

An Integrated Emissions Calculation and Data Management Tool for Nonroad Sources in Texas

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ABSTRACT

An integrated emissions calculation and data management tool was developed for nonroad mobile sources in Texas. The Nonroad Analysis and Emissions Estimation System (NAEES) utilizes an enhanced GUI written in VB.NET, a modified version of NONROAD's Access-based reporting utility, and a MySQL5.0 database back-end to provide enhanced emissions modeling and reporting capabilities. The system can operate on a stand-alone PC or on a local server. Data can be easily updated/revise to reflect local equipment populations, activity, growth, and temporal profiles at the Source Classification Code (SCC) and county-level, for multiple target years. Combinations of default and updated data are run through the NONROAD model in batch mode as a single scenario, rather than performing individual runs for each equipment category. The system is designed to provide great precision estimating construction equipment emissions, allowing for characterization of up to 24 construction sectors (e.g., highway, utility, etc.) Data are maintained in a MySQL5.0 database. MySQL queries automatically generate NONROAD2005 input files, launches NONROAD in batch mode, and associated output files are imported back into the database for further processing. Adjustment factors are then applied, including county-level adjustments for altitude, soil and ground cover conditions, fuel parameters, as well as temperature and humidity corrections for NO_x emissions. Separate ammonia emission factors have been incorporated for different fuel/technology type combinations. NONROAD's existing Access Reporting Utility was modified to output all emissions in NIF3.0 format. Additional functionality also allows reporting at the SCC/horsepower level for multiple counties, or aggregated county groups.

INTRODUCTION

The U.S. EPA's NONROAD2005 emission factor model provides a powerful tool for estimating emissions from a broad array of nonroad mobile sources. Relying on default equipment population and activity parameters, the NONROAD model can easily generate detailed emissions estimates for over 450 different equipment/fuel types, at various temporal and geographic levels of resolution. The model utilizes generalized surrogates to allocate national and/or state level equipment population and activity profiles to the county level. For example, county level recreational marine engine activity is assumed to be proportional to water body surface area. EPA readily acknowledges the limitations of such "top-down" approaches to emissions estimation, and encourages states and other entities to utilize equipment population and activity profiles based on surveys or other local data sources.¹

Numerous emission inventory studies have been conducted in Texas in recent years to improve upon the default data available in the NONROAD model. These studies have focused on various equipment categories operating in different areas of the state, including transportation refrigeration units and LPG forklifts operating in the Dallas/Fort Worth area,² diesel powered cranes in the Houston

region,³ and diesel construction equipment operating across the entire state,⁴ among others. In each case various NONROAD files were updated to reflect locality-specific data (for example, equipment population, activity, geographic/seasonal allocation, etc.), and the model was run using the modified files to generate updated emission estimates for the different source category/region combinations.

Modification of the NONROAD data files is usually a straightforward process involving a standard text editor. However, developing statewide, county level emissions estimates for one or more scenario years can become cumbersome and highly time consuming. Given the NONROAD model's structure, it is not possible to create a single set of equipment population/activity/allocation files that incorporates all of the regional updates developed for Texas. For this reason, estimating county level, statewide emissions requires large numbers of NONROAD model runs to accommodate the different equipment profiles. For example, a recent study for the Texas Commission on Environmental Quality (TCEQ) required approximately 100 person-hours of labor to prepare input files, conduct model runs, and aggregate outputs for annual and ozone-season daily emission estimates for nonroad sources in each of the state's 254 counties, for various target years.⁵ Substantial resources are also required to undertake even relatively simple baseline assessment and sensitivity analyses for the different ozone non-attainment regions in the state, due to the "patchwork" of different equipment population and activity data sets involved.

In order to facilitate the development of nonroad emission inventories, an integrated calculation and data management system was developed for estimating emissions from all sources included in the NONROAD model for Texas. The Nonroad Analysis and Emissions Estimation System (NAEES) includes several features that greatly expand the flexibility and power of the existing NONROAD model. First, a modified Graphical User Interface (GUI) allows for easy retrieval and modification of specific NONROAD data files. Second, the file management process permits highly complex batching of hundreds or even thousands of NONROAD runs within a single user-defined "scenario". NAEES runs the NONROAD2005 model in the background for single or multiple runs, as needed. Third, a back-end database maintains the various equipment population and activity profile updates developed for the different equipment types and regions of the state, as well as any user-defined updates. The database performs automated run aggregations as well as post-processing adjustments for county-specific factors such as ambient temperature and humidity, soil conditions (for earthwork activities), and fuel parameters, among others. Additional emission factors have been integrated into NAEES to estimate ammonia emissions for the different engine/fuel types. Finally, NONROAD's MSAccess reporting utility has been modified to provide additional standardized queries. The resulting system allows the user to develop baseline or revised nonroad emission inventory estimates using highly resolved data in much less time than it would take using the standard NONROAD model alone.

The following discussion of the NAEES tool assumes a basic familiarity with EPA's NONROAD emission factor model. Details regarding NONROAD's functionality and calculation methodologies can be found in EPA's latest User's Guide for the model.⁶

DEVELOPMENT OF THE NAEES TOOL

As discussed above, the NAEES tool consists of four basic elements:

- 1) A Graphical User Interface (GUI)
- 2) A MySQL database
- 3) EPA's NONROAD2005 model, and
- 4) An enhanced reporting utility

NONROAD's GUI was redesigned to incorporate more user-friendly features than the original NONROAD model, accommodating the need for a finer level of emissions processing, and allowing for more detailed documentation of each run. The new interface interacts with a MySQL5.0 database, which enhances the user's ability to manage data, group runs, and document scenarios. The database was populated with all of the population and related activity data developed for the latest State Implementation Plan (SIP) and other periodic inventories for Texas. The database automatically applies post-processing adjustments when necessary, and creates output files that can be imported into the modified reporting utility. The reporting utility allows the user more reporting options and creates a report including ammonia emissions. These basic components of the NAEES data management and emissions calculation process are discussed below.

Accommodation of Construction Equipment Subcategories

Diesel construction equipment (DCE) is usually the largest single emitter of nitrogen oxide emissions in urban areas. DCE is also used in a wide variety of different tasks, with different activity and emissions profiles. Accordingly, the DCE emissions inventory has been highly disaggregated for Texas, characterizing construction equipment use for 24 sectors, including highway, commercial building, residential, utility, and other distinct construction activities.⁷ The NAEES modeling system was designed to model each of these sectors individually.

Three factors were considered when defining the construction project categories for Texas. First, categories are fundamentally different in their equipment use requirements, relative to their associated physical quantities (e.g., the tasks required for highway and residential projects are quite different). Second, available population and activity surrogates for each project category are clearly associated with actual equipment use to the extent possible. (While it is not possible to directly estimate hours of equipment use for all DCE categories, certain correlates of activity can be identified and collected for the different project categories, such as the linear feet of utility line installation per year.) Third, all categories, when considered together, cover the great majority of DCE use in the State.

In a previous study, experts from various construction sectors and technical representatives from the TCEQ were solicited for their opinions regarding the distinct types of construction project categories, the likely relative contribution of the different categories, and the availability of appropriate surrogate data for each category.⁸ Based on this input it was determined that there are two fundamentally different types of DCE categories – those that have significant earthwork and surfacing requirements, and those that do not. Earthwork project categories include:

- Highway construction (state highway and bridge work, and city/county roads)
- Utility installation (sewer, water, gas, power, and communication line installation and repair)
- Single Family housing (residential developments/subdivisions)
- Commercial structures, and
- Other construction projects - e.g., very large, unique projects such as new liquefied natural gas storage depots.

Exhaust emissions are directly related to the horsepower-hours of work output by an engine. The horsepower-hours are in turn associated with the amount of work performed for a given task. While the engine work performed during non-earthwork tasks may be difficult to quantify (e.g., pothole patching, or the amount of lifting performed by cranes), earthwork and surfacing tasks are reasonably straightforward to quantify and link to available surrogates. Therefore, by developing equipment

activity profiles directly in terms of physical quantities such as cubic yards of earth moved, it became possible to develop more precise correlates for equipment activity for the earthwork categories listed above.

