Final Report

Maricopa Association of Governments 2006 Biogenics Study

Prepared for

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1. INTRODUCTION

BACKGROUND

The goal of this biogenics study is to equip the Maricopa Association of Governments (MAG) with a state-of-the-art biogenic emission model that is consistent and integrated with the MAG Air Quality Modeling Chain. This is accomplished through execution of the following steps:

1) Evaluating existing biogenic emission models;
2) Summarizing data available for improving biogenic emission estimates in the MAG domain;
3) Identifying and conducting high priority field measurements (e.g. land cover and emission measurements); and
4) Delivering an improved biogenic emissions model to MAG.

The MAG biogenics model framework will be easily updated with new parameterizations and driving variables as future research continues to improve our understanding and ability to simulate the processes controlling biogenic emissions.

The biogenics study is organized into several individual tasks in order to accomplish the overall objectives. The tasks include the following:

1) Task 1: Work Plan Development and Refinement
2) Task 2: Comparison of BEIS and MEGAN with the MAGBEIS Program
3) Task 3: Review of Previous Biogenic Studies Conducted by MAG and Other Entities
4) Task 4: Review of MAG Land Use Data and Biogenic Projection Methodology
5) Task 5: Review of the MAG Air Quality Modeling Chain
6) Task 6: Perform a Needs Assessment
7) Task 7: Conduct Biogenics Field Study
8) Task 8: Development of Emission Factor and Computer Model Updates
9) Task 9: Development of a Project Final Report

This document is the Project Final Report.

REPORT ORGANIZATION

The report is organized as follows:

- Section 2 documents the comparison of the BEIS and MEGAN biogenic models with the MAGBEIS program conducted as Task 2 of the project.
- Section 3 provides a review of previous biogenic studies conducted by MAG and other entities.
- Section 4 presents a review of MAG land use data and biogenic projection methodologies.
- Section 5 presents a review and discussion of the MAG air quality modeling chain.
- Section 6 discusses the recommendations from the Needs Assessment task.

- Section 7 documents the results of the biogenic field study conducted in Maricopa County and the Phoenix Metropolitan Area.
- Section 8 describes the development of the emission factor and computer model updates completed during the course of the study.
- Section 9 presents an overall summary of the project.
- Section 10 includes references for this report.

2. COMPARISON OF BEIS AND MEGAN WITH MAGBEIS PROGRAM

BACKGROUND

Biogenic emissions can be estimated using "top-down" or "bottom-up" approaches. The top-down approach uses ambient concentrations to infer emission rates. The bottom-up approach uses source distributions, emission factors and emission activity factors to estimate emissions. A top-down approach using satellite observations has been used to estimate isoprene emissions on regional and global scales (Abbot et al. 2004; Shim et al. 2005). Other biogenic emissions cannot be derived from current satellite sensors, but this could change in the future. Although the top-down approach is a very useful tool for emission model evaluation, it cannot replace the bottom-up approaches because it cannot be used to predict future emissions or responses to various emission management strategies.

The bottom-up approach was first used to estimate biogenic emissions 40 years ago by Rasmussen and Went (1965). They extrapolated a few biogenic VOC enclosure observations to the global scale by simply multiplying a typical emission rate by the global area covered by vegetation and the fraction of the year that plants are growing. The resulting annual total (isoprene plus all other non-methane biogenic VOC) flux estimate of 438 Tg (1 Tg = 10^{12} g) is about a factor of 3 lower than the global estimate of Guenther et al. (1995). The next advance in biogenic VOC emission modeling was the U.S. emission inventory generated by Zimmerman (1978) that used gridded landcover and weather data. In addition, Zimmerman made over 600 measurements of isoprene, monoterpene and other VOC emissions from vegetation at field sites in the southeastern, southwestern, and northwestern United States. Additional biogenic VOC emission studies were conducted in the 1980s (Winer 1982; Lamb et al. 1985, 1986) and incorporated into a U.S. national inventory (Lamb et al. 1987) with much higher resolution than the Zimmerman (1979) inventory. The Zimmerman and Lamb et al. procedures were adapted by USEPA for use in the Regional Oxidant Model (ROM) beginning in 1986. The first model, Biogenic Emissions Software System (BESS), was replaced in 1988 by the Biogenic Emissions Inventory System (BEIS). Second (BEIS2) and third (BEIS3) generation biogenic emission models have also been released by USEPA.

Due to various shortcomings associated with the BEIS family of models, including limited capabilities for introducing location-specific information, U.S. regional organizations have developed alternative models. The models include BIOME (developed for LADCO), GLOBEIS (develop for TNRCC), BEIGIS (developed for CARB) and MAGBEIS (developed for MAG). All of these models use the same general approach (emission factors, emission algorithms, source distributions) as the BEIS models. Table 2-1 provides a summary comparison of the five models. The purpose of this report is to describe the BEIS family of models, including MAGBEIS. In addition, we describe the Model of Emissions of Gases and Aerosols from Nature (MEGAN), which represents the current state-of-the-art for biogenic VOC emission model. The models are compared and the advantages and disadvantages of each are discussed below. Recommendations for biogenic emission modeling in Maricopa County, Arizona are provided in Section 6 of this report.

MODEL DESCRIPTIONS

BEIS, BEIS2 and BEIS3

The Biogenic Emission Inventory System (BEIS, Pierce and Waldruff 1991) was first used to generate biogenic VOC inputs for regional air quality modeling in 1988. This first version was based primarily on the emission factors and algorithms described by Lamb et al. (1987). The Lamb et al. procedures were based on field measurement studies conducted in the late 1970s and early 1980s. This first generation model placed all biogenic VOC into four categories: isoprene, a-pinene, other monoterpenes, and "unidentified" and allocated the emissions to 17 different vegetation categories. The BEIS vegetation categories included three forest types (oak, other deciduous, and coniferous), three grass/shrub categories (hay/scrub, range, and grass/pasture), ten crop categories, and one urban vegetation category.

The second version of the Biogenic Emission Inventory System (BEIS2) was developed in 1994 and included a new land use inventory, updated emission factors and revised environmental correction factors. In addition, BEIS2 introduced soil NO emission estimates. BEIS2 generates hourly emissions on the county level. BEIS2.3, released in 1998, is the latest PC version of BEIS. BEIS2 isoprene emissions tended to be about 5 times higher than BEIS isoprene emission estimates for forested areas, which generated considerable concern regarding the accuracy of BEIS or BEIS2 emission estimates. The updated emission factors, based on Guenther et al. (1994), were the primary reason for the difference between BEIS and BEIS2 estimates.

BEIS3 was developed in 2001 and is the latest generation in the BEIS family. All BEIS3 versions are designed for use with the Sparse Matrix Operational Kernel Emissions (SMOKE) system. BEIS3.09 is currently the default version in SMOKE. BEIS3.10 was developed for the 2002 release of the Community Multiscale Air Quality (CMAQ) modeling system. BEIS3.10 includes a 1-km vegetation database that resolves forest canopy coverage by tree species; emission factors for 34 chemicals including 14 monoterpenes and methanol; a soil NO algorithm dependent on soil moisture, crop canopy coverage, and fertilizer application; and speciation for the CBIV, RADM2, and SAPRC99 chemical mechanisms. The soil NO algorithm in BEIS3.10 has since been revised (BEIS3.11) to better distinguish between agricultural and nonagricultural land, and to limit adjustments from temperature, precipitation, fertilizer application, and crop canopy to the growing season and to areas of agriculture. A leaf shading algorithm has been added for estimating methanol emissions from non-forested areas. BEIS3.12 was released in November 2003 and is the most recent version of BEIS. It was assembled as a stand-alone module to the Sparse Matrix Operational Kernel Emissions (SMOKE) system for generating gridded, hourly emissions in a format consistent for air quality modeling.

MAGBEIS2 and MAGBEIS2004MM5

Chinkin et al. (1996) developed MAGBEIS2 by modifying BEIS2 so that it would accept user-supplied land use data. They also developed new isoprene and monoterpene emission factors for some of the ten landcover classes used in MAGBEIS2. The recommended isoprene emission factors of Chinkin et al. (1996) tend to be lower than what is reported in the recent literature (summarized in Section 3). There are two main reasons for these underestimated isoprene emission factors: 1) Chinkin et al. based many of their estimates on observations that were made in low light environments that can greatly reduce isoprene emissions relative to the emissions that occur from sun-lit leaves (Geron et al. 2000), and 2) most of the emission factors were based on branch level emission rate measurements (which includes self-shaded leaves). The rates reported by Chinkin et al. need to be adjusted in order to be used in an emissions model, such as MAGBEIS2, and furthermore, the emissions model must include a canopy radiation model.

A methodology was developed to generate the landcover required for MAGBEIS2 using the MAG detailed land use database that has 43 land use types. A preprocessor, called MAGLAND2, was developed for the task of collapsing the 43 MAG land use types into the nine categories (forests, urban, desert, parks/golf courses, citrus crops, other crops, stockyards, residential/schools/churches, water) required as input to MAGBEIS2. In addition, MAGBEIS2 generated a tenth land use category (desert parks) for areas classified by MAG as parks in non-urban areas. The land use fractions for the modeling domain where dominated by desert (43%), residential (17%) and other crops (17%). The 24 MAG land use categories for future-year land use were mapped to the nine MAGBEIS2 land use inputs categories in a similar manner as for present day.

The OVOC emission factor for three land use types (urban, residential, and parks) were assigned the same emission rate as for monoterpenes. Chinkin et al. (1996) states that “This assumption was based on the fact that the plant types responsible for the majority of monoterpene emissions are assigned nearly equal monoterpene and OVOC emission fluxes in BEIS2.” However, UAM-BEIS2 assigns a constant per biomass OVOC emission factor to all vegetation. Therefore, a more consistent approach would have been to assign an OVOC emission factor based on the biomass density determined for each of these categories.

The NOx emission factor for residential and urban land use types were based on the UAM-BEIS2 grass emission factor but were reduced to account for only partial vegetation cover in these land use categories.

Desert parks, desert, and forests were all assigned the UAM-BEIS2 NOx and OVOC emission factor for desert lands. Forests were assigned the same emission factor as desert based on a review of areal photos by MAG staff. Water and citrus crops were directly assigned the values used for UAM-BEIS2. Other crops were assigned emission factors that were estimated as the weighted average of the UAM-BEIS2 emission factors for various crop types. Maricopa county crop statistics were used to develop the weighting parameters. Stockyards were assigned the UAM-BEIS2 grass emission factors.

Chinkin et al. (1996) report that MAGBEIS2 VOC emissions were 50% higher than the UAM-BEIS2 estimates. This was attributed to an increase in isoprene emissions that resulted from 1) a higher fraction of residential and park areas, 2) higher emission factors, and 3) updated emission algorithms. They also found that MAGBEIS2 predicted a relatively larger contribution from non-urban areas than UAM-BEIS.

The MAGBEIS2 NO emission factors recommended by Chinkin et al. (1996) resulted in biogenic NOx emissions that were nearly ten times higher than the previous emission estimates (UAM-BEIS2).   This was attributed to the much higher NOx emission factors used by MAGBEIS2 in comparison to UAM-BEIS2. The highest predicted emissions were in the agricultural areas, in contrast to the UAM-BEIS2 prediction that identified higher NOx emissions from urban areas. This difference was due both to a decrease in predicted urban area emissions in the MAGBEIS2 estimates (because a lower fraction of vegetation coverage was assumed) and because of higher emissions estimated for agricultural areas.

MAGBEIS2004 is based on the BEIS3 model but has been adapted to use landcover and emission factor data that are more appropriate for Maricopa County. A gridded landcover file is generated by the MAGLAND2004 program using the most recent Maricopa County landcover data. MAGBEIS2004 includes four land use categories (in addition to the standard BEIS3.12 categories): residential, commercial, agriculture, and non-emitting. The MAGBEIS2004 non-emitting land use category has an associated emission factor of zero for all compounds and categories (similar to the BEIS3.12 water or snow/ice categories). The emission factors associated with the agriculture land use category for MAGBEIS2004 have been assigned the same values as the BEIS3.12 emission factors for the drycrop category.

The MAGBEIS2004 isoprene emission factor assigned to the residential land use categories is 96 times higher, and the emission factor assigned to the commercial category is 10 times higher than the BEIS3.12 isoprene emission factor for urban areas. The MAGBEIS2004 monoterpene emission factor for the residential land use category is 10 times higher than the sum of the BEIS3.12 individual monoterpene emission factors for urban areas. The MAGBEIS2004 monoterpene emission factor for the commercial land use category is about the same as the BEIS3.12 total monoterpene emission factor for urban areas. Following the approach of MAGBEIS, MAGBEIS2004 assigns the same emission factor to "other VOC" as it does for total monoterpenes. As a result, the MAGBEIS2004 "other VOC" emission factor for residential landcover is about 20% higher than the BEIS3.12 urban emission factor, while the emission factor for the commercial land use classification is about 90% lower than the BEIS3.12 emission factor. Since the Maricopa County urban area is a mixture of commercial, residential, and non-emitting landcover, the differences in emission factors will result in MAGBEIS2004 urban area emission estimates that are much higher for isoprene, substantially higher for monoterpenes, and similar for "other VOC".

The weather data required to estimate biogenic emission variations with MAGBEIS2004 can be input from either MM5 or UAM meteorology files.

MEGAN

The Model of Emissions of Gases and Aerosols from Nature (MEGAN) estimates the net emission rate (μg compound m^{-2} h^{-1}) of isoprene and other trace gases and aerosols from terrestrial ecosystems into the atmosphere at a specific location and time as

$$\text{Emission} = [\varepsilon]\,[\gamma]\,[\rho] \qquad (1)$$

where ε (mg compound m^{-2} h^{-1}) is an emission factor which represents the net above-canopy emission rate expected at standard conditions, γ (normalized ratio) is an emission activity factor that accounts for emission changes due to deviations from standard conditions and ρ is a factor that accounts for chemical production and loss within canopies. The standard conditions include landcover characteristics (leaf area index, LAI, of 5 and fully mature leaves), current environment (a solar zenith angle of 75 degrees, air temperature of 30C, photosynthetic photon flux density, PPFD, of 1500 μmol m^{-2} s^{-1}, humidity of 14 g kg^{-1}, wind speed of 3 m s^{-1}, ozone concentration of 50 ppb), and the environmental conditions of the past 24 to 240 hours (temperature and PPFD that are equal to the growing season average for that location). The factor γ is equal to unity at these standard conditions. Emissions are calculated separately for each plant functional type (PFT) that occurs within a given model grid cell. The emission from each PFT is summed to estimate the total emission. MEGAN is a global scale model with a base resolution of ~ 1 km^2 (30 sec latitude by 30 sec longitude) enabling both regional scale and global scale simulations. The MEGAN emission factors, algorithms and driving variables can be accessed through a public data portal (see http://bai.acd.ucar.edu/models/megan) at the base and lower resolutions for specific years. Methods for estimating each of the factors in equation 1 are described in the following sections.

Emission factor, ε

Isoprene is emitted by soil bacteria, algae, animals (including humans) and plants (Wagner et al. 1999). However, only vegetation emissions have been shown to occur at levels that can influence atmospheric composition, although relatively little is known about soil bacteria. The isoprene emission rates of different plant species range from < 0.1 to > 100 $\mu g\ m^{-2}\ h^{-1}$. Very low and very high emitters often occur within individual plant families and even within some globally important plant genera including *Quercus* (oaks), *Picea* (spruce), *Abies* (firs) and *Acacia*. The large taxonomic variability makes the characterization of isoprene emission factor distributions a challenging task. The MEGAN landcover approach divides all vegetation into six PFTs. These include three tree categories (broadleaf, fineleaf evergreen and fineleaf deciduous), categories for shrubs and crops, and a category for all other vegetation (i.e., grasses, sedges, forbs, and mosses). In contrast to the ecosystem approach, in which each location or model grid cell is characterized by a single ecosystem type, the PFT approach applies a variable fraction of each PFT to a defined model grid cell. MEGAN accounts for regional ε variations using geographically gridded databases of isoprene emission factors for each PFT.

There are significant differences in the global average isoprene emission factors for the six PFTs. Broadleaf trees and shrubs have the highest average emission factor. The average fineleaf evergreen tree isoprene emission factor is ~20% of the average broadleaf tree emission factor. The fineleaf deciduous tree and herbaceous PFTs tend to have emission factors that are ~5% of the average broadleaf tree emission factor, while the crop isoprene emission factor is < 1%. The substantial differences in global average isoprene emission factors demonstrates the value of the PFT approach but there is considerable variability associated with the isoprene emission factors assigned to a PFT. For example, the isoprene emission factor for broadleaf trees ranges from 0.1 to 30 $mg\ m^{-2}\ h^{-1}$. Global total isoprene emissions can be approximated using the PFT-average emission factors, but this will introduce significant errors due to correlations between ε and emission activity distributions. For example, the broadleaf trees that grow in relatively cooler mountain and boreal regions tend to have higher than average isoprene emission factors. Assigning constant ε for broadleaf trees will overestimate global isoprene emission by not accounting for the correlation between high ε and low γ (i.e. the product of the average ε and γ is different than the average of the product of ε and γ). Furthermore, there will be substantial errors in estimates for any location where ε deviates significantly from the PFT average ε. MEGAN accounts for regional ε variations with geographical gridded databases of isoprene emission factors for each PFT.

Isoprene emission factor distributions for each PFT were estimated by combining the isoprene observations described below with landcover information that includes ground measurement inventories, satellite based inventories, and ecoregion descriptions. The landcover and isoprene observations available for each of the 6 PFTs differ considerably, and also differ for geographic regions. In some cases, vegetation inventories were combined with satellite observations to generate high resolution (~1 km^2) species composition distributions, while general descriptions were used to characterize global ecoregions in other regions. A description of the methods used for each PFT is given below.

Since geographical distributions of PFTs and PFT-specific isoprene emission factors change with time, the distributions used to estimate emissions should be representative of the time period being simulated. Climate-driven changes in species composition can substantially modify both PFT and ε values on a time scale of decades to centuries (e.g., Turner et al., 1991; Martin and Guenther, 1995) while changes associated with land management can occur on time scales of years (e.g., Guenther et al., 1999b; Schaab et al., 2000). Global PFT and ε databases are needed on time scales of 50 to 100 years for simulating global earth system changes. A considerably shorter time step for PFT and ε inputs may be required for regional studies investigating the impacts of land cover change.

Trees

Trees have been the focus of most isoprene emission rate measurement studies and we have a relatively large database for assigning tree emission factors. Trees are also economically valuable, which has led to the compilation of high resolution, geographically referenced tree inventories in nations including the United States, Canada, Australia, New Zealand, Japan, China, Russia and Europe. Biogenic emission inventories have been developed using summaries (i.e. county, province, national totals) based on this information (e.g. Geron et al., 1994; Klinger et al., 2002; and Simpson et al., 1999). The current version of MEGAN uses these summaries, but we have initiated efforts for some regions to use plot level data that will improve the local accuracy of future version.

Our default approach for assigning tree isoprene emission factors uses the 867 ecoregions in the digital terrestrial ecoregion database developed by Olson et al. (2001). The assigned ε are based on ecoregion descriptions of common plant species and available isoprene emissions measurements. A default value, based on the global average for other regions, was assigned if no measurements were available for the ecoregion. This scheme provides global coverage using an approach that contains sufficient resolution to simulate biogeographical units with similar isoprene emission characteristics. The Olson et al. (2001) database is the product of over 1000 biogeographers, taxonomists, conservation biologists, and ecologists from around the world. Most ecoregions include a fairly detailed description of the dominant plant species found within the region. Uncertainties associated with ε distributions for tropical broadleaf trees are a major component of the overall uncertainty in global isoprene emission estimates.
Broadleaf trees in the northwestern U.S., and northeastern Amazon basin have a relatively low ε, while northern Canada, Australia, and the southwestern Amazon have relatively high isoprene emission factors. The assigned fineleaf evergreen tree ε are lower in Eurasia than in other regions. The isoprene emission factors for fineleaf deciduous trees are very low in regions dominated by larch (*Larix*) species.

Shrubs, grass and other vegetation

Relatively few isoprene emission measurements are available for plant species other than trees, although at least a few measurements have been reported for some dominant shrub, grass, and other plant species. In addition, there are fewer quantitative data on distributions of these plants due to their lesser economic importance. However, some countries (e.g. United States, United Kingdom) have landcover characterization efforts that include shrubs and ground cover. This information has not been incorporated into the current MEGAN emission factors but will be a high priority for future versions.

Since some plant species occur in both tree and shrub form, MEGAN estimates of shrub isoprene ε in forest dominated regions are based on tree isoprene emission factors. Emission factors for shrub dominated regions are based on available shrub emission measurements and available descriptions of species distributions within each ecoregion. The relatively large uncertainty associated with shrub emission factors and the substantial global emission results in a large contribution to the overall uncertainty in global isoprene emission estimates.

Isoprene emission is rarely observed from plants that are entirely "non-woody". A rare example is the spider-lily, *Hymenocallis americana* (C. Geron et al., submitted manuscript). However, there are a number of isoprene-emitting plants that fall within the MEGAN PFT for grass and other vegetation. Some of the important isoprene emitting genera in this category include *Phragmites* (a reed), *Carex* (a sedge), *Stipa* (a grass), and *Sphagnum* (a moss). Reported isoprene emission factors for herbaceous cover ranges from about 0.003 mg m^{-2} h^{-1} for grasslands in Australia (Kirstine et al. 1998) and central U.S. (Fukui and Doskey 1998) to about 0.4 for a grassland in China (J. Bai et al., submitted manuscript) and about 1.2 mg m^{-2} h^{-1} for grasses located in forests and wetlands in southern U.S. (Zimmerman 1979), northern U.S. (Isebrands et al. 1999), Canada (Klinger et al. 1994) and Scandanavia (Janson et al. 1999). We assign one of these three values to the grass and other vegetation PFT in each of the 867 ecoregions.

Crops

At least one enclosure measurement has characterized each of the 25 globally dominant crop genera and none have been found to emit isoprene (see http://bvoc.acd.ucar.edu). However, agricultural landscapes are isoprene sources in at least some regions. Plantations of isoprene-emitting trees (e.g. poplar, eucalyptus, oil palms) could be classified as crops by some PFT schemes. In addition, isoprene-emitting plants are introduced into croplands to increase nitrogen availability and to provide windbreaks. Nitrogen fixing plants that are grown in croplands to provide "green manure" include Velvet beans (*Mucuna pruriens*, a legume) in cornfields and *Azolla*, an aquatic fern, in rice paddies. Both of these plants produce substantial amounts of isoprene (Silver and Fall 1995). While the use of Velvet bean is relatively limited, *Azolla* is widely used in the major rice producing regions (Clark 1980). Tropical kudzu (*Pueraria phaseoloides*) is the most widely used "green manure" plant in tropical agricultural lands. Although there are no reported isoprene emission measurements for tropical kudzu, all other examined *Pueraria* species have been identified as isoprene emitters (e.g. Guenther et al. 1996). We have used the crop distribution database of Leff et al. (2004) to identify agricultural landscapes (oil palms and rice) where isoprene emissions are likely higher than in other agricultural regions. An isoprene ε of 1 mg m^{-2} h^{-1} was assigned to crop PFT in these landscapes and a value of 0.1 mg m^{-2} h^{-1} was assigned to all other regions.

Emission activity factor (γ)

The total emission activity factor, γ, describes variations due to the physiological and phenological processes that drive isoprene emission rate changes. The total emission activity factor is the product of a set of non-dimensional emission activity factors that are each equal to unity at standard conditions,

$$\gamma = \gamma_{P1} \cdot \gamma_{T1} \cdot \gamma_{P24} \cdot \gamma_{T24} \cdot \gamma_{T240} \cdot \gamma_{SM} \cdot \gamma_{age} \qquad (2)$$

Descriptions of the methods used to estimate each of the seven activity factors included in equation 2 are given below.

PPFD and temperature variations on seconds to minutes timescales (γ_{P1} and γ_{T1})

The algorithms described by Guenther et al. (1993) have been used extensively to simulate the response of isoprene emission to changes in light and temperature on a time scale of seconds to minutes. The simulated behavior reflects the activity of the enzyme isoprene synthase (Fall and Wildermuth 1998). MEGAN uses a modified version of these algorithms (Guenther et al. 1999a) to estimate the normalized factors γ_T and γ_L that respectively account for short-term variations in temperature and PPFD conditions throughout the canopy. They are calculated as

$$\gamma_{P1} = C_{P1} [(\alpha * PPFD) / ((1 + \alpha^2 * PPFD^2)^{0.5})] \qquad (3)$$

$$\gamma_{T1} = E_{opt} * [C_{T1b} * Exp(C_{T1a} * x) / (C_{T1b} - C_{T1a} * (1 - Exp(C_{T1b} * x)))] \qquad (4)$$

where PPFD is the photosynthetic photon flux density (μmol m^{-2} s^{-1}), x = [((1 / T_{opt}) - (1 / T)) / 0.00831], T is leaf temperature (K), and C_{P1}, α, E_{opt}, C_{T1a}, C_{T1b}, and T_{opt} are empirical coefficients. Guenther et al. (1999a) describe methods for estimating γ_T and γ_P for sun and shade leaves at different canopy layers using values of E_{opt}=1.9, C_{T1a} =95, C_{T1b} = 230, T_{opt}=312.5, α =0.001 +.00085 * LAI, and C_{P1} = 1.42 exp(-0.3 LAI). The coefficients α and C_{P1} vary with canopy depth. The value at a given canopy layer is a function of the LAI above that layer.

The PPFD and temperature of leaves within a canopy can differ substantially from above canopy conditions and are estimated for each layer using a canopy environment model. The canopy average γ_{P1} and γ_{T1} can then be estimated as the weighted average of the values for sun and shade leaves of each canopy layer. Leaves in direct sunlight often experience temperatures that are a degree or more higher than ambient air, while shaded leaves are often cooler than ambient air temperature. PPFD can be very low on shaded leaves in dense canopies and the PPFD of sun leaves depends on the angle between the sun and the leaf. Guenther et al. (1995) used a relatively simple canopy environment model to estimate PPFD on sun and shade leaves at several canopy depths and assumed that leaf temperature was equal to air temperature. The non-linear relationships between isoprene emission and environmental conditions, coupled with the strong correlation between PPFD and temperature, will result in a significant underestimation of isoprene emissions if canopy or daily average PPFD and temperature are used (rather than calculating emissions for each canopy level and each hour of the day). Guenther et al. (1999a) used a more detailed canopy radiation model and added a leaf energy balance model that predicts leaf temperature based on the solar radiation, air temperature, wind speed, and humidity at each canopy depth. Lamb et al. (1996) evaluated the use of several canopy environment models for predicting whole canopy isoprene fluxes and found that the results from both simple and complex canopy models were within the uncertainty range of observed isoprene fluxes. Although detailed canopy environment models may not always substantially improve isoprene emission estimates, these models may be better for investigating how changes in environmental conditions will perturb isoprene emission rates. The integration of MEGAN within the land surface model component of an earth system model will allow investigations of interactions between isoprene emissions and environmental conditions. MEGAN equations 3 and 4 can be used with any canopy environment model as long as the factors γ_{T1} and γ_{P1} are normalized so that they are equal to unity for the MEGAN standard conditions.

The MEGAN temperature algorithm predicts a lower isoprene response to ambient temperature changes than does any of the BEIS models. This is because the other models assume that leaf temperature is equal to air temperature. This may be a reasonable approach for some fineleaf vegetation but is likely to underestimate emissions from broadleaf vegetation, especially under certain environmental conditions (e.g., drought, high solar radiation, low wind, high humidity). The decreased change predicted by MEGAN is due to the model prediction that leaves are able to minimize leaf temperature changes by varying transpiration. The MEGAN predictions of isoprene response to short-term PPFD variations are similar to other models that include a canopy environment model. Models that do not include a canopy environment model, sometimes referred to as a big leaf model, will substantially overestimate isoprene emissions at PPFD below the standard conditions and slightly underestimate emissions at higher PPFD. The BEIS models underestimate isoprene emissions for LAI < 5 and overestimate emissions at higher LAI. This is particularly the case for any approach (e.g. big leaf model) that does not consider variations in canopy environment models.

