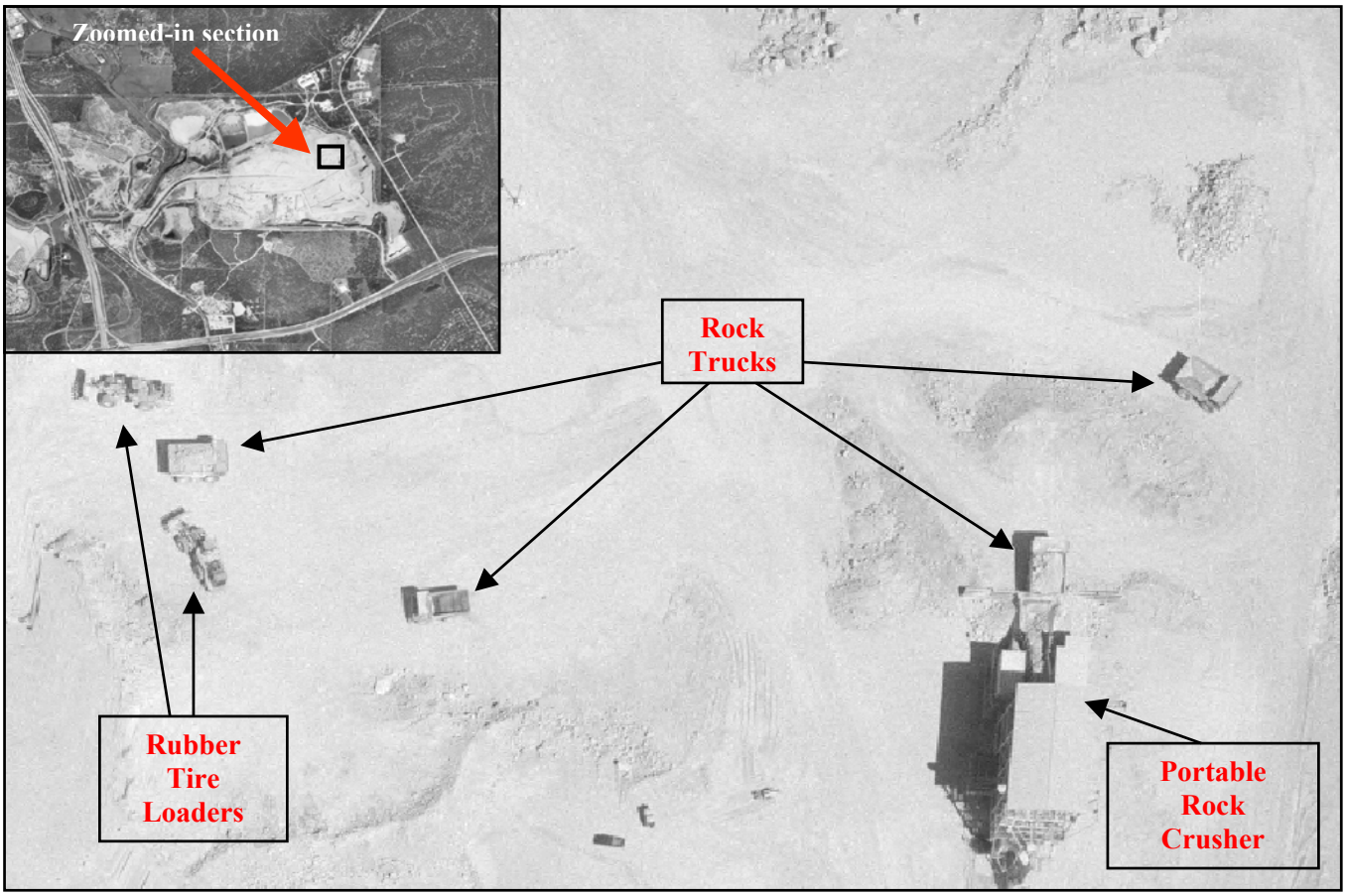
Step 2: Analysis of Aerial Photography

Due to the low response rate (only two quarries responded), an analysis of aerial photography was performed to determine the types and populations of equipment in use for all the quarries. Available imagery of 6-inch resolution sufficient for analysis was available for Bexar County, only. The aerial photography was projected on State Plane, NAD83, Texas South Central. The equipment for each quarry located in Bexar County was identified, marked, and counted in TransCAD.

