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**PROCEDURES FOR  
ESTIMATING AND ALLOCATING  
AREA SOURCE EMISSIONS  
OF AIR TOXICS**

WORKING DRAFT

Original  
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PROCEDURES FOR ESTIMATING AND ALLOCATING  
AREA SOURCE EMISSIONS OF AIR TOXICS

Interim Procedures For Estimating And  
Allocating Area Source Emissions of  
Air Toxics

Preface

Most of the initial draft of this report was prepared under contract to the Environmental Protection Agency (EPA) Pollution Characterization Section, Non-Criteria Pollutant Programs Branch (NPPB) in response to the recognized need to be able to estimate emissions of various toxic air pollutants to the atmosphere from various area sources. These area sources are generally individually small but numerous and often scattered throughout an air basin. Automobiles, for example, are categorized as an area source, as are residential woodstoves. Small commercial and industrial operations such as cooling towers may also be small localized sources of toxic air pollutants which collectively may have a major impact upon health risk estimates.

As a result of the contractor's effort, and other agency work, available methodologies and emission factors were examined and incorporated into this report. The procedures and factors that resulted are better in some areas than others. Many of the procedures can be traced to procedures developed for the National Emissions Data System (NEDS) over 15 years ago. Though age does not necessarily indicate inadequacy, the staff of the Pollutant Characterization Section has felt that there may be better ways for estimating emissions that could be developed or perhaps may already be in use in some State and local agencies. Also, it is felt that the source coverage may not be complete (see Table 1-1). Consequently, this document is being distributed as an interim or "Working Draft" document so that State and local personnel may (1) use it for benefit as applicable, (2) provide comments and alternate procedures or other



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TABLE 1-1

Source Categories Not Covered

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Structural Fires  
Motorboats  
Cutback Asphalt  
Cold Cleaning  
Construction Equipment  
Railroads  
Industrial Equipment  
Wastewater  
On-Site Incineration  
Vessels  
Pesticides  
Farm Equipment

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improvements, (3) use it to stimulate development of new procedures and factors, and (4) use it as the initiation of a "clearinghouse" of the agencies' methods and procedures.

Depending upon comments and other feedback, EPA will likely revise and upgrade this document in the future. The unbound format of this document is used to facilitate this concept. Users and specialists in the field are encouraged to provide reactions, ideas and comments directly to EPA at the following address:

Pollutant Characterization Section  
Non-Criteria Pollutant Programs Branch  
Office of Air Quality Planning and Standards  
U. S. Environmental Protection Agency  
MD-15  
Research Triangle Park, NC 27711

Any comments and feedback received by August 1989 will facilitate planning and implementation of the first update/revision. Holders of the document who wish to be provided with updates to the document should advise EPA, in writing, at the above address if they were not the original addressee of the document. It would also be helpful in this case to provide the name and address of the original addressee who will need to be dropped from the mail key.

## PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

### 1.0 INTRODUCTION

#### 1.1 Background

This manual is intended to provide methodologies, techniques, procedures, and emission factors that can be used by state and local environmental agencies in estimating and allocating area source emissions of toxic air pollutants in a given area. When applied in combination with a detailed point source inventory, this handbook can be used as a guide to develop the area source portion of a comprehensive air toxics inventory. The emissions data can then be used in combination with air dispersion modeling and risk assessment to estimate ambient levels of, and exposures to air toxics and the accompanying environmental and health impacts.

The content of this manual is based on information and data available at the time of preparation. In a number of cases, emission factors are based on limited test data of varying quality or may rely on gross assumptions that were the best possible at that time. It is generally assumed that emission rates are, on average, uniform throughout the country. Many of the activity coefficients (i.e., usage rates) that are used with emission factors to estimate pollutant loadings are also generic in nature, but are scaled to the local level based on employment by Standard Industrial Classification (SIC) code, population density, etc.

This document has been designed in a looseleaf format, permitting periodic updates and revisions as additional or more complete data become available, or as improved procedures are identified. The EPA's intent is for this format to facilitate its being a "clearinghouse" of procedures that exist or may be developed.

## PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

### 1.2 General Methodology

Area source emissions are estimated by multiplying an emission factor by some known indicator of collective activity for each source category within the inventory area. An indicator is any parameter associated with the activity level of a source, such as production, employment, or population, that can be correlated with the air pollutant emissions from that source. For example, emissions of volatile organic compounds (VOC) from dry cleaning facilities in an area correlate well with population; thus, it is possible to develop a per capita emission factor that can be used to estimate emissions. As another example, the total amount of gasoline handled by service stations in an area can be used to estimate collective evaporative losses from gasoline handling.

Estimates can be derived by (1) treating area sources as point sources, (2) surveying (e.g., telephone or questionnaire) local activity levels, (3) apportioning national or statewide activity totals to local inventory areas, (4) using per capita emission factors, (5) using emissions-per-employee factors, or (6) a combination of these. Each method has distinct advantages and disadvantages when used for developing area source emissions estimates. The merits of these alternative methods must be evaluated on a source-category-specific basis.

One alternate approach for estimating area source emissions is to assume that either population data or employment data are a good indicator of emission rates. Assuming that emissions are greatest in high population density areas is reasonable for many area source categories. Employment within an area source category, for example dry cleaners, can be used as an indicator of activity and emissions.

## PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

There are many approaches to estimating air toxics area source emissions. A simple approach, when practical, is to utilize output from the (now defunct) NEDS, a computerized data base that is now being replaced with the Aerometric Information Retrieval System (AIRS). This system is focused primarily on the five criteria air pollutants (particulates,  $\text{SO}_x$ ,  $\text{NO}_x$ , CO and hydrocarbons). The National Air Data Branch (NADB), Research Triangle Park, North Carolina, maintains the AIRS Data Base and NEDS area source data. These data are available as standard publications, computer printout reports, or magnetic tape files. The activity level information available may be most useful to the person or agency making a toxics area source estimate. Also available are data for particulate and volatile organic compound emissions, fuel use, vehicle miles traveled, solvent consumption, and gasoline marketed. The NEDS area source categories are shown in Table 1-2.