The MEGAN canopy environment model, described by Guenther et al. (1999a), has different parameters for each PFT. These parameters characterize canopy structure (e.g., clumped or horizontally arranged leaves) that influence the relationship between isoprene emission and LAI. Isoprene emissions from canopies with clumped leaves increase relatively slowly with increasing LAI for LAI < 3. Canopies with horizontal leaves exhibit more rapid increases in isoprene emission with increasing LAI for LAI < 3. The relationship between LAI and whole canopy isoprene emission is substantially different at low solar angles (<30 degrees) under clear skies. In this case, solar radiation cannot penetrate the canopy even when LAI < 2. This does not occur with low solar angles under cloudy skies when solar radiation is dominated by diffuse radiation that is more effective at penetrating the canopy than direct solar radiation.

PPFD and temperature on hours to days timescales (γ_{P24}, γ_{T24} and γ_{T240})

The Guenther et al. (1993) algorithms do not account for the influence of PPFD and temperature variations that occur on time scales of hours to days. The substantial deviations from the Guenther et al. (1993) algorithms that have been observed for longer time scales could be due to changes in production of the isoprene substrate, dimethylallyl pyrophosphate (DMAPP), or variations in the activity of the isoprene synthase enzyme that converts DMAPP to isoprene, or both of these factors. Variations in DMAPP supply could be due either to changes in production, either availability of the carbon precursor pyruvate of the supply of adenosine triphosphate (ATP) for phosphorylation, or changes in DMAPP consumption. Variations in isoprene synthase enzyme activity and DMAPP have been observed but are not well characterized (Bruggemann et al. 2002; Wolfertz et al. 2003). The factors controlling these variations may operate over a continuous range of time scales but for modeling purposes we consider only 24 and 240 hours.

MEGAN accounts for the response of isoprene emission to leaf temperature (γ_{T24} and γ_{T240}) and leaf PPFD (γ_{P24}) using leaf temperature and PPFD averaged over these two time scales. We consider the potential importance of each time scale and methods for simulating the behavior in MEGAN.

Isoprene emission rates, measured at standard light and temperature conditions, are higher if warm sunny conditions occurred during the previous day and are lower if there were cool shady conditions (Sharkey et al. 2000). MEGAN simulates this behavior using simple linear relationships,

$$\gamma_{T24} = \exp(C_{T24} (T_{24} - T_0)) \quad (5)$$

$$\gamma_{P24} = \exp(C_{P24} (PPFD_{24} - P_0)) \quad (6)$$

where C_{T24} (=0.05) and C_{P24} (=0.0005) are empirical coefficients; T_{24} and $PPFD_{24}$ are the leaf temperature (K) and PPFD (μmol m^{-2} s^{-1}) averaged over the past day; and T_0 and $PPFD_0$ are daytime leaf temperature and PPFD averaged over the growing season. The empirical coefficients C_{T24} and C_{P24} are based on the emission patterns observed by Sharkey et al. (2000), Geron et al. (2000), and Hanson and Sharkey (2001).

Petron et al. (2001) found that exposure to high or low temperatures can influence isoprene emission for several weeks. The influence of a decrease in temperature persisted longer than the impact of an increase in temperature indicating that down regulation is slower than up regulation of isoprene emission. In addition to changing the magnitude of emissions at standard conditions, past temperature can influence the temperature optimum, T_{opt} in equation 5. As a result of this acclimation, exposure to high temperatures enables plants to emit isoprene at higher temperatures (Petron et al. 2001, Monson et al. 1994). This behavior is simulated in MEGAN as

$$\gamma_{T240} = \exp(C_{T240} (T_{240} - T_0)) \quad (7)$$

$$T_{opt} = T_{240} + C_{Topt} \quad (8)$$

where C_{T240} (=0.05) and C_{Topt} (=10 K) are empirical coefficients and T_{240} is the leaf temperature (K) averaged over the daylight hours of the past 240 hours. The empirical coefficients C_{T240} and C_{Topt} are based on the observations of Petron et al. (2001) and Monson et al. (1994).

Leaf age (γ_{age})

Leaves begin to photosynthesize soon after budbreak, but isoprene is not emitted in substantial quantities until after the onset of photosynthesis (Guenther et al. 1991). In addition, old leaves eventually lose their ability to photosynthesize and produce isoprene. Guenther et al. (1999a) developed a simple algorithm to simulate the reduced emissions expected for young and old leaves based on the observed change in foliar mass over a month. An increase in foliage was assumed to imply a higher proportion of young leaves, while decreasing foliage was associated with the presence of older leaves. This algorithm required a time step of one month, assumed that young leaves and old leaves had the same emission rate, and included variables that could not easily be quantified. The following procedures to account for leaf age effects on isoprene emission estimates minimize these deficiencies but additional efforts are needed to parameterize the approach for a wide range of locations, especially in the tropics.

MEGAN divides the canopy into four fractions: new foliage that emits negligible amounts of isoprene (F_{new}), growing foliage that emits isoprene at less than peak rates (F_{gro}), mature foliage that emits isoprene at peak rates (F_{mat}) and senescing foliage that emits isoprene at reduced rates (F_{sen}). The canopy-weighted average factor is calculated as

$$\gamma_{age} = F_{new}A_{new} + F_{gro}A_{gro} + F_{mat}A_{mat} + F_{sen}A_{sen} \qquad (9)$$

where A_{new} (=0.01), A_{gro} (=0.5), A_{mat} (=1), and A_{sen} (=0.33) are the relative emission factors assigned to each canopy fraction. The values of these emission factors are based on the observations of Petron et al. (2001), Goldstein et al. (1998), Monson et al. (1994), Guenther et al. (1991) and Karl et al. (2003).

The canopy is divided into leaf age fractions based on the change in the LAI of the current time step (LAI_c) and the LAI of the previous time step (LAI_p). In cases where $LAI_c = LAI_p$ then F_{mat} = 1 and all other fractions (F_{new} , F_{gro} , F_{sen}) are equal to zero. When $LAI_p > LAI_c$ then F_{new} and F_{gro} are equal to zero, F_{sen} is estimated as $[(LAI_p – LAI_c)/LAI_p]$ and $F_{mat} = 1 - F_{sen}$. In the final case, where $LAI_p < LAI_c$, $F_{sen} = 0$ and the other fractions are calculated as

$$F_{new} = 1 – (LAI_p/LAI_c) \qquad \text{for } t <= t_i \qquad (10a)$$
$$F_{new} = [t_i/t]\,[1 – (LAI_p/LAI_c)] \qquad \text{for } t > t_i \qquad (10b)$$

$$F_{gro} = 0 \qquad \text{for } t <= t_i \qquad (10c)$$
$$F_{gro} = [(t_g-t_i)/t]\,[1 – (LAI_p/LAI_c)] \qquad \text{for } t > t_i \qquad (10d)$$

$$F_{mat} = (LAI_p/LAI_c) \qquad \text{for } t <= t_m \qquad (10e)$$
$$F_{mat} =(LAI_p/LAI_c) + [(t-t_m)/t]\,[1 – (LAI_p/LAI_c)] \qquad \text{for } t > t_m \qquad (10f)$$

where t is the length of the time step (days) between LAI_c and LAI_p, t_i is the number of days between budbreak and the induction of isoprene emission, t_m is the number of days between budbreak and the initiation of peak isoprene emission rates, and $t_g = t_m$ for $t > t_m$ and $t_g = t$ for $t <= t_m$. The observations of Petron et al. (2001) for plants growing under conditions typical of temperate regions result in values of t_i of about 12 days and t_m of about 28 days. Other studies show that t_i and t_m are temperature dependent and are considerably less for vegetation growing at high temperatures (Monson et al. 1994; Kuhn et al. 2002). Kuhn et al. (2002) investigated a tropical rainforest species, where emerging leaves are exposed to warm temperatures, and observed a rapid onset of isoprene emission within a few days, i.e. $t_i < 3$ days. We have developed a simple algorithm for predicting t_i based on ambient temperature but currently recommend using a constant value of $t_i = 10$ due to the limited observations. Model simulations using a constant t_i predicted global annual isoprene emissions that were about 5% lower than estimates based on a variable t_i. The emission rates estimated using constant t_i can be more than 20% higher in tropical regions and 20% lower in boreal regions when foliage is expanding. The differences are more pronounced when LAI variations have a higher time resolution (i.e. weekly rather than monthly).

Soil Moisture

Plants require both carbon dioxide and water for growth. Carbon dioxide is taken up through stomatal openings in leaves and water is transported up from the soil. However, large quantities of water can be lost through stomatal openings creating a need for adequate soil moisture in order to continue the photosynthetic process of carbon uptake. Field measurements have shown that plants with inadequate soil moisture can have significantly decreased stomatal conductance and photosynthesis, in comparison to well-watered plants, and yet can maintain approximately the same isoprene emission rates (Guenther et al. 1999b). However, isoprene emission does begin to decrease when soil moisture drops below a certain level and eventually becomes negligible when plants are exposed to extended severe drought (Pegoraro et al. 2004). MEGAN simulates the response of isoprene emission to drought through two mechanisms. Isoprene emissions are indirectly influenced by the impact of soil moisture on stomatal conductance which influences the leaf temperature estimated by the MEGAN canopy environment model. In addition, MEGAN includes an emission activity factor that is estimated as

$$\gamma_{SM} = 1 \qquad \theta > \theta_{opt} \qquad (11a)$$
$$\gamma_{SM} = (\theta - \theta_w)/(\theta_{opt} - \theta_w) \qquad \theta_w < \theta < \theta_{opt} \qquad (11b)$$
$$\gamma_{SM} = 0 \qquad \theta < \theta_w \qquad (11c)$$

where θ is soil moisture (volumetric water content, $m^3\ m^{-3}$), θ_w is wilting point (the soil moisture level at which, or below, plants cannot extract water from soil, $m^3\ m^{-3}$) and θ_{opt} is the isoprene optimum soil moisture (at which, or above, isoprene emission is maximum, $m^3\ m^{-3}$). The factor θ_{opt} is set at 50% of the soil moisture field capacity (θ_{ref}) based on the observations of Pegoraro et al. (2004). MEGAN assigns θ_w and θ_{opt} to different soil types using the values and soil database recommended by Chen and Dudhia (2001). Soil moisture varies significantly with depth and the ability of a plant to extract water is dependent on root depth. We follow the PFT dependent approach described by Zeng (2001) to determine the fraction of roots within each soil layer and use the weighted average γ_{SM} for all soil layers for which soil moisture estimates are available.

Other factors that influence isoprene emission activity

Isoprene emission activity can also be influenced by other environmental conditions such as atmospheric chemical composition including ozone (Velikova et al. 2005) and carbon dioxide (Buckley 2001; Rosenstiel et al., 2003), nutrient limitations such as nitrogen (Harley et al. 1994), and physical stress (e.g., Alessio et al. 2004). Additionally, there may be significant diurnal variations that are not entirely controlled by variations in environmental conditions (Funk et al. 2003). Emission activity factors accounting for these processes will be included in MEGAN as more reliable algorithms are developed.

<u>Canopy loss and production, ρ</u>

The gases and aerosols emitted by biological organisms do not always escape to the above canopy atmosphere. Some molecules are consumed by biological, chemical and physical processes on soil and vegetation surfaces, while others react within the canopy atmosphere. It is also possible for emitted material to escape to the above canopy atmosphere in a different chemical form. The ε defined by MEGAN is a net emission factor but not a net flux. This means that the MEGAN isoprene ε accounts for isoprene losses on the way out of the canopy but does not account for isoprene deposition from the above-canopy atmosphere. The net ecosystem-atmosphere isoprene flux can be estimated from the net isoprene emission rate estimated by MEGAN and an isoprene deposition rate based on the above canopy concentration and a deposition velocity.

Inverse modeling of within-canopy gradients of isoprene suggests that at least 90% of the isoprene emitted by tropical and temperate forests escapes to the above-canopy atmosphere (Karl et al. 2004; Stroud et al. 2005). The remainder is removed through a combination of chemical losses and dry deposition. While ambient mixing ratios within the canopy and roughness layer can change on the order of 10-30% due to chemistry (Makar et al., 1999), the bias of canopy scale isoprene flux measurements is small (e.g. on the order of 5-10%). This can be attributed to (1) near field effects within the canopy and (2) limited processing time between the location of isoprene emission (occurring mostly within the upper canopy) and the top of the canopy. Comparisons between canopy-scale emissions based on leaf-level emission measurements extrapolated with a canopy environment model and above-canopy flux measurements tend to show that any loss of isoprene is less than the uncertainty associated with these two measurement approaches (Guenther et al. 2000).

MEGAN includes a canopy loss and production factor, ρ, that is equal to unity for standard conditions and varies with changes in canopy residence time and isoprene lifetime which is determined by canopy oxidative capacity. Variations in isoprene canopy production and loss are estimated as

$$\rho = \rho_o - H / [\lambda \cdot u^* \cdot \tau + H] \qquad (12)$$

where H is canopy height (m), u* is friction velocity (m s^{-1}), τ is isoprene lifetime (s), λ (=1.5±0.1) and ρ_o (=1.01) are empirically determined parameters (m). Standard conditions (where ρ = 1) include u* =0.5 m s^{-1}, τ = 3600 s and H = 30 m. Since variations in ρ for isoprene are typically less than 5%, ρ can be assigned a constant value of unity for many isoprene emission estimation efforts. Equation 12 is based on measured isoprene emission profiles and turbulence profiles obtained during recent field studies (Karl et al. 2004, Stroud et al. 2005). The variation of the isoprene lifetime inside the canopy was scaled to the above canopy lifetime and based on measured O_3 profiles and modeled OH and NO3 levels reported by Stroud et al. (2005). A random walk model similar to the one described by Baldocchi (1997) and Strong et al. (2004) was used to estimate the 1st order decay of isoprene. Trajectories for 5000 particles were released at 4 levels (25%, 50%, 75% and 100% of canopy) and computed for typical daytime conditions. The chemical loss by the ensemble mean was used to assess ρ integrated over the whole canopy. A sensitivity analysis indicated that canopy height, friction velocity and lifetime were the most important variables controlling ρ. Model simulations were performed for a range of canopy heights (13.5m, 27m and 54 m), isoprene lifetimes (1370 to 6870 s) and friction velocities (0.1 to 2 m s^{-1}).

Model simulations of the impact of isoprene on atmospheric chemistry depend on estimates of net isoprene emission as well as estimates of the regional uptake of isoprene and its oxidation products, e.g. methylvinylketone, methacrolein and peroxyacetyl nitrate (PAN), from the above canopy atmosphere. Karl et al. (2004) conclude that current model procedures can underestimate the uptake of these oxidation products which would cause an overestimate of the impact of isoprene on oxidants and other atmospheric constituents. They also report that isoprene oxidation products deposit more rapidly during night than predicted by standard dry deposition schemes. During daytime, the net effect of deposition and in-canopy production of these compounds can be on the same order. These observations raise the possibility that various products of isoprene chemistry can be taken up by the forest canopy more efficiently then previously assumed. This could lead to an overestimation of the impact of isoprene by chemistry and transport models, even if they have correctly simulated isoprene emission rates and oxidation schemes, and could explain the need for some chemistry and transport models to use isoprene emission rates that are lower than observed.

POTENTIAL EMISSIONS MODEL OPTIONS

Option 1: Update MAGLAND and MAGBEIS3

The main advantage of this option is that MAG staff is already familiar with the model. The main disadvantage is that the resulting model will not reflect current understanding processes controlling biogenic emissions. This will presumably result in less accurate biogenic emission estimates. Another disadvantage is that BEIS-type models are becoming less widely used by the regulatory community and may not be further supported or updated.

Option 2: MEGAN

The main disadvantage of this approach is that MAG staff is not currently familiar with the model. The main advantages are that it will reflect current understanding processes controlling biogenic emissions, and so should provide more accurate biogenic emission estimates, and that MEGAN has an active research and development program that will provide future updates. In addition, MEGAN allows user developed input so no modified version (i.e. MAGMEGAN) is required.

Table 2-1. Summary comparison of biogenic emission models.

Model	BIEGIS	BEIS2	BEIS3	BIOME3	GLOBEIS3	MAGBEIS 2	MEGAN
Sponsors/ developers	CARB	EPA/MCNC	EPA/MCNC	LADCO/ Alpine Geophysics	TNRCC/Environ	MAG/STI	EPA/NSF/ NCAR
Programming Language	ARCGIS	FORTRAN	FORTRAN	SAS	Microsoft Access	FORTRAN	ARCGIS/ FORTRAN
Website	None	www.epa.gov/asmdnerl	www.epa.gov/asmdnerl	www.ladco.org/biome3	www.globeis.com	None	bai.acd.ucar.edu/Megan/index.shtml
Canopy Model	None	BEIS2	BEIS2	BEIS2 or GLOBEIS3	GLOBEIS3	BEIS2	MEGAN
Assumed number of canopy layers	5	5	5	2 to 99(flexible)	2 to 99(flexible)	5	2 to 99(flexible)
PPFD	?	Calculated	Calculated	Input	Input	Calculated	Input
Emission factor type	Canopy	Average leaf	Average leaf	Average or sun leaf	Average or sun leaf	Average leaf	Canopy
Emission factor database	BIEGIS	BEIS2	BEIS2	BEIS2 or GLOBEIS3	BEIS2 or GLOBEIS3	MAGBEIS 2	MEGAN
Landcover data	CARB	BELD3	BELD3	BELD3	user database	MAGLAND 2	MEGAN
Emission activity algorithms	BEIS2	BEIS2	BEIS2	BEIS2 or GLOBEIS	GLOBEIS	BEIS2	MEGAN
Canopy production and loss algorithm	None	none	none	none	none	none	MEGAN
Chemical species or categories	4	4	34	34	34	4	134

3. REVIEW OF PREVIOUS BIOGENIC STUDIES CONDUCTED BY MAG AND OTHER ENTITIES

THE 1996 MAG BIOGENICS STUDY (Chinkin et al. 1996)

The state-of-the-art biogenic emission model available to MAG in 1995 was the UAM-BEIS2 model. Chinkin et al. (1996) assessed the use of UAM-BEIS2 for Maricopa County and found that the biogenic emission factors were not appropriate for Maricopa County. Since UAM-BEIS2 did not allow user supplied landcover types and emission factors, Chinkin et al. (1996) developed a modified model, MAGBEIS2, that contained modified parameters. In addition, they developed a landcover scheme consisting of 10 landcover types (urban, residential, parks, desert parks, citrus crops, other crops, stockyards, water, desert, and forests) and they developed an isoprene, monoterpene, OVOC and NO emission factor for each of the ten landcover types. The VOC emission factors were based on field measurements of landcover characteristics and species-specific emission factors based on a literature review. The NO emission factors were primarily based on UAM-BEIS2 values. The Chinkin et al. (1996) approaches used for characterizing species-specific biomass density and emission factors, and the resulting landcover average emission factors are assessed in this section.

Biogenic Emissions Model (MAGBEIS2)

Chinkin et al. (1996) developed MAGBEIS2 by modifying UAM-BEIS2 so that it would accept user-supplied land use data. This was accomplished in a manner similar to ROM-BEIS2. They also developed new isoprene and monoterpene emission factors for some of the ten landcover classes used in MAGBEIS2. Their recommended isoprene emission factors tend to be lower than what is reported in the recent literature summarized in section 2.4. There are two main reasons for these underestimated isoprene emission factors: 1) Chinkin et al. based many of their estimates on observations that were made in low light which can greatly reduce isoprene emissions relative to the emissions that occur from sun-lit leaves (Geron et al. 2000), and 2) most of the emission factors were based on branch level emission rate measurements (which includes self shaded leaves). These rates need to be adjusted in order to be used in a model, such as MAGBEIS2, that includes a canopy radiation model.

Locale-specific Landcover Data and Preprocessor (MAGLAND2)

A methodology was developed to generate the landcover required for MAGBEIS2 using the MAG detailed land use database which has 43 land use types. A preprocessor, called MAGLAND2, was developed for the task of collapsing the 43 MAG land use types into the nine categories (forests, urban, desert, parks/golf courses, citrus crops, other crops, stockyards, residential/schools/churches, water) required as input to MAGBEIS2. In addition, MAGBEIS2 generated a tenth category (desert parks) for areas classified by MAG as parks but in non-urban areas. The land use fractions for the modeling domain where dominated by desert (43%), residential (17%) and other crops (17%). The 24 MAG land use categories for future-year land use were mapped to the nine MAGBEIS2 land use inputs categories in a similar manner as for present day.

Urban, Residential, Parks/Golf-Course Land Use Categories

A field survey was conducted to characterize vegetation cover and plant species composition for urban, residential and parks categories. This was combined with a literature search of isoprene and monoterpene emission factors and resulted in a landcover average emission factor that is likely more accurate than the UAM-BEIS2 estimate.

The OVOC emission factor for three land use types (urban, residential, and parks) were assigned the same emission rate as for monoterpenes. Chinkin et al. (1996) states that "This assumption was based on the fact that the plant types responsible for the majority of monoterpene emissions are assigned nearly equal monoterpene and OVOC emission fluxes in UAM-BEIS2." However, UAM-BEIS2 assigns a constant per biomass OVOC emission factor to all vegetation. Therefore, a more consistent approach would have been to assign an OVOC emission factor based on the biomass density determined for each of these categories.

The NOx emission factor for residential and urban land use types were based on the UAM-BEIS2 grass emission factor but were reduced to account for only partial vegetation cover in these land use categories.

Desert parks, Desert and Forest Land Use Categories

A field survey was also conducted to characterize desert vegetation cover and plant species composition. However, the resulting biomass densities were higher than expected for desert scrubland and were not used to assign emission rates. Instead, values from desert scrub landscapes in California were used. These values could be representative of desert landscapes in general but may differ significantly from the actual values in Maricopa County.

Desert parks, desert, and forests were all assigned the UAM-BEIS2 NOx and OVOC emission factor for desert lands. Forests were assigned the same emission factor as desert based on a review of areal photos by MAG staff.

Citrus Crops, Other Crops, Stockyards, and Water Land Use Categories

Table 4-5 of Chinkin et al. (1996) indicates that isoprene, monoterpene, other VOC and NOx emission factors for these four categories were assigned USEPA recommended values. Water and citrus crops were directly assigned the values used for UAM-BEIS2. Other crops were assigned emission factors that were estimated as the weighted average of the UAM-BEIS2 emission factors for various crop types. Maricopa county crop statistics were used to develop the weighting parameters. Stockyards were assigned the UAM-BEIS2 grass emission factors.

MAGBEIS2 VOC and NOx Emissions

Chinkin et al. (1996) report that MAGBEIS2 VOC emissions were 50% higher than the UAM-BEIS estimates. This was attributed to an increase in isoprene emissions that resulted from 1) a higher fraction of residential and park areas, 2) higher emission factors, and 3) emission algorithms. They also found that MAGBEIS2 predicted a relatively larger contribution from non-urban areas than UAM-BEIS.

The MAGBEIS NO emission factors recommended by Chinkin et al. (1996) resulted in biogenic NOx emissions that were nearly ten times higher than the previous emission estimates (UAM-BEIS2). This was attributed to the much higher NOx emission factors used by UAM-BEIS2 in comparison to UAM-BEIS. The highest predicted emissions were in the agricultural areas, in contrast to the UAM-BEIS2 prediction of higher emissions from urban areas. This was due both to a decrease in predicted urban area emissions (because a lower fraction of vegetation coverage was assumed) and because of higher emissions estimated for agricultural areas.

OTHER BIOGENICS EMISSION STUDIES

Investigators in the former Soviet Union began to characterize the release of biogenic volatile organic compounds into the atmosphere as early as the late 1920s (Isidorov 1990). Efforts to characterize emissions of these compounds for the purpose of managing regional air quality began in the early 1970s in the U.S. (Rasmussen 1972). However, the potential role of these compounds in oxidant and aerosol formation was recognized in the U.S. at the beginning of the previous decade (e.g. Went 1960) and observations of a positive correlation between ambient terpene and ozone concentrations was observed in the Ukraine in 1940 (Isidorov 1990).

The MAGBEIS2 model is based on investigations conducted up to ~1995. In this section, we review biogenic studies conducted since that time. The end of the second millennium coincided with the publication of a large number of review papers on biogenic VOC, CO and NO emissions. Various manuscripts focused on emission measurements and modeling (Fuentes et al. 1999, Kesselmeier and Staudt 1999, Guenther et al. 2000), biological processes (Fall 1999, Kreuzwieser et al. 1999; Harley et al. 1999, Logan et al. 2000, Wolfertz et al. 2003) and atmospheric chemistry (Atkinson and Arey 2003). The combined references of these 8 manuscripts include hundreds of biogenic VOC studies. Most of the biogenic VOC investigations of the past decade focused on a single compound, isoprene, reflecting the recognized dominant contribution of this compound to global total emissions. However, there has been a shift towards investigations of other compounds, particularly oxygenated VOC and sesquiterpenes, in the past five years. The recent peer reviewed literature describing emission studies of various compounds, and the modeling techniques and driving variables required to extrapolate these emissions, are described in this section.

Landcover Distributions

Substantial improvements have been made in approaches to characterize plant functional types (PFTs) using satellite data and applied algorithms (e.g., Zeng et al., 2000, Hansen et al., 2000, 2003; Defries et al. 2000). These PFT classifications distinguish broadleaf and needle leaf deciduous and evergreen trees, as well as grasses. They are available on global scales at 500 m resolution and can be generated on local scales at resolution of less than 1 m. A significant advantage of satellite based data are their ability to characterize land cover which is rapidly changing in many parts of the world and resulting in substantial changes in biogenic emissions (e.g. Guenther et al. 1999b, Schaab et al., 2000).

Biogenic VOC emission estimates have been considerably improved by incorporating the tree inventories that are available for southern Africa (Otter et al. 2003), China (Klinger et al., 2002), Europe (Simpson et al. 1999, Stewart et al. 2002), Australia, Canada and other regions (Guenther et al. 2005). Harley et al. (1999) note that tree species distributions in some regions are changing considerably due to increasing tree plantations (Harley et al. 1999).

Several landcover databases that have been developed in recent years are likely to be useful for improving MAG landcover distributions. These include high resolution (30 meter) satellite-derived land cover maps. The Southwest Regional Gap Analysis Project, GAP (USGS, 2005) should be particularly useful for non-urban areas and the Stefanov et al (2001) land cover data may improve estimates for the Greater Phoenix area. The Stefanov et al (2001) land cover map distinguishes xeric and mesic residential types, which can potentially improve biogenic emission estimates in the Phoenix metropolitan area. These satellite maps need to be calibrated using ground measurements. Urban land cover field measurements described by Hope et al. (2003) have characterized 30 m x 30 m field plots at >200 randomly selected sites across the MAG urban area. The land-use designation for this database is directly related to the MAG land-use types. All perennial woody vegetation in each plot will be mapped, measured and identified using the procedures defined for the Hope et al. (2003) database. For the desert scrub and forest landscapes, there are two databases available: the USDA Forest Inventory analysis (FIA) database contains measurements of tree distributions and the US Natural Resources Conservation Service (NRCS) database contains measurements of shrub distributions.

Leaf Density and Age

Leaf area index (LAI) or foliar density is a key variable in biogenic VOC emission models. In addition, leaf age influences the emission rates of at least some compounds including isoprene, monoterpenes, sesquiterpenes, MBO and methanol biogenic VOC (Guenther et al. 1999a, 2005; Harley et al. 1998; Fall et al. 1999, 2001; Wiedinmyer et al. 2005). Recent advances in remote sensing techniques have improved LAI estimates (e.g., Preußer et al., 1999, Myneni et al., 2002). The MODIS (Moderate Resolution Imaging Spectroradiometer) sensors aboard the U.S. National Aeronautics and Space Administration (NASA) Terra (EOS AM-1) and AQUA satellites provide global scale 1- and 8-day averages at 1 km resolution (ref).

Isoprene emission is diminished in immature and senescing leaves while methanol is increased. Guenther et al. (1999a, 2005) have implemented methods for simulating this variation on global scales using weekly to monthly LAI variations. Lehning et al. (2001) describe the potential for enhancing this method by correlating emission activity with the photosynthetic pigment content of leaves.

