SECTION 6

NATURAL SOURCES

Emissions of primary particulate and particulate precursors from natural sources are included in the 2002 inventory to gain a more complete picture of fine particulate emissions. For Delaware, natural sources include biogenic source emissions (VOCs and NO_x), NO_x emissions due to lightning, and PM_{10}-PRI and $PM_{2.5}$-PRI from wind-blown dust. The wildfire category was included in the non-point section because most wildfires in Delaware are a result of human activities (i.e., untended fire, discarded cigarette butt, arson). Emissions for natural sources are reported under the following SCCs:

Table 6-1. SCCs for Natural Sources

SCC	Description 1	Description 3	Description 6	Description 8
2701000000	Natural Sources	Biogenic	Vegetation/Soils	Total
2730100000	Natural Sources	Geogenic	Wind Erosion	Total
2740001000	Natural Sources	Miscellaneous	Lightning	Total

6.1 Biogenic Emissions

Biogenic source emissions result from biological activity and represent a significant portion of the natural source emissions. The biological activity of plants, especially trees, creates a significant amount of VOCs in Delaware. Microbial activity within soils is responsible for emissions of nitrogen-containing compounds, including nitrogen oxides (NO_x).

The U.S. Environmental Protection Agency developed 2002 monthly county-level biogenic emissions for the entire country (EPA, 2004) using the Biogenic Emissions Inventory System (BEIS) model, version 3.12 (EPA, 2003). EPA allowed states to accept the EPA estimates for purposes of satisfying the requirements of the Consolidated Emissions Reporting Rule (CERR). Delaware opted to accept EPA's estimate of biogenic emissions for Delaware for inclusion in the NEI. Delaware is also adopting these emissions for submission in this 2002 PM SIP inventory. EPA's report on the estimation of biogenic emissions for 2002 is included in the supporting documentation accompanying this report.

EPA used land use data from the Biogenic Emissions Land Use Database (BELD3) as the primary activity data. Primary sources of data for BELD include the USDA Forest Service, USGS satellite data, and the Census of Agriculture from the U.S. Department of Commerce Bureau of Census. Land use is divided into four main categories: forest, urban forest, agriculture and other. Other categories consist of grassland, scrubland, rangeland, barren land, water and urban other (treated as barren).

EPA relied on 2001 meteorological data since 2002 data were not available at the time biogenic emissions were estimated.

The rate of biogenic emissions is highly dependent on the amount of biological activity, which is at its maximum in the summer and at its minimum in the winter. EPA created monthly emission tables, and these values were summed to obtain annual emissions.

6.2 Lightning

Lightning is a source of nitric oxide (NO). Lightning forms NO through a high temperature reaction from the energy released during a lightning flash. Lightning can release about 10^5 Joules per meter (J/m), and produce temperatures of about 30,000 degrees Kelvin (°K). NO is in thermodynamic equilibrium with nitrogen and oxygen at temperatures above 2300°K, and as the heated air rapidly cools below 2000°K, NO becomes a steady-state species.

Activity for this category can be collected from commercial lightning detection networks, such as the National Lightning Detection Network operated by Vaisala (formerly Global Atmospherics Inc. of Tucson, AZ.) Global Atmospherics had the only national database for lightning strikes available for 2002. Since archived data is only available for a fee, AQMS has relied on an average annual lightning strike rate of one cloud-to-ground strike per km^2 per year provided by Bill Geitz of Global Atmospherics, with a network detection efficiency of 86% (Geitz, 1997). Mr. Geitz also stated that most of the strikes occur during the peak ozone season, and that using a value of 75% of the annual number of strikes would be a realistic estimate for calculating peak ozone season daily emissions. This information was used to develop 2002 emission estimates for NO_x from lightning.

When estimating NO_x emissions, the *EIIP, Volume V* (EPA, 1997) preferred method estimates NO production by assuming the frequency and type of lightning strikes, and the amount of energy released. The method derives emission estimates for cloud-to-ground (CG) flashes and intra-cloud (IC) flashes. The method relies on the following four assumptions:

1) Global production of NO by lightning is six Tg N/yr;

2) Global flash rate is 100 flashes/sec;

3) IC flashes occur approximately four times more frequently than CG flashes, a number which varies with latitude; and

4) CG flashes are approximately ten times more energetic than IC flashes.