Area source emission estimates are calculated for each source category, utilizing criteria pollutant emission factors contained in the area source emission factor file. For many categories, the same emission factors are used for all counties; however, for some source categories, state- or county-specific emission factors account for local variability that affect emissions. Locale specific emission factors are used in NEDS calculations for highway motor vehicle categories, fugitive dust categories and for selected other categories in a few counties where more detailed data are available to develop more applicable emission factors than the national emission factors. Provision is also made to override computer-calculated emissions for any county source category by hand calculated emissions, which may allow more judgmental applications than simple computerized emission-factor calculations.

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TABLE 1-2

Standard NEDS Area Source Categories  
(Criteria Pollutants)

Residential Fuel

Commercial and Institutional Fuel

Industrial Fuel

Gasoline Fuel

Gasoline Powered Vehicles

Highway

Off Highway

Diesel Powered Vehicles

Highway

Off Highway

Railway Locomotives

Aircraft

Vessels

Evaporative Loss

Solid Waste Disposal

Residential

Commercial and Institutional

Industrial

Fugitive Dust

Other

Wildfires

Managed Burning

Orchard Heaters

Structure Fires

## PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

The NEDS-based approach has the advantage of easy access. There are, however, alternative approaches for estimating activity levels and emission rates. Sometimes these alternative approaches will be more accurate; activity or emissions might, for example, be based on a site-specific survey of sources in the area, or many differ because of local regulation.

Once countywide emissions of area sources are estimated, air dispersion modeling may be conducted to predict the contribution of area source emissions on ambient levels and population exposures. It is generally recommended that county wide area source emissions be distributed within the study area into rectangular area source grid cells and that spatial seasonal and temporal variations of emissions be factored into the apportionment. Modeling results can then more accurately reflect ongoing activities in different sections of the county.

### 1.3 Steps In Conducting An Emission Inventory<sup>1</sup>

An air toxics area source emission inventory may generally be conducted in five initial steps:

1. Collecting data on national, state and local area source activity levels (NEDS reports can be the source of many of these data);
2. Collecting demographic, economic and other data to be used to apportion activity levels and emission factor parameters;
3. Apportioning the areawide (typically a State) activity levels of area sources to the county level using apportionment factors;
4. Calculating estimated area source emissions by applying emission factors to the apportioned area source activity levels, and
5. Converting the source information and emissions to a formal formatted record and placing this record in a file (manual or automatic).

Alternatively, however, many agencies chose to use existing inventory data for VOC and particulate and speciate them into their toxic components.<sup>2</sup>

## PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

It is essential to document data and procedures used in compiling the inventory. Thorough documentation allows the agency to identify sources of raw data and data-handling methods used to estimate emissions.

Documented procedures must be followed during quality assurance checks and when the inventory is being updated with new data.

### 1.4 Format Of This Manual

The remainder of this manual consists of individual sections organized by source category. Each of these sections describes the source category and presents procedures and emission factors to estimate toxic emissions on an annualized basis. Multiple techniques to predict emission rates are described. Example calculations have also been provided to demonstrate how to apply the various factors and algorithms. Spatial apportionment techniques can be used once countywide annual emission estimates are determined to distribute emissions throughout the county, concentrating emissions in those parts (grids) of a county where the emissions are likely to be greatest. Temporal factors are provided so that emissions can reflect seasonal, daily or hourly variations of emissions; this input is especially useful when used in conjunction with air dispersion modeling. Appendix A elaborates on these apportionment methodologies.

Figure 1-1 is a matrix indicating sources and pollutants covered in this manual. The absence of an entry for a pollutant does not necessarily imply that the source does not emit contaminants, but rather that no emission factor has been identified.



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Figure 1-1 Area Source/Pollutant Matrix

Pollutant	Surface Coating	Dry Cleaning	Degreasing	Rubber & plastics	Graphic arts	Commercial/consumer	Other industrial	Heating	Road vehicles	Aircraft	Cooling towers	Agricultural/forest fires	Waste oil	Gas stations	Chrome plating	Sterilizers
Acetaldehyde								X	X	X						
Acrolein								X	X	X						
Arsenic								X	X	X						
Asbestos								X	X	X						
Benzene								X	X	X						
Benzo(a)pyrene								X	X	X						
Beryllium								X	X	X						
Bromomethane								X	X	X						
Bromochloromethane								X	X	X						
Bromoform								X	X	X						
1,3-Butadiene								X	X	X						
Cadmium								X	X	X						
Carbon tetrachloride								X	X	X						
Chlorobenzene			X			X	X									
Chloroform																
Chromium																
1,3-Dichlorobenzene (m)																
1,3-Dichlorobenzene (p)				X												
1,3-Dichlorobenzene (o)						X	X									
Dichlorobromomethane																
Dichloroethane																
Ethylene Oxide																
Formaldehyde								X	X	X						
Lead								X	X	X						
Methylene chloride	X		X			X	X									
Nickel						X	X									
Perchloroethylene		X	X			X	X									
Polycyclic Organic Matter																
1,1,1-Trichloroethane	X		X			X	X		X							
Trichloroethylene	X		X			X	X									
Vanadium																
Vinyl chloride								X								
Vinylidene chloride																

Note: Emission factors are available for these sources/pollutants. It is possible that a source may emit other pollutants; however, no emission factor(s) has (have) been identified.