Canopy Environment

Lamb et al. (1996) compared the results of several canopy environment models to field observations of above canopy isoprene emission fluxes. The models differed by about 25%, but it was difficult to determine which had better model performance due to uncertainties in flux footprints and because of measurement uncertainties of a similar magnitude. A more important consideration is how the models may perform in extreme conditions, such as drought, that can occur during periods of high ozone.

Several studies (Sharkey et al., 1999; Geron et al., 2000a; Lehning et al., 2001; Pétron et al., 2000) have shown that isoprene emission is dependent not only on the present temperature but also on the temperature that the leaf has experienced over the preceding hours to days. Algorithms for incorporating this effect have been suggested by Guenther et al. (1999a, 2005).

The weather data needed for determining canopy environmental conditions can be obtained from various sources including ground and satellite observations, model simulation outputs, or combinations of both. A variety of satellite measurements and meteorological data are available for use in biogenic emissions models including Fractional Photosynthetically Active Radiation (FPAR) (Myneni et al., 2002), cloud characteristics (e.g., King et al., 1997), and atmospheric water vapour (Gao and Kaufman, 1998). Biogenic emissions models have also been incorporated in several on-line land-surface, ocean, and atmospheric models that can predict simultaneously BVOC emissions and meteorological parameters (Wang and Shallcross, 2000; Levis et al., 2002).

Isoprene and Monoterpenes

Guenther et al. (2000) summarize more than 30 enclosures and above canopy isoprene and monoterpene flux studies conducted in the U.S. during the 1990s. Kesselmeier and Staudt (1999) review a similar number of terpenoid emission studies in Europe. Recent studies have also been conducted in Central and South America (e.g., Keller and Lerdau, 1999, Kesselmeier et al. 200x, 2000; Harley et al. 200x; Kuhn et al., 2002; Greenberg et al. 2000), Africa (e.g., Guenther et al. 1999; Otter et al. 200x; Harley et al. 200x; Greenberg et al. 200x), and Asia (e.g., Baker et al. 2005, Klinger et al. 2002, Owen et al.). These studies have added to the database of emission enclosure measurements that can be used to assign emission factors and they have improved our understanding of the processes controlling emission variations.

Emission enclosure studies have shown that much of the previously observed isoprene variability among plant species with significant emission rates (e.g. *Quercus, Liquidambar, Nyssa, Populus, Salix*, and *Robinia* species) can be attributed to weather, plant physiology and the location of a leaf within the canopy rather than genetics (Geron et al., 2000). Other studies have characterized how emissions respond to various factors including leaf age (Petron et al., 2001), nutrient availability (Litvak et al., 1996), weather of the past 1 to 10 days (Sharkey et al., 2000; Geron et al., 2000a; Hanson and Sharkey, 2001) and the chemical composition of the atmosphere (Loreto et al., 2004; Rosentiel et al., 2003). Another important finding from enclosure measurements is that plants other than trees can have high isoprene emission including mosses (Hanson et al. 1999), grasses (Bai et al. submitted manuscript) and other herbaceous plants (Geron et al. submitted manuscript). Geron et al. (2000b) summarized monoterpene emission enclosure data for the dominant U.S. tree species. They focused on speciation of individual compounds and did not attempt to characterize the magnitude of the emissions.

Another important finding is that monoterpene emissions from some plants are dependent on light, in a manner similar to what has been observed for isoprene (Seufert et al., 1997).
This was first reported for some European trees but has now been identified as important for trees in Africa (Otter et al., 2003), South America (Kuhn et al., 2002) and North America (Guenther et al., unpublished data). Studies show that monoterpene emission capacities may be biased under some physiological conditions, and that tree and needle age, needle wetness, relative humidity, phenological state (e.g., budbreak, senescence), and stomatal control must be

considered in attempts to realistically model monoterpene emissions (Kim, 2001; Schade et al., 1999).

Isoprene and monoterpene fluxes can now measured routinely using eddy flux techniques such as relaxed eddy accumulation (e.g., Guenther et al., 1996) and eddy covariance (Guenther and Hills, 1998; Karl et al. 200x). Eddy flux techniques are suitable for long-term whole canopy measurements and there are now several records of up to 4 years for evaluating predictions of seasonal and interannual variations (Pressely et al. 2004, Schade et al.). In addition to these direct flux measurement methods, inverse modeling and gradient approaches use isoprene concentrations obtained from aircraft and tethered balloon sampling platforms to characterize isoprene emissions for across spatial scales of tens to hundreds of km^2 (e.g., Greenberg et al., 1999, 2004).

Sesquiterpenes (e.g., b-caryophyllene, a-humulene)

Sesquiterpenes (SQT) are terpenoid hydrocarbons with the molecular formula C15H24. These compounds have very high yields of atmospheric secondary organic aerosol (3 to 5 times higher than monoterpenes and much higher than other biogenic VOC). Although this makes these compounds extremely important for regional air quality modeling, there are relatively few studies that have characterized the emissions of these compounds. This is partly due to the very challenging analytical methods required to quantify emissions of these compounds. Qualitative studies are easier and there have been more studies that have characterized the role of SQT as mediators of plant-insect and plant-plant interactions. Many of these studies, however, provide some indication of how SQT respond to stress (e.g. herbivory) or environmental conditions such as light (e.g., Arimura et al., 2004; De Moraes et al., 2001; Gouinguene and Turlings, 2002; Helsper et al., 1998; Maes and Debergh, 2003; Martin et al. 2003; Zhang et al. 1999).

Helmig et al. (1999) report substantial sesquiterpene emissions from some North American plants, including desert plants, oaks, and conifers. SQT emissions have been detected from numerous plant species, including conifer and broadleaf trees and agricultural crops. Other studies have shown that SQT emissions are widespread in European plants (Hakola et al., 2001 Hansen and Seufert, 2003 Schuh et al., 1997), including some plants that are common in Maricopa county (e.g. *Citrus* trees). These European studies also provide insights into the light and temperature controls over SQT emissions. The light and temperature controls of SQT emissions from North American trees have also recently been characterized (Harley et al., manuscript in preparation; Helmig et al. submitted manuscript).

2-methyl-3-buten-2-ol (MBO)

MBO is an "isoprene alcohol" that is emitted at high rates (>20 $\mu g\ C\ m^{-2}\ h^{-1}$) from needles of some, but not all, pine species (Harley et al., 1998). Since these trees include major western North American pines such as lodgepole (Pinus contorta) and Ponderosa (P. ponderosa), MBO is the dominant emission from some U.S. forests (Baker et al., 2001, Karl et al. 2002; Schade et al., 2000). MBO emission factors vary with light and temperature in a manner similar to isoprene (Harley et al., 1998; Schade et al., 2000).

Other Hydrocarbons (e.g., ethene, propene, ethane, toluene)

Ethene production is widespread in plants and is likely to be a significant emission from most landscapes (Goldstein et al., 1996). Propene and butene are emitted at lower rates but are still significant (Goldstein et al., 1996). Other hydrocarbons (e.g., ethane, toluene) have been reported as emissions, but there is not yet any indication that these are significant relative to other biogenic VOC emissions (Guenther et al., 2000).

Other VOC (e.g., methanol, acetone, etc.)

Warneke et al. (2002) measured a large above-canopy fluxes of methanol from an undisturbed alfalfa field in Colorado and a much smaller flux of hexenal. Emissions of the two compounds were greatly increased during harvesting and continued to emit at high rates as the alfalfa was drying. In addition, fluxes of hexenylacetate, hexenol, hexanal, butanone were observed during harvesting. Similar results have been observed for hay harvesting and lawn mowing (Karl et al.). These emissions could dominate total fluxes from some regions during periods of harvesting (Karl et al.)

Substantial acetaldehyde and formaldehyde emissions have been observed from European conifer and broadleaf trees (Kesselmeier et al., 1997; Kreuzwieser et al., 1999) and are particularly high during flooding (Kreuzwieser et al., 2000). Other stress factors such as hypoxia, drought, chilling, and wounding cause an increased production of formaldehyde in plants (see Kreuzwieser et al., 2001). Formic and acetic acid were emitted at somewhat lower rates. Emissions of all of these compounds have an atmospheric compensation point below which plants emit the compounds and above which the plants take up the compounds (Kesselmeier, 2001). Martin et al. (1999) and Knowlton et al. (1999) report similar results for trees founds in montaneforests in New Mexico.

Acetone emissions have been observed from conifer and broadleaf trees and the emissions have a compensation-point (Janson et al., 1999; Janson and de Serves, 2001). Methanol, acetaldehyde and acetone are the major non-terpenoid BVOC emissions observed above most plant canopies (Karl et al. 2000, 2002, 2004; Baker et al. 1999; Schade et al. 2003).

NO

The primary means for developing NO emission factors from soils has been through measurements with static or dynamic chambers. Thousands of measurements have been made in the southeastern U.S. by Thornton *et al.* (1997) and in many other parts of the world (Davidson and Kingerlee 1997). These studies have shown that there is very large small scale heterogeneity in soil NO emissions. Above canopy flux studies have the advantage of averaging over a larger footprint and accounting for canopy losses. However, there have been relatively few of this type of measurement. Yienger and Levy (1995) and Potter et al. (1996) summarize the factors controlling NO emissions and developed algorithms for describing the response of soil NO emissions to temperature, soil moisture and fertilization applications. The Yienger and Levy approach is used for the BEIS3 soil NO emission rates. More mechanistic soil NO emission models have been developed but they are heavily parameterized and difficult to apply on regional scales.

CO

The formation and emission of CO on or in live plant foliage is the result of direct photochemical transformation and occurs inside the leaf (Tarr *et al.*, 1995). The factors controlling these emissions are not well known and biogenic CO emission estimates are very uncertain. Guenther et al. (2000) recommended an emission factor of 0.3 carbon μg g^{-1} h^{-1} which results in a small but significant contribution to total U.S. CO emissions.

Organic Aerosol

Plant canopies have the potential to emit significant amounts of particles into the atmosphere (Andreae and Crutzen, 1997). For example, the organic matter that accounts for about 90% of the measured aerosol mass in pristine regions of Amazonia is attributed to biogenic aerosol production (Kubátová et al., 2000). Aerosol emissions from plant canopies fall into two categories: primary and secondary. Primary aerosols are emitted directly by biological organisms. Examples include pollens, leave fragments, and liquids leaving the leaf or ground surface. Secondary aerosols arise from oxidation of precursor gases within the canopy airspace.

Secondary biogenic organic aerosol produced in canopies

It is generally accepted that that gas-to-particle conversion of biogenic hydrocarbons accounts for a significant fraction of the organic aerosol in some regions (e.g., O´Dowd et al. 2002; Kavouras et al. 1998), but the component that is generated within the canopy has only recently been considered (Nemitz et al. 2004; Stroud et al. 2005; Morris et al. 2005). Major uncertainties associated with characterizing these emissions include accounting for within canopy oxidant concentrations, aerosol yields and lifetimes, and canopy exchange rates. Aerosol yields from the reactions of organic compounds with OH, O3, and NO3 are extremely variable and depend on the composition of the hydrocarbons as well as on the circumstances under which the oxidation reactions are taking place (Andreae and Crutzen, 1997; Kamens et al., 1999; Moldanova and Ljungstro, 2000). Yields for the daylight photo-oxidation of terpenes range from 5 to 100%, with the highest values obtained for sesquiterpenes (Yu et al., 1999; Kavouras et al., 1999; Kamens et al., 1999). For most compounds, nighttime oxidation by ozone produces even higher aerosol yields than the daytime photochemical process (Hoffmann et al., 1997). Andreae and Crutzen (1997) estimate that within and above canopy production of secondary organic aerosols is between 30 to 270 Tg year-1, a magnitude comparable to the production of biogenic and anthropogenic sulfate aerosols (90 and 140 Tg year-1, respectively).

Primary biogenic aerosol

Biogenic aerosols consist of many different types of particles, including pollen, spores, bacteria, algae, protozoa, fungi, fragments of leaves, and excrement and fragments of insects (Matthias-Maser and Jaenicke, 1995). Jaenicke (2005) recently estimated that ~25% of atmospheric aerosol is of primary biological origin. These particles are mainly observed in the coarse size fraction (D_p>2 μm). The mechanisms of primary biogenic particle emission are still not well understood but probably include mechanical abrasion by wind, biological activity of microorganisms on plant surfaces and forest litter, and plant physiological processes.

AVAILABILITY OF INFORMATION NEEDED FOR ESTIMATING BIOGENIC EMISSIONS FOR THE MAG DOMAIN

Urban/suburban Emission Factors

Source distributions (land use, vegetation cover, species composition)

The 1990 MAG land use database includes 43 landcover types. MAGBEIS2 collapsed 15 of these land use types into a single urban land use category, 10 of these land use types into a residential/schools/churches category, and 2 of these types into a parks/golf course category (which was split into a parks and desert parks categories). The MAG 2004 "Existing Land Use" has expanded to include 102 land use and land cover categories, most of which appear to be urban/suburban. The previous approach of assigning emission factors to MAG land use types can likely be continued with the 2004 MAG land use database. However, an effort should be made to determine if more of the land use categories can be applied in the emission estimation process in order to characterize the significant differences in the vegetation cover and species composition that occur throughout the MAG region. An important tool for characterizing the MAG urban and suburban land use types is the SURVEY 200 vegetation cover and plant species composition database (http://caplter.asu.edu/home/survey200/index.jsp) described by Hope et al. (2003). Each survey plot is associated with a MAG land use type and can be used to determine representative vegetation characteristics. Chinkin et al. (1996) report that MAG residential landcover can be divided into flooded (oasis), mesic, and xeric (dry) types. However, they were unable to use this information other than for developing a rough estimate of the relative areal contribution of each of the three types in the region, and using this to develop a weighted average emission factor for the MAGBEIS2 residential land use category. A more current approach include identifying the relative contribution and the spatial distribution of oasis, mesic and xeric using the 30 m X 30m landcover dataset developed by Stefanov et al. (2001).

Species-specific emission rates

The Chinkin et al. (1996) study identified the plants that dominate the foliar biomass in the urban, residential and parks land use areas. Enclosure measurements have been reported for all of the four major genera identified by Chinkin et al.: *Eucalyptus*, *Citrus*, *Platycladus* and *Washingtonia*. Intensive whole canopy biogenic VOC emission studies have been conducted in a *Citrus* plantation (Valencia orange) in Spain (Ciccioli et al. 1999) and a Eucalyptus plantation in Portugal (Trapp et al. 2001) and there are many enclosure measurements reported for these two genera. These studies suggest that the isoprene and monoterpene emission factors assigned to *Citrus* and *Eucalyptus* by Chinkin et al. are somewhat low. In contrast, there are only a few enclosure measurements reported for *Platycladus* and *Washingtonia*. Although Chinkin et al. (1996) classified *Platycladus* as a low monoterpene emitter, Klinger et al. (2002) report very high monoterpene emissions from a member of the same genus. Measurements characterizing monoterpene emissions from Platycladus in the MAG study domain are a high priority due to the high biomass density and the potentially large emission rate.

Other genera with relatively high biomass density include *Rhus, Pittosporum, Juniperus, Ficus, Bougainvillea, Albizia, Fraxinus, Nerium, Pinus, Olea, Prosopis, Chaemerops, and Phoenix.* Of these genera, only *Pinus* (including the common species, *Pinus halapensis* in the MAG urban area) and *Ficus* have been well characterized (Owen et al 2002, Klinger et al. 2002). There are a few reported measurements for most of the other genera (e.g., Zimmerman 1978, Winer et al. 1989, Guenther et al. 1996a,b, 1999, Klinger et al. 1998, 2002; Helmig et al. 1999). However some genera have been identified as both emitting isoprene and not emitting isoprene by various studies (e.g. Albizia, Rhus) and additional measurements are needed to assign emission rates to these plants.

Lightly Managed (natural) Landscape Emission Factors

Source distributions (landcover)

The 1990 MAG land use database includes 6 lightly managed (i.e. natural) landscapes. One category was titled "Nondevelopable – forest" but was considered to be desert scrubland along with the other 5 categories. In addition, 2 MAG land use classes were assigned to the desert category and 2 to the desert parks category. The 2004 MAG land use category does not define any categories as desert scrubland although the categories with titles "vacant", "active open space" and "passive open space" are likely to be lightly managed landscapes dominated by desert scrubland.

An initial characterization of the vegetation cover and species composition within each lightly managed land use type can be accomplished using the NRCS shrubland database. These ground surveys should be used to determine which land use types include desert scrubland and to determine the relative species composition. In addition, it should be determined if there are significant variations in landcover type within a given land use category. This initial exercise will determine what landcover measurements are needed as part of the biogenics field study (Task 7 of this project).

Using LAI or foliar density to characterize tree distributions is a reasonable approach for forests, but it may not be suitable for desert vegetation. Ephedra is an example of a desert shrub that has high isoprene emissions but essentially nothing that would be classified as foliage. A better way to characterize desert plant distributions may be canopy cover. This could be accompanied by enclosure measurements that report emissions relative to vegetation cover (m^2). Studies are needed to determine which method is most suitable.

Emission factors

Chinkin et al. (1996) report that Encelia farinosa (Brittlebush), Larrea tridentata (creosote bush), Ambrosia deltoidea (Triangleleaf Bursage), and Simmondsia chinensis (jojoba) are the prevalent desert plant species in the MAG domain. The GAP landcover data indicate that *Acacia, Artemesia, Atriplex, Cercidium, Ephedra, Eriogonum, Fouquieria, Krameria, Lycium, Olneya, Opuntia* are also important in at least some areas of Maricopa County. Isoprene, monoterpene and oxygenated VOC emission rates were recently determined for thirteen common desert shrubs at field sites in the Sonoran Desert of Arizona and the Mohave Desert of Nevada (Geron et al., submitted manuscript). The investigated plants include Larrea tridentata and Ambrosia deltoidea which are two of the dominant shrubs in the MAG region. Both of these species had significant monoterpene emission rates (2 to 4 mg g-1 h-1) and negligible isoprene emission rates. Ephedra and Olneya are desert shrubs found in Maricopa county that were identified by Geron et al. as having substantial isoprene emission rates. They also found that some species of Atriplex and

Artemesia have high monoterpene emissions. Some species of Acacia have been identified as having high isoprene emissions (Guenther et al. 1996). While there are a few reported measurements on some of the common desert shrubs in Maricopa County, a substantial portion of the large uncertainties associated with desert scrub biogenic emissions can be associated with the lack of emission measurements.

Agriculture Emission Factors

Source distributions (landcover)

The 1990 MAG land use data included 3 agriculture categories: citrus, other crops, and stockyards. The 2004 MAG land use scheme has increased the number of land use types (from 43 to 102), but has decreased the number of agricultural types from the previous three to just a generic “agriculture” land use. Of particular value for biogenic emissions estimates was the “Agriculture- citrus” category in the 1990 MAG land use database. Although the Maricopa county orchard area declined from 18232 acres in 1997 to 10832 in 2002, this is still an important category to distinguish from other agricultural lands. In 1992, cotton was the dominant crop with about twice the area of the second most prevalent crop, Hay (including alfalfa). In 2002, hay had replaced cotton as the dominant Maricopa county crop. Hay and cotton could be particularly important biogenic VOC sources during harvesting. Aerial photos or satellite data could be used to identify the spatial distribution of these crops.

Emission factors

The limited emissions measurements reported for Citrus, cotton, and hay/alfalfa indicate that these three dominant Maricopa county crops are likely to contribute significantly to overall biogenic VOC emissions. Citrus could contribute throughout the growing season while cotton and hay/alfalfa may be most important during harvesting episodes. Field measurements of biogenic VOC emissions from these crops are needed to characterize their contributions to Maricopa VOC emissions.

Emission Activity Variations

The biogenic VOC emission activity algorithms included in BEIS3, BEIS2 and MAGBEIS2 consists of a light and temperature dependent algorithm for isoprene and a temperature dependent algorithm for monoterpenes, other VOC and NO. BEIS3 includes a fertilizer and precipitation dependency for BEIS3 NO emissions. MEGAN adds algorithms that account for the influence of past light and temperature, soil moisture, and leaf age.

BEIS2, MAGBEIS and BEIS3 assume that isoprene emissions increase with leaf temperature up to about 40C and then begin to decrease. This has little impact on emission estimates for most regions but could be important for MAG county where air temperatures can exceed 40C and leaf temperatures can be even higher. Geron et al. examined the temperature response of desert plants and found that they could continue to respond with increasing isoprene emissions even when leaf temperatures exceed 50C. This follows a pattern where plants grown in cold temperatures have a maximum isoprene emission at temperatures considerably below 40C. MEGAN accounts for this behavior by varying the temperature at which maximum emission occurs depending on the temperature of the past 10 days. The MEGAN soil moisture dependence algorithm could also be important for Maricopa County where drought conditions can occur. The ability of existing algorithms to simulate variations that occur in desert landscapes should be evaluated with field measurements and improved algorithms could be developed if necessary.

Some of the dominant vegetation in urban (e.g. *Platycladus*) and natural (e.g. *Ambrosia*) landscapes of Maricopa county have been observed to have very high monoterpene emission rates. This could be due to disturbances caused by the enclosure method or it could be an indicator of monoterpenes that are produced and emitted at very high rates (similar to isoprene). This type of emission has now been observed in many different landscapes and it would not be surprising to find that it occurs in some of these plants. This could easily make a factor of 2 or more change in the monoterpene emission estimated for these landscapes and so should be investigated with a field measurement system that can identify this type of emission.

4. REVIEW MAG DATA AND BIOGENIC PROJECTION METHODOLOGY

The Biogenic Emissions Landcover Database (BELD, Kinnee et al. 1997) was developed by the USEPA to provide the landcover information required to estimate biogenic emissions from North American landscapes. BELD provides reasonable landcover data for trees in Eastern U.S. counties but is not sufficient for the Western U.S. For example, BELD assigns a high percentage of tree cover to portions of Maricopa County that have a very low tree cover. The MAGLAND2 database is a significant improvement on the BELD data but even this database can be substantially improved using additional data including quantitative observations of species composition. An additional deficiency of existing biogenic emission models is the lack of methods for characterizing emissions for future scenarios. Studies have shown that climate change can result in substantial BVOC emission changes over time scales of decades to centuries, while landcover change can significantly modify BVOC emissions on times scales of years to decades. The rapid land use changes occurring in Maricopa County require that any future biogenic emission estimates be based on best estimates of future landcover. In this report, we will review the MAG current land use database and future year projection methods and identify areas of potential improvement. In addition, we provide specific recommendations that are expected to lead to improved current and future biogenic emission estimates.

MARICOPA COUNTY LAND USE AND LANDCOVER DATA

Satellite and ground observational data available for characterizing Maricopa County landcover include:

- The MAG 2004 existing land-use database, referred to here as MAGEXLU. This is a vector (polygon) GIS database containing land-use information that is based on observed current land-use. It can be used to characterize land-use for all of Maricopa County, but is particularly detailed in the developed portions of Maricopa County.
- The SouthWest regional Gap Analysis Project, SWreGAP (USGS, 2005) database. This is a raster database with a high spatial resolution (30 m by 30 m) that is based on LANDSAT thematic mapper satellite imagery for 1999 to 2001 that has been calibrated with ground observations. It identifies urban and agricultural lands and provides a detailed characterization of vegetation types in undeveloped lands. The SWreGAP database covers Arizona, Colorado, Nevada, New Mexico and Utah and was developed through a $5 M multi-agency project conducted from 1998 to 2005.
- The Stefanov et al. (2001) LANDSAT-TM satellite derived landuse database, referred to here as S1998, is a raster database with 30 m spatial resolution that covers the Phoenix metropolitan area. This database has three urban classes: built-up, xeric residential, and mesic residential.
- Vegetation Continuous Fields (VCF) and Leaf Area Index (LAI)_products are available from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor aboard the U.S. National Aeronautics and Space Administration (NASA) Terra (EOS AM-1) and AQUA satellites. The vegetation cover has an annual and 500 m resolution and the resolution of the LAI database is 250 m and every 16 days. The VCF product is currently available for 2001 (although data for 2002-2004 will be released shortly), and LAI data are available for year 2000 to present.

- The Central Arizona – Phoenix Long Term Ecological Research (CAP-LTER) ground survey database (Hope et al. 2003). This survey consists of detailed observations on each plant within 30 m X 30 m plots at over 200 georeferenced locations in Maricopa County. This database can be used to characterize plant species composition of the most important MAG land-use types.
- The USDA Forest Inventory Analysis (FIA) database containing tree species composition information at georeferenced plot locations. This database can be used to characterize tree species composition for some of the MAG undeveloped lands.
- The US Natural Resources Conservation Service (NRCS) database is a vector (polygons) GIS database that includes shrub, grass and forbland species composition distributions for all of Maricopa County.
- The USDA-NASS Census of Agriculture is a database containing county level statistics of all agricultural crops, including orchards, for years 1992, 1997 and 2002.
- Observations by Chinkin et al. 1996 and Martin et al. 2003 which include species composition and LAI estimates at several sites representing important Maricopa county land use types.

A geographically referenced database of present day landcover that is suitable for biogenic emission modeling can be generated using a combination of the databases listed above. This composite database can then be used to calibrate the landcover characteristics of each of the MAG land-use categories, which can then be used to generate landcover scenarios for future years. The first step in developing a current landcover characteristics database for Maricopa County is to identify areas associated with three broad land-use categories that we refer to as urban, agriculture, and undeveloped. Different databases are more appropriate for characterizing the landcover of each of the general land-use categories. The approach for each general land-use type is described below. The urban category includes any built-up land use, such as residential, recreational, commercial, and industrial. A substantial fraction of the landcover in these areas are planted vegetation and includes many exotics. The MAGEXLU database indicates that Maricopa County landscapes are 81% undeveloped, 11% urban, and 8% agriculture. The S1998 database will be used to evaluate the occurrence of agricultural and urban land-use within areas designated as open space by MAGEXLU, as well as open space and urban land-use in areas designated by MAGEXLU as agricultural. Any major discrepancies will be investigated during the planned field study program.

Developed --Urban/residential/industrial: planted vegetation

About 90% of the MAGEXLU land-use types fall into our broad urban category, but they only cover ~ 11% of the total land area of Maricopa County. The CAP-LTER survey sites are located within 24 MAGEXLU urban land-use types that together cover 84% of the MAG urban land-use area. The urban land-use types that are not covered by the CAP-LTER survey sites represent only a very small fraction of the total urban area. The dominant vegetation for urban and undeveloped landscapes reported by Chinkin et al. and Martin et al. generally agree with the CAP-LTER survey results and can be used to extend the CAP-LTER database.

Residential areas are expected to be the major urban source of biogenic emissions in the MAG domain. The MAGEXLU database should provide an accurate distribution of the total residential area, but does not distinguish between oasis and mesic residential areas, with high vegetation density, and xeric (dry) neighborhoods, with low vegetation density. The biogenic emission potential of oasis/mesic and xeric residential areas are expected to differ greatly and an effort is needed to characterize their distributions. We will use the S1998 database to identify the oasis/mesic residential neighborhoods within the MAG domain. Although there has been considerable land use change since this database was developed in 1998, it may be reasonable to assume that the oasis/mesic residential areas have not changed and that all new residential areas are xeric. This assumption should be evaluated during the field survey.

Developed --Agriculture: orchard and cropland vegetation

The MAGEXLU agricultural lands cover about 8% of Maricopa County. Nearly all of this land is classified as agricultural (lucode=750) with a very small contribution from "greenhouse commercial" (lucode=203). The USDA-NASS 2002 census will be used to characterize landcover characteristics for agricultural land-use types. Hay, cotton and citrus crops are the most important biogenic VOC sources in the agricultural land-use category. The USDA-NASS can provide an estimate of county total agricultural land emissions but cannot be used to simulate the spatial distribution of these emissions. We will attempt to use the MODIS PFT data to determine the spatial variability of the relative coverage of orchards and cropland, but this should be evaluated by ground observations during the field study.