Non-earthwork project categories may also involve the use of DCE. Equipment use for these categories may involve specialized activities (e.g., landfill compacting). In other cases the work performed may involve earthmoving and/or surfacing, but cannot be determined from available surrogates (e.g. for mining activities, where production data is considered confidential business information).

The following lists the non-earthwork DCE categories used in Texas:

- Road or utility maintenance/repair activities performed by municipalities/counties/state agencies
- Landfill operations
- Surface mining – including stone/quarry operations, sand/aggregate pits
- Boring/drilling operations, including water wells, deep foundation work (piles/piers), and utility pole installation/repair.

A database of DCE purchases in the Dallas- Fort Worth area was obtained to help identify other industry sectors that are also significant users of DCE.⁹ These include:

- Special construction trades (e.g., performing post-earthwork activities such as concrete, electrical, heating and air conditioning installation, and other tasks)
- Landscaping companies
- Agricultural entities
- Scrap handling and recycling facilities
- Concrete product manufacturers
- Brick and stone product manufacturers
- General manufacturing operations
- Transportation/Wholesale and Retail Sales/Services

Other DCE categories were found to be inadequately characterized by the earthwork profiles. These equipment types are numerous and therefore potentially significant emitters, but were often difficult to link to available earthwork or surfacing surrogates. These included:

- Cranes
- Rough terrain forklifts
- Skid steer loaders
- Trenchers

Population data for these equipment types were derived from an equipment sales database, with activity estimates provided by industry experts, for both earthwork and non-earthwork project categories.¹⁰

Graphical User Interface (GUI)

The NAEES GUI performs the following tasks.

- 1) Provides interface screens for selecting run parameters and allows the user to review/edit supporting data for a given scenario
- 2) Interacts with the MySQL database to generate Option and supporting data files for each NONROAD run
- 4) Launches the NONROAD model for each run associated with a scenario.
- 5) Calls the NAEES post-processing driver upon run completion. (The NAEES post-processing module imports all NONROAD model output files into the database, performs all aggregation functions, and creates one aggregated output file for each scenario.)

The GUI allows the user to group almost any number of NONROAD input files and save them to a MySQL5.0 database as a single scenario. For example, the modified GUI builds a NONROAD input (Option) file for each county selected by the user. Should the user choose to estimate emissions for DCE, an Option file is built for each county and distinct DCE sector combination. By performing a separate NONROAD model run for each county/DCE sector, it is possible to apply activity, growth, and post-processing adjustments to emissions estimates at the county and DCE sector level. However, this approach has substantial implications for the number of Option files required to estimate emissions, as is discussed below. The GUI, however, greatly facilitates the creation of the numerous Option files required for modeling emissions for DCE as well as other equipment categories.

The GUI interacts with the MySQL database to generate an Option file for each run required by a scenario. For example, by specifying a particular county, analysis year, and season, an Option file can be constructed containing county specific fuel and temperature data (which are stored in the database). In this way the GUI populates the Option files with the region specific data necessary for the NONROAD model to execute. Once the Option and supporting data files are generated, the user can execute the NONROAD model through the GUI for each Option file contained within the associated scenario. Once the NONROAD model is launched, the interface tracks the progress of the current run and launches the next run sequentially. The user interface also checks for error messages generated by the NONROAD model. If a “warning” is reported, it is recorded in the message file, but does not affect processing. However, if an “error” is reported, the entire scenario is stopped and the user is presented with information on the error(s) that occurred. All output files created by the NONROAD model are retained for post-processing and aggregation within the database.

Executing NONROAD to account for county and SCC specific data and post-processing adjustments can require a multitude of runs. Each county requires its own Option file. This approach has an inherent advantage over the standard NONROAD model, in that the NAEES user can designate “all counties” in a single scenario, to obtain county level, statewide emission estimates. (Due to file size limitations, the standard NONROAD model cannot execute all 254 counties in a single run, so counties must be grouped and run separately.) In addition, DCE requires emission calculations at a sector level. Each of the 24 DCE sectors corresponds to a unique equipment activity profile. Each county-DCE sector combination also requires its own Option file. Furthermore, in order to appropriately apply temperature, humidity, and fuel property adjustments, seasonal emissions must be calculated separately and summed together to estimate annual emissions. A summary of the number of the Option files necessary for each model run within a scenario is presented in Table 1 below.

Table 1. Required number of NONROAD2005 model runs for selected scenario types.

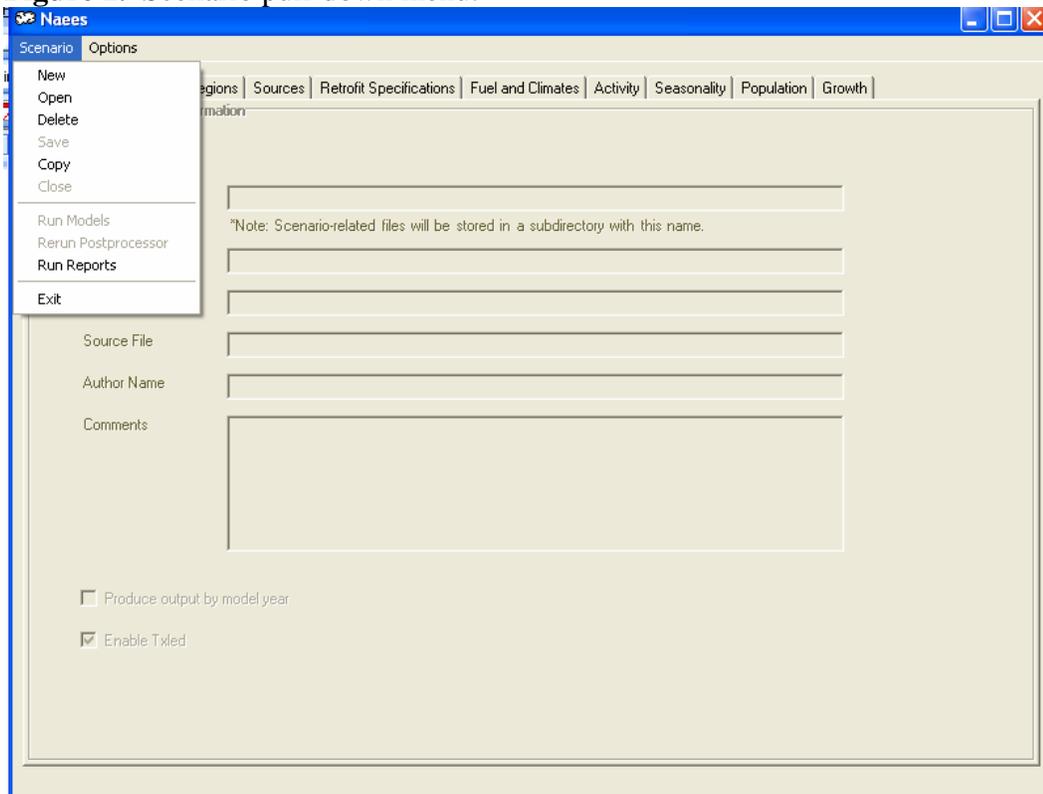
User Selections			Number of Runs	How the Number of Runs are Calculated
Period	Region	Equipment		
Ozone Season Day (OSD) or One Season	One County	Non-Diesel Construction Equipment (Non-DCE)	1	One for the selected county [1 segment * 1 county]
Annual	One County	Non-DCE	4	One for each County and Season [1 segment * 1 county * 4 seasons]
OSD or One Season	Three Counties	Non-DCE	3	One for each selected county [1 segment * 3 counties]
OSD or One Season	One County	DCE	24	One for each of the 24 DCE sectors for the selected county [24 segments * 1 county]
Annual	One County	DCE	96	One for each of the 4 seasons and each of the 24 DCE sectors for the selected county [24 segments * 1 county * 4 seasons]
OSD or One Season	Three Counties	DCE	72	One for each of the 24 DCE sectors for each of the selected counties [24 segments * 3 counties]
Annual	Statewide	All	25,400	One for each of the DCE sectors and one for Non-DCE equipment for each county for each season [(24 + 1) SCC segments * 254 counties * 4 seasons]

The GUI organizes user inputs through 10 tabs. In addition to overall scenario management, the tabs allow for the update of selected supporting data, as well as assorted county-specific factors used in post-processing adjustments. (Note that certain supporting data fields are “hard-coded” into the tool and cannot be modified through the GUI, including the criteria pollutant emission factors.) The NAEES menu options as well as the tabs in the GUI are discussed in more detail below.