## REFERENCES

1. Air Emissions Species Manual, Volume I: Volatile Organic Compound (VOC) Species Profiles And Volume II: Particulate Matter (PM) Species Manual. EPA-450/2-88-003a and b, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1988.
2. Procedures For Emission Inventory Preparation, Volume III: Area Sources. EPA-450/4-81-026c, Office of Air Quality Planning and Standards, Research Triangle Park, NC, September 1981.

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2. SOLVENT USAGE

2.1 General

For purposes of toxic inventories, solvents are defined as any liquid organic compounds (or group of compounds) that are used to dissolve other materials. These compounds can be used as cleaning agents or in the application of a product. Some or all of the solvent typically evaporates into the atmosphere, resulting in potentially significant emissions of a variety of chlorinated and unchlorinated organic toxic air pollutants.

Solvents are used in numerous industrial, commercial, and domestic applications, thus complicating the development of a solvent emission inventory. As with other area source categories, major sources should be treated as point sources, using methods described in AP-42<sup>1</sup> and Procedures for the Preparation of Emission Inventories for Volatile Organic Compounds, Volume 1.<sup>2</sup> However, because of the large number of small solvent users, it is necessary to develop countywide area source estimates.

Organic solvent usage can be divided into seven major subcategories:

- Surface coating;
- Dry cleaning;
- Degreasing;
- Graphic arts (printing and publishing);
- Rubber and plastics;
- Other industrial; and
- Commercial/consumer (nonindustrial);

Walden<sup>3</sup> allocated consumption of specific organic solvents by county according to national solvent consumption of 17 photochemically

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reactive solvents. That technique estimated consumption by major user category based on county population or user category employment data. GCA<sup>4</sup> updated Walden's estimates to reflect 1985 consumption patterns. For this manual, the list of solvents has been further expanded to include data for two nonreactive organic compounds, 111-trichloroethane and methylene chloride; this revised table is presented in Table 2-1.

By assuming that all solvent consumed in the study area is emitted somewhere within the study area (at the user site; during transport; at a treatment, storage, and disposal facility; or at a sewage or wastewater treatment plant), they can then estimate total emissions from solvent consumption, by category, can be estimated.

Based on this conservative assumption, two sets of emission factors--population-based and employment-based--have been derived. These factors should be used only when area-specific data, usually based on surveys, are not available. The former set, of these factors assumes that area source solvent emissions within a study area (e.g., county, city, state) are directly proportional to the population living within the study area, as reported in the 1980 U.S. Census. The latter set of emission factors, generally believed to be more accurate for industrial user categories, assumes that emissions are directly proportional to employment in Standard Industrial Classification (SIC) codes (as reported in County Business Patterns<sup>9</sup>) of likely solvent users such as dry cleaners or degreasers. (For commercial/consumer solvent use, population serves as an indicator of consumption.) Table 2-2 shows which industrial categories comprise each solvent user category. Table 2-3 presents employee-based factors, while Table 2-4 contains per capita factors.

In the discussion below, each user category is described along with methodologies for estimating emissions. Example calculations are provided in Section 2.8.

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Table 2-1 National Solvent Consumption by User Category  
(Thousand Tons/Year)

Solvent	Surface coating	Degreasing	Dry cleaning	Graphic arts	Rubber & plastics	Other industrial	Commercial/ consumer	TOTAL
Special naphthas	1,794	247	74	236	354	262	394	3,360
Perchloroethylene		27	66				12	104
Ethanol						1,182		1,182
Trichloroethylene	1	68				3	1	72
Isopropanol	88					53	218	359
Acetone	160						108	268
Glycol ethers	83					19		102
Cyclohexanone						1		1
Methyl ethyl ketone	175			10		25		211
Ethyl benzene							17	17
Propylene glycol					121	9	13	143
Methanol						488	915	1,403
Butyl acetate	33			3			2	37
Ethyl acetate	44				9		14	66
Butyl alcohols	69					8	4	81
Methyl isobutyl ketone	48					6	13	67
Monochlorobenzene		25				25	13	62
o-Dichlorobenzene						6	1	7
p-Dichlorobenzene					7		15	22
111-Trichloroethane	6	186				68	3	263
Methylene chloride	35	33				25	78	170

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Table 2-2 SIC Codes Comprising Solvent Use Categories

Solvent Use Categories	SIC Codes
<u>Surface Coatings</u>	
Trade Paints-Auto Refinishing	
Auto Refinishing (Trade)	7535 (Paint Shops)
Automotive	371 (Motor Vehicles)
Wood Furniture and Fixtures	25 (Furniture and Fixtures)
Metal Furniture and Fixtures	
Metal Containers	34 (Fabricated Metal Products)
Sheet Strip and Coil	
Appliances	35 and 36 (Machinery, Electrical)
Machinery and Equipment	Equipment and Supplies
Paper	26 (Paper and Allied Products)
Factory-finished Wood	243, 244 (Millwork, Plywood- Related Supplies, Wooden Containers)
Transportation (Non-Auto)	37 (Transportation Equipment) Less 371 (Motor Vehicles) and 373 (Shipbuilding Repair)
Electric Insulation	36 (Electrical Equipment and Supplies)
Other, Exterior, Interior	19-39 (Total Manufacturing)
Marine	373 (Shipbuilding and Repair)
<u>Degreasing</u>	34-39 (Metal Products, Machinery, Transportation Equipment, Instruments, Miscellaneous)
<u>Dry Cleaning</u>	2 x 7216, Plus 7215 and 7218 (Dry Cleaning and Combination with Wet Laundering)
<u>Printing</u>	264, 265, and 27 (Paper Products, Containers, Printing and Publishing)
<u>Rubber and Plastics</u>	30 (Rubber and Plastics)
<u>Other Industrial</u>	1/2 of 19-39 Employment + 1/2 County Employment

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Table 2-3 Employee-Based Emission Factors for Solvent Usage  
(Pounds/Year/Employee\*)