Undeveloped: native vegetation

The MAGEXLU open space lands include seven land-use types (lucodes= 573, 700, 710, 730,731, 799, and 900) of various lightly managed and protected areas that are covered primarily by desert shrublands. The landcover characteristics for these areas will be based on the SWreGAP, NRCS, FIA and CAP-LTER databases. The spatial distributions of vegetation alliances in the SWreGAP and NRCS databases will be compared and areas of disagreement identified. Resolving these discrepancies will be one focus of the planned field study.

Using LAI or foliar density to characterize tree distributions is a reasonable approach for forests, but it may not be suitable for desert vegetation. Ephedra is an example of a desert shrub that has high isoprene emissions but lacks foliage. A second focus of the planned field study will be to determine if there are more suitable methods for characterizing the VOC emission potential of desert plants. This can be accompanied by enclosure measurements that report emissions relative to foliar density, LAI, total biomass density, vegetation cover and other plant characteristics.

The landuse categories for each of the datasets evaluated are summarized and displayed below. Table 4-1 presents the detailed landuse classes available in the MAGEXLU data. Figure 4-1 displays these data in terms of the relevant landuse classes for an extent covering the MAG 4-km modeling domain. The relevant landuse classes (…,…,..,) were developed by aggregating the detailed data as presented in Table 4-1. Figure 4-2 presents these data zoomed into the Phoenix urban area. Figure 4-3 displays the detailed MAGEXLU data for the Phoenix urban area. Table 4-2 presents the landuse classes available in the SW GAP database. Figures 4-4 through Figure 4-6 display the SW GAP landuse data. The Stephanov 1998 landuse classes are presented in Table 4-3 and displayed in Figures 4-7 through 4-9.

Table 4-1. Landuse classes in the MAG 2004 LULC database.

MAG LU_Code	Description
100	General Residential - Residential where no detail available
110	Rural Residential - <= 1/5 du per acre
120	Estate Residential - 1/5 du per acre to 1 du per acre
130	Large Lot Residential (SF) - 1 du per acre to 2 du per acre
140	Medium Lot Residential (SF) - 2-4 du per acre
150	Small Lot Residential (SF) - 4-6 du per acre
160	Very Small Lot Residential (SF) - >6 du per acre (includes mobile home parks)
161	Very Small Lot Res (SF-Mobile Homes) - Mobile home parks/RV Parks (>6 du per acre)
170	Medium Density Residential (MF) - 5-10 du per acre
180	High Density Residential (MF) - 10-15 du per acre
190	Very High Density Residential (MF) - > 15 du per acre
198	Parking structures serving Residential - Parking structures serving Residential
199	Parking lots serving Residential - Parking lots serving Residential
200	General Commercial - Commercial where no detail available
201	Very Low Density Commercial - Amusement facilities
202	Low Density Commercial - Movie Theatres, Skating Rinks
203	Greenhouse Commercial - Nurseries, Greenhouses
210	Specialty Commercial - <=50,000 square feet
220	Neighborhood Commercial - 50,000 to 100,000 square feet
230	Community Commercial - 100,000 to 500,000 square feet
240	Regional Commercial - 500,000 to 1,000,000 square feet
250	Super-Regional Commercial - >= 1,000,000 square feet
298	Parking structures serving Commercial - Parking structures serving Commercial
299	Parking lots serving Commercial - Parking lots serving Commercial
300	General Industrial - Industrial where no detail available
310	Warehouse/Distribution Centers -
320	Industrial -
398	Parking structures serving Industrial - Parking structures serving Industrial
399	Parking lots serving Industrial - Parking lots serving Industrial
400	Office General - Office where no detail available
410	Office Low Rise - 1-4 stories
420	Office Mid Rise - 5-12 stories
430	Office High Rise - 13 stories or more
498	Parking structures serving Office - Parking structures serving Office
499	Parking lots serving Office - Parking lots serving Office
500	General Employment - Employment where no detail available
510	Tourist and Visitor Accommodations - Hotels, motels and resorts
511	Motels - Motels
512	Hotels - Hotels
513	Resorts - Resorts
520	Educational - Public schools, private schools, universities
521	Schools (K-12 grade) - Schools
522	Post High School Institutions - Including public and private colleges and technical training institutions
523	Arizona State University - ASU Main and Extended Campuses
524	Dormitories - Dormitories associated with educational institutions
525	Preschool/Daycare facilities - Preschool/Daycare facilities
530	Institutional - Includes hospitals, churches
531	Medical Institutions - Hospitals/Medical Centers
532	Religious Institutions - Churches/Religious Institutions
533	Nursing Homes - Nursing Homes (Group Quarter)
534	Assisted Care Facilities - Assisted Care Facilities
540	Cemeteries -
550	Public Facilities - Includes community centers, power sub-stations, libraries, city halls, police and fire stations and other government facilities
551	Public Offices - Includes city halls
552	Public Services - Includes community centers, libraries, police and fire stations, courts, prisons and other government services
553	Large Public Facilities - Includes power sub-stations, Work yards, Sewer and Water treatment plants

MAG LU_Code	Description
554	Military - Military Use
555	Limited Use Public Facilities - Very small difficult to access parcels
560	Special Events - Includes stadiums, sports complexes, and fairgrounds
570	Other Employment (low) - Proving grounds, land fills
571	Landfill - Landfill
572	Sand and Gravel - Sand and Gravel
573	Proving Grounds - Proving Grounds
574	Mining - Mining
580	Other Employment (medium) -
590	Other Employment (high) -
598	Parking structures serving Facilities/Emp - Parking structures serving Facilities/Employment
599	Parking lots serving Facilities/Employment - Parking lots serving Facilities/Employment
600	General Transportation - Transportation where no detail available
610	Transportation - Includes railroads, railyards, transit centers and freeways
611	Parking Lots - Parking Lots
612	Parking Structures - Parking Structures
613	Park and Ride lots - Park and Ride lots
614	Transit Center - Transit Center
620	Airports - Includes public use airports
621	Sky Harbor Airport - Sky Harbor Airport
700	General Open Space - Open Space where no detail available
710	Active Open Space - Includes parks
720	Golf courses -
730	Passive Open Space - Includes mountain preserves and washes
731	Restricted Open Space - Restricted Open Space (Including Firing Range)
740	Water -
750	Agriculture -
800	Multiple Use General - Multiple Use where no detail available
798	Parking structures serving Open Space - Parking structures serving Open Space
799	Parking lots serving Open Space - Parking lots serving Open Space
810	Business Park - Includes enclosed industrial, office or retail in a planned environment
820	Mixed Use - Jurisdiction defined
821	Mixed Use/Indian Community - Mixed Use/Indian Community
830	Planned Developments -
898	Parking structures serving Multiple Use - Parking structures serving Multiple Use
899	Parking lots serving Multiple Use - Parking lots serving Multiple Use
900	Vacant (existing land use database only) - Vacant
910	Developing Residential - Residential Under Construction
920	Developing Commercial - Commercial Under Construction
930	Developing Industrial - Industrial Under Construction
940	Developing Office - Office Under Construction
950	Developing Public/Other Employment - Employment Under Construction
960	Developing Transportation - Transportation Under Construction
970	Developing Open Space - Developing Open Space
980	Developing Multiple Use - Multiple Use Under Construction
999	Salvage/Unknown - Evaluate on an individual basis

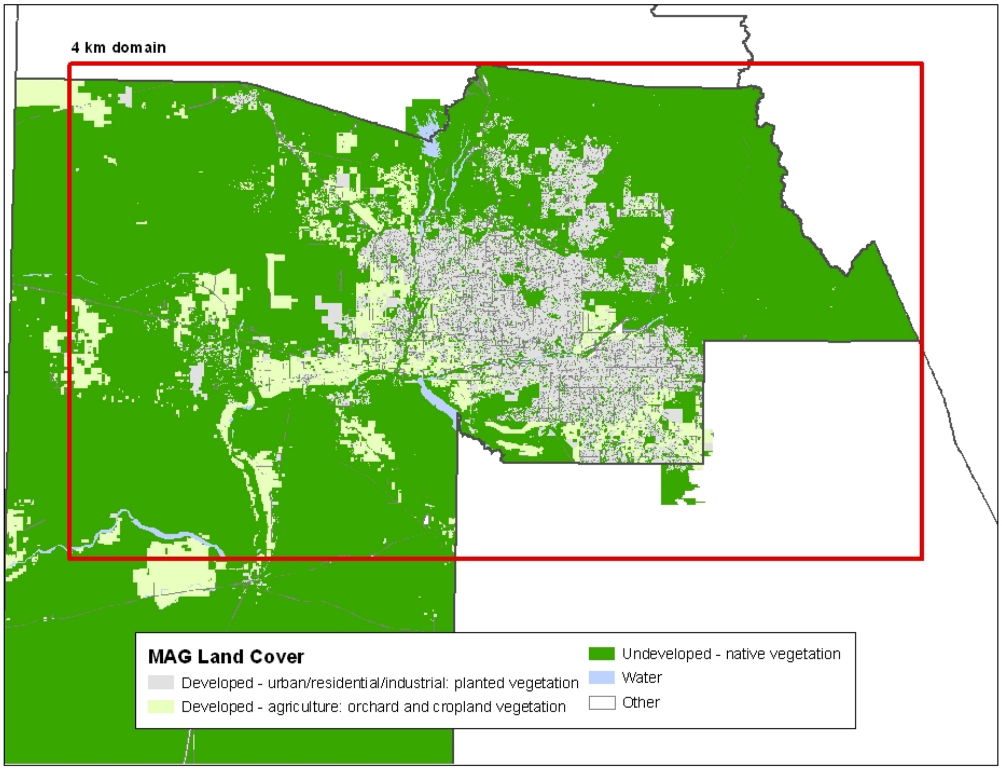

Figure 4-1. MAG 2004 aggregated LULC for the 4-km modeling domain.

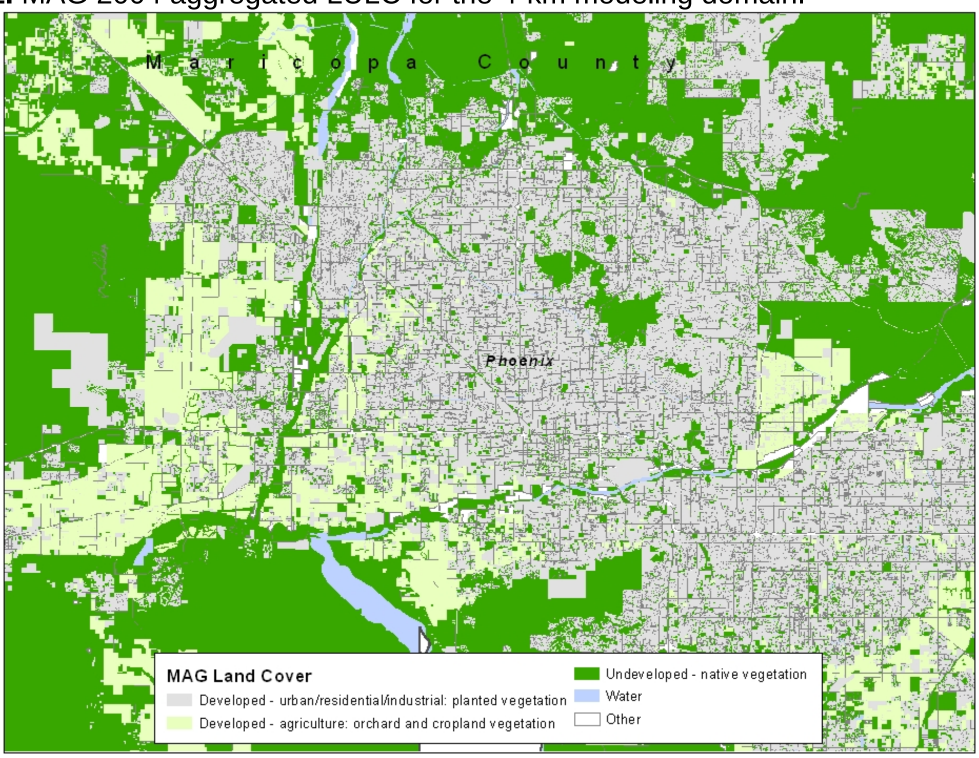

Figure 4-2. MAG 2004 aggregated LULC for the Phoenix urban area.

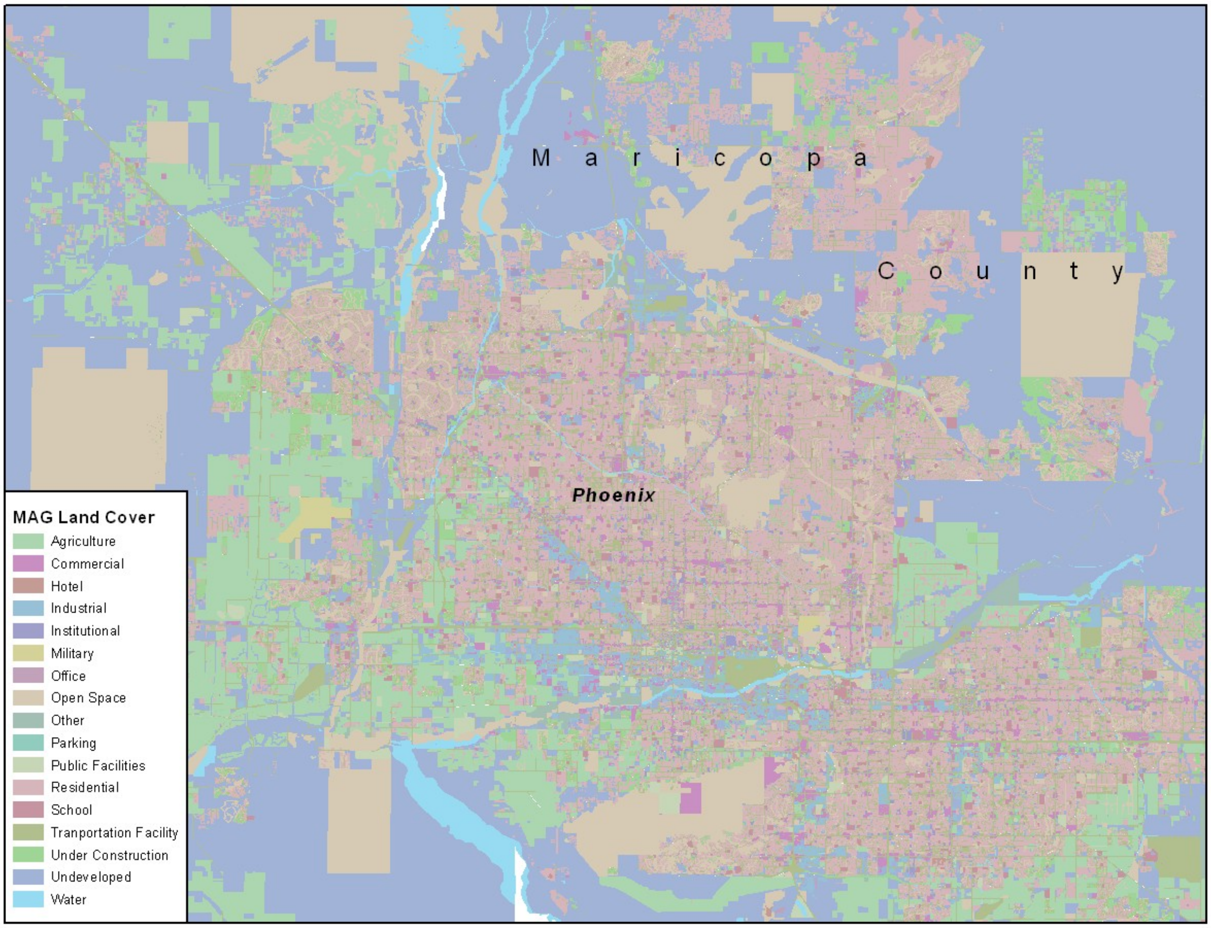

Figure 4-3. MAG 2004 detailed LULC for the Phoenix urban area.

Table 4-2. Landuse classes in the SW Regional GAP LULC database.

Value	LU_Code	Description
1	S001	North American Alpine Ice Field
2	S002	Rocky Mountain Alpine Bedrock and Scree
3	S003	Mediterranean California Alpine Bedrock and Scree
4	S004	Rocky Mountain Alpine Fell-Field
5	S006	Rocky Mountain Cliff and Canyon
6	S007	Sierra Nevada Cliff and Canyon
7	S008	Western Great Plains Cliff and Outcrop
8	S009	Inter-Mountain Basins Cliff and Canyon
9	S010	Colorado Plateau Mixed Bedrock Canyon and Tableland
10	S011	Inter-Mountain Basins Shale Badland
11	S012	Inter-Mountain Basins Active and Stabilized Dune
12	S013	Inter-Mountain Basins Volcanic Rock and Cinder Land
13	S014	Inter-Mountain Basins Wash
14	S015	Inter-Mountain Basins Playa
15	S016	North American Warm Desert Bedrock Cliff and Outcrop
16	S017	North American Warm Desert Badland
17	S018	North American Warm Desert Active and Stabilized Dune
18	S019	North American Warm Desert Volcanic Rockland
19	S020	North American Warm Desert Wash
20	S021	North American Warm Desert Pavement
21	S022	North American Warm Desert Playa
22	S023	Rocky Mountain Aspen Forest and Woodland
23	S024	Rocky Mountain Bigtooth Maple Ravine Woodland

Value	LU_Code	Description
24	S025	Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland
25	S026	Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland
26	S028	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
27	S029	Northern Pacific Mesic Subalpine Woodland
28	S030	Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland
29	S031	Rocky Mountain Lodgepole Pine Forest
30	S032	Rocky Mountain Montane Dry-Mesic Mixed Conifer Forest and Woodland
31	S033	Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland
32	S034	Rocky Mountain Montane Mesic Mixed Conifer Forest and Woodland
33	S035	Madrean Pine-Oak Forest and Woodland
34	S036	Rocky Mountain Ponderosa Pine Woodland
35	S038	Southern Rocky Mountain Pinyon-Juniper Woodland
36	S039	Colorado Plateau Pinyon-Juniper Woodland
37	S040	Great Basin Pinyon-Juniper Woodland
38	S042	Inter-Mountain West Aspen-Mixed Conifer Forest and Woodland Complex
39	S043	Rocky Mountain Alpine Dwarf-Shrubland
40	S045	Inter-Mountain Basins Mat Saltbush Shrubland
41	S046	Rocky Mountain Gambel Oak-Mixed Montane Shrubland
42	S047	Rocky Mountain Lower Montane-Foothill Shrubland
43	S048	Western Great Plains Sandhill Shrubland
44	S050	Inter-Mountain Basins Mountain Mahogany Woodland and Shrubland
45	S051	Madrean Encinal
46	S052	Colorado Plateau Pinyon-Juniper Shrubland
47	S053	Great Basin Semi-Desert Chaparral
48	S054	Inter-Mountain Basins Big Sagebrush Shrubland
49	S055	Great Basin Xeric Mixed Sagebrush Shrubland
50	S056	Colorado Plateau Mixed Low Sagebrush Shrubland
51	S057	Mogollon Chaparral
52	S058	Apacherian-Chihuahuan Mesquite Upland Scrub
53	S059	Colorado Plateau Blackbrush-Mormon-tea Shrubland
54	S060	Mojave Mid-Elevation Mixed Desert Scrub
55	S061	Chihuahuan Succulent Desert Scrub
56	S062	Chihuahuan Creosotebush Mixed Desert and Thorn Scrub
57	S063	Sonoran Paloverde-Mixed Cacti Desert Scrub
58	S065	Inter-Mountain Basins Mixed Salt Desert Scrub
59	S068	Chihuahuan Stabilized Coppice Dune and Sand Flat Scrub
60	S069	Sonora-Mojave Creosotebush-White Bursage Desert Scrub
61	S070	Sonora-Mojave Mixed Salt Desert Scrub
62	S071	Inter-Mountain Basins Montane Sagebrush Steppe
63	S074	Southern Rocky Mountain Juniper Woodland and Savanna
64	S075	Inter-Mountain Basins Juniper Savanna
65	S077	Apacherian-Chihuahuan Piedmont Semi-Desert Grassland and Steppe
66	S078	Inter-Mountain Basins Big Sagebrush Steppe
67	S079	Inter-Mountain Basins Semi-Desert Shrub Steppe
68	S080	Chihuahuan Gypsophilous Grassland and Steppe
69	S081	Rocky Mountain Dry Tundra
70	S083	Rocky Mountain Subalpine Mesic Meadow
71	S085	Southern Rocky Mountain Montane-Subalpine Grassland
72	S086	Western Great Plains Foothill and Piedmont Grassland
73	S087	Central Mixedgrass Prairie
74	S088	Western Great Plains Shortgrass Prairie
75	S089	Western Great Plains Sandhill Prairie
76	S090	Inter-Mountain Basins Semi-Desert Grassland
77	S091	Rocky Mountain Subalpine-Montane Riparian Shrubland
78	S092	Rocky Mountain Subalpine-Montane Riparian Woodland
79	S093	Rocky Mountain Lower Montane Riparian Woodland and Shrubland
80	S094	North American Warm Desert Lower Montane Riparian Woodland and Shrubland
81	S095	Western Great Plains Riparian Woodland and Shrubland
82	S096	Inter-Mountain Basins Greasewood Flat
83	S097	North American Warm Desert Riparian Woodland and Shrubland

Value	LU_Code	Description
84	S098	North American Warm Desert Riparian Mesquite Bosque
85	S100	North American Arid West Emergent Marsh
86	S102	Rocky Mountain Alpine-Montane Wet Meadow
87	S103	Temperate Pacific Montane Wet Meadow
88	S105	Mediterranean California Subalpine-Montane Fen
89	S108	Western Great Plains Saline Depression Wetland
90	S109	Chihuahuan-Sonoran Desert Bottomland and Swale Grassland
91	S111	Madrean Upper Montane Conifer-Oak Forest and Woodland
92	S112	Madrean Pinyon-Juniper Woodland
93	S113	Chihuahuan Sandy Plains Semi-Desert Grassland
94	S114	Sonora-Mojave-Baja Semi-Desert Chaparral
95	S115	Madrean Juniper Savanna
96	S116	Chihuahuan Mixed Salt Desert Scrub
97	S117	Coahuilan Chaparral
98	S118	Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland
99	S120	Western Great Plains Floodplain Herbaceous Wetland
100	S121	Mediterranean California Red Fir Forest and Woodland
101	S122	Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland
102	S123	Mediterranean California Ponderosa-Jeffrey Pine Forest and Woodland
103	S125	Rocky Mountain Foothill Limber Pine-Juniper Woodland
104	S128	Wyoming Basins Low Sagebrush Shrubland
105	S129	Sonoran Mid-Elevation Desert Scrub
106	S132	Western Great Plains Tallgrass Prairie
107	S134	North Pacific Montane Grassland
108	S136	Southern Colorado Plateau Sand Shrubland
109	S138	Western Great Plains Mesquite Woodland and Shrubland
110	N11	Open Water
111	N21	Developed Mixed Desert and Thorn Scrub
112	N22	Developed Medium - High Intensity
113	N31	Barren Lands Non-specific
114	N80	Agriculture
115	D01	Disturbed Non-specific
116	D02	Recently Burned
117	D03	Recently Mined or Quarried
118	D04	Invasive Southwest Riparian Woodland and Shrubland
119	D06	Invasive Perennial Grassland
120	D07	Invasive Perennial Forbland
121	D08	Invasive Annual Grassland
122	D09	Invasive Annual and Biennial Forbland
123	D10	Recently Logged Areas
124	D11	Recently Chained Pinyon-Juniper Areas
125	D14	Disturbed Oil Well

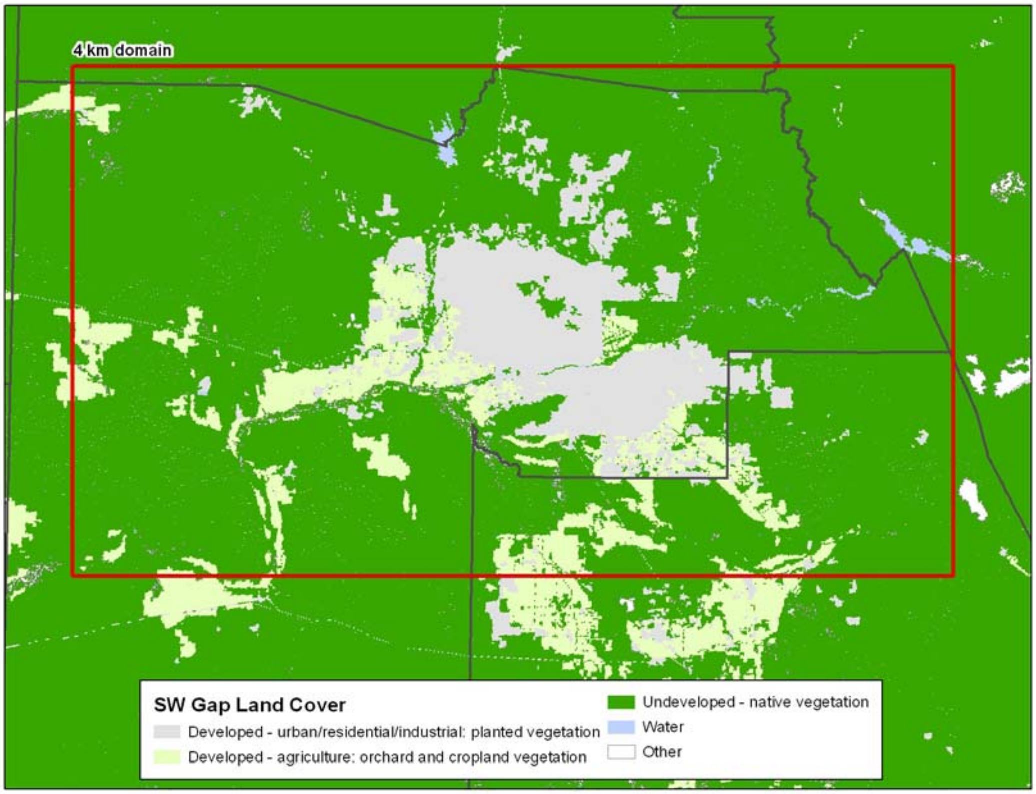

Figure 4-4. SW Regional GAP aggregated LULC for the MAG 4-km modeling domain.

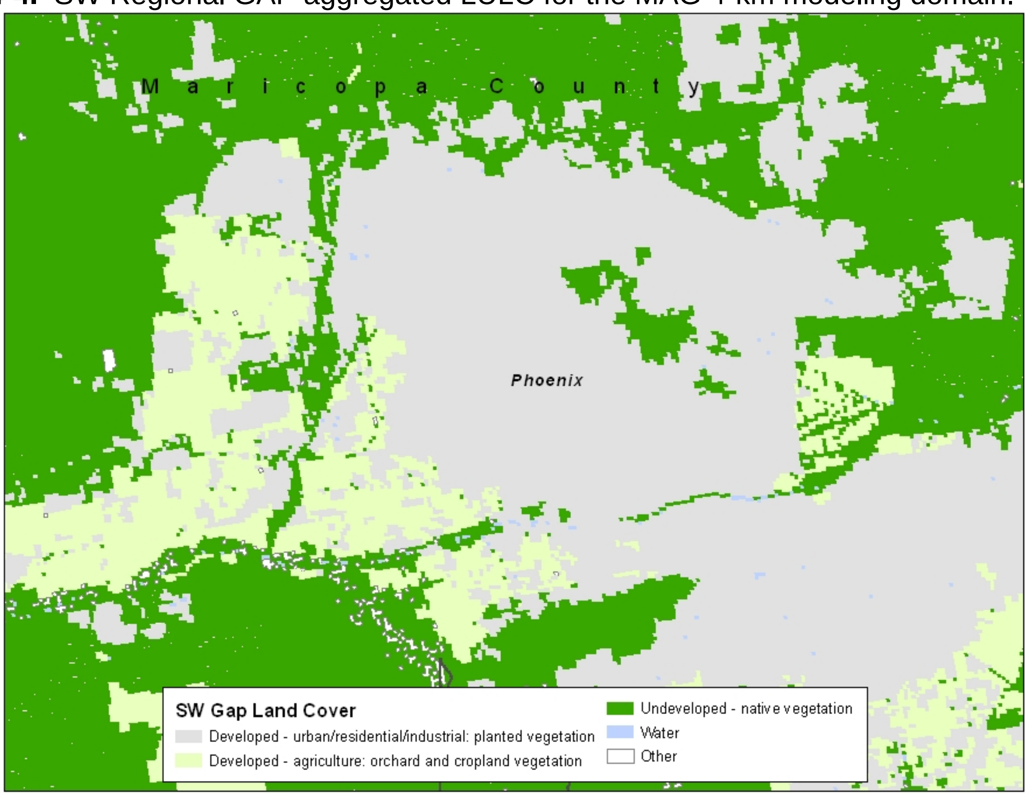

Figure 4-5. SW Regional GAP aggregated LULC for the Phoenix urban area.