Menu options

There are two menu options for NAEES. The “Options” menu is used for initial system installation and is not discussed further. By selecting “Scenario” from the menu, the user can choose to create a new scenario, copy an existing scenario, or close an opened scenario, as shown in Figure 1 below. A NAEES modeling “Scenario” consists of a set of equipment SCC/geographic region combinations, for a specified modeling time period, as discussed above. The Scenario menu option also allows a user to launch NONROAD, or the modified reporting utility. Finally, a user may choose to exit the system from this menu.

Figure 1. Scenario pull-down menu.



At a minimum, the user must complete the first four tabs within NAEES (Scenario, Period, Regions, and Sources) to set up a scenario. These four tabs are discussed below.

Scenario tab

The user may enter or revise descriptive scenario information to help document scenarios. The data entry fields in the Scenario Tab include:

- 1) **Scenario Name.** The user may enter a descriptive scenario name up to 255 characters long. This offers an advantage over the standard NONROAD naming convention, which is limited to just eight characters.
- 2) **Report Title.** The user may enter a report title for the resulting scenario reports generated by the enhanced reporting utility. The report title may be up to 175 characters long.
- 3) **Report Title Cont.** This field allows the user to enter a second report title to appear on any reports generated by the enhanced reporting utility for a given scenario.
- 4) **Source File.** The source file field is not active if a user is creating a new scenario. It is only active when the user is editing an existing scenario, and is pre-populated with the name of the scenario that is being edited. This allows the user to trace changes and associated documentation over a scenario's evolution.
- 5) **Author Name.** Identifies the author of the scenario.
- 6) **Comments.** The user may enter documentation for a given scenario. Documentation could include details about the source/reason for any changes made to supporting data and/or the purpose of the scenario run.
- 7) **Produce Output Files by Model Year.** If the user checks this box, NONROAD will produce and preserve by-model-year output files for each model run. (If left unchecked,

only the aggregated output files, summed across model years and technology types, will be retained.)

- 8) **Enable TxLED.** This box is checked by default. If checked, the database will apply an adjustment factor to NOx emissions estimates during post-processing to reflect the reductions associated with the use of Texas Low Emission Diesel (TxLED) fuel.

Figure 2 provides an example of the Scenario Tab screen.

Figure 2. Scenario tab screen.

The screenshot shows a software window titled "Naees" with a menu bar containing "Scenario" and "Options". Below the menu bar is a tabbed interface with tabs for "Scenario Info", "Period", "Regions", "Sources", "Retrofit Specifications", "Fuel and Climates", "Activity", "Seasonality", "Population", and "Growth". The "Scenario Info" tab is active, displaying a form titled "General Scenario Information". The form includes several input fields: "Scenario Name", "Report Title", "Report Title Con't", "Source File", and "Author Name", each followed by a text input box. A note below the "Scenario Name" field reads: "*Note: Scenario-related files will be stored in a subdirectory with this name." Below the input fields is a large text area for "Comments". At the bottom of the form are two checkboxes: "Produce output by model year" and "Enable Txled".

The user may enter or revise descriptive scenario information to help document and organize scenarios. Scenario descriptions will be displayed on reports generated through the MSAccess reporting utility. Users can also create a new scenario by using the Scenario pull-down menu at the top of the screen. The GUI will populate new scenarios using the baseline equipment population and activity profile data contained in the database, specific to the equipment SCC/geographic regions specified.

Period tab

The Period Tab maintains much of the NONROAD2005 GUI structure. However, there are some notable exceptions. First, NAEES allows a user to specify a "meteorological year". The GUI will then refer to lookup tables in the database to obtain the minimum, maximum, and average temperatures

corresponding to the particular county for the specified season and year. Average relative humidity is also obtained from the lookup tables for use in adjusting exhaust NOx emission estimates during post-processing. These data are then used to populate the Option files for the appropriate NONROAD runs.

Also, should a user select to run an Annual Period, NAEES processes this request differently than NONROAD. NAEES calculates an annual period by summing together four separate model runs, one for each season. This allows climate and fuel specification changes throughout the year to be more accurately reflected in the resulting emissions estimates.

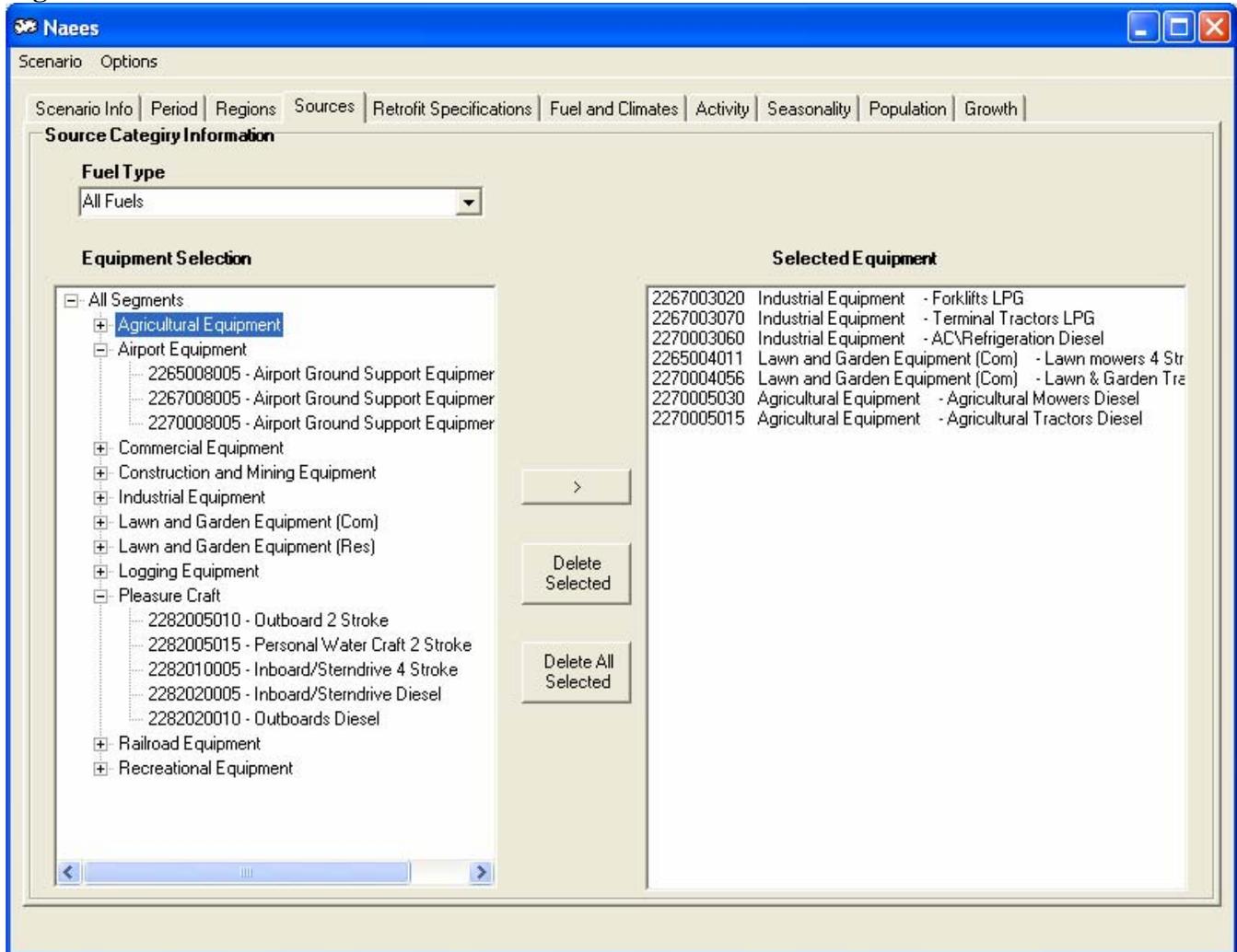
Regions tab

The Regions tab within NAEES is also similar to the corresponding screen in NONROAD, albeit restricted to Texas counties. Unlike the NONROAD model the user can designate “all counties” in a single NAEES scenario, to obtain county level, statewide emission estimates. In addition, over 30 pre-defined geographic regions can be selected by the user, including all counties within specific non-attainment areas, as well as other regions of interest to regulators and policy analysts.