Figure 1 clearly shows 4 rock trucks and 2 rubber tire loaders active in quarry operations in the aerial photograph. At the bottom of the figure, there are two pickups and a flatbed truck for comparison. The image also shows a portable rock crusher that could be a significant source of air pollutants. The zoomed-in image is only a small fraction of the total quarry shown in the upper left hand corner of the figure. For example, the aerial photography of one quarry in Bexar County revealed 3 scrapers, 8 excavators, 1 grader, 11 off-highway (rock) trucks, 18 rubber tire loaders, and 3 tractors/loaders/ backhoes working in the quarry. These equipment counts were used as the equipment population for that quarry, in the absence of survey data.

For quality assurance purposes, aerial counts for the two quarries that responded to the initial survey were compared with the survey responses. In both cases the types and counts of equipment determined through the use of aerial photography was almost identical to the data provided by the quarries.

Figure 1. Aerial photography of a quarry showing rock trucks and front-end loaders



Step 3: Determining equipment population for quarry sites without local data

As aerial photographs were available for Bexar County only, the equipment populations for quarries outside Bexar County were estimated based on number of employees. To estimate equipment populations for these facilities, all quarries were separated into two categories: quarries with kilns and/or asphalt plants and quarries without kilns or plants.

An employee to equipment ratio was calculated for kiln/asphalt sites and non-kiln sites by dividing the total pieces of equipment counted (at quarries within Bexar County) for the category by the total number of employees (at quarries within Bexar County). The ratio was then used to calculate estimated equipment populations for the remaining quarry sites. The number of employees at a quarry was multiplied by the equipment ratio and the result was rounded to the nearest whole number. Equation 1 is an example of the calculation used to determine the ratio for rubber tire loaders/employee at a quarry with kiln(s).

Equation (1) $\text{EE Ratio} = \text{EP} \div \text{EMP}$

where
EE Ratio = Equipment to employee ratio
EP = Equipment population at quarries with kilns
EMP = Number of employees at quarries with kilns

EE Ratio for Rubber Tire Loaders
= 32 Rubber Tire Loaders ÷ 541 Employees
= 0.05915 Rubber Tire Loaders per employee

The population of each equipment type for quarries without survey data was estimated through the use of Equation 2.

Equation (2) $\text{POP} = \text{EMP} \times \text{EE Ratio}$

where
POP = Estimated population of equipment at the quarry (rubber tire loaders)
EMP = Number of employees at the quarry
EE Ratio = Equipment to employee ratio (rubber tire loaders at sites with kilns)

Rubber tire loaders at Quarry "A"
= 118 employees at Quarry "A" x 0.05915 rubber tire loaders/employee
= 6.9797 rubber tire loaders
= 7 estimated rubber tire loaders at Quarry "A" (after rounding)

Step 4: Conduct a Second Survey of Local Quarry Equipment Activity

After analyzing aerial photographs and determining equipment populations for each quarry, a second survey was sent out to the local quarries with the estimations of their equipment population, HP, and activity hours. This survey used the same format as the initial survey. Completed analysis of aerial photography allowed Alamo Area Council of Governments (AACOG) to provide accurate equipment counts on the second survey in Bexar County. Companies were asked to correct estimations and to send the surveys back to AACOG.

There was a 34 percent response rate to the second survey. Aerial photography provided equipment populations data on 28 percent of the remaining quarries. The combined survey and aerial photography analysis (62 percent of quarries) provided an excellent guide for equipment population, activity, and horsepower estimates for the remaining quarries.

Step 5: Estimating Annual Emissions of Ozone Precursors (tons/yr.)