Solvent	Surface coating	Degreasing	Dry cleaning	Graphic arts	Rubber & plastics	Other industrial	Commercial/consumer*	TOTAL
Special naphthas	1.2E+02	5.8E+01	4.1E+02	2.8E+02	1.0E+03	2.7E+01	3.5E+00	1.9E+03
Perchloroethylene		6.3E+00	3.6E+02				1.1E-01	3.7E+02
Ethanol						1.2E+02		1.2E+02
Trichloroethylene	5.9E-02	1.6E+01				2.8E-01	7.9E-03	1.6E+01
Isopropanol	5.8E+00					5.4E+00	1.9E+00	1.3E+01
Acetone	1.1E+01						9.5E-01	1.1E+01
Glycol ethers	5.5E+00					2.0E+00		7.5E+00
Cyclohexanone						1.0E-01		1.0E-01
Methyl ethyl ketone	1.2E+01			1.2E+01		2.6E+00		2.6E+01
Ethyl benzene					3.5E+02	9.2E-01	1.5E-01	1.5E-01
Propylene glycol						5.0E+01	1.2E-01	3.5E+02
Methanol				3.0E+00			8.1E+00	5.8E+01
Butyl acetate	2.2E+00						1.4E-02	5.2E+00
Ethyl acetate	2.9E+00				2.5E+01		1.2E-01	2.8E+01
Butyl alcohols	4.5E+00						3.9E-02	5.4E+00
Methyl isobutyl ketone	3.2E+00					8.1E-01	1.2E-01	3.9E+00
Monochlorobenzene		5.8E+00				6.0E-01	1.1E-01	8.4E+00
o-Dichlorobenzene						2.5E+00	9.7E-03	5.7E-01
p-Dichlorobenzene					2.1E+01	5.6E-01	1.3E-01	2.2E+01
111-Trichloroethane	3.9E-01	4.4E+01				6.9E+00	2.6E-02	5.1E+01
Methylene chloride	2.3E+00	7.6E+00				2.6E+00	6.8E-01	1.3E+01

\* Commercial/Consumer emission factors are in pounds/year/capita, rather than pounds/year/employee

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Table 2-4 Per Capita Emission Factors for Solvent Usage  
(Pounds/Year/Capita)

Solvent	Surface coating	Degreasing	Dry cleaning	Graphic arts	Rubber & plastics	Other industrial	Commercial/ consumer	TOTAL
Special naphthas	1.6E+01	2.2E+00	6.5E-01	2.1E+00	3.1E+00	2.3E+00	3.5E+00	3.0E+01
Perchloroethylene		2.4E-01	5.8E-01				1.1E-01	9.2E-01
Ethanol						1.0E+01		1.0E+01
Trichloroethylene	8.8E-06	6.0E-01				2.4E-02	7.9E-03	6.3E-01
Isopropanol	7.8E-01					4.7E-01	1.9E+00	3.2E+00
Acetone	1.4E+00						9.5E-01	2.4E+00
Glycol ethers	7.3E-01					1.7E-01		9.0E-01
Cyclohexanone						8.8E-03		8.8E-03
Methyl ethyl ketone	1.5E+00			9.0E-02		2.2E-01		1.9E+00
Ethyl benzene							1.5E-01	1.5E-01
Propylene glycol					1.1E+00	7.9E-02	1.2E-01	1.3E+00
Methanol						4.3E+00	8.1E+00	1.2E+01
Butyl acetate	2.9E-01						1.4E-02	3.3E-01
Ethyl acetate	3.9E-01						1.2E-01	5.9E-01
Butyl alcohols	6.1E-01			2.3E-02	7.6E-02		3.9E-02	7.2E-01
Methyl isobutyl ketone	4.2E-01						1.2E-01	5.9E-01
Monochlorobenzene		2.2E-01					1.1E-01	5.5E-01
o-Dichlorobenzene						4.9E-02	9.7E-03	5.8E-02
p-Dichlorobenzene					6.5E-02		1.3E-01	1.9E-01
111-Trichloroethane	5.2E-02	1.6E+00				6.0E-01	2.6E-02	2.3E+00
Methylene chloride	3.1E-01	2.9E-01				2.2E-01	6.8E-01	1.5E+00



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2.2 Surface Coating

The surface coating solvent use subcategory involves the application of paint, varnish, lacquer, or paint primer for decorative or protective purposes. This is accomplished by brushing, rolling, spraying, flow coating, and dipping operations.

Solvents are emitted as the coating material dries. Compounds released include aliphatic and aromatic hydrocarbons, alcohols, ketones, esters, alkyl and aryl hydrocarbon solvents, and mineral spirits.. The trend toward water-based coatings is reducing the magnitude of solvent emissions.

Surface coatings can be divided into the following categories:

Architectural surface coatings, often called "trade paints," are used primarily by homeowners and painting contractors to coat the interior or exterior of houses and buildings and of other structures such as pavements, curbs, or signs. Painting contractors and homeowners are the major users of architectural coatings.

Solvents used for thinning architectural surface coatings and for clean up after application also contribute significantly to volatile organic compound (VOC) emissions associated with the architectural coating process.

Automobile refinishing encompasses the repainting of worn or damaged automobiles, light trucks, and other vehicles. Surface coating during manufacture is not considered refinishing. In automobile refinishing, lacquers and enamels are usually spray-applied in paint booths. Since vehicles contain heat-sensitive plastics and rubber, solvent-borne

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coatings that can dry in low-temperature ovens are used. Paint booths may be equipped with paint arrestors or water curtains to handle overspray.