Sources tab

The Sources tab is structured somewhat differently within NAEES than in NONROAD. Namely, selection of equipment for evaluation at the SCC or broader equipment category level is facilitated through the adoption of a tree structure, as shown in Figure 3. This structure allows the user to expand a source category to view individual SCCs and their descriptions before selecting them for inclusion in a scenario. Furthermore, the user can apply a filter so that only the applicable SCCs are displayed in the tree view. The 10 digit SCC codes are also displayed onscreen for user reference.

Figure 3. Sources tab screen.



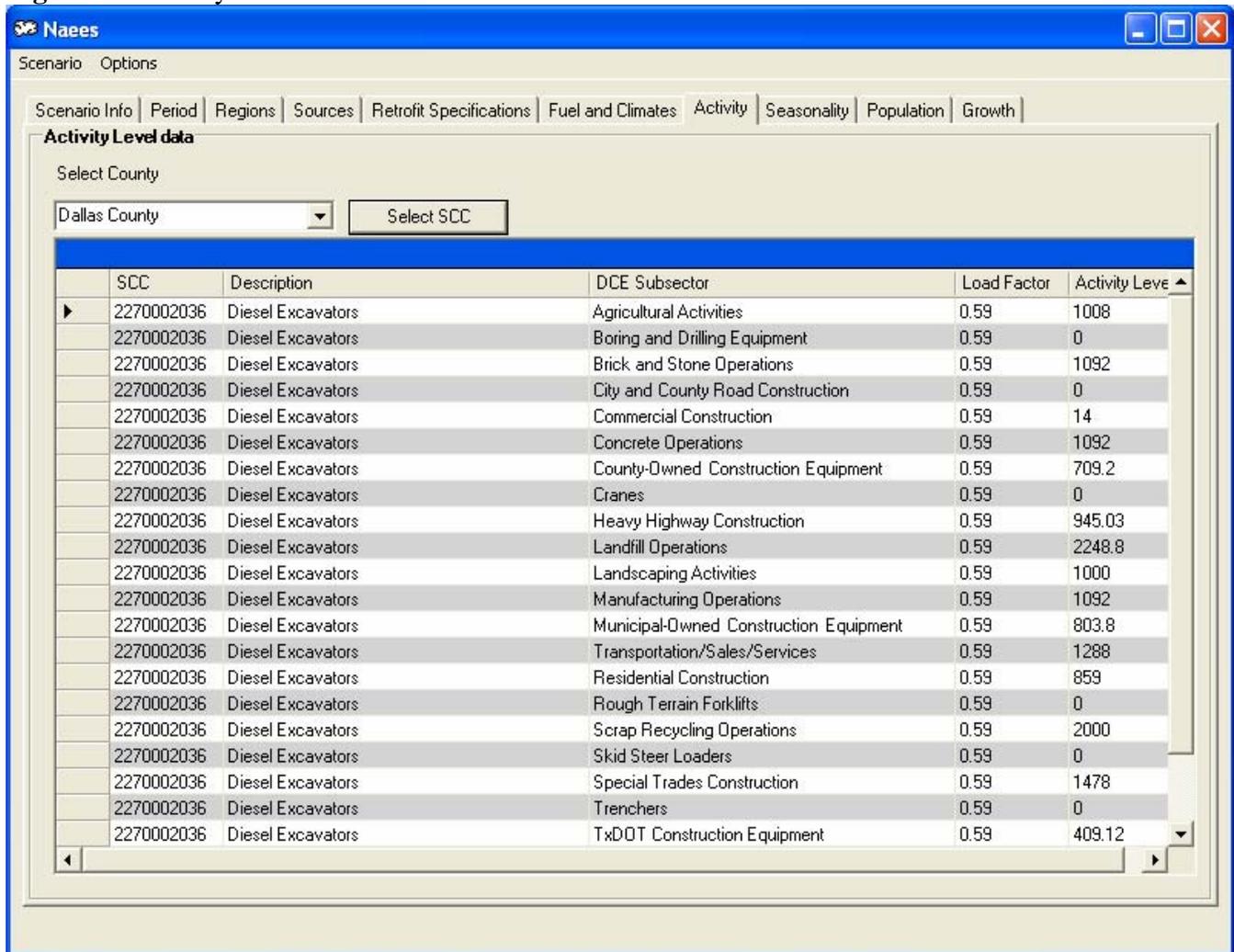
Management of supporting data

Once the basic scenario parameters have been specified for Period, Regions, and Sources, NAEES allows the user to review and update equipment population and activity profile data. Tabs are provided for activity, population, growth, and temporal profiles, corresponding to NONROAD's activity.dat, txpop.dat, nation.grw and season.dat., respectively. For any given county/SCC combination, certain key data elements may be modified by the user to reflect site-specific fleet and operating conditions, as noted below.

Activity tab

The Activity tab allows the user to view and modify the assumed hours per year for each SCC, for any given county. Load factor is displayed for reference, but cannot be changed by the user. An example is shown in Figure 4 below.

Figure 4. Activity tab screen.



Season tab

Under the Season tab the user can select equipment category “segments”, such as construction, recreational marine, etc. As with the NONROAD2005 model, if the modeling period is annual, monthly activity adjustment factors may be edited. For daily modeling periods, day-of-the-week adjustments may be made. The first of the two values on each line of daily data is the fraction of weekly activity in a typical (average) weekday day. This represents activity occurring on any single day, Monday - Friday. The second Daily value is the fraction of activity occurring Saturday – Sunday. As under the Activity tab, changes may be made for single counties, or county groups.

Population tab

The Population tab displays equipment populations by SCC and horsepower group, specific to each county, as shown in Figure 5. For each record, assumed values for base year, minimum, maximum, and average horsepower, useful life, and equipment count is displayed. Of these, the user may modify average horsepower, equipment count, and base year of the population estimate.

Figure 5. Population screen tab.

Scenario Options

Scenario Info | Period | Regions | Sources | Retrofit Specifications | Fuel and Climates | Activity | Seasonality | Population | Growth