Equipment population, horsepower, and annual hours of use were developed with local data described above for each quarry. In the absence of reliable local data, the values for HP were taken from an Eastern Research Group (ERG) study "Diesel Construction Equipment Emissions in the Austin Region" for backhoe and Dozer equipment categories. Table 2 lists estimated HP ratings, by type of equipment used in this study, and the NONROAD 2004 default value for HP. NONROAD defaults had lower horsepower for Excavators and Front-end loaders compared to the survey responses. Off-Road Trucks had lower horsepower compared to NONROAD defaults. For each type of equipment at each quarry, VOC, NOx, and CO emissions were calculated using Equation 3.

Equation (3) Emissions in g/yr. (VOC/CO/NOx) = EP x HRS x HP x LF x EF

where EP = equipment population
HRS = hours per piece of equipment
HP = horse power
LF = load factor
EF = emission factor (VOC/CO/NOx)

Local surveys indicated that the values for HP used in the ERG study were too low for scrapers and rock trucks, while the estimates for loaders were too high for the San Antonio region. In all three cases, the HP was changed based on the average HP from the returned surveys. For other categories, AACOG survey responses were similar to the results of the ERG survey.

Table 2. Estimated HP by equipment type for San Antonio quarries, 2005

Equipment Type	SCC	NONROAD Model Default HP	ERG Austin Study Estimated HP	AACOG Study Estimated HP
Scrapers	2270002018	409	250	**400**
Excavators	2270002036	171	500	500
Graders	2270002048	204	200	200
Trucks	2270002051	783	400	**411**
Loaders	2270002060	243	500	**400**
Backhoes	2270002066	93	80	80
Dozers	2270002069	260	250	250

Equipment type hours per year were updated in the NONROAD model based on the survey responses. Table 3 lists the hours per year used when survey responses were not available. In almost all cases, local activity rates were greater than provided by the NONROAD model. Quarry operations tend to have longer operating hours than other facilities that use these types of equipment. Also, there is a significant amount of equipment usage on the weekends because quarries operate nearly constantly to meet the demands of cement kilns and hot asphalt plants.

Table 3. Annual hours of use by equipment type, 2005

Equipment Category	SCC	NONROAD Model Default Hours/year	AACOG Study Estimated Hours/Year
Scrapers	2270002018	914	**2208**
Excavators	2270002036	1092	1092*
Graders	2270002048	962	**1135**
Trucks	2270002051	1641	**2138**
Loaders	2270002060	761	**1692**
Backhoes	2270002066	1135	**1172**
Dozers	2270002069	936	**1467**

* The NONROAD Model default for hours/year was used for excavators; survey responses were not statistically significant.

The values for the load factor (LF) and emission factor (EF) were obtained from the EPA NONROAD Emission Inventory Model. LF values were easily obtainable from the data files of this model. The values for EF had to be calculated by first determining the default input values used in the model, performing a run, and then using the results of the run to work in reverse through the formula to determine what Efs were used by the model for an average ozone season day. The equation below provides an example of how emissions were calculated for 7 rubber tire loaders at Quarry A. These rubber tire loaders are operated an average 1,692 hrs/yr. (HRS), and are 400 HP. From the NONROAD Model, the typical LF for front-end loaders is 0.59 and the 2005 NOx EF, during the ozone season, is 5.8320 g/hp-hr. Equation 3 provides an estimate of NOx emissions in tons/year generated by the 7 rubber tire loaders at Quarry A.

NOx Emissions = EP x HRS x HP x LF x EF
= 7 x 1,692 hrs/yr. x 400 hp x 0.59 x 5.8320 g/hp-hr
= 16,301,513 g/yr.
= 17.97 tons/yr.

A final step in the calculation was to determine the percent of weekday versus weekend emissions. Equipment hours of operation on weekdays for all survey responses were added and divided by the total number of hours. It was determined that 78.1 percent of the equipment hours of operation are during weekdays and 21.9 percent of the equipment hours of operation occur during the weekend. Emissions for an average ozone season weekday were calculated using Equation 4.