Industrial surface coating includes the coating, during manufacture, of magnet wire, automobiles, cans, metal coils, paper, fabric, metal and wood furniture, and miscellaneous products. Materials applied in coating include adhesives, lacquers, varnishes, paints, and other solvent-borne coating material. Many surface coating facilities generate sufficient emissions to be considered major sources, and should be included in the point source inventory. However, small sources probably will still be present in any developed inventory area.

There are two generic methods of estimating emissions from the application of surface coating:

Method 1. Calculate emissions based on employment data in County Business Patterns<sup>9</sup> for industrial categories listed in Table 2-2 that conduct surface coating. Apply emission factors provided in Table 2-3. Be certain to subtract emissions accounted for in point source inventories (or subtract point source employment prior to calculating area source emissions).

Method 2. Apply per capita emission factors contained in Table 2-4 (a less accurate method requiring fewer resources). Here, too, it is necessary to subtract any emissions included in the point source inventories. Countywide population data can be collected from the U.S. Census Bureau.

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2.3 Dry Cleaning

Dry cleaning operations vary in size, type of service, and type of solvent used. Industrial, commercial, and self-service facilities clean not only personal clothing, but also uniforms, linens, drapes, and other fabric materials. Three basic solvent types are used in dry cleaning: petroleum (Stoddard), tetrachloroethylene or perchloroethylene ("perc"), and trichlorotrifluoroethane (Freon® 113). Perchloroethylene is used in approximately 80 to 90 percent of all dry cleaning establishments and constitutes about 70 percent of all cleaning solvent consumed. Almost all other establishments use petroleum solvent. The use of fluorocarbons as a dry cleaning solvent is decreasing in popularity and is not considered in this report.

VOC emissions from dry cleaning vary with the type of process and solvent used. Detailed process descriptions and information on emissions and controls can be obtained in AP-42<sup>1</sup>.

Virtually all commercial and self-service dry cleaning facilities are area sources, while industrial dry cleaning facilities may be either point or area sources. There are several methods of estimating dry cleaning emissions; three widely applicable methods are given below.

Method 1. Calculate emissions based on employment data provided in County Business Patterns<sup>9</sup> for SICs 7215, 7216, and 7218. Apply emission factors provided in Table 2-3. Be certain to subtract emissions accounted for in point source inventories (or subtract point source employment) prior to calculating area source emissions.

Method 2. Multiply per capita emission factors contained in Table 2-4 by county population data (from the U.S. Census Bureau). (This is a less accurate method requiring fewer resources). Again it is necessary to subtract any emissions included in the point source inventories.

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Method 3. Send survey forms to a representative sample of dry cleaners taken from the Yellow Pages or a similar telephone directory. The data to be collected are number of employees, quantity of clothes cleaned (ton/year), type and amount of solvent used (solvent purchased minus solvent returned for recycle), and normal operating schedule. Assume that all of the solvent used is emitted, and check the survey values with emissions calculated as the product of the AP-42<sup>1</sup> emission factors and the quantity of clothes cleaned. Emissions by solvent type can then be estimated based on the survey results assumed that alternatively, it can be 70 percent of all emissions are perchloroethylene, with the remainder being Stoddard Solvent (petroleum distillates or special naphthas).

### 2.4 Degreasing (Solvent Cleaning Operations)

There are basically three types of degreasers: small cold cleaners, open top vapor degreasers, and conveyORIZED degreasers. According to recent estimates, there are about 1,300,000 small cold cleaning units operating in the U.S. Seventy percent of these units are devoted to maintenance of servicing operations, including service stations, auto dealerships, and miscellaneous repair stations; the remaining 30 percent are devoted to manufacturing operations. A typical cold cleaning unit emits approximately one-third metric ton of VOC per year. In contrast, typical open-top vapor degreasers and conveyORIZED degreasing units emit 10 and 27 metric tons of VOC per year, respectively. These larger units are commonly used in the metalworking industry. The design and operation of each of these types of degreasers will vary, as will emissions and the types of control measures used.<sup>2</sup> A broad spectrum of organic liquids, including petroleum distillates (special naphthas), chlorinated hydrocarbons, ketones, and alcohols is used in solvent cleaning operations.

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The development of degreasing emission estimates is complicated by a number of factors. First, some degreasers are large enough to be considered point sources, yet a large fraction of all degreasers will fall below the point source cutoff and should be accounted for as area sources. Second, degreasing operations are not associated with any particular industrial activity. Instead, degreasing of some sort may be carried out in a wide variety of industries including (1) metal working facilities (e.g., automotive, electronics, appliances, furniture, jewelry, plumbing, aircraft, refrigeration, business machinery, fasteners), (2) nonmetalworking facilities (printing, chemicals, plastics, rubber, textiles, glass, paper, electric power), (3) maintenance cleaning operations (electric motors, forklift trucks, printing presses), and (4) repair shops (automobile, railroad, bus, aircraft, truck, electric tool). Third, the fact that some of the VOC emissions associated with degreasing occur at the solvent waste disposal site complicates the location of emissions within the inventory area.

Open top vapor (OTV) cleaners and conveyorized cleaners are larger operations that should be included in the point source inventory whenever possible. These types of equipment tend to be associated with industrial plants that are already included in the point source inventory. Cold cleaners are smaller and usually are treated as area sources in an inventory. For all degreasers not included in the point source inventory, one of the following methods should be used to estimate emissions for the category.

Method 1. Calculate emissions based on employment data provided in County Business Patterns<sup>9</sup> for SICs 34 through 39. Apply emission factors provided in Table 2-3. Be certain to subtract emissions accounted for in point source inventories (or subtract point source employment prior to calculating area source emissions).

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Method 2. A less accurate method requiring fewer resources is to multiply per capita emission factors contained in Table 2-4 by U.S. Census Bureau population data. Here, too, it is necessary to subtract any emissions included in the point source inventories.