The following emission factors have been developed based upon the above assumptions:

- CG flashes: $2.9 * 10^{26}$ molecules NO per flash; and
- IC flashes: $2.9 * 10^{25}$ molecules NO per flash.

In order to calculate emission estimates for this source, the emission factors are applied to activity for the inventory area taking into account any corrections to the activity measurements. The correction factor compensates for lightning flash detection network efficiency, including a lack of detection of IC flashes by the network.

The preferred method for estimating emissions from lightning requires the collection of activity level data on CG lightning flashes and determination of the study area's latitude. Activity for IC

flashes is calculated from the CG activity. It is assumed that IC flashes occur about four times more frequently than CG flashes, and this ratio varies with latitude.

The equation to calculate emissions from lightning is as follows:

$$L_{NO} = AREA \times \left\{ \left(N_{CG} \times \left(1 / E_{CG}\right) \times EF_{CG} \right) + \left[N_{CG} \times \left(1 / E_{CG}\right) \times EF_{IC} \times \left(\frac{10}{1 + \left(\frac{\theta}{30}\right)^2} - 1 \right) \right] \right\}$$

where:

L_{NO} = NO emissions for lightning flashes in study area, molecules NO
$AREA$ = Square kilometers of study area (county, including waters of DE Bay)
N_{CG} = Number of CG flashes recorded by detection network (strikes/km^2 per year)
E_{CG} = Efficiency of the detection network
EF_{CG} = Emission factor of NO for each CG lightning flash (in molecules NO/flash)
θ = Latitude of the study area in degrees
EF_{IC} = Emission factor of NO for each IC lightning flash

6.3 Wind-blown Dust

Particulate emissions result from wind erosion of vacant lands, such as tilled agricultural land and other disturbed land without vegetation. Wind-blown dust emissions from vacant agricultural lands are believed to be the only significant source in Delaware. Therefore, this is the only type of land use that was covered. Emissions were calculated at the county level using crop acreage data from the Delaware Agricultural Statistics Service (DASS).

6.3.1 Activity Data

The method for estimating wind-blown dust emissions is based on methods applied in many western states. It involves the use of emission factors based on wind tunnel tests for various land uses. In addition to erodible surface area (e.g., crop acreage), the method requires local meteorological data (wind speed and precipitation). For agricultural lands, it is assumed that PM_{10} emissions are negligible during seasons when crops are present. Hence, emissions were estimated only during the months when agricultural tilling occurs. County-level acreage for the major crop categories were collected from the DASS (DASS, 2003). Months in which agricultural tilling takes place were consistent with the crop calendar reviewed by the Delaware Department of Agriculture. AQMS restricted the calendar window for each crop to be only the months during which tilling occurs and to assume that only a fraction of the crop land has been freshly tilled (e.g., 25% of the crop land where tilling occurs during four months out of the year).

The number of hours of wind in each wind speed range was determined using 2002 average hourly wind speed data from one representative meteorological station in each Delaware county. The National Climatic Data Center (NCDC) data were used (NCDC, 2003). All days with measurable precipitation were removed from the meteorological databases, since rain dramatically reduces erosion potential. The original meteorological data showed no rain from March through June in 2002. It was determined that the precipitation days were not correctly

recorded. For quality control purposes, AQMS obtained a different set of precipitation data from NCDC and found large discrepancies in the numbers of precipitation days (NCDC, 2004). Since the latter data set does not have wind speed information as needed for windblown dust estimates, AQMS combined the precipitation data from the latter data set with the wind speed data from the original set for estimating the number of wind events for each of three wind speed ranges.