Equation (4) Emissions in g/day (VOC/CO/NOx) = Emissions (g/yr.) x WA ÷ WD

where WA = Weekday adjustment factor from survey responses
WD = Weekdays per year

NOx Emissions = 17.97 tons/yr. x 0.781 ÷ 261 weekdays/year
= 0.0538 tons/weekday

This same procedure was used for CO and VOCs to produce estimates of pollutants by quarry. Emission estimates were added up for each quarry in a county to determine total county emissions. A summary of the results is provided in Table 4.

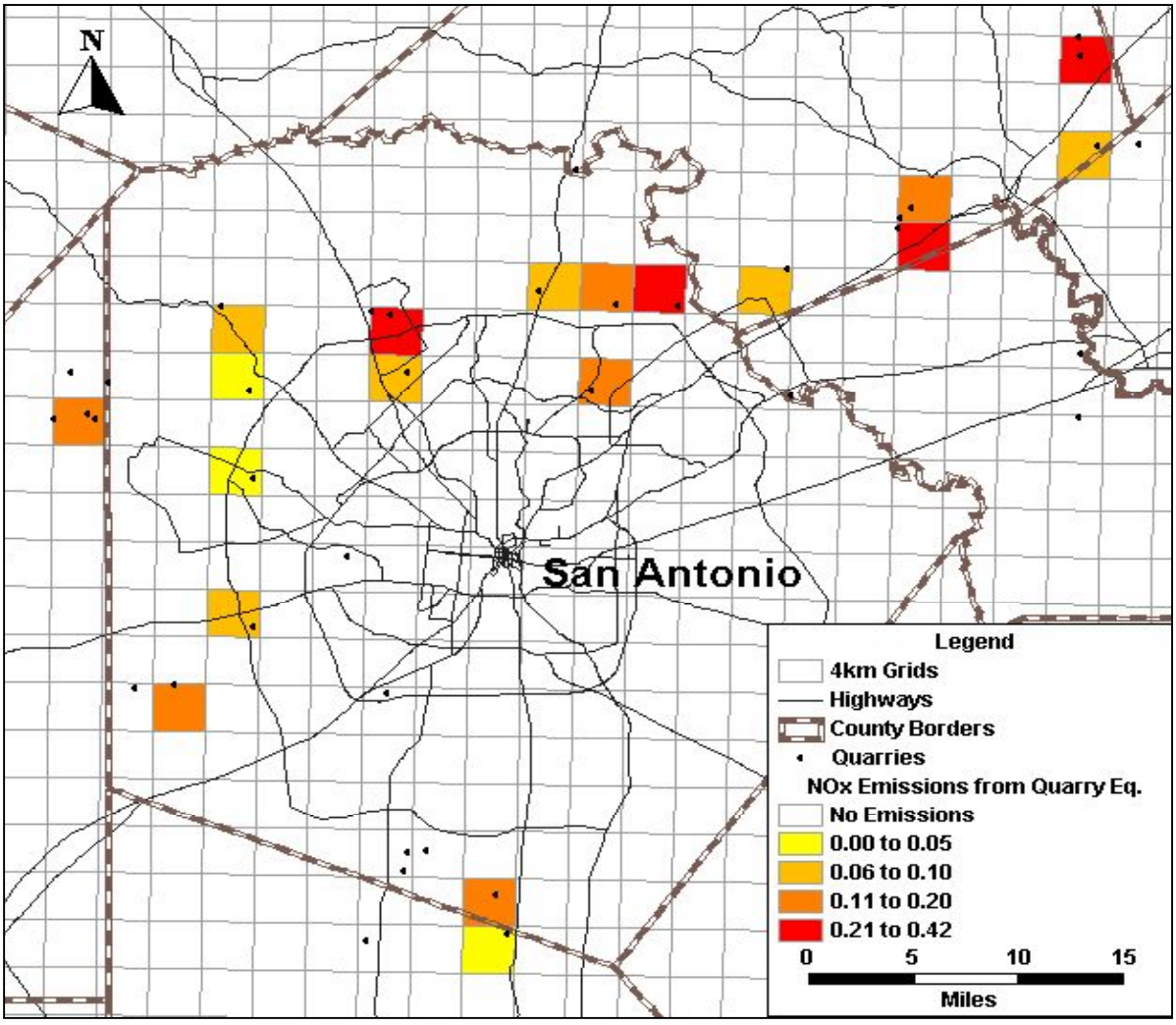
Table 4. Quarry equipment emissions by county in the San Antonio region, 2005