## 2.5 Rubber and Plastics

The rubber and plastics solvent user category (SIC 30 industries) includes tire and inner tube manufacturing and the fabrication of other rubber and plastic products such as footwear and hoses. Solvents are used by these industrial categories for cleaning, molding, sealing, and gluing. Special naphthas are the solvents used in greatest volumes; lesser amounts of propylene glycol, ethyl acetate, and p-dichlorobenzene are used.

Using emission factors provided on a per capita or per employee basis, estimate emissions are explained below.

Method 1. Calculate emissions based on employment data provided in County Business Patterns<sup>9</sup> for SIC 30. Apply emission factors provided in Table 2-3. Be certain to subtract emissions accounted for in point source inventories (or subtract point source employment prior to calculating area source emissions).

Method 2. Multiply U.S. Census Bureau data for the county by per capita emission factors contained in Table 2-4 (a less accurate method requiring fewer resources). Again it is necessary to subtract any emissions included in the point source inventories.

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### 2.6 Graphic Arts (Printing and Publishing)

Printing of newspapers, books, magazines, fabrics, wall coverings, and other materials is considered to be a graphic art application. Inventorying the graphic arts (printing and publishing) industry is complicated by the fact that the industry consists of approximately 50,000 facilities.<sup>9</sup> About half of these establishments are in-house printing services in nonprinting industries, further complicating estimating techniques.

While printing inks vary in composition, they consist of three major components: (1) organic or inorganic pigments that produce the desired color, (2) the binder or solid components (organic resins, polymers, oils, or rosins) that lock the pigments to the receiving material or "substrate," and (3) solvents that dissolve or disperse the pigments and binders and are usually composed of organic compounds. The solvent evaporates, typically as heated air is passed across the wet surface, and is exhausted to the atmosphere.

Solvent emissions vary depending on the type of printing process and the ink used. Printing techniques used include:

Wet offset lithography, the process used to produce the majority of books and pamphlets and an increasing number of newspapers, typically uses inks containing between 5 (newspaper) and 40 percent solvent. Solvents are usually petroleum derived (naphthas). Isopropanol can be used to dampen the printing plate.<sup>2</sup>

Letterpress is the oldest form of movable type printing. Letterpress newspaper and sheet-fed printing use oxidative drying inks, which are not a source of solvent emissions. Publication letter printing, on the other hand, uses solvent-borne inks that are usually 40 percent petroleum-based solvents; the solvents are driven off with heat.<sup>2</sup>

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Rotogravure systems are used in publications and advertising, such as newspaper supplements; mail order catalogues; folding cartons and other flexible packing materials; and specialty products such as wall and floor coverings, decorated household paper products, and vinyl upholstery. The inks typically contain 55 to 95 volume percent low-boiling-point solvents, such as alcohols, aliphatic naphthas, aromatic hydrocarbons, esters, glycol ethers, ketones, and nitroparaffins.<sup>2</sup>

Flexography is used in flexible packing and laminates such as multiwall bags, milk cartons, gift wrap, folding cartons, corrugated cardboard, paper cups and plates, labels, tapes, and envelopes. It uses water-based or organic-based solvents depending on the specific product. Among the solvents used are alcohols or alcohols mixed with aliphatic hydrocarbons or esters, glycols, ketones, and ethers.

Screen printing is used to print patterns or designs on fabrics. Organic solvents (predominately mineral spirits) or water-based solvents are used in the print pastes that are applied in the roller, flat screen, and rotary screen printers.

Currently graphic arts emissions can be estimated by using one of three methods:

Method 1. Multiply U.S. Census Bureau data for the county by per capita emission factors contained in Table 2-4. It is necessary to subtract any emissions included in the point source inventories.

Method 2. Calculate emissions based on employment data provided in County Business Patterns<sup>9</sup> for SICs 264 (Paper Products), 265 (Containers), and 27 (Printing and Publishing). Apply emission factors provided in Table 2-3. Note that an emissions-per-employee approach may not be as reliable as a per capita approach in the graphic arts solvent



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user category because of the uncertainty as to which facilities and industries have captive graphic art capabilities. It is important to subtract emissions accounted for in point source inventories (or subtract point source employment prior to calculating area source emissions.)

Method 3. OAQPS has prepared a new air toxics speciation manual<sup>12</sup> that contains speciation factors for various printing and publishing processes. If data are available on VOC emission rates from printing and publishing processes in the study area, the speciation factors can be applied to estimate emissions of individual compounds.

### 2.7 Other Industrial Solvent Usage

This category covers solvent releases from a variety of manufacturing process and industries including:

- Synthetic organic chemical manufacturing (SOCM);
- Paint formulating;
- Ink formulating;
- Textiles;
- Iron and steel manufacturing (cold rolling mills);
- Pharmaceuticals; and
- Pesticides, herbicides, etc.;

All of these industries used and release solvents to the air. Nationally, a variety of solvents are used in large quantities. (See Table 2-2).

The diversified nature of the industries in this category, and the multiple uses of many of the solvents make it impractical to survey facilities to estimate emissions. However, emissions can be estimated on a per capita basis or based on employment in user subcategories. Two methods for estimating emissions are described below.

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Method 1. Calculate emissions based on employment data for industries conducting surface coating according to County Business Patterns<sup>9</sup> listed in Table 2-3. Apply emission factors provided in Table 2-3. Be certain to subtract emissions accounted for in point source inventories (or subtract point source employment prior to calculating area source emissions).

Method 2. Multiply U.S. Census Bureau population data for the county by per capita emission factors contained in Table 2.4. Here, too, it is necessary to subtract any emissions included in the point source inventories.