Delaware crop lands are considered to have a limited reservoir of erodible material. Land uses with limited reservoirs typically form a crust after a short period of time during high winds that binds particles from additional erosion. Hence, emissions are assumed to occur only during the first hour of each "wind event". Consecutive hours of wind over a threshold value were considered one "wind event". For estimating wind-blown dust from crop lands, a threshold wind speed of 15 miles per hour (mph) was assumed. Since the reservoir of erodible material would not be expected to recharge that quickly, AQMS restricted the number of wind events to only one per 24-hour period. The numbers of "wind events" were computed and are shown in Table 6-2.

Table 6-2. Wind Event Counts by County in 2002

Wind Speed (mph)	Kent			New Castle			Sussex		
	15-19.9	20-24.9	>25	15-19.9	20-24.9	>25	15-19.9	20-24.9	>25
March	8	4	2	14	3	0	13	6	1
April	11	4	0	9	6	1	7	10	0
May	21	1	0	18	2	0	17	5	1
June	14	3	2	14	3	1	13	6	0
July	16	5	0	19	3	0	18	4	0
August	15	7	0	18	8	0	17	7	1
September	20	0	0	15	5	0	11	4	0
October	10	4	0	8	4	0	7	2	2
November	7	3	0	9	4	0	10	3	1

6.3.2 Emission Factors

PM_{10} emission factors were taken from a recent University of Nevada, Las Vegas wind tunnel testing program in Clark County, Nevada (James et al., 2000). For different land use types (disturbed vacant lands and stabilized vacant land), wind speed-specific emission factors were provided. Table 6-3 provides these emission factors. The emission factors are based on those developed for disturbed vacant lands by James et al (2000). The wind speed ranges are 15-19.9 mph, 20-24.9 mph, and 25-29.9 mph.

$PM_{2.5}$ emissions were calculated by applying a particle size factor of 0.15 to PM_{10} emissions (WRAP, 2005).

Table 6-3. Windblown Dust Emission Factors for Agricultural Fields

Emission Factor (ton/acre/hour)	Wind Speed Range (mph)		
	15 - 19.9	20 - 24.9	25 - 29.9
PM_{10}	4.95E-3	5.21E-3	6.40E-3
$PM_{2.5}$	7.43E-4	7.82E-4	9.60E-4

After emissions were calculated at the county-level, the following transport factors were initially applied as per EPA guidance (Pace, 2003) for the draft inventory. AQMS later removed the transport factor, since emissions models often perform this function.

Table 6-4. Delaware Transportable Fractions for Fugitive Dust

County	U.S. EPA Transportable Fraction
Kent	0.68
New Castle	0.49
Sussex	0.60

6.3.3 Controls

Controls were applied to the land preparation component of this category to account for conservation tillage or no till practices that occur in Delaware. The percent acreage where no till was practiced was treated as the rule penetration percentage which varied by county; the data on conservation tillage was derived from data taken from the U.S. Department of Agriculture, Natural Resource Conservation Service's website. CE was considering 100% since no PM emissions occur where the land is not tilled. An RE of 80% was assumed.

6.3.4 Sample Calculations

An example calculation of annual emissions for crop x at the county level (E_x) follows:

$$E_x = \sum_{i=1}^{12} \left(\{a_{x,i} \times f_{x,1} \times w_{i,1}\} + \{a_{x,i} \times f_{x,2} \times w_{i,2}\} + \{a_{x,i} \times f_{x,3} \times w_{i,3}\} \right)$$

where: $a_{x,i}$ = area for crop x in month i (acres)
$f_{x,1}$ = emission factor for crop x and wind speed range 1(ton/acre-hour)
$w_{i,1}$ = number of wind events in range 1 in month i

6.4 Results

Table 6-5. 2002 Statewide Emissions for Natural Sources

		Annual Emissions (TPY)			
SCC	Category Description	PM_{10}-PRI	$PM_{2.5}$-PRI	NO_x	VOC
2701000000	Biogenic	---	---	612	26,580
2730100000	Windblown Dust	20,682	3,009	---	---
2740001000	Lightning	---	---	151	---
27xxxxxxxx	**Total : Natural Sources**	**20,682**	**3,009**	**764**	**26,580**

6.5 References

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