County	VOC (tons/day)	NOx (tons/day)	CO (tons/day)
Atascosa	0.00	0.06	0.02
Bexar	0.13	1.88	0.71
Comal	0.08	1.15	0.43
Gillespie	0.00	0.06	0.02
Kerr	0.00	0.01	0.00
Medina	0.01	0.09	0.04
Total	0.23	3.24	1.22

Step 6: Spatial Allocation

Emissions were geo-coded to quarry locations using TransCAD. As Figure 2 shows, emission were aggregated to the 4km photochemical model grid system. The 4km grid system is based on the September 1999 modeling episode used in the San Antonio Early Action Compact (EAC) State Implementation Plan (SIP).

Figure 2. Allocation of quarries and quarry equipment emissions to photochemical model grids



Only quarries with more then 9 employees had emissions allocated to the 4km grids. As shown in the figure, most of the quarry emissions were generated in north San Antonio as well as to the northeast of the City. By allocating emissions to actual quarry sites, ozone predictions in the photochemical model are more accurate.

CONCLUSION

The NONROAD model default values proved inappropriate for quarry equipment in the San Antonio region because local quarries usually operated larger construction equipment and nearly constant usage rates compared to the data in the model. For some equipment, horsepower estimates were higher for quarry equipment as compared to the NONROAD construction equipment defaults. Whereas for rock trucks, the NONROAD defaults had the higher horsepower estimations compared to the survey responses. Although the survey results are different then the NONROAD defaults, the hp values were similar to the ERG study in Austin.

Survey responses indicate that equipment hours at quarry sites are much higher than NONROAD defaults. Similarly, because quarries operate almost constantly to meet the demands of the cement kilns and hot asphalt plants, equipment is used often on weekends.

By using aerial photography, accurate equipment counts at each quarry could be determined. Quarry equipment is a significant part of the emission inventory and companies are reluctant to release data; thus, reliable equipment counts are essential for an accurate emission inventory. For one quarry, the equipment was covered with dust from the quarry that made the equipment harder to detect on the aerial photography. However, with the constant improvements in aerial and satellite imagery, this limitation will be less significant over time.

Using GIS software to allocate emissions to the photochemical model grid systems improves the accuracy of predicting ozone formation and the effectiveness of control strategies. This methodology can be used to improve estimations for other categories of the emission inventory including landfill equipment, above ground storage tanks, crops, open pit lignite mining, other open pit mining activities, etc. Further research on this topic includes examining the impact of the improved quarry emission inventory on photochemical modeling results.

Appendix A
Survey used to determine quarry equipment population, horsepower, and hours

AACOG
Alamo Area Council
Of Governments

May 1, 2003

[COMPANY NAME]
[STREET ADDRESS]
[CITY] [STATE] [ZIP]

ATTENTION: OPERATIONS MANAGER

Re: 2002 San Antonio Emissions Inventory

The Alamo Area Council of Governments (AACOG) requests your assistance in the development of a 2002, air quality emission inventory for San Antonio and the surrounding counties. AACOG is conducting this inventory in order to assess and quantify local air quality within the San Antonio Metropolitan area and contiguous counties. This inventory is especially significant because the San Antonio region currently risks being declared in non-attainment of federal air quality standards (NAAQS).

AACOG will calculate the equipment source component of this inventory from information submitted by local organizations involved in equipment activities in and around the San Antonio region using the enclosed survey. With this survey, we are requesting information on equipment used during the 2002 calendar year within Atascosa, Bandera, Bexar, Comal, Frio, Gillespie, Guadalupe, Karnes, Kendall, Kerr, Medina, and Wilson counties. The purpose of this survey is to provide better information and services to the region, as well as help minimize additional regulation on the community.