### 2.8 Commercial/Consumer Solvent Usage

Commercial/consumer uses of products containing solvents are not easily quantified using questionnaires, surveys, or other inventory methods that can make emission estimates locale-specific. Among the commercial/consumer products that often contain solvents are aerosol products such as (1) insect sprays, (2) paints and finishes, (3) household products, (4) personal products, (5) animal products, (6) automotive and industrial products, (7) food products, and (8) miscellaneous products, as well as nonaerosol products such as (1) personal products, (2) household products, and (3) garage products.<sup>10</sup> Certain subcategories account for the vast majority of commercial/consumer VOC emissions:

- Paints, primers, and varnishes,
- Hair sprays,
- All-purpose cleaners,
- Insect sprays,
- Car polishes and waxes,
- Room deodorants and disinfectants,
- Adhesives,
- Caulking and sealing compounds,
- Moth control products,

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- Window and glass cleaners, and
- Herbicides and fungicides.

These sources account for 75 percent of commercial/consumer VOC emissions, as reported in ongoing work by EPA.<sup>11</sup>

Commercial/consumer solvent usage can be estimated using per capita emission factors contained in Table 2-3 or 2-4. Emission factors are multiplied by county population as listed in the U.S. Census.

## 2.9 Example Calculations

Examples are provided below to demonstrate the application of per capita and employee-based factors.

### Example Calculation 1

Estimate the annual area source emissions from degreasing in Delaware County, Pennsylvania.

SIC codes 34-39 are identified in Table 2-1 as conducting degreasing. Based on data in County Business Patterns,<sup>9</sup> the employment in Delaware County in SICs 34-39 is 12,704. Applying emission factors from Table 2-3, emissions can be estimated.

Special naphthas =  $(12,704) \times (58 \text{ lb/yr/employee}) = 736,832 \text{ lb/yr}$

Perchloroethylene =  $(12,704) \times (6.3 \text{ lb/yr/employee}) = 80,034 \text{ lb/yr}$

Trichloroethylene =  $(12,704) \times (16 \text{ lb/yr/employee}) = 203,264 \text{ lb/yr}$

Monochlorobenzene =  $(12,704) \times (58 \text{ lb/yr/employee}) = 736,832 \text{ lb/yr}$

1,1,1-Trichloroethylene =  $(12,704) \times (44 \text{ lb/yr/employee}) = 558,976 \text{ lb/yr}$

Methylene chloride =  $(12,704) \times (7.6 \text{ lb/yr/employee}) = 96,550 \text{ lb/yr}$

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Example Calculation 2

What are the total annual trichloroethylene emissions from solvent usage in DeKalb County, Georgia?

The 1980 U.S. Census reports the population of DeKalb County to be 466,600.

Applying emission factors in Table 2-4, countywide emissions can be calculated.

Surface Coating	$(466,600) \times 8.8 \times 10^{-6}$ lb/capita	=	4 lb/yr
Degreasing	$(466,600) \times 6.0 \times 10^{-1}$ lb/capita	=	270,960 lb/yr
Other Industrial	$(466,600) \times 2.4 \times 10^{-2}$ lb/capita	=	11,198 lb/yr
Commercial/Consumer	$(466,600) \times 7.9 \times 10^{-3}$ lb/capita	=	<u>3,686 lb/yr</u>
TOTAL			= 294,848 lb/yr

2.10 Methods to Apportion Countywide Emissions from Solvent Usage

As described in Section 1.0 and Appendix A when performing air dispersion modeling, it is generally recommended that countywide emissions be distributed within the study area into rectangular area source grid cells reflecting spatial variations in activity and emissions. Similarly temporal in activities can be factored into the modeling to reflect seasonal or diurnal fluctuations in emissions. Modeling results would then reflect on-going activities in that portion of the county, e.g., residential heating in the winter, commercial solvent usage during working hours on weekdays.

There are three alternative approaches that can be used in spatially distributing emissions: (1) population, i.e., the magnitude of emissions

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within a grid are directly proportional to the population living in the grid, (2) land area, i.e., emissions from a countywide distributed based on the size of the area source grid, and (3) landuse patterns, that assume that certain area source activities, most likely occur in certain areas of the county, e.g., commercial, residential or industrial.

In apportioning emissions from solvent usage any of these methods may be appropriate. Land area and population data can be readily obtained, and applied as described in Appendix A. Land use data, available from the U.S. Geological survey and other sources can be used in combination with the spatial resolution for each category of solvent usage, to distribute emissions based on the type of activity being performed, as shown in Table 2-5.

Estimated seasonal, daily, and hourly temporal resolution for each category of solvent usage are also included in Table 2-5, and can be used with annual countywide emissions data to estimate temporal variations.

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Table 2-5 Spatial and Temporal Resolution of County Wide  
Emissions Totals for Solvent Usage

1. Industrial Surface Coating (Solvent)

Spatial Resolution

Surrogate indicator: commercial/industrial areas (Codes  
12, 13, and 15)  
Information source(s): land use map

Temporal Resolution

Seasonal: uniform through the year  
Daily: uniform through the week  
Hourly: 80 percent from 0700 to 1900, 20  
percent from 1900 to 2400, otherwise  
zero

2. Nonindustrial Surface Coating<sup>13</sup>

Spatial Resolution

Surrogate indicator: urban or builtup land (codes 11  
through 17)  
Information source(s): land use map

Temporal Resolution

Seasonal: uniform through the year  
Daily: uniform through the week  
Hourly: uniform 0700 to 1900, otherwise zero

3. Dry Cleaning<sup>13</sup>

Spatial Resolution

Surrogate indicator: commercial areas (codes 12 and 15)  
Information source(s): Retail service employment, land use  
map

Temporal Resolution

Seasonal: uniform through the year  
Daily: uniform Monday through Saturday  
Hourly: uniform 0700 to 1900, otherwise zero

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Table 2-5 (continued)

## 4. Degreasing<sup>13</sup>

### Spatial Resolution

Surrogate indicator: industrial area (codes 13 and 15)  
Information source(s): land use map and Reference 14