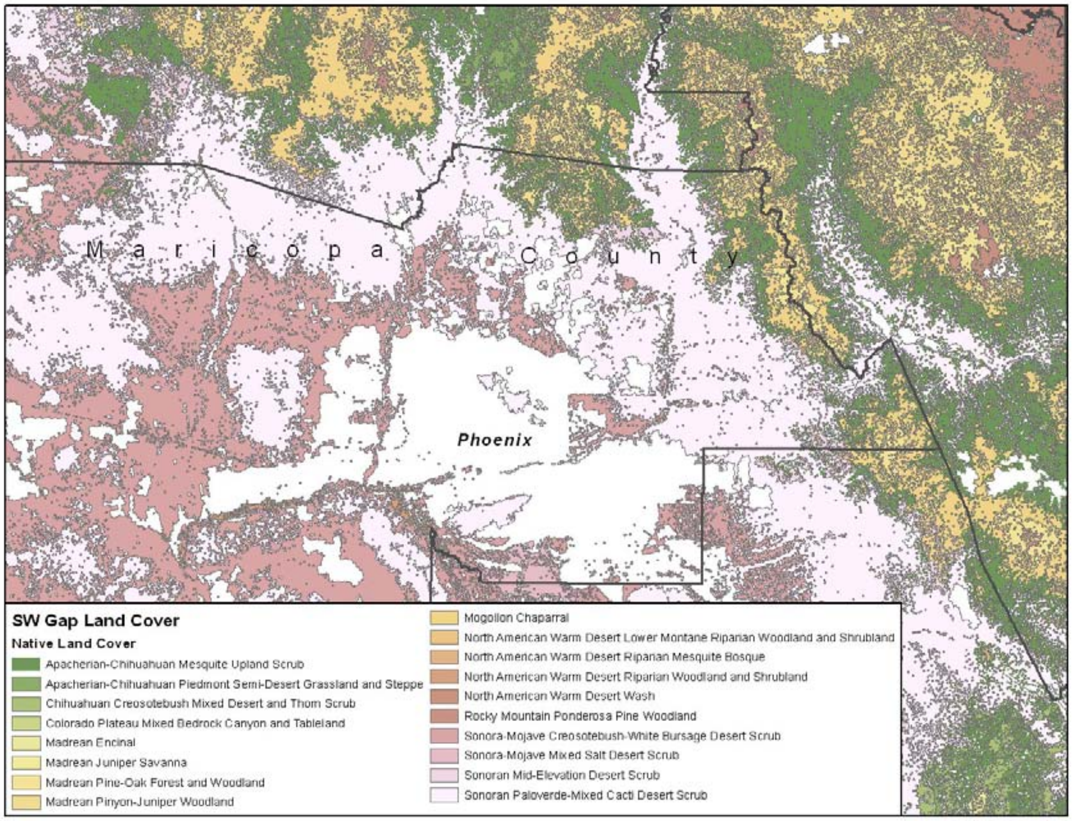

Figure 4-6. SW Regional GAP detailed LULC for the Phoenix urban area.

Table 4-3. Landuse classes in the Stephanov 1998 (S1998) LULC database.

LU_Code	Description
1	Compacted Soil
2	Compacted Soil (prior Agricultural)
3	Cultivated Grass
4	Cultivated Vegetation (Active)
5	Disturbed (Asphalt & Concrete)
6	Disturbed (Commercial/Industrial)
7	Disturbed (Mesic Residential)
8	Disturbed (Xeric Residential)
9	Fluvial & Lacustrine Sediments
10	Undisturbed
11	Vegetation
12	Water

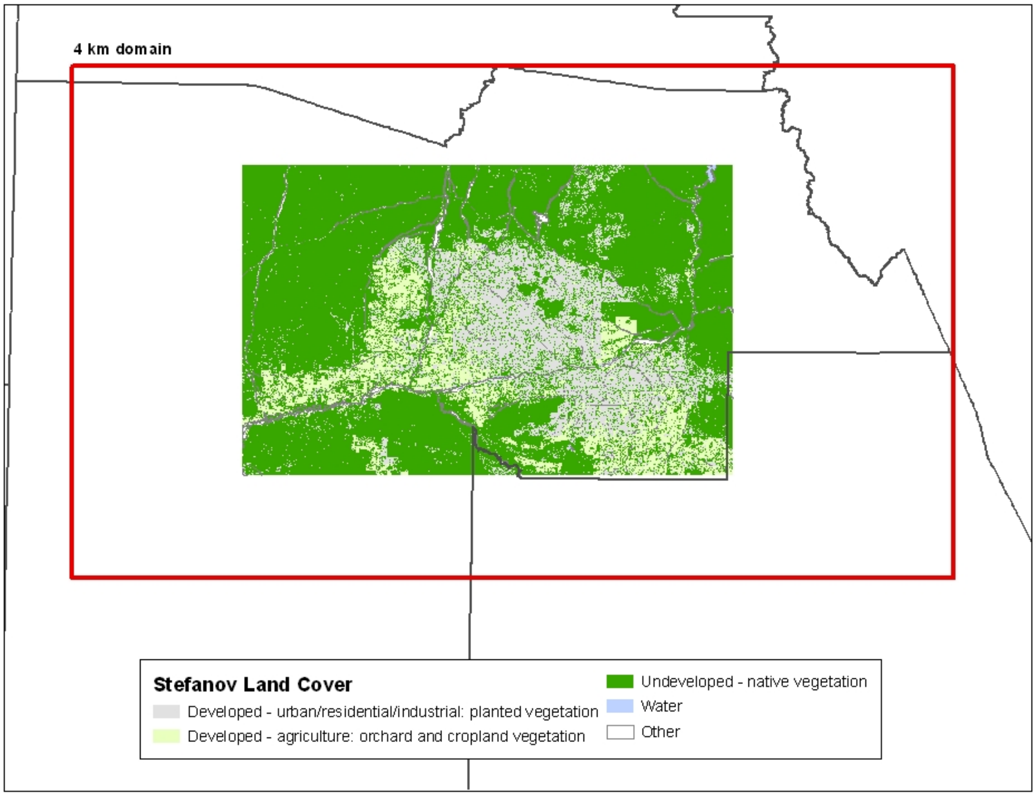

Figure 4-7. Stephanov 1998 aggregated LULC for the MAG 4-km modeling domain.

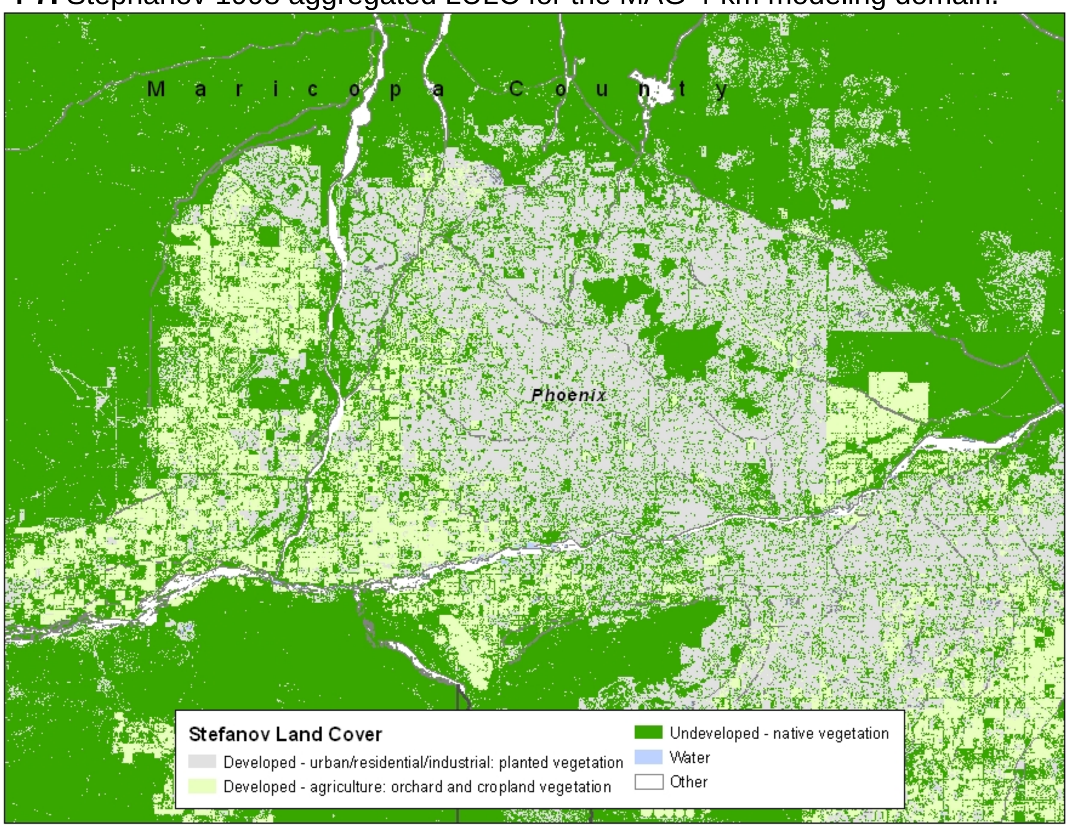

Figure 4-8. Stephanov 1998 aggregated LULC for the Phoenix urban area.

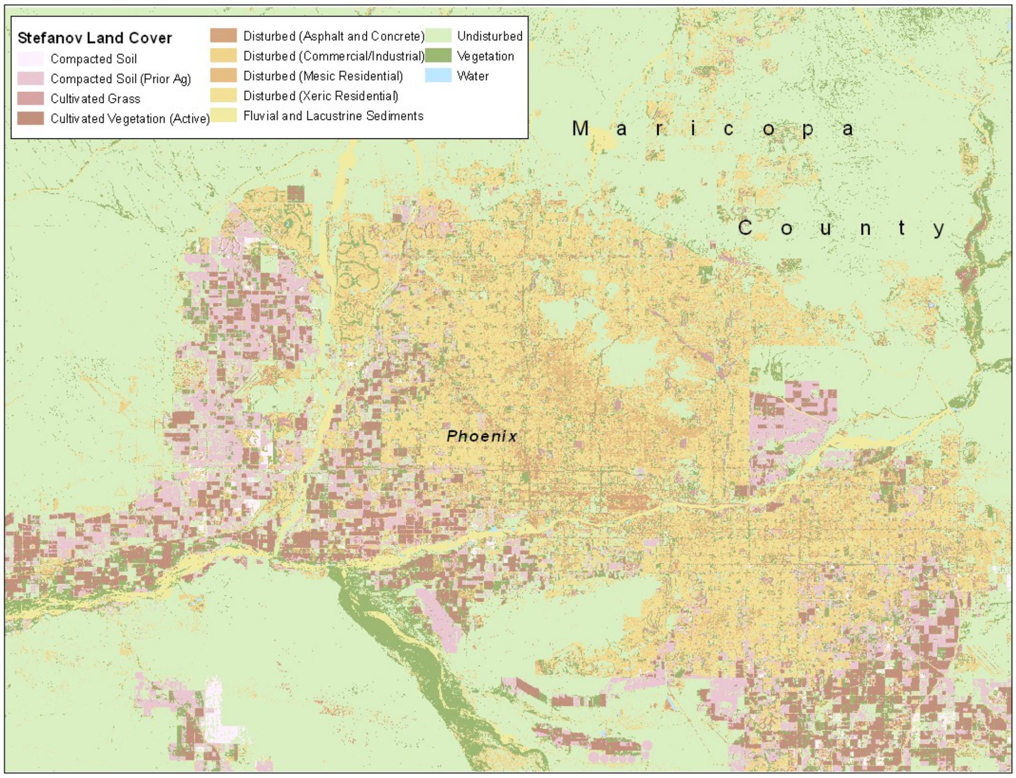

Figure 4-9. Stephanov 1998 detailed LULC for the Phoenix urban area.

5. REVIEW MAG MODELING CHAIN

In this section we provide a review of the MAG modeling chain specifically as it relates to incorporation of the recommended biogenic emission model and the interface with other emission source categories data and the air quality model.

Background

Pursuant to the 1990 Clean Air Act Amendments (CAAA), on April 30, 2004, the EPA designated eight-hour ozone nonattainment areas, effective June 15, 2004. Maricopa County, and part of neighboring Pinal County, was designated as a nonattainment area for eight-hour ozone. The nonattainment area was classified as "Basic" with an attainment date of June 15, 2009. As such, Maricopa County must demonstrate attainment by this date through the development and implementation of a State Implementation Plan. The Maricopa Association of Governments (MAG) is tasked with the responsibility of developing such a plan through emissions inventory modeling and development and air quality modeling to provide supporting technical information and to identify and evaluate control measures and strategies, as necessary, to achieve attainment of the eight-hour ozone standards.

To guide the development of their plan and attainment demonstrations, MAG has prepared a Modeling Protocol (MAG, 2006) which specifies the technical procedures and analyses to be used to support their attainment demonstration. The primary elements of MAG's air quality modeling program, described in detail in the Protocol, include:

- Identify the background, objective, schedule and organizational structure
- Developing the necessary inputs
- Performing quality assurance and diagnostic model analyses
- Conducting model performance evaluations
- Interpreting modeling results and evaluating the relationships between precursor emissions and ozone formation
- Describing the procedures used to evaluate control strategies and demonstrate attainment based on modeling results

A key element of the attainment demonstration is the emission and air quality modeling and analysis. The Protocol specifies the particular models MAG intends to use and their interrelationships via the Air Quality Modeling Chain. In this section we provide a review MAG's AQ Modeling Chain. Specifically as it pertains to the biogenic emission model and processing.

The MAG Air Quality Modeling Chain

Figure 5-1 displays the MAG Air Quality Modeling Chain as presented in MAG's modeling protocol. The modeling chain consists of two primary components: emissions forecasting, or modeling, and; concentration forecasting, or air quality modeling. The emissions forecasting component includes the models and processing steps required for the development of the necessary emissions inventories for air quality modeling. Both anthropogenic and biogenic emissions processing streams are shown, as are the interrelationships among the various components, indicated by the flow of data through the system. Concentration forecasting includes both the meteorological and photochemical dispersion modeling necessary, in conjunction with the emissions inventory data, to simulate and evaluate ambient air quality. As shown, MAG will use the Penn State Fifth generation Mesoscale Meteorological Model (MM5) and the Comprehensive Air quality Model with extensions (CAMx). Although not indicated in Figure 5-1, MAG intends to also utilize the Community Mutli-scale Air Quality Model (CMAQ), as noted in the Protocol, to corroborate and augment their air quality modeling and analyses. As the focus of the current study is the biogenic emissions inventories, we address herein only the emission forecasting component of the Air Quality Modeling Chain. In particular, the integration of the anthropogenic emissions and models for the mobile, area and point source categories, with the biogenic emissions models and processing recommended for the study.

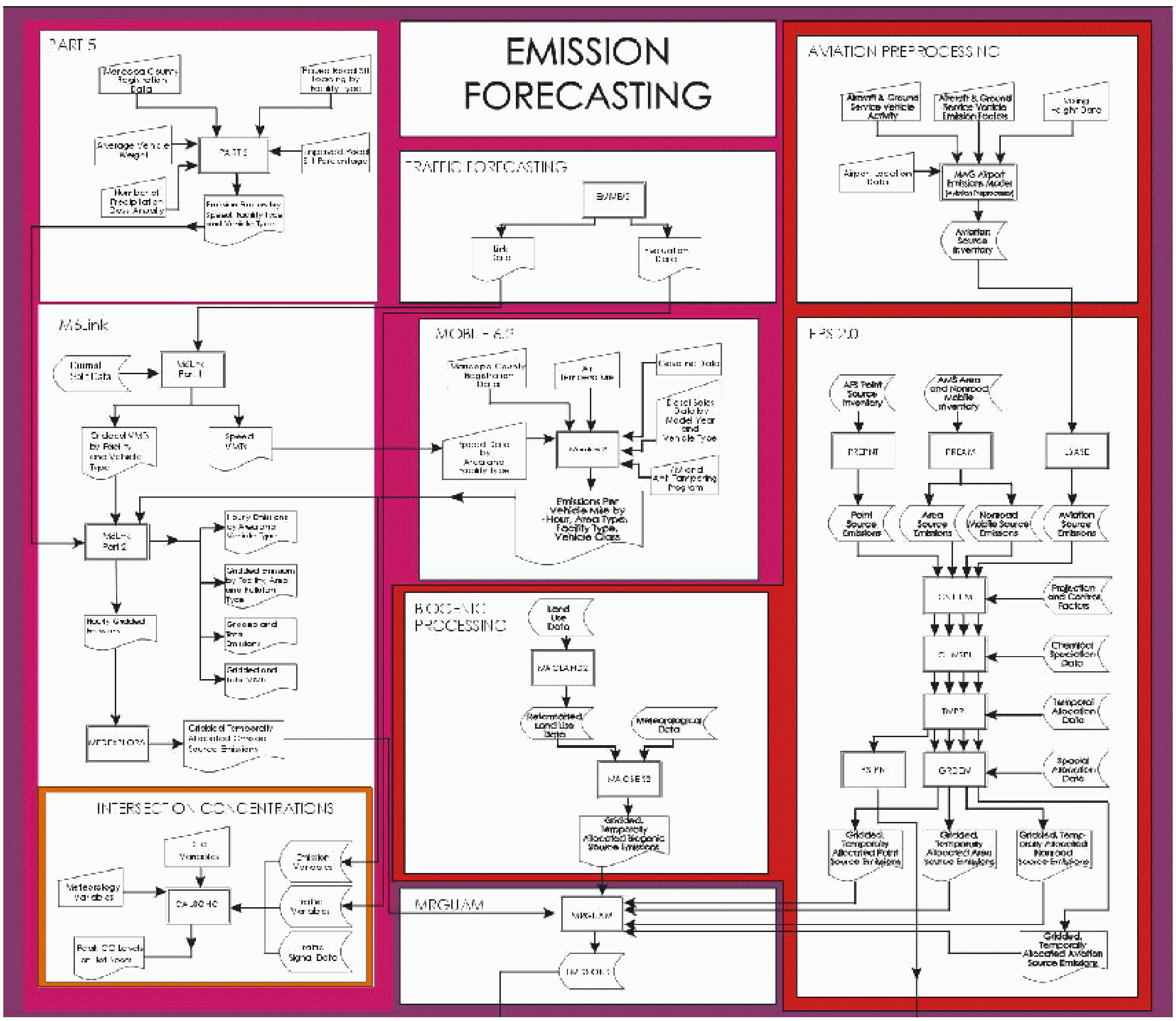

Figure 5-1. MAG Air Quality Modeling Chain (Concentration Forecasting component not shown) (Source: MAG, 2005).

MAG Emissions Forecasting

Overall, the MAG emission forecasting component of the modeling chain consists of the models and processing necessary for development of mobile, area, stationary point source and biogenic emission inventories. The modeling chain includes a detailed treatment of on-road mobile source emissions using specialized models and methodologies, including traffic demand and intersection modeling, aircraft preprocessing and road dust modeling. The traffic demand models are used to generate the on-road mobile source activity data, vehicle miles traveled (VMT) on each road segment, or link, while the MOBILE6.2 model generates emission factors by pollutant, vehicle type and roadway class. On-road mobile emissions are further processed using MAG's M6Link processors to combine activity data and emission factors at the link level, chemically speciate emissions for the mechanism used in the air quality models. Temporal allocation and spatial allocation is performed to generate hourly, gridded and speciated emissions data for on-road mobile sources. The PART5 model estimates emissions from paved and unpaved roads which are combined with other mobile sources within M6Link. Aviation emission sources are processed using MAG's Airport Emissions Model to generate link-based emissions estimates.

Area, non-road mobile and stationary point source emissions are modeled using the Emissions Processing System (EPS). Although the MAG Air Quality Modeling Chain presented in Figure 5-1 indicates the use of version 2 of EPS (EPS2), in fact, MAG will use version 3 of the processing system (EPS3) as stated in the modeling Protocol. Operationally, EPS2 and EPS3 are essentially the same; some additional features are available in EPS3 allowing increased flexibility regarding pollutants processed and detailed reporting and quality assurance. EPS3 also allows the processing of link-based emissions data as necessary to generate gridded data for air quality modeling using the LBASE modules. EPS3 is also the necessary processor for merging all emissions source categories, including biogenic emissions.

Biogenic Emissions Modeling

Biogenic source emissions are typically developed and processed using specialized models. As shown in the modeling chain, this step is independent of the development of the anthropogenic emissions source categories. Biogenic and anthropogenic emissions are merged together for air quality modeling using the MRGUAM module of EPS3. MAG's current modeling chain includes the biogenic emissions processing with the MAGLAND2 and MAGBEIS2 models as shown in Figure 5-2. MAGLAND2 inputs land use data and pre-processes and re-formats the data for input to the MAGBEIS2 model. Meteorological data along with the land use data from MAGLAND2 are used in MAGBEIS2 to generate gridded, hourly resolved and speciated biogenic emissions data.

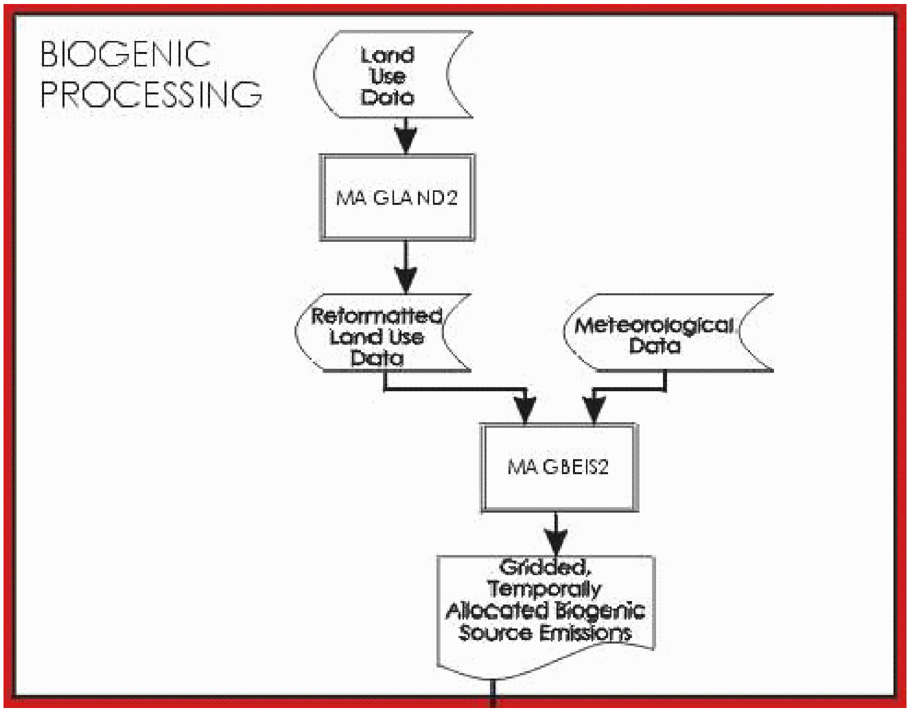

Figure 5-2. Biogenic emissions processing component of the MAG Air Quality Modeling Chain. (Source: MAG, 2005)

As recommended in previous sections of this report, the MEGAN biogenic emissions model should be incorporated into the modeling chain by MAG. The MEGAN model will estimate gridded, temporally resolved and speciated biogenic emissions from landuse and meteorological input data. No additional land use preprocessors, such as MAGLAND2, are required. The output of the MEGAN model will be directly compatible with the anthropogenic source emissions data as generated with EPS3. The MEGAN model will also be revised to allow for the option to output emissions data in NetCDF format, as appropriate for use in the CMAQ air quality model. This feature is being included at the request of MAG staff in anticipation of using the CMAQ air quality model to corroborate results obtained with the CAMx photochemical dispersion model. An issue often associated with the development of NetCDF files for use with CMAQ is the version and compatibility of the NetCDF Input/Output Application Programming Interface (I/O API) libraries. The versions of these libraries currently in use by MAG were reviewed and a determination was made that the most recent versions of these utilities should be used and incorporated into the overall modeling chain. The development of the MEGAN model for use in the MAG biogenic study will address this issue.

The final step in preparation of emissions data for air quality modeling is to merge all the anthropogenic source categories with the biogenic source emissions. As shown in Figure 5-1, this is accomplished using the MRGUAM module of EPS3. The use of MRGUAM results in emissions data that are directly compatible with the CAMx air quality model. The original modeling chain, as presented in MAG's Modeling Protocol, indicates an additional emissions processor, MAGECIP, to convert the output of MRGUMA for input to the air quality modeling system. This processor will no longer be necessary, as emissions generated with EPS3 are already compatible with the CAMx model.

Recommendations

Based on the review of MAG's Air Quality Modeling Chain and for the purpose of documentation of MAG's air quality modeling program, the following recommendations are made:

- The MAG Air Quality Modeling Chain should be revised to reflect the inclusion of the MEGAN biogenic emission model and removal of MAGLAND2 and MAGBEIS2
- The modeling chain should be updated to indicate the use of Version 3 of the Emissions Processing System, EPS3
- References to MAGECIP should be removed
- For completeness, consideration should be given to the inclusion of CMAQ as a supporting air quality model as part of MAG's overall air quality modeling program

6. NEEDS ASSESSMENT

The goal of this biogenics study is to equip the Maricopa Association of Governments (MAG) with a state-of-the-art biogenic emission model that is consistent and integrated with the MAG Air Quality Modeling Chain. This will be accomplished through execution of the following steps:

1) Evaluating existing biogenic emission models;
2) Summarizing data available for improving biogenic emission estimates in the MAG domain;
3) Identifying and conducting high priority field measurements (e.g. land cover and emission measurements); and
4) Delivering an improved biogenic emissions model to MAG.

The MAG biogenics model framework will be easily updated with new parameterizations and driving variables as future research continues to improve our understanding and ability to simulate the processes controlling biogenic emissions.

The February 2006 interim report on the Maricopa Association of Governments 2006 Biogenics study recommends using the MEGAN model to estimate Maricopa County biogenic emissions. This report also identified and described the key land-use and landcover databases and literature reports that are available for developing the driving variables needed to apply MEGAN in Maricopa County. The February 2006 report provided background information for the Needs Assessment report in this document which includes

- a summary of the findings from Tasks 2 through 5,
- suggested improvements to the MAG estimation process and
- an assessment of available observations and field measurements that will be conducted during the June 2006 field study.

Summary of Task 2 through 5 Findings

- Task 2: Comparison of BEIS and MEGAN with MAGBEIS Program: The MEGAN model and various BEIS versions were described in detail. These models, and others (BIEGIS, BIOME3, and GLOBEIS3), were compared and contrasted. The main finding was that MEGAN reflects the current understanding of processes controlling biogenic emissions, and so should provide more accurate biogenic emission estimates. It was also noted that MEGAN has an active research and development program that will provide future updates. In addition, MEGAN allows user developed input so no modified version (i.e. MAGMEGAN) is required.
- Task 3: Review of Previous Biogenic Studies Conducted by MAG and other Entities: The 1996 MAG Biogenics study (Chinkin et al. 1996) and other relevant studies were described in detail. The availability of the information needed for biogenic emission modeling in the MAG domain was assessed and gaps were identified. The man findings were that the emission algorithms used in existing biogenic emission models may not be appropriate for desert landscapes and that no biogenic emission factors are available for some important Maricopa County plant species.