Your input is vital to this process and will serve to effect a true and correct emissions inventory for 2002 that will be delivered to the EPA. Please provide your responses on the attached survey and return it to us in the self-addressed envelope by the date indicated. The information you provide will be considered strictly confidential and unavailable to publ ic information requests. Please submit your response by, May 30, 2003.

Thank you for your time and participation. If you have any questions or comments please feel free to contact Steven Smeltzer, Environmental Manager at (210) 362-5266.

Regionally yours,

Al J. Notzon III
Executive Director
Enclosures (2)

Alamo Area Council of Governments
Equipment Environmental Impact Survey
Internal Combustion Engine

The Alamo Area Council of Governments (AACOG) is conducting a study to assess and quantify local air quality within the San Antonio Metropolitan area and contiguous counties by performing an emission inventory. AACOG has defined the study area to include Atascosa, Bandera, Bexar, Comal, Frio, Gillespie, Guadalupe, Karnes, Kendall, Kerr, Medina, and Wilson counties. Our goal is to provide better information and services to businesses and individuals, and help minimize additional regulation on the community. The purpose of this survey is to gather data on emissions produced by several types of equipment in the region.

The study area does not presently exceed Environmental Protection Agency (EPA) air quality standards. However, if the standards are exceeded in the future we will be classified as nonattainment, which will result in expensive and stringent regulations for your business and the community. By filling out this confidential survey, you will be providing valuable data that will be used to evaluate cost-effective approaches to pollution control. Thank you for taking the time to provide this information.

Instructions:
1. Please look through the equipment types shown on the following page.
2. List any of the equipment types regularly operated at your business.
3. Fill in the appropriate figures for each equipment type you listed. (Estimates are acceptable.)

If you have other internal combustion equipment that is not shown, please include it as well.

NOTE: IF YOUR BUSINESS HAS MORE EQUIPMENT THAN WILL FIT IN THE SPACE PROVIDED, PLEASE MAKE ADDITIONAL COPIES OF THE SURVEY.

Completed surveys can be faxed to (210) 225-5937, or mailed to:
Alamo Area Council of Governments
8700 Tesoro, Suite 700
San Antonio, Texas 78217
Attn: Chris Langston

If you have any questions or comments, please call us at (210) 362-5270.

SURVEY STARTS ON THE OTHER SIDE OF THIS PAGE

	Internal Combustion Equipment Type	Engine Type Gasoline 2-cycle Gasoline 4-cycle Diesel Propane Natural Gas	Approx. Horse-Power Rating	Number of Units Typically Operated	Avg. No. of Hours and Time of Day Each Unit Operated (MON-FRI)	Avg. No. of Hours and Time of Day Each Unit Operated (SAT & SUN)
Construction Equipment						
1	Bore/Drill Rigs					
2	Excavators					
3	Concrete & Mortar Mixers					
4	Cranes					
5	Graders					
6	Crushing/Processing Eqmt.					
7	Rough Terrain Forklifts					
8	Rubber Tire Loaders					
9	Other Loaders					
10	Dozers					
11	Tractors/Backhoes					
12	Scrapers					
13	Rollers					
14	Trenchers					
15	Pavers					
16	Other Construction Equipment Type: _____					

REFERENCES

Eastern Research Group Inc., *Diesel Construction Equipment Emissions in the Austin Region, Draft 1.4,* Texas. November 30, 2001, p. 15.

Caliper Corporation, *TRANSCAD: Transportation GIS Software Version 4.7,* 2005, Newton MA

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U.S. Environmental Protection Agency, *National Nonroad Emissions Model 2004: Draft Version*, 2005, Ann Arbor, MI.

KEY WORDS

Aerial Photography
Construction Equipment
Emission Inventory
GIS
Non-road
Quarries
Quarry Equipment