Population Estimates

Select County

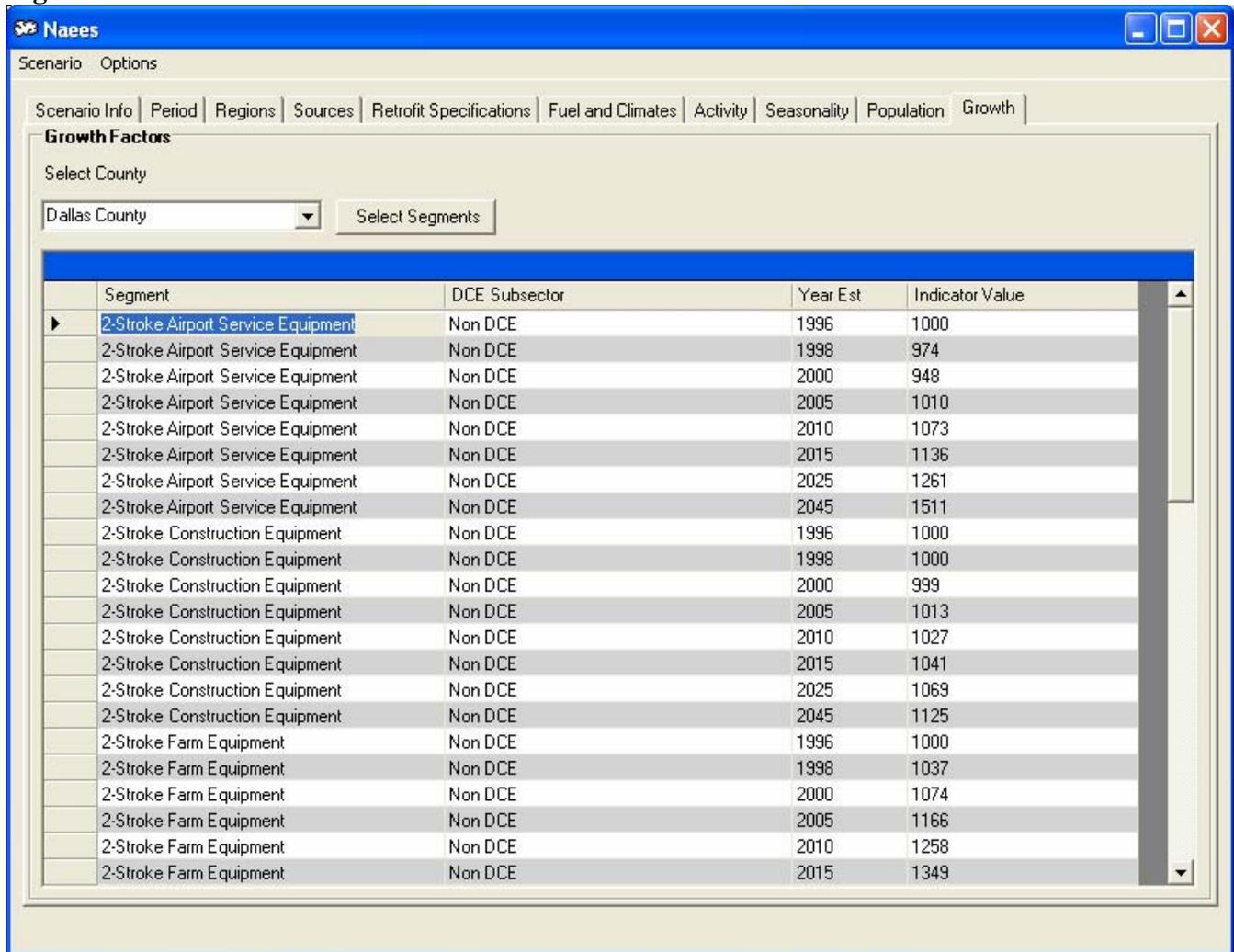
Harris County Select SCC

SCC	SCC Description	DCE Subsector	Base Year	Min HP	Max HP	Avg HP	Useful Life (hrs)	Population Estimate
2270002036	Diesel Excavators	Agricultural Activities	2004	3	6	6	2500	0
2270002036	Diesel Excavators	Agricultural Activities	2004	6	11	7.967	2500	0
2270002036	Diesel Excavators	Agricultural Activities	2004	11	16	13.14	2500	0
2270002036	Diesel Excavators	Agricultural Activities	2004	16	25	21.54	2500	0
2270002036	Diesel Excavators	Agricultural Activities	2004	25	40	33.05	2500	0.22
2270002036	Diesel Excavators	Agricultural Activities	2004	40	50	45.77	2500	0
2270002036	Diesel Excavators	Agricultural Activities	2004	50	75	61.3	4667	0
2270002036	Diesel Excavators	Agricultural Activities	2004	75	100	91.67	4667	1.82
2270002036	Diesel Excavators	Agricultural Activities	2004	100	175	137.6	4667	7.36
2270002036	Diesel Excavators	Agricultural Activities	2004	175	300	233.3	4667	5.74
2270002036	Diesel Excavators	Agricultural Activities	2004	300	600	410.6	7000	7.65
2270002036	Diesel Excavators	Agricultural Activities	2004	600	750	719.4	7000	1
2270002036	Diesel Excavators	Agricultural Activities	2004	750	1000	884	7000	0
2270002036	Diesel Excavators	Agricultural Activities	2004	1000	1200	1200	7000	0
2270002036	Diesel Excavators	Agricultural Activities	2004	1200	2000	1768	7000	0
2270002036	Diesel Excavators	Agricultural Activities	2004	2000	3000	2350	7000	0
2270002036	Diesel Excavators	Boring and Drilling E	2004	3	6	6	2500	0
2270002036	Diesel Excavators	Boring and Drilling E	2004	6	11	7.967	2500	0
2270002036	Diesel Excavators	Boring and Drilling E	2004	11	16	13.14	2500	0
2270002036	Diesel Excavators	Boring and Drilling E	2004	16	25	21.54	2500	0
2270002036	Diesel Excavators	Boring and Drilling E	2004	25	40	33.05	2500	0

Growth tab

The Growth tab allows a user to make adjustments to equipment segments as a whole, rather than on an SCC basis. The GUI will display the growth indicator values and corresponding years present in the default (or user-defined) scenario data, for specified equipment segments, as shown in Figure 6. When adjusting growth data, the user must either remove old indicator values for the segment in question, or assure that any new data added is consistent with existing indicator values. Readers can refer to the NONROAD2005 User’s Guide for details on modification of growth data.

Figure 6. Growth screen tab.



Fuel and Climate tab

The NONROAD model requires inputs for several fuel parameters in order to generate emission estimates. These data are required for NONROAD's Option file.

- Gasoline Reid Vapor Pressure (RVP)
- Gasoline oxygen weight percent
- Gasoline sulfur weight percent
- Diesel sulfur weight percent
- Recreational marine diesel sulfur weight percent
- CNG/LPG sulfur weight percent

No Texas specific data was identified for recreational marine diesel and CNG/LPG sulfur levels, so NONROAD default values are assumed. Given the required specificity of the data tables, specifications for other fuels were sought by season and year, at the county level for the remaining parameters. Historical gasoline and diesel fuel sampling data collected for the TCEQ were utilized to populate the needed specification table. Gasoline RVP, oxygen weight percent, and gasoline as well as diesel sulfur weight percent were available for all locations.¹¹ Federal specifications for upcoming sulfur and other standards were used for populating fuel parameters for future years. Fuel parameter (as well as