- Task 4: Review MAG Data and Biogenic Projection Methodology: Satellite and ground observations available for characterizing Maricopa County landcover were described in detail. The main findings were that most of the observations needed to develop MEGAN driving variables for Maricopa County are available from existing databases but should be evaluated with field observations. One exception is that landcover characteristics are not available for Tonto National Forest because it is not covered by the NRCS database.
- Task 5: Review MAG Modeling Chain: The MAG air quality modeling chain was reviewed specifically as it relates to incorporation and interfacing of MEGAN. The major findings were that MEGAN could be incorporated into the MAG air quality modeling chain. In addition, the modeling chain should be updated to use the latest emission processing systems.

Suggested Improvements to the MAG Estimation Process

General Recommendation

- We recommend that MEGAN be used to estimate biogenic emissions from Maricopa County. MEGAN is expected to provide more accurate emission estimates and will be easier to update in the future.

Specific Recommendations

- The vegetation cover and species composition of each of the new MAG land use types should be calibrated using available ground measurements and satellite based landcover distributions. The resulting database should then be assessed and the needs for additional vegetation characterization measurements be made. This action is highly cost effective and will lead to improved estimates of the magnitude and distribution of biogenic emissions in Maricopa County.
- Isoprene and monoterpene emission factors of the four or five most dominant plants in urban, desert and agricultural landscapes should be measured. In addition, measurements should also be made for any prevalent plants for which there are few or no reported emission rate measurements. These surveys should include determinations of whether there are light dependent monoterpene emissions. This action is highly cost effective and will lead to improved estimates of the magnitude and distribution of biogenic emissions in Maricopa County.
- Sesquiterpene and oxygenated VOC emission factors are almost completely unknown for plants in Maricopa County (and in most other places) but recent studies indicate that sesquiterpene emissions may be the primary source of biogenic secondary organic aerosol in some landscapes. This action requires significant effort but is important if accurate characterization of aerosol is important for MAG.
- The ability of existing model algorithms to simulate isoprene and monoterpene emission rate variations should be evaluated with field measurements in desert landscapes. The influence of high light and high temperature should be targeted. This action will require a moderate effort that can significantly improve MAG emission estimates.

Needs Assessment

Maricopa County land-use includes about 80% wildlands, 12% urban and other developed use, and 8% agriculture. The distribution of these major land-use types represented in three different databases, shown in Figure 6-1, generally agrees but there are some significant differences. Given the rapid decline of agricultural lands, we expected the MAG2004 database to have developed lands where the Stephanov (representative of 1998) and SWregGAP (representative of ~2000) databases have agricultural lands. However, the area indicated in Figure 6-1 with a blue circle shows several areas that are designated as agricultural land in the MAG2004 database and are classified as wildland by the Stephanov and/or SWregGAP databases. Figures 6-2 and 6-3 illustrate the main databases available for characterizing urban and wildlands, respectively.

The June 2006 field study measurements will be conducted in the areas indicated in Figure 6-4. Field activities will include 1) biogenic volatile organic compound (BVOC) emission measurements, 2) aerial reconnaissance, 3) and ground surveys measurements of landcover characteristics. BVOC measurements will be made using two in-situ enclosure measurement systems. Each system consists of a gas exchange enclosure and a portable gas chromatograph with flame ionization detector that is optimized for identifying and quantifying biogenic terpenoid concentrations. Aerial reconnaissance will be conducted using a light aircraft and geo-located high resolution digital photography. Ground landcover surveys will use a combination of step-point transects for grasslands and occular cover surveys for shrublands and woodlands.

Landcover and emissions data needs for urban, wildlands and agricultural lands are assessed in the following sections and high priority measurements for the June 2006 field study are identified. Tables 6-1 through 6-6 summarize the available databases and the planned field measurements and indicate how they will be integrated to generate the required MEGAN driving variables.

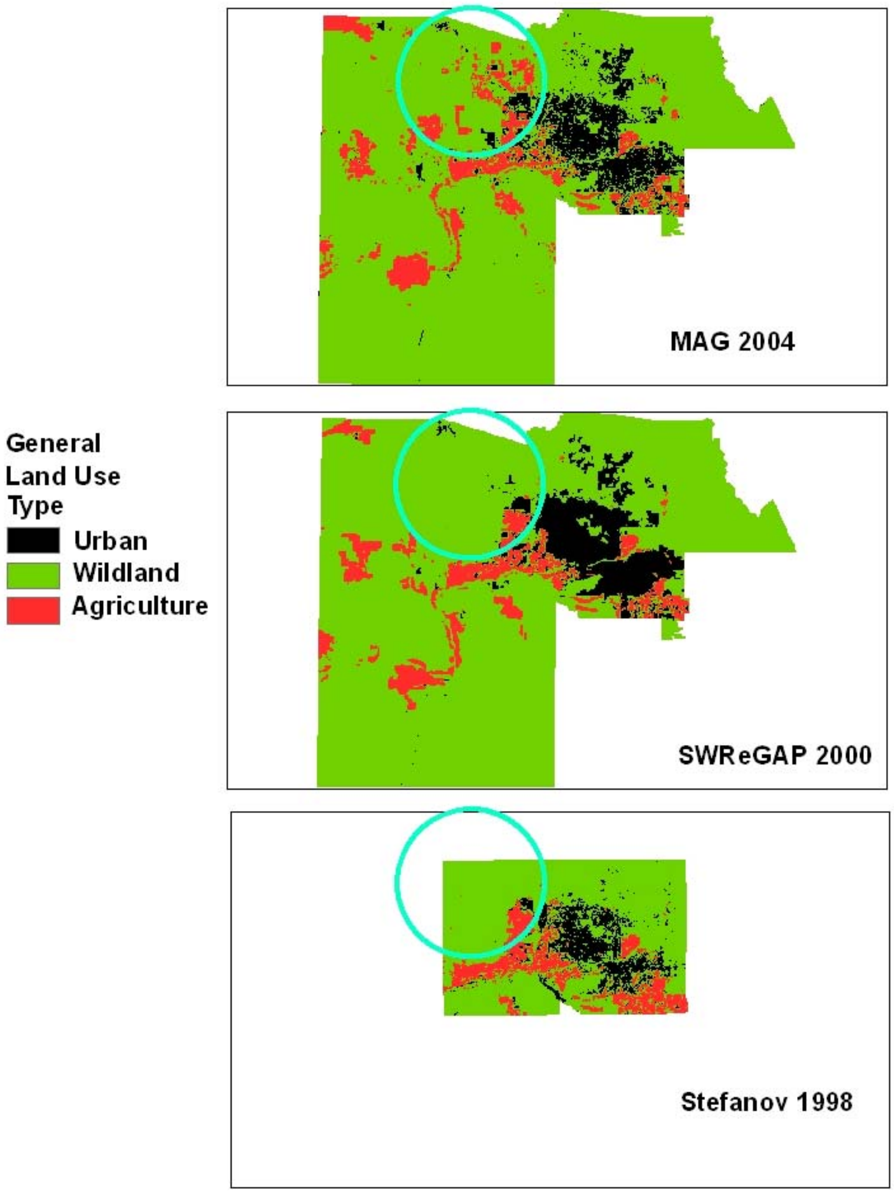

Figure 6-1. MAG 2004, SWReGAP and Stefanov land-use distributions. Blue circle indicates area of disagreement.

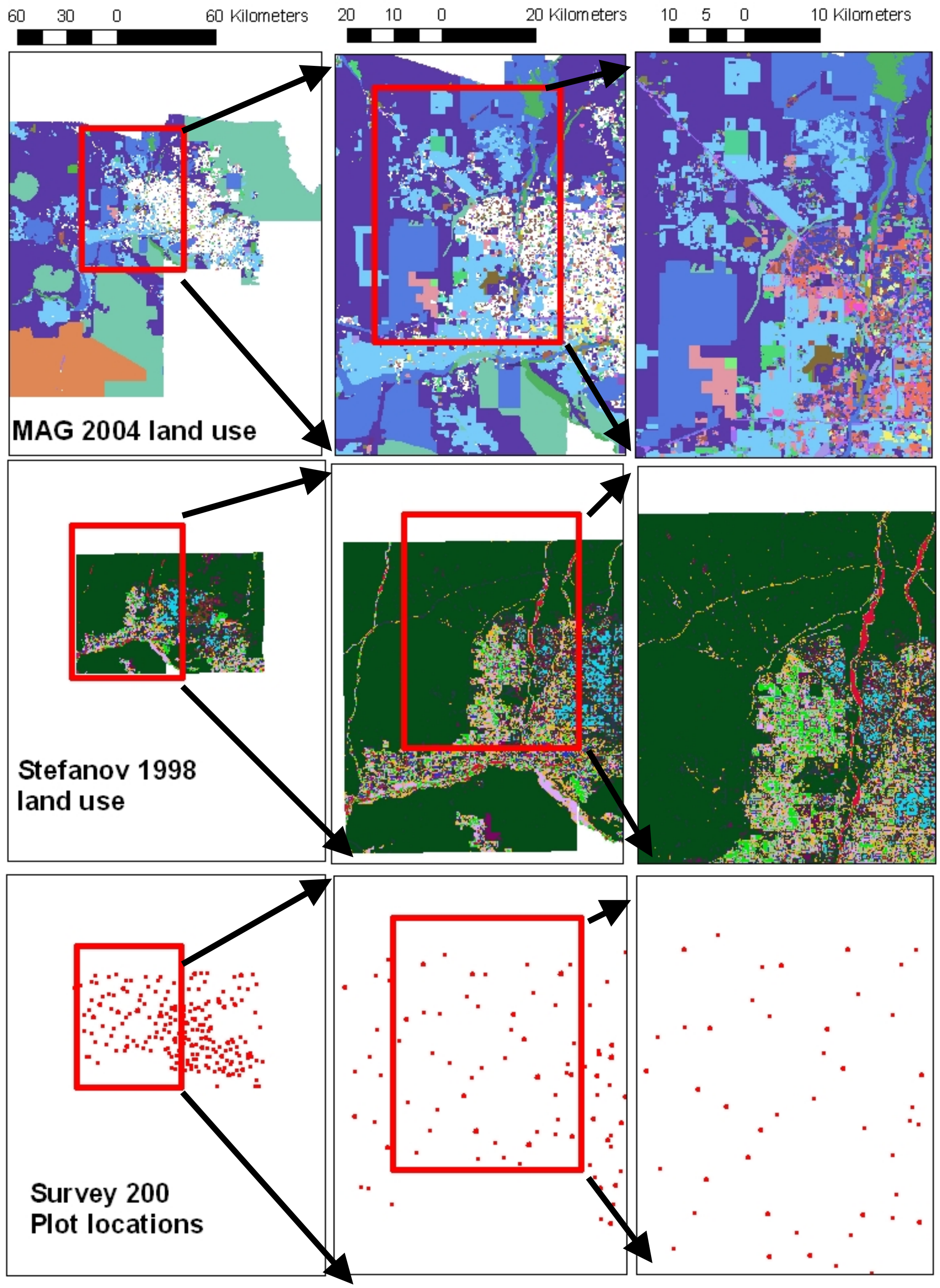

Figure 6-2. MAG 2004, Stefanov and Survey 200 land characteristics for urban areas. Leftmost column shows distributions for all of Maricopa County.

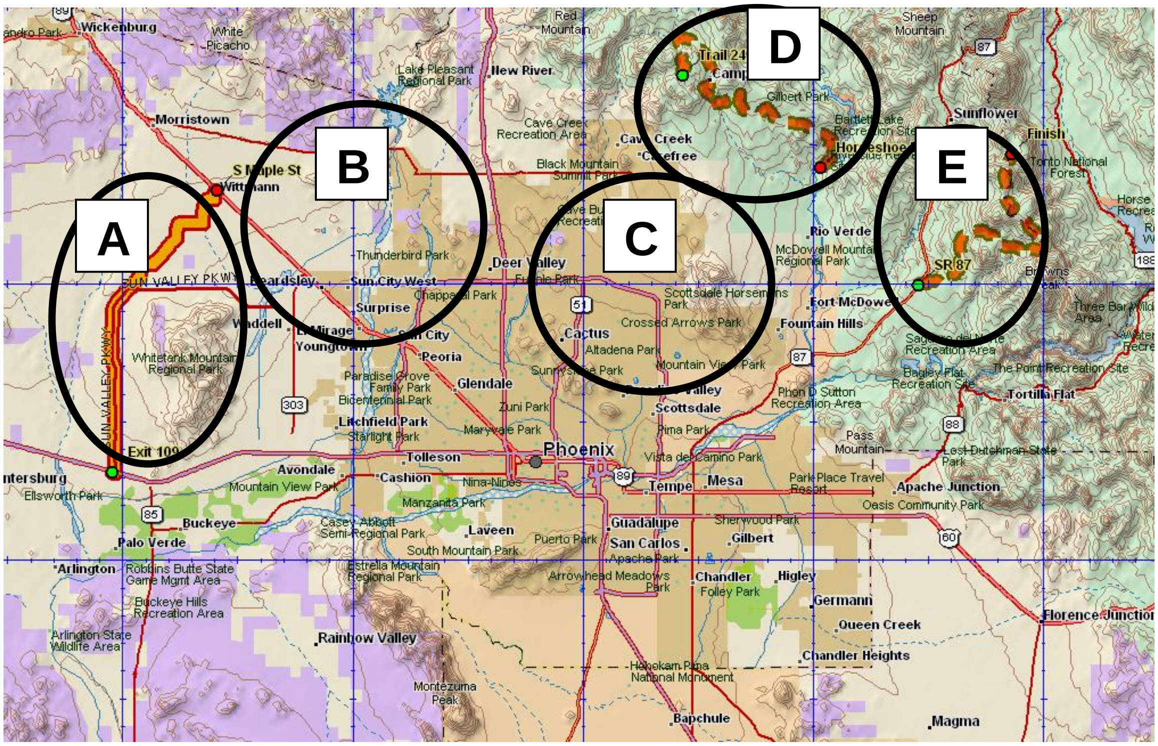

Figure 6-4. General locations of planned Maricopa County field measurements. Aerial reconnaissance will be conducted in all regions. Ground landcover surveys will focus on regions D and E in Tonto National Forest but will include some transects in other regions.

Assessment of urban lands

Table 6-1. Summary of available data for developing MEGAN driving variable databases for urban portions of Maricopa County.

Available Database	**Land-use classification**	**PFT cover fractions**	**LAI**	**Species composition**	**Species BVOC emission rates**
MAG2004 land-use database	Primary source				
Stefanov land-use database		Extrapolate MEGAN urban PFT			
SURVEY200 landcover database		Calibrate MEGAN urban PFT		Primary source	
MEGAN urban PFT cover database		Primary source			
Literature values			Primary source		Primary source

Table 6-2. Summary of additional data needed for developing MEGAN driving variable databases for urban portions of Maricopa County.

June 2006 field study activity	Land-use classification	PFT cover fractions	LAI	Species composition	Species BVOC emission rates
Aerial Reconnaissance	Evaluate				
Emission measurements					Determine emission factors for >12 genera

Land use classification

Maricopa County urban land use covers ~ 12% of the total land area. The MAG2004 land use database includes 74 different urban land use types. However, five land use types cover ~ 60% of the urban area. These include MAG2004 code 610 (Transportation), 140 (Medium lot residential), 120 (Estate Residential), 150 (small lot residential), and 910 (Developing residential). In addition, over 90% of the urban land area is comprised of just 19 land use types. The remaining 10% of the urban area is divided into 55 land use types that each cover an average of only 0.18% of the urban area (which is only 0.02% of Maricopa County). Table 6-1 illustrates the landcover scheme we will use to represent Maricopa County urban areas. The 74 MAG2004 land use types are collapsed into 12 land use types and then expanded into 22 landcover types by identifying areas of high and low vegetation density within each of the land use areas.

Biogenic emissions from urban area vegetation will directly mix with the urban plume and may be more likely to impact Maricopa County air pollution. In addition, the biomass density of the urban area is expected to be higher than the surrounding desert wildlands and so may have a greater contribution to total BVOC emissions than what would be expected by the small area.

PFT cover fractions

The standard global MEGAN PFT distributions (Guenther et al. 2006) are not expected to be representative of the actual PFT distributions in any urban area. In response to this known deficiency, NCAR has developed an urban MEGAN PFT database that is based on very high resolution geo-referenced digital imagery (earth.google.com). The urban PFT distributions for Maricopa County have been incorporated into the MEGAN PFT database that has been transmitted to MAG. It is the first of several urban areas that will be characterized and incorporated into the MEGAN PFT database and was chosen because of the availability of existing ground truth (the SURVEY200 database) and satellite (the Stephanov database) observations in Maricopa County. The MEGAN urban PFT cover database for Maricopa County builds on the already extensive SURVEY200 database and is expected to provide reasonable estimates of urban PFT cover areas.

LAI

The standard global MEGAN LAI distributions (Guenther et al. 2006) are not expected to be representative of the actual LAI distributions in any urban area. Instead, we have used literature values in a manner similar to that used for BEIS3.

Species composition

An initial assessment integrating the MAG2004 land use distributions and the SURVEY200 species composition data indicates that the urban Maricopa County area covered by woody vegetation is ~40% exotic trees, ~35% shrubs, 20% native tree/shrub and 5% cacti. Urban cacti cover is dominated by *Yucca* and *Opuntia* (e.g., Texas Prickly Pear) species. The native tree/shrub area is covered by *Prosopis* (Mesquite) and *Parkinsonia* (palo verde). More than a third of the urban shrub cover is associated with *Larrea* (Creosote bush) species. The remaining shrub cover is dominated by *Eriogonum* (California Buckwheat), *Simmondsia* (jojoba), *Leucophyllum* (e.g., Texas Sage) and *Nerium* (e.g., Oleander) species. Members of the *Fraxinus* (e.g. Tropical Ash), *Citrus* (e.g., Orange), *Morus* (e.g. White Mulberry), *Ulmus* (e.g., Chinese Elm), *Pinus* (e.g. Aleppo Pine), and *Rhus* (e.g., African Sumac) genera each cover 5 to 10% of the urban tree area while *Populus* (e.g. Fremont cottonwood), *Acacia*, *Washingtonia* (Mexican Fan Palm), *Eucalyptus*, *Melia* (Chinaberry), *Brachychiton* (e.g., Lacebark Kurrajong), *Lysiloma* (e.g., Desert Fern), *Olea* (olive), *Phoenix* (e.g., Date Palm), *Juniperus* (e.g., Chinese Juniper), *Ficus* (fig), *Thevetia* (e.g., luckynut), and *Carya* (e.g., pecan) species each contribute 2 to 5% of the total. The extensive SURVEY200 study (see Hope et al. 2003 and http://caplter.asu.edu/home/survey200/index.jsp) provides an excellent tool for characterizing Maricopa urban area species composition. An effort that could significantly enhance the SURVEY200 data base is beyond the scope of this project.

Species specific emission factors

Of the 28 dominant Maricopa County urban woody genera described above, the BVOC emission factors of six genera (*Acacia, Citrus, Eucalyptus, Ficus, Pinus, Populus*) have been studied extensively. Measurements have shown that two of these genera (*Acacia* and *Pinus*) have very different BVOC emission characteristics for different species in the genera. However, most of the specific species that occur in Maricopa County have been examined. Emission factors for another ten genera (*Carya, Fraxinus, Juniperus, Morus, Olea, Phoenix, Prosopis, Rhus, Ulmus, Washingtonia*) have been investigated in more than one study while a single study (and in some cases a single measurement) have characterized BVOC emissions from five of the genera (*Eriogonum, Larrea, Melia, Nerium, Opuntia*). There have been no reported BVOC measurements of any species of seven genera (*Brachychiton, Leucophyllum, Lysiloma, Parkinsonia, Simmondsia, Thevetia, Yucca*).

BVOC emission measurements of the dominant species of the seven genera that have not previously been investigated, and the five genera with very few measurements, will be a high priority. Species that have previously been studied but make a large contribution to the urban cover (especially *Prosopis* but also *Citrus, Fraxinus, Morus, Ulmus, Pinus and Rhus*) will also be a high priority.

Assessment of wildlands

Table 6-3. Summary of available data for developing MEGAN driving variable databases for wildland portions of Maricopa County including Tonto National Forest (TNF).

Available Database	Land-use class	PFT cover fractions	LAI	Species composition	Species BVOC emission rates
MAG2004 land-use database	Primary source				
NRCS landcover database		Primary source except TNF	Primary source except TNF	Primary source except TNF	
SWReGAP landcover database		Extrapolate field data in Tonto N.F.	Extrapolate field data in Tonto N.F.	Extrapolate field data in Tonto N.F.	
SURVEY200 landcover database		Evaluate NRCS		Primary source	
Literature values					Primary source

Table 6-4. Summary of additional data needed for developing MEGAN driving variable databases for wildland portions of Maricopa County including Tonto National Forest (TNF).

June 2006 field study activity	Land-use class	PFT cover fractions	LAI	Species composition	Species BVOC emission rates
Aerial Reconnaissance	Evaluate	Evaluate			
Landcover transects		Evaluate; Primary source for TNF	Evaluate; Primary source for TNF	Evaluate; Primary source for TNF	
Emission measurements					Determine emission factors for >12 genera

Land use classification

The seven wildland land use categories in the MAG2004 land use database cover about 80% of Maricopa County. Almost 99% of the wildlands are covered by just four of these land-use types: Vacant (MAG2004 code 900), Passive open space (MAG2004 code 730), Restricted open space (MAG2004 code 731), and active open space (MAG2004 code 710). Two of the other categories (MAG2004 codes 700 and 573) have been grouped with one of the major four wildland land use types in Table 6-1 while water (MAG2004 code 740) is left as a category. An assessment with the Stefanov database suggests that about a third of the MAG2004 water category is covered by vegetation, probably riparian. Table 6-1 shows that the four major wildland land use types have each been expanded into 2 to 5 landcover types.

PFT cover fractions

PFT cover fractions can be estimated from the NRCS database for all of Maricopa County except for Tonto National forest. PFT cover fraction for Tonto National forest will be determined by ground surveys during the June 2006 field study and will be extrapolated using the SWReGAP database.

LAI

LAI can be estimated from the NRCS database forage distribution data for all of Maricopa County except for Tonto National forest. LAI for Tonto Natonal forest will be determined by ground surveys during the June 2006 field study and will be extrapolated using the SWReGAP database. These observations will also be compared with the MODIS satellite LAI product, used as the standard MEGAN LAI data.

Species composition

The NRCS data records 126 plant species in Maricopa County (excluding Tonto National Forest) that comprise 72% of the total foliar biomass. The remaining plants were unidentified. Shrubs and grasses each comprise ~40% of the total foliar mass. Tree/shrub contribute about 16% and the remainder is cacti (mostly *Opuntia* species). Of the identified plants, > 75% of the foliar biomass was comprised of just 14 plant species belonging to 11 genera. Over 90% of the identified biomass was comprised of 31 species that are members of 25 different genera. About two-thirds of the total shrub foliar mass is associated with *Larrea* and *Ambrosia* species. Genera contributing 2 to 7% of the shrub total include *Krameria, Encelia, Atriplex, Lycium*. Five other shrub genera (*Fouquieria, Simmondsia, Calliandra, Ephedra,* and *Suaeda*) each contribute 1 to 2% of the total shrub foliar mass. together comprise ~18% of the total identified foliage. About a third of the tree/shrub foliage is comprised of *Parkinsonia* (Palo Verde) with important contributions from *Prosopis* (mesquite), *Olneya* (Ironowood) and *Acacia*. The grass/forb foliage is dominated by *Muhlenbergia, Pleuraphis* and *Aristida* species with additional contributions from *Tridens, Digitaria, Eriogonum* and *Hilaria* species.

In addition to some of the genera reported in the NRCS data, the SWReGAP data for the Maricopa County portion of Tonto National Forest indicate the presence of three important tree genera: *Pinus, Juniperus,* and *Quercus*.

Species specific emission factors

Of the dominant 26 Maricopa County wildland plant genera, the BVOC emission factors of three genera (Acacia, Pinus, Quercus) have been studied extensively. Measurements have shown that all of these genera have very different BVOC emission characteristics for different species in the genera. Emission factors for another three genera (Atriplex, Juniperus, Prosopis,) have been investigated in more than one study while a single study (and in some cases a single measurement) have characterized BVOC emissions from eight of the genera (Encelia, Ephedra, Eriogonum, Krameria, Larrea, Lycium, Olneya, Opuntia). There have been no reported BVOC measurements of any species of eleven genera (Aristida, Calliandra, Digitaria, Fouquieria, Hilaria, Muhlenbergia, Parkinsonia, Pleuraphis, Simmondsia, Suaeda, and Tridens).

BVOC emission measurements of the dominant species of the genera that have few or no measurements will be a high priority. Species that have previously been studied but make a large contribution to the wildland vegetation cover will also be a priority.

Assessment of agricultural lands

Table 6-5. Summary of available data for developing MEGAN driving variable databases for agricultural portions of Maricopa County.

Available Database	Land-use class	PFT cover fractions	LAI	Species composition	Species BVOC emission rates
MAG2004 land-use	Primary source				
SURVEY200		Evaluate	Evaluate	Evaluate	
USDA NASS census				Primary source	
Literature values			Primary source		Primary source

Table 6-6. Summary of additional data needed for developing MEGAN driving variable databases for agricultural portions of Maricopa County.

June 2006 field study activity	Land-use class	PFT cover fractions	LAI	Species composition	Species BVOC emission rates
Aerial Reconnaissance	Evaluate	Evaluate			
Emission measurements					Determine emission factors for *Citrus, Carya*

Land use classification

The MAG2004 land use database indicates that agricultural covered ~8% of Maricopa County. Much of this area is located near urban areas and any BVOC emissions from these landscapes would be likely to interact with the urban plume. The MAG2004 land use scheme has two agricultural land use types but one of these, general agriculture (MAG2004 code 750), covers more than 99% of agricultural lands while the other, Nurseries and greenhouses (MAG2004 code 203) covers less than 1%. In addition, our analysis of the Stefanov 30-m resolution data base shows that both “general agriculture” and “nurseries, greenhouses) are covered by ~ 50% high density vegetation, ~40% desert and other low density vegetation, and ~10% barren. As shown in Table 6-1,we will divide MAG2004 code 750 into “crops” (LC42 code 41) and “orchards/nurseries” (LC42 code 41). MAG2004 code 203 will be considered “orchards/nurseries” (LC42 code 41).

The USDA NASS census results from 1987 to 2002 show that there has been a steady decline in Maricopa agriculture lands. Total cropland declined about ~2% per year from 1987 to 1992 and ~4% per year from 1992 to 2002.

PFT cover fractions

USDA NASS 2002 census statistics indicate that Maricopa agricultural lands are 5.4% broadleaf trees (orchards) and 94.6% croplands. There is no available database that provides the spatial distribution of orchards vs. croplands. Since orchards are expected to have substantially different emission factors than croplands, quantifying the spatial distributions of orchards, using aerial photography and discussions with county agricultural experts, could improve the accuracy of the spatial distribution of emission estimates if all of the orchards are concentrated in one region. However, the relatively small contribution (only 5.4%) of agricultural lands makes this only a moderate priority. We will determine if the orchards are concentrated in one region, and if so then we will identify the location of this region. Aerial photography will also be used estimate cover fraction (i.e. fraction of bare ground) of crop and orchard lands.

LAI of vegetation covered surface

The standard MEGAN LAI database may not be representative of Maricopa County agricultural lands. If so, then agricultural land LAI peak values and seasonal variations will be determined from literature values and by discussions with county agricultural experts. USDA NASS statistics indicate that all Maricopa farmland is irrigated. It is thus unlikely that agricultural land LAI is limited by seasonal precipitation patterns.

Species composition

The USDA NASS 2002 statistics show that Maricopa County orchards were composed of 72% citrus species (about half oranges with the remainder including lemons, grapefruit and tangelos) and 6% pecans. Maricopa County croplands were 50% alfalfa/hay, 26% cotton, 9% barley, 7% wheat, 3% cantaloupes, and ~1% each for broccoli, watermelon, sorghum, cabbage and beans in 2002. The crops vary considerably for different census periods. For example, there was ~50% decrease in cotton, sorghum, corn and wheat and ~40% increase in alfalfa/hay and barley from 1997 to 2002. The availability of reliable county wide statistics and the large year-to-year variability limit the value of any additional efforts to characterize Maricopa County agricultural species composition.

Species specific emission factors

Isoprene and monoterpene emission factors are already available for dominant Maricopa County cropland and orchard species from results of greenhouse studies and field studies in other regions. In most cases, there are only results from one or two studies. However, given the availability of these emission factor measurements and the large year-to-year variability in the agricultural land species composition, improved emission factor estimates for agricultural vegetation species is not a priority for the June 2006 field study.

7. BIOGENICS FIELD STUDY

The major objectives of the June 2006 MAG biogenics field study included

- Quantitative plant species composition and cover fraction for all major wildland landcover types in Maricopa County.
- Quantify isoprene and monoterpene emission rates for the dominant Maricopa County plants. Characterize temperature and light dependence.

The study was conducted from June 11 to 23 and all of the major objectives were accomplished.

Landcover Characterization

Landcover was characterized at approximately 100 sites around Maricopa County at the locations shown in Figure 7-1. The sites were chosen to represent all of the major wildland landcover types which ranged from forest in northeastern Maricopa county (Figure 7-2) to desert scrubland in southwestern Maricopa county (Figure 7-3). The location of each site with respect to the dominant wildland landcover types is show in Figure 7-4. Aerial digital photographs were obtained during the study along the flight path shown in Figure 7-5. These images will be used to determine the variability in plant cover distributions within the GAP landcover types.

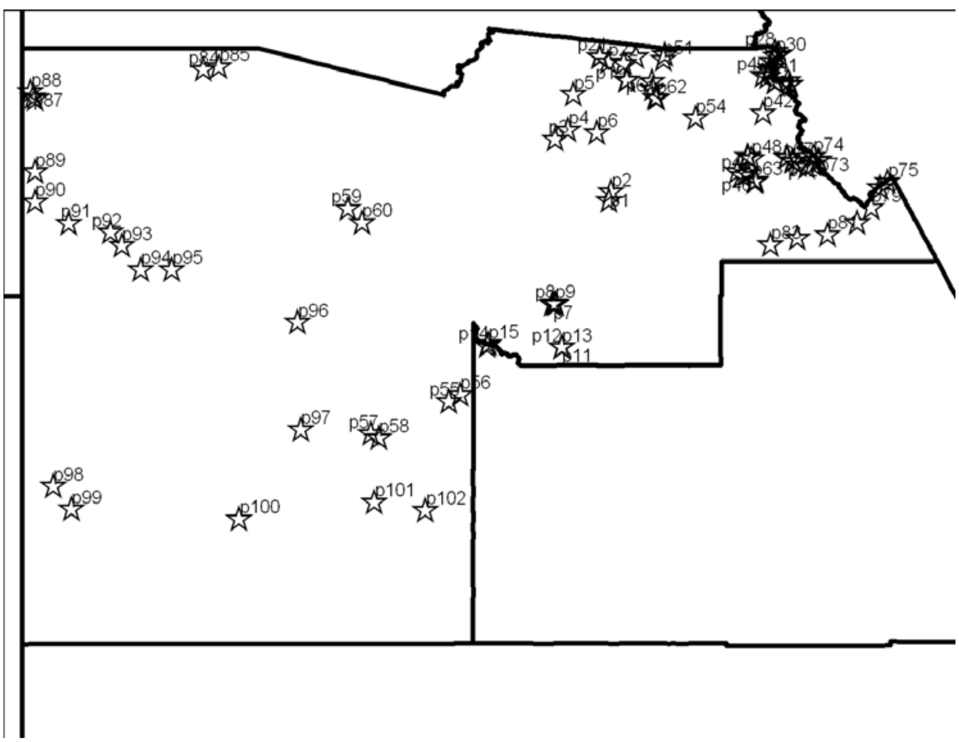

Figure 7-1. Location of the MAG biogenic study survey sites.

Figure 7-2. Pine-oak forest in northeastern Maricopa County (Plot #30).

Figure 7-3. Sonoran desert creosotebush in southwestern Maricopa County (plot #100).

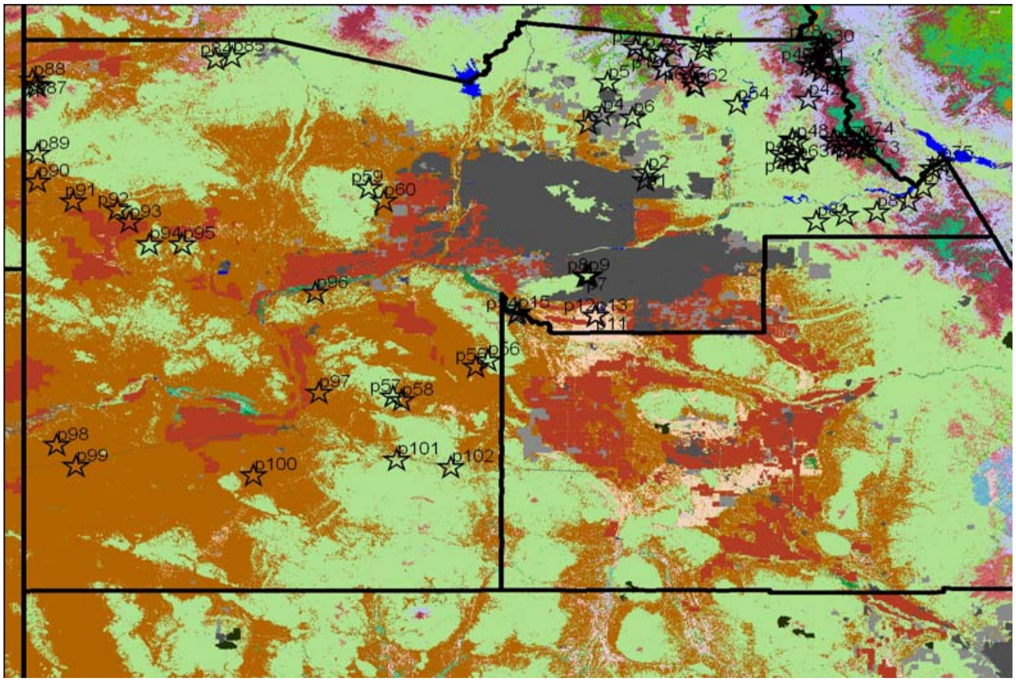

Figure 7-4. Location of the MAG biogenics study survey sites with respect to the GAP landcover distribution. The selected sites include locations representative of all the dominant landcover types (shown as different colors in this figure).

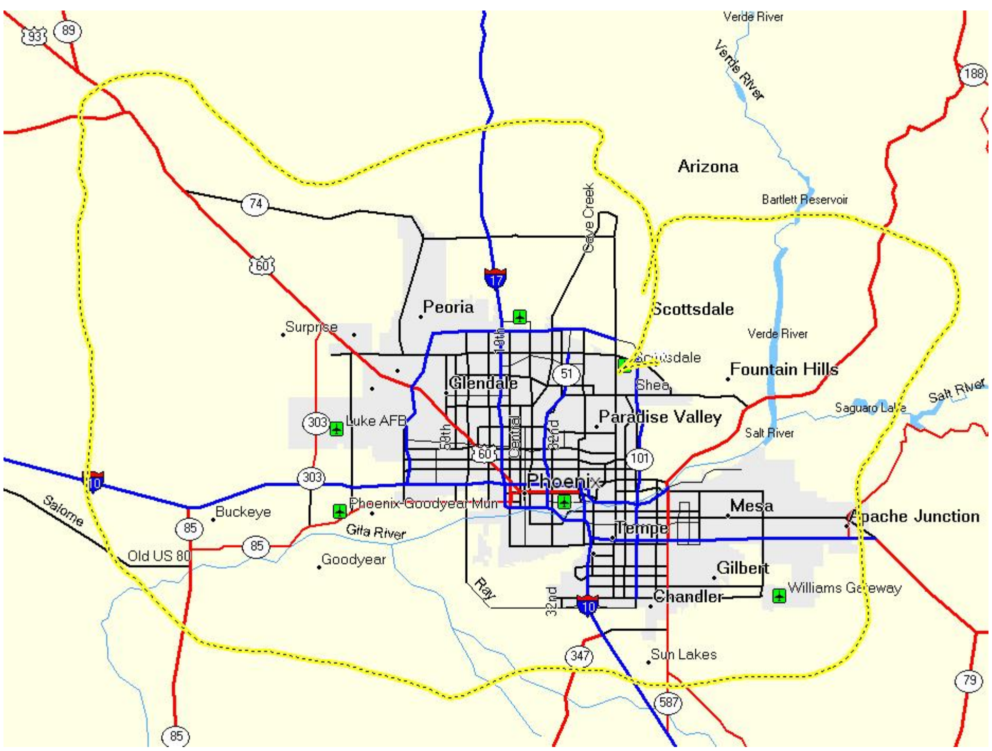

Figure 7-5. Yellow line illustrates flight path used to obtain aerial digital images for characterizing plant cover variability.

Over 90% of all woody plants were identified in landcover survey. The species observed and identified include the following:

Annotated Plant list for Maricopa County Plant Survey – June 2006

Agavaceae – Agave Family
Agave deserti Engelm. "desert agave"
Yucca sp. "yucca"

Anacardiaceae – Sumac Family
Rhus ovata S. Wats. "sugar sumac"
Rhus trilobata Nutt. "skunkbush Sumac"

Asteraceae – Sunflower Family
Ambrosia ambrosioides (Cav.) Payne "canyon ragweed"
Ambrosia deltoidea (Torr.) Payne "triangle leaf bursage"
Ambrosia dumosa (Gray) Payne "white bursage"
Artemisia sp. "sagewort"
Baccharis sarothroides Gray "desert broom"
Baileya multiradiata Harvey & Gray ex Gray "desert marigold"
Brickellia californica (Torr. & Gray) Gray "California brickellbush"
Encelia farinosa Torr. ex Gray "brittlebush"
Ericameria laricifolia (Gray) Shinners "turpentine bush"
Gutierrezia sarothrae (Pursh) Britt. & Rusbey "broom snakeweed"

Berberidaceae – Barberry Family
Mahonia haematocarpa (Woot.) Fedde "alegrita"

Bignoniaceae – Trumpet-creeper Family
Chilopsis linearis (Cav.) Sweet "desert willow"

Cactaceae – Cactus Family
Carnegiea gigantea (Engelm.) Britt. & Rose "saguaro"
Cylindropuntia acanthocarpa (Engelm. & Bigelow) Knuth "buckhorn cholla"
Cylindropuntia arbuscula (Engelm.) Knuth "pencil cactus"
Cylindropuntia bigelovii (Engelm.) Knuth "teddybear cactus"
Ferocactus sp. "barrel cactus"
Opuntia engelmannii Salm-Dyck ex Engelm. "Engelman prickly pear"

Caprifoliaceae – Honeysuckle Family
Sambucus sp. "elderberry"

Celastraceae – Bittersweet Family
Canotia holacantha Torr. "crucifixion thorn"

Chenopodiaceae – Goosefoot Family
Atriplex canescens (Pursh) Nutt. var. *linearis* (S. Wats.) Munz "thinleaf saltbush"
Atriplex polycarpa (Torr.) S. Wats. "littleleaf saltbush"
Suaeda moquinii (Torr.) Greene "seepweed"

Cupressaceae – Cypress Family”
Cupressus arizonica Greene “Arizona cypress”
Juniperus deppeana Steud. “alligator juniper”
Juniperus osteosperma (Torr.) Little “Utah juniper”

Ephedraceae – Mormon Tea Family
Ephedra sp. “mormon tea”

Ericaceae – Heath Family
Arctostaphylos pungens Kunth “pointleaf manzanita”

Euphorbiaceae – Spurge Family
Chamaesyce albomarginata (Torr. & Gray) Small “rattlesnake weed”

Fabaceae – Pea Family
Acacia constricta Benth. “whitethorn acacia”
Acacia greggii Gray “catclaw acacia”
Calliandra eriophylla Benth. “fairyduster”
Mimosa aculeaticarpa Ortega var. biuncifera (Benth) Barneby “wait a minute bush”
Olneya tesota Gray “desert ironwood”
Parkinsonia florida (Benth. ex Gray) S. Wats. “blue paloverde”
Parkinsonia microphylla Torr. “yellow paloverde”
Prosopis glandulosa Torr. “honey mesquite”
Robinia neomexicana Gray “New Mexico locust”
Senna covesii (Gray) Irwin & Barneby “desert senna”

Fagaceae – Beech Family
Quercus arizonica Sarg. “Arizona white oak”
Quercus emoryi Torr. “Emory oak”
Quercus gambelii Nutt. “Gambel oak”
Quercus palmeri Engelm. “Palmer oak”
Quercus turbinella Greene “sonoran scrub oak”

Fouquieriaceae – Ocotillo Family
Fouquieria splendens Engelm. “ocatillo”

Garryaceae – Silk Tassel Family
G*arrya flavescen* S. Wats. “Quinine bush”

Juglandaceae – Walnut Family
Juglans major (Torr.) Heller “Arizona walnut”

Krameriaceae – Krameria Family
Krameria grayi Rose&Painter “white ratany”

Liliaceae – Lily Family
Nolina sp. “beargrass”

Malvaceae – Mallow Family
Sphaeralcea ambigua Gray “desert globemallow”

Oleaceae – Olive Family
Fraxinus velutina Torr. “velvet ash”

Papaveraceae – Poppy Family
Argemone pleiacantha Greene “prickly poppy”

Pinaceae – Pine Family
Pinus edulis Englm. “twoneedle pinyon”
Pinus monophylla Torr. & Frem. “singleleaf pinyon”
Pinus ponderosa P. & C. Lawson “ponderosa pine”

Plantaginaceae – Plantain Family
Plantago sp. “plantain”

Platanaceae – Plane Tree Family
Platanus wrightii S. Wats. “Arizona sycomore”

Poaceae – Grass Family
Aristida purpurea Nutt. “Fendler three awn”
Bouteloua curtipendula (Michx.) Torr. “sideoats grama”

Polygonaceae – Buckwheat Family”
Eriogonum fasciculatum Michx. “wild buckwheat”

Rhamnaceae – Buckthorn Family
Ceanothus fendleri Gray “Fendlers ceanothus”
Ceanothus greggii Gray “desert ceanothus”
Ziziphus obtusifolia (Hook. ex Torr.&Gray) Gray “graythorn”

Rosaceae – Rose Family
Amelanchier utahensis Koehne “Utah serviceberry”
Cercocarpus montanus Raf. “true mountain mahogany”

Rutaceae – Rue Family
Thamnosma montana Torr. & Frem. “turpentine broom”

Salicaceae – Willow Family
Populus fremontii S. Wats. “Fremont cottonwood”
Salix sp. “willow”

Sapindaceae – Soapberry Family
Dodonaea viscosa (L.) Jacq. “hopbush”

Simmondsiaceae – Jojoba Family
Simmondsia chinensis (Link) Schneid. “jojoba”

Solanaceae – Potato Family
Lycium sp. "wolfberry"

Tamaricaceae – Tamarix Family"
Tamarix chinensis Lour. "salt cedar"

Zygophyllaceae – Creosote Bush Family
Larrea tridentata (Sesse & Moc. ex DC) Coville "creosote bush"

The species composition and cover fraction were estimated for each of the 36 GAP wildland landcover types that occur within Maricopa County. The quantitative species composition determined by the June survey generally agreed with the qualitative description of each GAP type. For example the dominant species in the GAP "creosotebush – White bursage" type was creosotebush (49%) and bursage(7%) although the dominant bursage was triangle bursage instead of white bursage. Other GAP descriptions were not representative for Maricopa County. For example, the GAP "Madrean pinyon-juniper woodland was dominated by jojoba (18%), catclaw acacia (15%) and scrub oak (15%). Oaks were determined to be a significant component of many upland landscapes. The high isoprene emission rates of oaks result in their making a substantial contribution to the total Maricopa county BVOC emission. The landcover survey results shown in Table 7-1 demonstrate that only 9 plant species contribute 1.5% or more to the total woody plant cover in Maricopa County. Initial comparisons with MODIS satellite based estimates of LAI and plant cover fractions indicate that the MODIS estimates would overestimate the abundance of vegetation in Maricopa County.

The revised values, based on the June landcover survey, will reduce estimated emissions.

Table 7-1. Percent contribution of individual plant species to total woody plant cover in Maricopa County wildlands.

Larrea tridentata (creosote bush)	29.4%
Ambrosia deltoides (triangle leaf bursage)	8.2%
Parkinsonia microphylla (yellow paloverde)	7.6%
Encelia farinosa (brittlebush)	3.9%
Simmondsia chinensis (jojoba)	3.7%
Acacia greggii (catclaw acacia)	2.9%
Prosopis glandulosa (honey mesquite)	2.2%
Cylindropuntia acanthocarpa (buckhorn cholla)	1.8%
Quercus turbinella (sonoran scrub oak)	1.5%

Emission Rate Characterization

Over 120 emission rate measurements characterized the dominant plant species in both the wildland and urban landscapes. Measurements were made on all of the dominant wildland (see Table 7-1) and urban plant species as well as many other common Maricopa county plant species. Many of the plant species examined had not previously been studied or had been characterized by only one or two measurements. Of particular importance are the observations that jojoba

(Simmondsia chinensis) and ironwood (Olneya tesota) are both high isoprene emitters. Jojoba contributes 3.7% of the wildland woody plant cover and 4.2% of the urban woody plant cover while ironwood contributes about 1% of wildland woody plant cover and 3% of urban cover. Substantial monoterpene emissions were observed from the four dominant plant species in Maricopa county: creosotebush (Larrea tridentate), triangle bursage (Ambrosia deltoides), foothills paloverde (Parkinsonia microphylla), and brittlebush (Encelia farinose). Light dependent monoterpene emissions were observed for some plant species. The ability of isoprene emission to continue to increase at high temperatures, which has previously been observed for desert plants, was also observed. Most measurements were made with environmental controlled glass cuvettes and analyzed in-situ using field portable gas chromatographs (Figure 7-6).

Figure 7-6. In-situ using field portable gas chromatographs.

The structure of some plant species, e.g. saguaro cactus, prevented the use of standard enclosures and instead emissions were characterized using Teflon bag enclosures (Figure 7-7). This led to the surprising finding that saguaro emit isoprene and sesquiterpenes. However, the low emission rates and sparse cover of saguaro result in only a minor contribution to total biogenic emissions in Maricopa County.

Figure 7-7. Emissions measurements using Teflon bag enclosures.

8. EMISSION FACTOR AND COMPUTER MODEL UPDATES

The results from Tasks 2-7 have been incorporated to improve estimates of key MEGAN driving variables including biogenic emission factors and plant functional type (tree and shrub/grass) cover fractions specific to Maricopa County. Different methodologies were used for urban, agriculture and wildlands. The methods and results are described in this report. Additional information (e.g., emission factors for individual landcover types) is provided in digital format.

SPECIES SPECIFIC BIOGENIC VOC EMISSION RATES

Isoprene and monoterpene emission rate measurements conducted during the June 2006 field study characterized the dominant Maricopa County plant species in both wildland and urban landscapes. The field study results are shown in Table 8-1 along with literature emission rates for important Maricopa County plant species. Measurements were made on all of the dominant wildland (see Table 8-1) and urban plant species as well as many other common Maricopa County plant species. Many of the plant species examined during the June 2006 field study had not previously been studied or had been characterized by only one or two measurements. Of particular importance were the observations that Jojoba (Simmondsia chinensis) and Ironwood (Olneya tesota) are both high isoprene emitters. Jojoba contributes 3.7% of the wildland woody plant cover and 4.2% of the urban woody plant cover while ironwood contributes about 1% of wildland woody plant cover and 3% of urban cover. Substantial monoterpene emissions were observed from some dominant plant species in Maricopa County such as brittlebush (Encelia Farinosa). A more detailed description of the methods and results will be published in a peer reviewed journal. Note that the emission rates reported by different studies can differ substantially. These differences may be due to within-species genetic variability or phenological and physiological variations. They could also be due to measurement errors or artificial disturbances associated with enclosure measurement techniques. We have used the approach of Guenther et al. (1994), which considers the quantity and quality of the emission rate data, to integrate these observations into the MEGAN emission factors.

VEGETATION DISTRIBUTIONS AND LANDSCAPE AVERAGE EMISSION FACTORS

Urban

Vegetation distributions for Maricopa County urban landscape were characterized using a combination of high resolution imagery available from Google Earth, landcover data based on 30 m resolution Landsat imagery (Stefanov et al. 2001) and SURVEY200 ground measurements (Hope et al. 2003). A detailed description of the methodology and results will be published in a peer reviewed journal. The first step in the urban characterization approach involved dividing the MAG2004 urban landcover classes into 9 categories that were representative of different biogenic emission classes. Table 8-2 shows the 9 categories and how they map onto the MAG2004 landuse classification system. Each of the nine categories were characterized by several (from 2 to 22) of the Phoenix SURVEY200 plots (Hope et al. 2003). This database indicates that native tree/shrubs are primarily Prosopis (Mesquite) and Parkinsonia (Palo Verde). More than a third of the urban shrub cover is associated with Larrea (Creosote bush). The remaining shrub cover is dominated by Eriogonum (California Buckwheat), Simmondsia (jojoba), Leucophyllum (e.g., Texas Sage) and Nerium (e.g., Oleander) species. Members of the Fraxinus (e.g. Tropical Ash), Citrus (e.g., Orange), Morus (e.g. White Mulberry), Ulmus (e.g., Chinese Elm), Pinus (e.g. Aleppo Pine), and Rhus (e.g., African Sumac) genera each cover 5 to 10% of the urban tree area while Populus (e.g. Fremont Cottonwood), Acacia, Washingtonia (Mexican Fan Palm), Eucalyptus, Melia (Chinaberry), Brachychiton (e.g., Lacebark Kurrajong), Lysiloma (e.g., Desert Fern), Olea (olive), Phoenix (e.g., Date Palm), Juniperus (e.g., Chinese Juniper), Ficus (Fig), Thevetia (e.g., Luckynut), and Carya (e.g., Pecan) species each contribute 2 to 5% of the total. The species composition information from these plots was combined with the MEGAN species specific database to generate the landscape average emission rates shown in Table 8-3. Only selected emission factors are shown in Table 8-3. The 52 emission factors (26 each for both trees and for ground cover) for each of the over 4,000 MEGAN landcover categories (over 200,000 emission factors) are provided in a digital file. As expected, analysis of high resolution imagery indicated that the MODIS vegetation cover estimates did not accurately characterize Maricopa urban areas. The vegetation cover fractions in Maricopa urban areas determined from the high resolution imagery, shown in Table 8-3, was used instead of the MODIS values in the MEGAN vegetation cover database.

Agriculture

The USDA NASS 2002 statistics were used to characterize Maricopa County orchards and crops. These data indicate that orchards were composed of 72% citrus species (about half were oranges with the remainder including lemons, grapefruit and tangelos) and 6% pecans. Maricopa County croplands were 50% alfalfa/hay, 26% cotton, 9% barley, 7% wheat, 3% cantaloupes, and ~1% each for broccoli, watermelon, sorghum, cabbage and beans in 2002. 1997 USDA NASS crop statistics were used to quantify crop species composition for other U.S. counties which fall within the MAG modeling domains. The location of Maricopa County agricultural lands was based on the MAG2004 land use database. However, the June 2006 field study observations indicate that some landscapes designated as agriculture in this database are rangeland, rather than crop or orchards, and so are better designated as wildlands for the purpose of biogenic emission modeling. These areas were identified using the GAP database. If a region was designated as agriculture by MAG2004, but not by GAP, then it was considered to be wildland.

Wildland

Landcover was characterized at approximately 100 sites around Maricopa County at the locations shown in Figure 8-1. The sites were chosen to represent all of the major wildland landcover types which ranged from forest in northeastern Maricopa County to desert scrubland in southwestern Maricopa County. These landcover types include Riparian/Wetland (4 study plots), Interior Chapparal (15 study plots), Pinyon-Juniper (29 study plots), Creosote Bursage (17 study plots) and Paloverde-Mixed-Cacti-shrub (42 study plots). The plant species composition within each of these landcover types, used to develop landscape average emission factors for MEGAN, is based on the June 2006 field study results. An additional 9 wildland landcover types occur within the MAG 4 km domain and others are found within the 12 km domain. The plant species composition within these landscapes are based on USDA FIA data for trees and NRCS data for shrubs and grass. The major landcover types are characterized by hundreds of FIA and NRCS plots. Landcover types with limited distributions (e.g Arizona cypress which covers only

12 km^2) have only a few FIA and NRCS plots. The spatial distribution of the wildland landcover types in Maricopa County is based on the Western GAP landcover database (ftp://ftp.gap.uidaho.edu/products/regional/wst_veg.e00.tar.gz). Other portions of the MAG 4 km and 12 km domain that fall within the boundaries of the U.S. are also based on the Western GAP landcover database. The plant species composition of the grids covering Mexico are characterized using the Olson et al. (2001) global ecoregion database.

A key result from the June 2006 field study is that the MODIS observations considerably underestimate vegetation cover in sparsely vegetated landscapes within Maricopa County. Based on the field study observations, we set a lower limit of 20% shrub and grass cover and an LAI of 0.1 in all landscapes except for the "water" and "barren" categories. The wildland landscape vegetation characterization and landscape average biogenic emission factors will be described in more detail in a peer-reviewed journal paper.

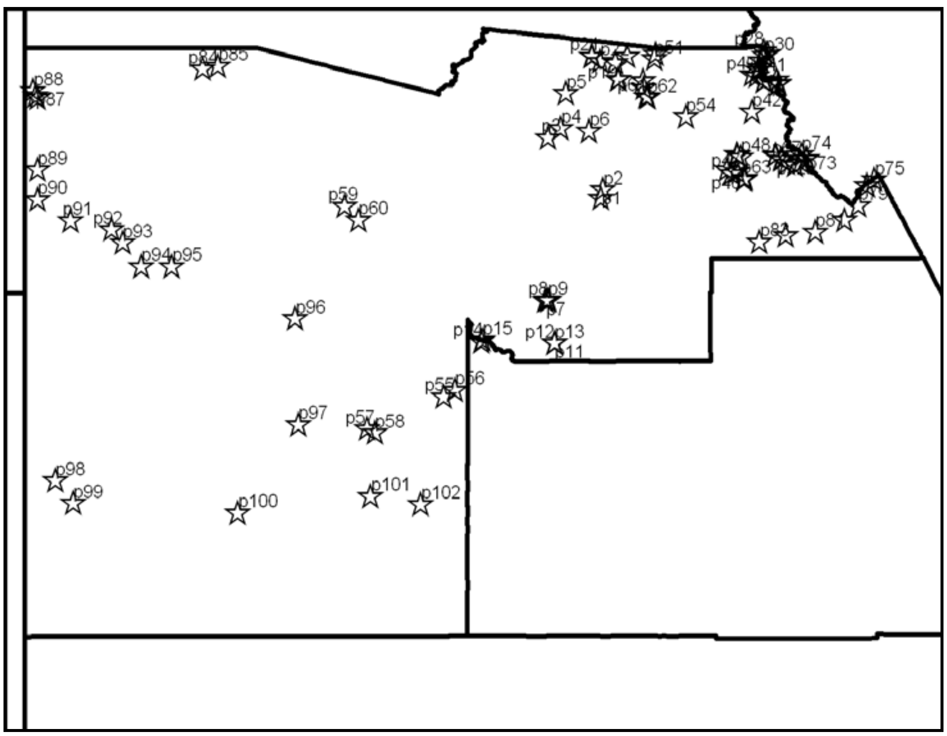

Figure 8-1. Location of the MAG biogenic study survey sites.

Table 8-1. Emission rates ($\mu g\ g^{-1}$ dry weight h^{-1}) for selected Maricopa County plant species determined during the June 2006 field study and comparison with other reported measurements.