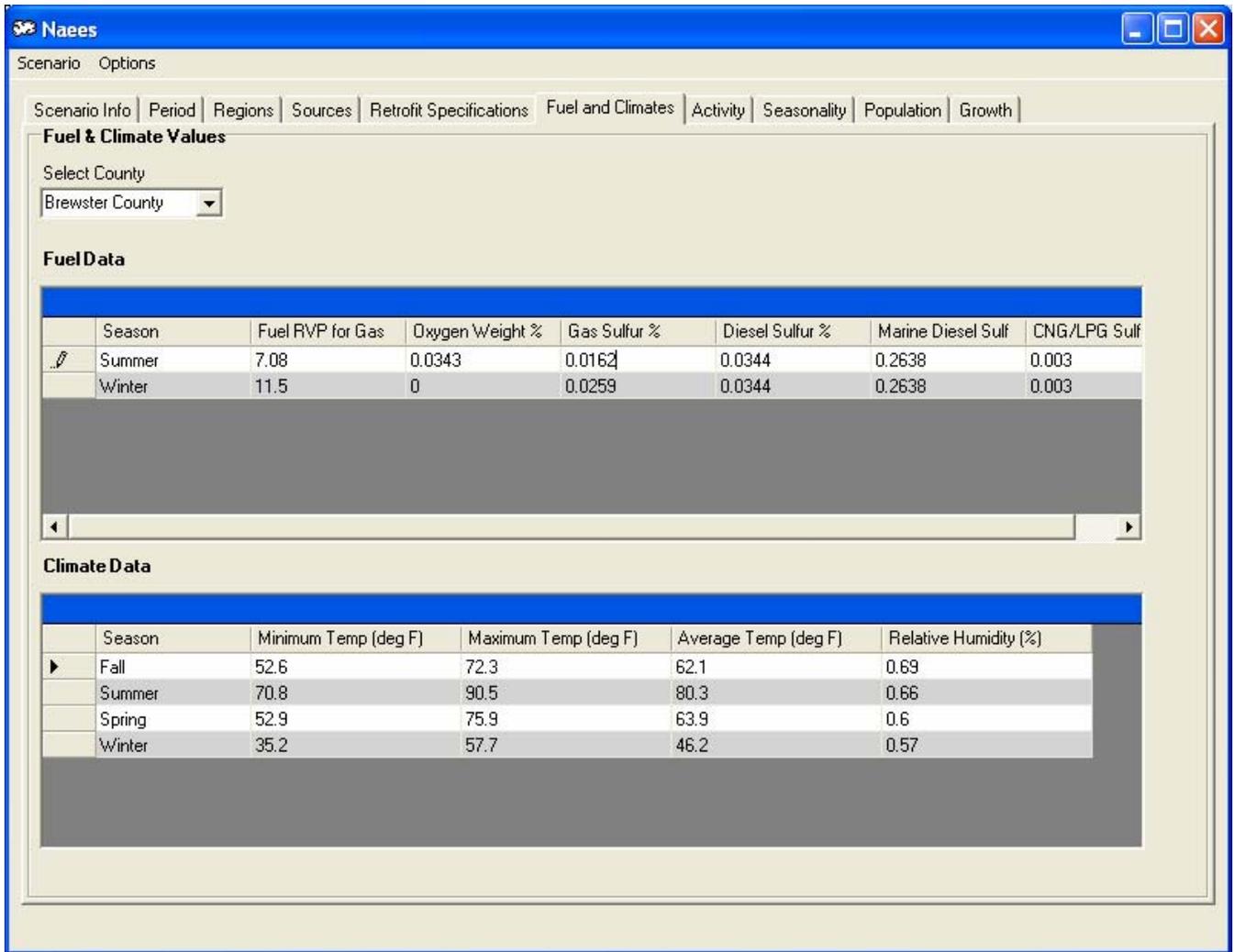
climate) data can be modified by the user for any season/year combination selected through the GUI screen.

NONROAD utilizes high, low and average temperature data, primarily to calculate evaporative emissions from gasoline engines. These data are required as part of NONROAD's Option file. In addition, related data on relative humidity and atmospheric pressure are also used during post-processing of NONROAD model outputs to adjust diesel NOx emissions for temperature and humidity effects, as discussed below. Ideally, these data should be specific to each county and episode day of interest. Although meteorological data was not available at this level, daily temperature, relative humidity, and atmospheric pressure information was available for 17 weather stations across the state, from the Texas A&M Energy Systems Laboratory.¹² Assignments relating specific counties to representative weather stations were developed in consultation with TCEQ.

Hourly temperature and relative humidity data was obtained for each of these weather stations for three specific Texas air quality planning base years (i.e. 1999, 2000, and 2002), as well as an averaged "typical meteorological year". From the hourly data the daily minimum, maximum, and average temperatures, and average relative humidity were extracted. These values were then sorted into four seasonal groups: winter (December – February), spring (March – May), summer (June – August), and fall (September – November). For each of these seasonal groupings, and for each of the four years, averages were calculated for daily minimum, maximum, and average temperatures, as well as averages for relative humidity. These values were used as inputs for NONROAD modeling as well as post-processing adjustments for NOx.

The Fuel and Climate tab displays the fuel parameters and climate data for each county selected. These data are contained in lookup tables in the MySQL database, and are specific to the Episode Year and Meteorological Year specified in the Period tab. Figure 7 provides an example of available data for one particular county. These data can be edited at the county level to represent new data, or to perform sensitivity analyses.

Figure 7. Fuel and climate screen tab.



Retrofit tab

The NAEES model also provides a template for creating or updating a retrofit file for use in NONROAD. The NONROAD2005 User’s Guide contains details regarding retrofit file requirements.

Other supporting data

Certain NONROAD modeling parameters cannot be changed by the user, including equipment model year distribution and scrappage rates, emission factors, and engine technology phase-in schedule. (Technology phase-in can be manipulated through use of the Maximum Technology Year option on the Period tab however, just as in the NONROAD model.)

In addition, since the NAEES tool performs runs at the county-level only, NONROAD’s allocation files are effectively bypassed. Normally, NONROAD’s equipment population files contain statewide equipment totals, which are then allocated to the county level using the ALO files. However, the NAEES tool creates population files for each particular county of interest, assigning 100% of the population to the specified county through a “hard-coded” allocation file. Users can modify county-level equipment populations directly, without reference to allocation files.

File Management and Post-Processing Adjustments

Once all of the data edits have been completed by the user, NAEES will create the necessary Option and supporting data files for NONROAD, and batch the runs needed to model the prescribed scenario. Once the runs for a scenario have executed successfully, the GUI automatically calls the post-processing driver. The post-processing driver imports all of the NONROAD output files, generated at the by-model-year level of detail, into the MySQL database. The database then post-processes all of the data, applying adjustment factors to the emissions estimates in the output files to generate the final criteria pollutant and ammonia emissions values. Post-processing applies county specific adjustments to emissions estimates for the appropriate SCCs. Depending upon the SCC and county, the following adjustments may be applied within the database:

- County and year specific temperature and humidity adjustments for NO_x emissions
- Adjustments for Texas Low Emission Diesel (TxLED) impacts
- Altitude, correcting for decreased engine efficiency at increasing altitude
- Soil compaction, reflecting relative ease or difficulty digging
- Ground cover, reflecting relative ease or difficulty in land-clearing activity

Once post-processing adjustments are made to the NONROAD output files, the database performs county-level aggregation of the data by SCC and horsepower range, summing population, activity, fuel-consumption, and emissions fields. Once this is completed, the database creates a single output file. The output file contained in the database is then ready to be imported into the modified reporting utility. The NAEES reporting utility has all of the basic functionality of the original NONROAD utility, but has been modified to accommodate ammonia emissions estimates. In addition, the modified reporting utility allows the user to generate more reports than the original utility, including emission totals by county and SCC, as well as emission totals by horsepower and SCC.

Altitude adjustments

Adjustments are applied to all pollutants, as well as equipment activity estimates (in hours per year), for all diesel powered equipment. In general, diesel engines are assumed to suffer a 1% penalty in power output, and therefore productivity, per 1,000 feet in altitude.¹³ In other words, an activity requiring 100 hours at sea level would require 1001 hours at 1,000 in elevation. Representative altitudes for each county were determined from GIS data containing altitude for each county seat.

Soil and ground cover adjustments

Substantial variations in construction equipment productivity, and therefore activity, can arise depending on soil and ground cover conditions in a given county. In a previous study, industry experts were consulted to develop activity adjustment factors to be applied to the DCE activity profiles, accounting for county specific conditions. Adjustments for standard soil and ground cover conditions were based on field experience and engineering judgment, and are summarized in Table 2.¹⁴ (Note these factors are only applied to the DCE earthwork categories within NAEES.)

Table 2. Site condition activity adjustments.

Ground Cover	Adjustment Factor (1.0=base conditions)
Wooded lot (dense/moderate)	1.5
Small trees, shrubs, and weed	1.3
Weed and Grass	1.0
Other	Varies
Soil Type	Adjustment Factor
Good common earth (loam)	1.0
Sand/Gravel	1.0
Easy digging (moist silt/clay)	1.0
Hard digging (dry clay)	1.1
Fragmented Rock	1.2
Intact Rock	1.7
Other	Varies

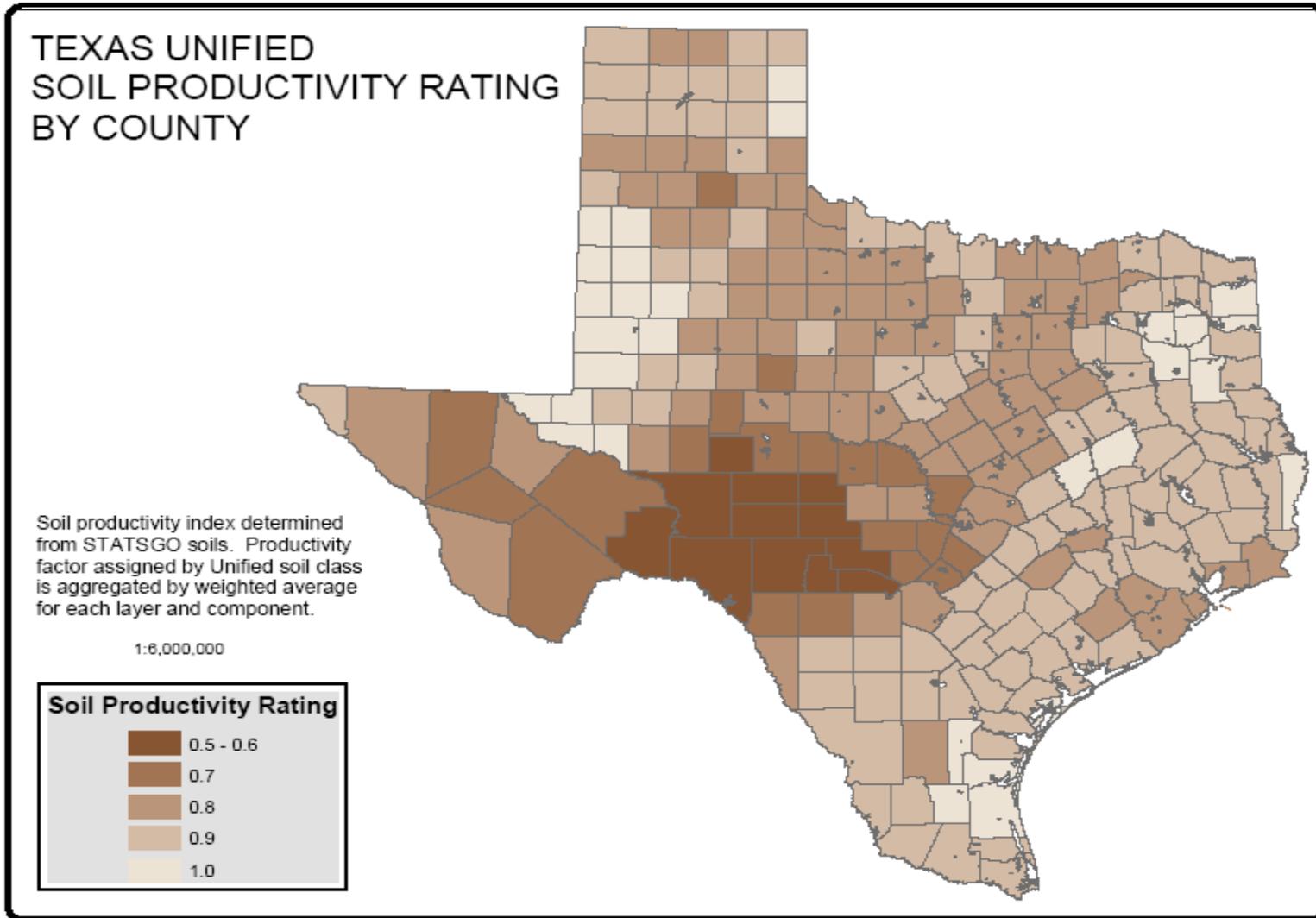
The above factors represent the increase in the time required to complete a certain task, relative to base case conditions, (equivalent to an increase in work, since engine load factors are assumed constant under all conditions). Ground cover adjustments are applicable to the commercial and residential DCE profiles, but only for equipment involved in land clearing activities (crawler dozers). U.S. Geological Survey (USGS) data were used for determining ground cover characteristics.¹⁵ The ground cover categories provided in the USGS data for Texas were mapped to one of the four standard classifications shown in Table 2.

Average values for ground cover characteristics were developed for each county, weighted by relative area. Areas designated as having water or impermeable/existing structures were excluded, and the relative areal extent of the remaining categories was renormalized. Weighted average adjustment factors specific to each county are then applied to the base case DCE profiles within NAEES to account for area-specific conditions.

Soil type adjustments for productivity are applicable to equipment involved in earthwork operations as well as boring/drilling tasks. For example, excavation work in areas with fragmented rock will require an additional 20% increase in horsepower-hours compared to “easy digging” soil conditions. In order to characterize soil conditions across the State, the Soil Survey Geographic Database (SSURGO) was obtained from the U.S. Natural Resource Conservation Service.¹⁶ Three soil layers were extracted from this database, including the surface layer, the layer found at 90 cm., and the layer found at 150 cm., near or at the maximum depth of the data set, to provide a cross-section for analysis. The classifications of these layers were then correlated with the standard soil classifications shown in Table 2.

Both the spatial extent and depth of each layer were used to develop weights for the DCE adjustments. The productivity adjustment for each layer was weighted by the relative thickness of the layers, and summed to provide a weighted average adjustment for the soil as a whole. The inverse of the resulting county-level soil adjustment factors is shown in Figure 8. The resulting countywide activity adjustment factors are applied to the commercial, residential and utility sector DCE profiles, as well as the trencher and boring/drilling profiles.

Figure 8. County level weighted average soil adjustment factors (inverse)



The DCE equipment profiles were evaluated to establish what portion of equipment activity should be subject to the soil productivity adjustments. The fraction of time each equipment type spends performing earthwork is summarized below in Table 3.

Table 3. Earthwork weighting factors for soil adjustments

DCE Sector	Equipment Type	Earthwork Fraction (% of time, weighted by horsepower-hrs)
All	Trencher	100%
All	Boring/Drilling	100%
Commercial	Excavator	100%
	Backhoe	100%
	Grader	49%
	Crawler Dozer	40%
Utility	Excavator	100%
Residential	Excavator	100%
	Crawler Dozer	41%

Temperature and humidity NOx adjustments

Additional temperature and humidity correction factors were identified for adjustment of diesel engine NOx emissions. These factors were developed in a previous study for the Houston Advanced Research Center.¹⁷ The NOx adjustment equations developed in this study are a function of temperature, humidity, and atmospheric pressure. For the purposes of this calculation, annual average pressure for each station was calculated for the 2000 meteorological year. (Average station pressure was found to vary by insignificant amounts over time.) Using the climate data described above, temperature and humidity adjustment factors are calculated within NAEES for diesel equipment operating in each county in the State, for each season and meteorological year. The calculation and application of these adjustment factors is summarized below.

Adjustments utilize absolute humidity, which is calculated as follows:

Equation (1) $H = [RH \times 38.017 \times e^a] / [P - 6.112 \times e^a]$

where H=absolute humidity (kg water/kg air)
 RH = relative humidity (%)
 P = atmospheric pressure (millibars)
 a=exponent - function of temperature (see Equation 2)

Equation (2) $a = [9.8245 \times (T - 32)] / [0.556 \times (T - 32) + 243.5]$

where T=temperature (in degrees Fahrenheit)

There are two adjustment equations for NOx; one equation for naturally-aspirated diesel engines, another for turbocharged diesel engines.

Equation (3) $Adj_{NA} = 1 + 0.001368 \times [0.556 \times (T - 32) - 29.444] - 0.01512 \times (H - 10.71)$

where Adj_{NA} =naturally-aspirated engine adjustment

Equation (4) $Adj_{Turbo}=1 + 0.00446 \times (0.556 \times (T - 32) - 25) - 0.018708 \times (H - 10.71)$

where Adj_{Turbo} =turbo-charged engine adjustment

The fraction of naturally-aspirated and turbo-charged engines depends upon engine model year and horsepower. Relative fractions were estimated based on the number of engine entries in EPA’s certification database.¹⁸ Data were available electronically from EPA for model years 1998 through 2006. Note that data from EPA’s certification records are not sales-weighted, and therefore may not represent the actual in-use distribution of naturally-aspirated and turbo-charged engines. However, sales data is considered proprietary by manufacturers, and was not available for this analysis.