Reference (1)	Common Name	species	Iso-prene	alpha-pinene	b-pinene	Cam-phene	myrcene	Limo-nene	3-carene	g-terpinene	Other MT	Total MT
Arey95	chamise	Adenostoma fasciculatum	0									0
Arey95	manzanita	Arctostaphylos	0									0
Arey95	California sagebrush	Artemisia californica	0									47
Arey95	greenbark	Ceanothus spinosus	0									1.8
Arey95	mountain mahogany	Cercocarpus betuloides	0									0
Arey95	Black sage	Salvia mellifera	0									5
DRI-Clark	Sage	Artemisia	0	0.09	Not reported	0.1	0.14	1.96	0	0	Not reported	2.29
DRI-Clark	Saltbush	Atriplex	0	0	Not reported	0	0	0.23	0	0	Not reported	0.23
DRI-Clark	Mtn Mahogany	Cercocarpus	0.04	0	Not reported	0	0	0.27	0	0.06	Not reported	0.33
DRI-Clark	Blackbrush	Coleogyne ramosissima	0	0.24	Not reported	0.24	0.07	0.66	0	1.24	Not reported	2.45
DRI-Clark	Juniper	Juniperus	0	0.14	Not reported	0.02	0.04	0.06	0.19	0	Not reported	0.45
DRI-Clark	Larrea	Larrea	0	0.01	Not reported	0.03	0	0.04	0	0.04	Not reported	0.12
DRI-Clark	Cacti	Opuntia	0	0	Not reported	0	0	0	0	0	Not reported	0
DRI-Clark	Pinyon Pine	Pinus monophylla	0	0	Not reported	1.65	0.05	0.03	0.15	0.05	Not reported	1.93
DRI-Clark	Cliffrose	Purshia	1.0	10.72	Not reported	0	1.06	2.99	0.23	0.38	Not reported	15.38
DRI-Clark	Oak	Quercus	22	0	Not reported	0	0	0	0	0.01	Not reported	0.01
DRI-Clark	Yucca	Yucca	0	0	Not reported	0.01	0	0	0	0	Not reported	0.01
DRI-Maricopa	ambrosia	ambrosia	0	0	Not reported	0	0.02	0.15	0	0	Not reported	0.17
DRI-Maricopa	salt brush	Atriplex	0	0	Not reported	0	0	0	0.05	0	Not reported	0.05
DRI-Maricopa	encelia	encelia	0	1.05	Not reported	0.01	0.47	0.52	0.05	0.02	Not reported	2.12
DRI-Maricopa	ephedra	ephedra	1.0	0	Not reported	0	0	0	0	0	Not reported	0
DRI-	juniper	Juniperus	0	0.12	Not	0	0.12	0.04	0.01	0.02	Not	0.31

Reference (1)	Common Name	species	Iso-prene	alpha-pinene	b-pinene	Cam-phene	myrcene	Limo-nene	3-carene	g-terpinene	Other MT	Total MT
Maricopa					reported						reported	
DRI-Maricopa	larrea	Larrea	0	0	Not reported	0	0	0	0	0	Not reported	0
DRI-Maricopa	iron wood	Olneya	13	0	Not reported	0	0	0	0	0	Not reported	0
DRI-Maricopa	palo verde	Parkinsonia	0	0	Not reported	0	0	0.03	0	0.02	Not reported	0.05
DRI-Maricopa	pinyon	Pinus	0	0.04	Not reported	0	0	0	0	0	Not reported	0.04
DRI-Maricopa	jojoba	Simmondsia chinensis	16	0	Not reported	0	0	0.06	0	0	Not reported	0.06
DRI-Maricopa	yucca	Yucca	0	0	Not reported	0	0	0	0	0	Not reported	0
Geron06		Ambrosia deltoidea	0	0.06	0.31	0.51	2.3	1	Not reported	Not reported	Not reported	4.1
Geron06		Ambrosia dumosa	0	1.6	3	0.06	1.1	2	Not reported	Not reported	Not reported	7.9
Geron06		Atriplex canescens	0	0	0	0.17	0.13	0	Not reported	Not reported	Not reported	0.31
Geron06		Chrysothamnus nauseosus	0	0.28	0	0	0.16	0.21	Not reported	Not reported	Not reported	0.65
Geron06		Ephedra nevadensis	10	0.05	0.03	0.01	0.09	0.11	Not reported	Not reported	Not reported	0.3
Geron06		Hymenoclea salsola	0	1.4	0.06	0.02	0.35	0.3	Not reported	Not reported	Not reported	2.6
Geron06		Krameria eracta	0	0.02	0.06	0.03	0.14	0.05	Not reported	Not reported	Not reported	0.3
Geron06		Larrea tridentata	0	0.37	0.12	0.44	0.3	0.74	Not reported	Not reported	Not reported	2
Geron06		Lycium andersonii	0	0.1	0.27	0.11	0.39	0.27	Not reported	Not reported	Not reported	1.1
Geron06		Olneya tesota	~25	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported
Geron06		Psorothamnus fremontii	35	0.5	0	0	1	0.5	Not reported	Not reported	Not reported	2
Guenther99	Acacia	Acacia greggii	0	0	0	0	0	0	0	0	0	0
Helmig99	serviceberry	Amelanchier alnifolia	0	0	0	0	0	0	0	0	0	0
Helmig99	sagebrush	Artemisia tridentata	0	0.2		0.5	0	0	0	0	9.2	9.9
Helmig99	saltbush	Atriplex canescens	0	15	1.3	0.7	0.2	2.2			7	26.4
Helmig99	mountian mahogany	Cercocarpus montanus	0	0	0	0	0	0	0	0	0	0

Reference (1)	Common Name	species	Iso-prene	alpha-pinene	b-pinene	Cam-phene	myrcene	Limo-nene	3-carene	g-terpinene	Other MT	Total MT
Helmig99	rabbitbrush	Chrysothamnus nauseosus	0	15	1.7	2.3	1.6	39	0	2.9	18	80.5
Helmig99	snowberry	Symphoricarpos occidentalis	0	0	0	0	0	0	0	0	0	0
Knowlton99	Saltbrush	Atriplex	0	0.02	0.01	0	0.03	0.01	0.01	Not reported	Not reported	0.08
Knowlton99	juniper	Juniperus	0	3.1	0.03	0.02	0.04	0.09	0.002	Not reported	Not reported	3.28
Knowlton99	creosote	Larrea	0	0.1	0.06	0.04	0.09	0.09	0.08	Not reported	Not reported	0.46
Knowlton99	mesquite	Prosopis	0	0.05	0	0	0.04	0.02	0	Not reported	Not reported	0.11
Knowlton99	Oak	Quercus	26	0.02	0.03	0	0	0.02	0.01	Not reported	Not reported	0.08
Knowlton99	sumac	Rhus	0	1.2	0.04	0.07	0	0	0	Not reported	Not reported	1.3
Knowlton99	salt cedar	Tamarix	0	0	0.05	0.15	0.19	0	0.09	Not reported	Not reported	0.48
SAC-Maricopa		Acacia erioloba	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Ambrosia deltoidea	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Aristida longistea	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Atriplex canescens	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Brachychiton populneus	0.052	0.14	0	Not reported	0.038	0.02	0.003	Not reported	0.06	0.26
SAC-Maricopa		Brachychiton rupestris	0.03	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Buddleja marrubifola	0.42	0.079	0	Not reported	0	0	0	Not reported	0.39	0.47
SAC-Maricopa		Caesalpinia pulcherrima	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Caliandra eriophylla	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Carnegiea gigantea	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Chilopsis linearis	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Cylindropuntia acanthocarpa	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Encelia farinosa	0	35	0.62	Not reported	0	0.2	0	Not reported	0.43	37

Reference (1)	Common Name	species	Iso-prene	alpha-pinene	b-pinene	Cam-phene	myrcene	Limo-nene	3-carene	g-terpinene	Other MT	Total MT
SAC-Maricopa		Ephedra nevadensis	46	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Fouquieria splendens	0.44	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Gleditsia triacanthos	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Juniperus osteosperma	0.044	1.7	0.52	Not reported	0.32	0.34	0	Not reported	0.49	3.4
SAC-Maricopa		Leucophyllum zygophyllum	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Mahonia fremontii	6.5	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Muhlenbergia lindheimeri	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Nerium oleander	1.2	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Olea europaea	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Olneya tesota	22	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		ornamental shrub	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Parkinsonia floridum	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Parkinsonia microphyllum	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Parkinsonia praecox	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Pinus monophylla	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Platanus wrightii	0.38	0.11	0	Not reported	0	0.19	0	Not reported	0	0.3
SAC-Maricopa		Proposis velutina	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Prosopis pubesens	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Quercus arizonica	8.4	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Quercus buckleyi	11	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Quercus fusifornis	79	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Quercus suber	5.3	0.84	0.53	Not reported	0.11	0.14	0	Not reported	0.42	2.1

Reference (1)	Common Name	species	Iso-prene	alpha-pinene	b-pinene	Cam-phene	myrcene	Limo-nene	3-carene	g-terpinene	Other MT	Total MT
SAC-Maricopa		Salix gooddingii	15	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Sapium sebiferum	0	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Senna nemophila	0.052	0	0	Not reported	0	0.01	0	Not reported	0.021	0.031
SAC-Maricopa		Simmondsia chinensis	30	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Sophora secundiflora	19	0	0	Not reported	0	0	0	Not reported	0	0
SAC-Maricopa		Ungnadia speciosa	0.29	0	0	Not reported	0.27	15	0	Not reported	16	31.
Winer82		Encelia										6

1. The DRI-Maricopa and DRI-Clark measurements were conducted by Dr. Mark Potosnak and colleagues in Maricopa County Arizona and Clark county Nevada, respectively. The SAC-Maricopa measurements were conducted by Dr. Brad Baker and colleagues in Maricopa County, Arizona. Literature values from Arey et al. 1995, Geron et al. 2006, Guenther et al. 1999, Helmig et al. 1999, Knowlton et al. 1999 and Winer et al. 1982 are also shown.

Table 8-2. Description of 25 MEGAN landcover (LC) classes that fall within the MAG 4 km domain and the number of study plots characterizing each landcover type. Wildlands are defined as all lands other than urban and agriculture and are primarily classified as open space in the MAG2004 landuse scheme.

Type	Description	MEGAN LC Code	LU83 codes included	Area (km2) in 4 km domain	# of Greater Phoenix LTER Plots	# Google Maricopa County plots	# Maricopa Co. 2006 study plots	# of FIA plots	# of Arizona NRCS plots
Urban	MAG Low-veg. residential	4290	150, 160, 161, 180, 190	632	22	99			
Urban	MAG Med-veg. residential	4291	140, 170	517	20	114			
Urban	MAG High-veg. residential	4292	110, 120, 130	726	13	85			
Urban	MAG Developing and other residential	4293	910 and other codes	321	6	61			
Urban	MAG Very low-veg. commercial	4295	250, 299, 399, 499, 554, 560, 571, 599, 612, 620, 621, 920, 930, 940, 950	138	4	23			
Urban	MAG Low-veg. commercial	4296	200, 240, 310, 320, 420, 430, 551, 572, 580, 611, 613, 614, 799	214	2	28			
Urban	MAG Med-veg. commercial	4297	199, 201, 202, 210, 220, 230, 410, 510, 511, 512, 531, 532, 533, 534, 553, 570, 810	338	12	43			
Urban	MAG High-veg. parks/golf/commercial	4298	513, 520, 521, 522, 523, 524, 525, 530, 550, 552,540, 555, 720	289	9	28			
Urban	MAG Transportation	4299	610, 960	884	21	136			
Agriculture	Maricopa Co. Agriculture	1242	203, 750	671					
Agriculture	Pinal Co. Agriculture	1246		620					
Wildlands	Ponderosa Pine	905		116				4304	100
Wildlands	Ponderosa P. / Oak-Juniper-Pinyon	907		38				190	257
Wildlands	Madrean Oak	928		89				27	153
Wildlands	Cypress	933		12				1	2
Wildlands	Riparian / Wetland	955		358			4	62	359

Type	Description	MEGAN LC Code	LU83 codes included	Area (km2) in 4 km domain	# of Greater Phoenix LTER Plots	# Google Maricopa County plots	# Maricopa Co. 2006 study plots	# of FIA plots	# of Arizona NRCS plots
Wildlands	Interior Chapparal	959		2391			15	22	262
Wildlands	Pinyon-Juniper	968		869			29	1406	823
Wildlands	Basin Grassland	975		5				200	633
Wildlands	Creosote - Bursage	985		6889			17	12	890
Wildlands	Paloverde-Mixed Cacti-Scrub	996		14852			42	61	783
Wildlands	Semidesert Mixed Grass	1000		47				70	500
Wildlands	Water	1008		346				61	137
Wildlands	Other urban	1011		2140				103	531
Wildlands	Barren	1013		3				163	59

Table 8-3. MEGAN landcover types in the MAG 4 km domain with ground cover fractions and biogenic emission factors (μg m^{-2} canopy area h^{-1}). Light dependent fraction (LDF) is the fraction of total emission that follow a light dependent emission activity behavior.

			Tree Emission Factors								LDF	Shrub/grass emission factors			
MEGAN lc code	% tree cover	# ground cover	meoh	Isop.	MBO	Camp.	Carene	Limo.	a-pinene	cary.	a-pinene	Isop.	limo.	a-pin.	sabi.
4290	9	11	1037	3827	5.6	6.1	19.3	28.1	166.0	63.1	0.1	728	1.3	5.2	0.8
4291	9	17	877	1916	12.7	10.6	42.0	35.0	147.8	52.8	0.1	486	2.8	12.0	1.1
4292	9	33	740	2213	14.6	3.2	29.8	10.5	59.7	23.8	0.1	337	11.3	44.2	4.5
4293	9	20	885	2652	11.0	6.6	30.4	24.5	124.5	46.6	0.1	517	5.1	20.5	2.1
4295	1	3	1200	0	0.0	0.8	1.4	2.2	8.6	11.5	0.2	365	11.9	46.8	4.7
4296	1	10	933	954	119.2	0.8	200.1	12.5	196.5	72.4	0.1	82	0.2	1.1	0.1
4297	7	12	840	3429	21.4	5.2	49.1	30.5	123.3	61.2	0.1	352	20.4	79.6	8.0
4298	6	46	648	1557	0.0	2.2	10.1	12.9	99.9	18.1	0.1	338	40.8	159.3	15.6
4299	7	16	680	424	0.0	5.1	9.9	15.2	58.3	19.6	0.1	80	13.4	52.3	5.0
1242			1200	0	0.0	34.7	69.5	100.7	376.3	57.5	0.0	222	41.4	160.2	14.3
1246			1200	0	0.0	34.7	69.5	100.7	376.3	57.5	0.0	26	57.8	223.8	19.8
905			740	1526	1154.0	13.3	261.9	44.3	273.0	87.7	0.0	790	11.8	45.8	5.3
907			811	4229	928.1	5.4	207.9	27.4	229.8	82.5	0.0	1645	19.5	76.4	9.8
928			689	5796	117.8	0.4	129.8	21.9	105.2	64.7	0.0	1515	20.3	79.5	10.4
933			664	587	0.0	0.1	1.0	56.3	37.1	30.9	0.0	843	18.8	73.4	9.2
955	68	17	1004	5131	0.0	7.3	22.7	22.6	146.7	25.6	0.1	5886	27.1	161.9	18.7
959	28	35	542	5208	0.9	0.4	12.5	10.0	128.9	31.7	0.2	6443	23.1	177.1	18.6
968	51	25	854	12546	338.2	0.7	87.9	16.7	162.7	84.4	0.1	13362	23.8	187.3	44.2
975			437	647	489.9	3.1	125.2	19.9	114.6	40.1	0.0	1155	40.5	156.4	16.9
985	3.5	30	113	137	0.0	0.8	1.3	2.3	13.5	4.6	0.0	435	29.6	119.8	12.1
996	20	30	407	1430	0.0	1.2	2.0	7.3	99.8	17.1	0.1	2059	40.3	227.8	15.4
1000			659	3790	5.2	1.0	59.3	17.8	77.3	36.0	0.0	1785	21.1	82.2	11.0
1008			527	369	568.6	13.4	105.5	39.1	194.9	40.4	0.0	1226	25.9	101.5	11.7
1011			409	390	508.1	7.5	95.3	26.7	143.1	37.4	0.0	1154	29.2	114.1	12.8
1013			523	254	584.3	22.2	137.8	56.8	243.8	48.4	0.0	1065	15.7	60.4	8.1

9. SUMMARY

A biogenic study was conducted for the Maricopa Association of Governments by a project Team consisting of ENVIRON and Dr. Alex Guenther to provide revised biogenic emission factors and an updated modeling system. The project involved an evaluation and assessment of existing models, landuse databases and emission factors and a field study to collect the necessary data for the development of biogenic emission factors specifically for vegetation species found across the study region. An updated biogenic emission model, MEGAN, was developed in an Access database to incorporate the new emission factors. The various project tasks associated with these developments are documented in previous sections of this report.

The final version of the MEGAN model was run using temperature and PAR data for a single day on the MAG 4-km modeling domain and compared to the GloBEIS model results. A comparison of the two biogenic models is presented below. Figure 9-1 presents the spatial distribution of daily total VOC emission (in tons per day) using MEGAN, while Figure 9-2 presents corresponding results using GloBEIS. Corresponding displays of biogenic NOx emissions are presented in Figures 9-3 and 9-4. A comparison of the daily total VOC and NOx emissions is presented in Table 9-1.

Table 9-1. Comparison of MEGAN and GloBEIS biogenic emissions.

Daily total biogenic emissions for May 31 on the MAG 4-km modeling		
	VOC	NOx
GloBEIS	728.66	53.26
MEGAN2	712.53	11.00

A comparison of the biogenic emissions using the MEGAN and GloBEIS model for the Phoenix urban area are presented in Table 9-2. Daily total VOC and NOx emissions are presented for the June 2002 modeling episode. The MEGAN model results in significantly lower biogenic emission estimates for both VOC and NOx. Reductions on estimated daily total VOC emissions range from approximately 43% to 50% while daily total NOx emission reductions range from approximately 47% to 71%

Table 9-2. Comparison of MEGAN and GloBEIS biogenic emissions in the Phoenix urban area.

Biogenic VOC and NOx Emission in the Phoenix Urban Area (metric tons/day)						
	MEGAN		GloBEIS		% Reduction	
Date	VOC	NOx	VOC	NOx	VOC	NOx
5/31/2002	76.1	4.0	136.2	7.6	-44.1%	-47.4%
6/1/2002	72.8	3.4	133.1	7.2	-45.3%	-52.8%
6/2/2002	56.3	1.8	111.4	6.3	-49.5%	-71.4%
6/3/2002	48.2	1.6	89.5	5.5	-46.1%	-70.9%
6/4/2002	51.7	1.7	99.7	5.9	-48.1%	-71.2%
6/5/2002	65.7	2.1	132.4	7.1	-50.4%	-70.4%
6/6/2002	80.8	2.5	152.0	8.0	-46.8%	-68.8%
6/7/2002	83.0	2.5	146.9	7.9	-43.5%	-68.4%

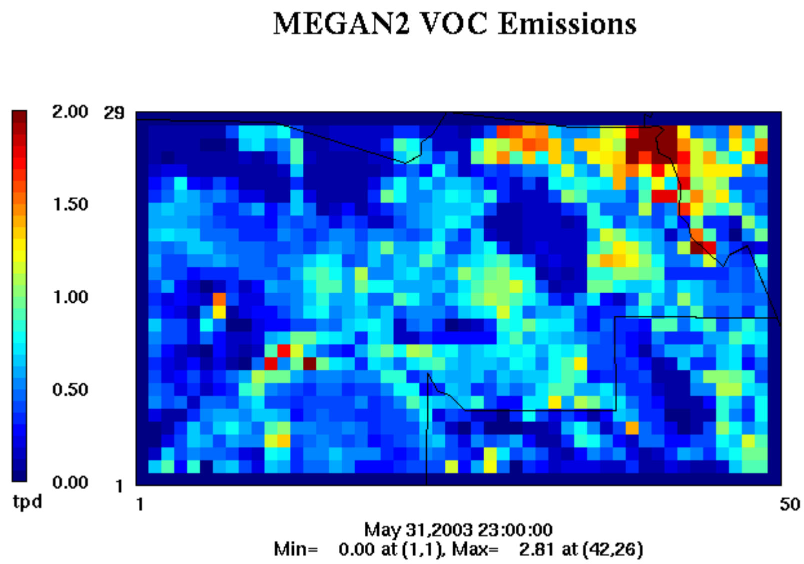

Figure 9-1. Biogenic VOC emissions on the MAG 4-km modeling domain from the MEGAN model (tons/day).

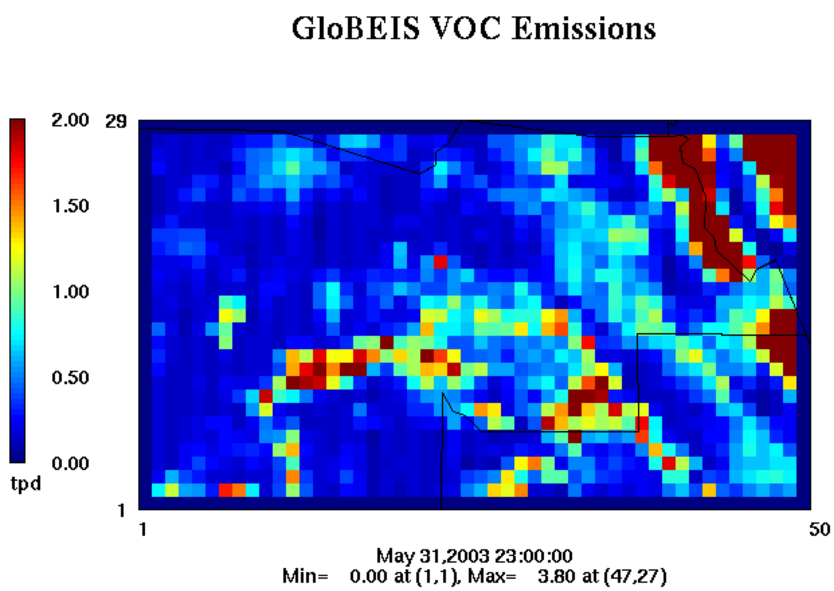

Figure 9-2. Biogenic VOC emissions on the MAG 4-km modeling domain from the GloBEIS model (tons/day).

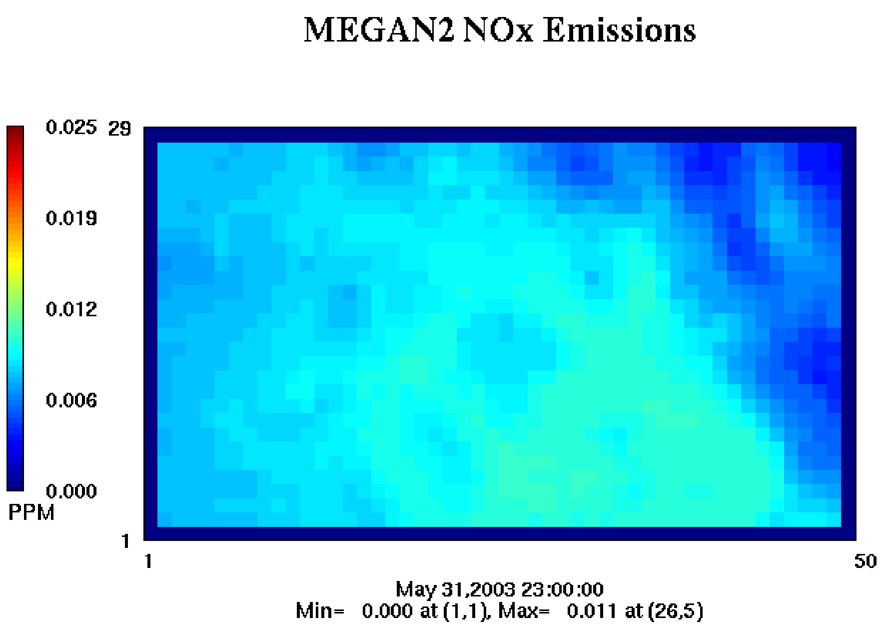

Figure 9-3. Biogenic NOx emissions on the MAG 4-km modeling domain from the MEGAN model (tons/day).

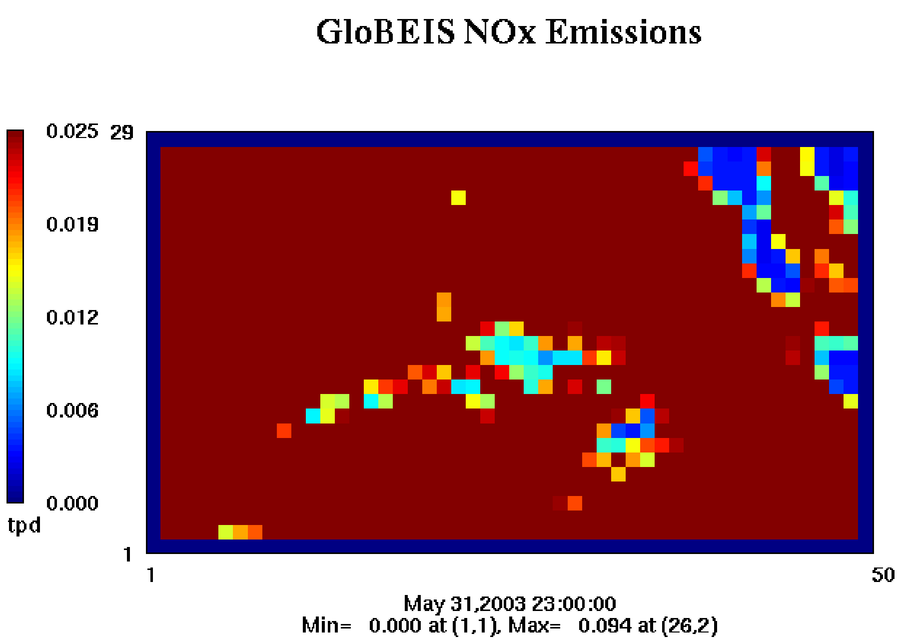

Figure 9-4. Biogenic NOx emissions on the MAG 4-km modeling domain from the GloBEIS model (tons/day).

Based on the evaluation and development work for the study, the following advantages of using MEGAN are noted:

- MEGAN is being developed to replace the EPA BEIS models and the NCAR global emission models. Long term funding and support for MEGAN is expected from both NSF and EPA. The current target date for integrating MEGAN into the EPA modeling framework is February 2007.

- MEGAN is driven by satellite observations of Leaf Area Index (LAI) and plant functional type (PFT)- which can be calibrated with ground observations. GLOBEIS can use satellite LAI but can not easily take advantage of satellite PFT distributions.
- MEGAN considers emissions of 134 compounds which are typically lumped into chemical schemes (e.g. SAPRC99, CBIV). The advantages of this approach, rather than the GLOBEIS/BEIS method of estimating emissions for a couple of categories and then speciating those categories, are that different compounds can have different emission algorithms. For example, GLOBEIS assumes that methanol and acetone have the same response to changes in light and temperature but it I swell known that this is not the case. In addition, MEGAN will be a step ahead of future chemical schemes that may have different speciation. This may be particularly important for secondary aerosol production where a different aerosol yield could be applied to each biogenic compound.
- MEGAN uses a landscape-level emission factor, rather than the leaf-level emission factor used in GLOBEIS/BEIS. This is preferred for several reasons. First, future observations will increasingly rely on above-canopy flux measurements from towers and aircraft to assign emission factors. This will be straightforward for landscape-level emission factors but difficult to do with leaf-level emission factors. Secondly, landscape-level emission factors are independent of the canopy environment model that is used to account for emission variations.
- MEGAN accounts for canopy loss and production which are factors that are not considered by BEIS/GLOBEIS. Canopy loss is particularly important for very reactive gases such as b-caryophyllene and g-terpinene. Only 30% or less of these compound actually escape the canopy. Canopy production of secondary aerosol within canopies, which can then be emitted into the atmosphere, can be an important flux which is neglected by BEIS/GLOBEIS.
- MEGAN incorporates recent advances in our understanding of the processes controlling emission variations, including seasonal variations associated with phenology and the influence of soil moisture (i.e. drought). In addition, MEGAN has been updated with recent emission factor and landcover data.
- MEGAN will continue to be updated in the future by integrating observations of researchers in the U.S. and other countries.

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