The weighting factors applied to the two different adjustment equations above correspond to the relative fraction of naturally-aspirated to turbo-charged engines, as summarized Table 4 below:

Table 4. Ratio of turbo- to naturally-aspirated models for diesel engines by horsepower and model year.

Horsepower Range	Model Year						
	1999 (and older)	2000	2001	2002	2003	2004	2005+
<25	0%	0%	0%	0%	0%	0%	0%
25 – 50	10%	14%	15%	17%	15%	14%	18%
50 - 100	28%	28%	28%	28%	47%	55%	55%
100 – 175	63%	84%	84%	84%	98%	98%	98%
175+	100%	100%	100%	100%	100%	100%	100%

In order to apply the temperature and humidity adjustment factors, NAEES first calculates the naturally-aspirated and turbo-charged adjustments for each county and season, then weights and sums the factors using the relative fractions shown in Table 2 for each horsepower range and model year, and applies the final weighted factors to the NOx emissions value by the appropriate horsepower range and model year in the NONROAD by-model-year exhaust (BMX) file. (Since the fraction of naturally-aspirated and turbo-charged engines depends upon engine model year and horsepower range, adjustments must be applied to NONROAD’s BMX output file, rather than the standard *.out file. The BMX file provides emission estimates for each SCC and horsepower range combination, as well as by-model-year and engine technology type. Since there are no NOx emissions in the by-model-year evaporative emissions (BMV) file, no adjustments are needed there.)

Adjustments for emission controls

Various control programs have been implemented to reduce emissions from nonroad engines. Federal controls, including the introduction of new emission standards, are accounted for by the NONROAD model. While evaporative refueling (Stage II) VOC emission controls can be modeled by NONROAD, these emissions are categorized as area sources in Texas. For this reason any Stage II emission control benefits associated with nonroad engine refueling are excluded from NAEES.

The introduction of TxLED fuel in certain Texas counties is not accounted for by the NONROAD model, and is addressed during post-processing. Specifically, NOx emissions from diesel engines are reduced by 6.2% beginning with the 2005 calendar year, for the 110 counties affected by the TxLED program.¹⁹

Other rules and regulations that effect nonroad engines include multiple Memoranda of Understanding and Agreements with specific fleets in different nonattainment areas, such as airport ground support equipment, locomotives, and activities at the Port of Houston Authority. Texas Emission Reduction Program (TERP) projects also fall under this category.²⁰ However, these fleet-level control initiatives have to be modeled using fleet-specific equipment and activity profiles. Similarly, emissions from unusual construction projects previously profiled on an individual basis (such as the construction of three large liquid natural gas depots on the Gulf Coast) must also be modeled on a fleet-specific basis.²¹ Given adequate data, NAEES could be used to characterize these initiatives in the future.

Calculation of ammonia emissions

The NONROAD model does not provide estimates for ammonia emissions. In order to provide ammonia estimates using NAEES, a list of available ammonia emission factors for the different nonroad mobile engine fuel types, including diesel, gasoline, and gaseous fuels such as propane and natural gas, were identified and documented. A literature review was performed, and contacts were made with air quality researchers from EPA’s Office of Transportation and Air Quality (OTAQ), the California Air Resources Board (ARB), and others to identify available data sources. A detailed web search was also conducted to identify additional sources of emissions test data and analysis. Available data were evaluated for applicability to nonroad engine applications, and emission factors were processed and adjusted to account for the impact of future engine technology impacts to the extent possible. Emission factors in NAEES are expressed in terms of grams per brake horsepower-hour of engine use, and/or grams per gallon of fuel consumption.

Only a limited amount of information was identified regarding ammonia emissions from nonroad engines. An attempt was made to identify the most representative data, considering fuel and engine types, as well as the influence of future emission standards on control technologies. The ammonia emission factors identified can be combined with activity data outputs from NONROAD to estimate mass emissions for each SCC and county in Texas. Ammonia is estimated within NAEES in tons for all SCCs. There are four emission factors in NAEES: one for diesel engines, one for spark ignition engines (gasoline and gaseous fuel) without three-way catalysts (TWCs), one for gasoline engines with TWCs, and one for natural gas/LPG engines with TWCs. The emission factors and corresponding technology types are presented in Table 5 below.²²

Table 5. Ammonia emission factors used in the NAEES tool.

Engine Type	Emission Factor	Units
Diesel	0.00162	g/hp-hr
Gasoline w/ TWC	0.0690	g/hp-hr
CNG/LPG w/ TWC	0.1030	g/hp-hr
Spark Ignition w/out TWC	0.15	g/gal

Note that all emission factors are in g/hp-hr except for spark ignition engines without TWCs, which is in g/gal. Emissions for SCC/technology type combinations with emission factors in g/hp-hr are calculated in NAEES by multiplying the factor by the average horsepower value, the load factor, and the activity value in BMX file. Results were then converted from grams to tons for output. For SCC/Tech Type combinations expressed in g/gal, emissions are calculated by multiplying the emission factor by the fuel consumption value in the BMX file, then converting from grams to tons. In NAEES the

ammonia emission factors can be changed through a database interface as more accurate factors become available in the future.

File aggregation and reporting

NAEES applies the appropriate ammonia emission factors to the adjusted NONROAD output files for each county and SCC for each scenario. The NONROAD by-model-year output files are then aggregated by model year, technology group, and fuel type. The final aggregated output files can be loaded directly into a modified version of NONROAD's reporting utility. The modified reporting utility is accessed through the Scenario drop down menu within NAEES, and is almost identical to the NONROAD version in appearance and functionality. There are only two differences between the NAEES and NONROAD versions of the utility. First, NAEES provides the user with two additional standard query reports, providing emission totals by county and SCC, as well as by horsepower and SCC. Second, exported reports to NIF3.0 format, as well as Excel, contain ammonia estimates, in addition to the other standard NONROAD pollutants. (Note that the standard Crystal Reports format utilized by NONROAD's MSAccess-based utility to display results on screen has not been modified to display ammonia, so exports to Excel or NIF format must be used to view results for this pollutant.)

CONCLUSIONS

The NAEES tool greatly expands the precision, functionality, efficiency, documentation, and data integrity of the emissions modeling process for nonroad mobile sources in Texas. The MySQL database serves as a central repository for a wide array of studies and survey results, characterizing different equipment population and activity profiles for various regions across the state. Without this central organizing feature, developing regional or statewide nonroad emissions inventory estimates across multiple scenario years has become extremely labor intensive. Prior to NAEES, manual aggregation of the multiple NONROAD output files required extensive QA to assure consistency of input parameters such as temperature and fuel specifications, across all NONROAD runs. NAEES automates the aggregation of multiple NONROAD output files, making the process more efficient, minimizing the potential for human error. The tool drastically reduces the effort associated with NONROAD file preparation, model execution, and output file aggregation, while assuring internal consistency and reproducibility across different users. In addition, using a database back-end to create Option files for the model runs allows NAEES to dynamically populate key fields and enforce certain data constraints, again minimizing errors. (For example, the user does not have to know which year specific fuel standards are phased in; NAEES will automatically select the appropriate fuel standards based on the episode year of the run.)

The NAEES GUI screens allow the user to directly view and update much of the supporting NONROAD input file (and post-processing) data, in a convenient, well-organized format. This level of "data transparency" is highly valuable for QA of emission inventories, as well as for potential emission control assessments. The descriptive detail captured through the Scenario Tab allows the user to clearly document iterative modeling changes for sensitivity analyses and inventory updates. In the future, additional functionality can be incorporated into the GUI to allow the user even more control in defining a scenario.

Finally, the NAEES structure provides the user with great flexibility and precision, especially with respect to modeling emissions from diesel construction equipment. NAEES provides a foundation for highly resolved inventory development within equipment use categories, and can easily be expanded to other sectors. For example, agricultural equipment population and activity may vary significantly with location and crop type, lending it to a similar disaggregation of population and activity data.

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KEY WORDS

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Diesel Construction Equipment
Ammonia Emissions

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