### Temporal Resolution

Seasonal: uniform through the year  
Daily: uniform Monday through Saturday  
Hourly: 80 percent from 0700 to 1900, 20 percent from 1900 to 2400

## 5. Rubber and Plastics (Solvent)

### Spatial Resolution

Surrogate indicator: commercial/institutional areas (codes 12, 13, and 15)  
Information source(s): land use map

### Temporal Resolution

Seasonal: uniform through the year  
Daily: uniform through the week  
Hourly: 80 percent from 0700 to 1900, 20 percent from 1900 to 2400, otherwise zero

## 6. Graphic Arts (Solvent)

### Spatial Resolution

Surrogate indicator: commercial areas (code 12)  
Information source: land use map

### Temporal Resolution

Seasonal: uniform through the year  
Daily: 80 percent Monday through Saturday, 20 percent Sunday  
Hourly: uniform through the day

## 7. Other Industrial (Solvent)

### Spatial Resolution

Surrogate indicator: commercial areas (code 12).  
Information source: land use map

### Temporal Resolution

Seasonal: uniform through the year  
Daily: uniform through the week  
Hourly: 80 percent from 0700 to 1900, 20 percent from 1900 to 2400, otherwise zero.

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Table 2-5 (continued)

8. Commercial/Consumer Solvent Use<sup>13</sup>

Spatial Resolution

Surrogate indicator: residential,  
commercial/institutional areas  
(codes 12, 13, and 15)  
Information source(s): land use map

Temporal Resolution

Seasonal: uniform through the year  
Daily: uniform through the week  
Hourly: 80 percent from 0700 to 1900, 20  
percent from 1900 to 2400

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3. HEATING (INCLUDING WASTE OIL COMBUSTION)

3.1 General

The combustion of fossil fuels and wood to generate heat produces emissions of a variety of air toxics including volatile organic compounds, metals, and polycyclic organic matter (POM). Emissions from larger sources such as electric utilities and major industrial and commercial/institutional boilers are typically included in a point source inventory. Area source emissions from heating occur from fuel combustion in small stationary sources. Emissions from smaller sources can be organized into three major area source categories: (1) industrial (small), (2) commercial/institutional, and (3) residential.

Emissions vary based on the fuel type, burner type, operating parameters, and pollution controls. It is assumed, unless otherwise noted, that all area source heating is uncontrolled or at best has minimal (i.e., mechanical) pollution control equipment. Major fuels used for area source heating include coal, virgin oil (distillate and residual), natural gas, wood, and waste oil, which are discussed below.

Coal. Area sources burning coal usually use bituminous and lignite coal. (Anthracite, bituminous, and lignite coals are all burned in point source boilers.) Small coal units, common to area sources, are usually stoker-fired. There are three types of stoker units: (1) spread stokers, (2) overfeed stokers, and (3) underfeed stokers. Generally these small boilers have no air pollution controls.

Major toxic pollutants emitted from coal combustion include metals and organic compounds (including aldehyde and polycyclic organic matter). Some unburnt combustibles, including numerous organic compounds, are usually emitted even under proper boiler operating conditions.

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Virgin Oil. Both distillate and residual virgin oils (hereafter referred to as distillate and residual oils) are burned in area source heating units. Distillate oils (fuel oil grade Nos. 1 and 2) are used mainly in domestic and small commercial applications in which easy fuel burning is required. Distillates are more volatile and less viscous than residual oils, having negligible ash and nitrogen contents and usually containing less than 0.3 weight percent sulfur. Residual oils (grade Nos. 4, 5, and 6), on the other hand, are used mainly in industrial and utility boilers and larger commercial applications. Residual oils, which are produced from the residue left after lighter fractions (gasoline, kerosene, and distillate oils) have been removed from the crude oil, usually contain higher quantities of ash, nitrogen, and sulfur. Thus, burning residual oils generally produces greater concentrations of air toxics than does burning distillate oils.

Pollutant loadings from fuel oil combustion are also influenced by the type (tangential, wall, etc.) and size of the boiler, firing and loading practices, and equipment maintenance. If a boiler unit is operated improperly or is poorly maintained, the concentrations of toxic pollutants may increase by several orders of magnitude.

Natural Gas. Natural gas is often used as a fuel in heating units to produce heat in small industrial boilers and domestic and commercial space heaters. Because natural gas is a gaseous, homogenous fluid, the effective operation of the combustion unit is more easily achieved with its use.

Even though natural gas is a relatively clean fuel, some emissions do occur from the combustion reaction. For example, improper operating conditions, including poor mixing and insufficient air, may cause increased amounts of formaldehyde, polycyclic organic matter, and other pollutants to be emitted.

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It is assumed that no emission controls are used for area sources burning natural gas.<sup>1</sup>

Wood. The combustion of wood, primarily in residences, can be a significant source of air toxics, most notably polycyclic organic matter. As with other fuel combustion technologies, emissions vary depending on the characteristics of the fuel burned (e.g., moisture content, wood type), the operating parameters (most notably the fuel:air ratio), combustion unit (fireplace, catalytic stove, noncatalytic stove), and wood load.

Wood stoves are commonly used as space heaters to supplement conventional heating systems in residences. They are increasingly found as the primary source of heat, as well.

Because of differences in both the magnitude and the composition of emissions from wood stoves, four different categories of stoves should be considered when estimating emissions of the conventional noncatalytic wood stove, the noncatalytic low emitting wood stove, the pellet fired noncatalytic wood stove, and the catalytic wood stove.

Among these categories there are many variations in wood stove design and operation characteristics.

The conventional stove category comprises all stoves without catalytic combustors not included in the other noncatalytic categories. Stoves of many different airflow designs, such as updraft, downdraft, crossdraft, and S-flow, may be in this category.

"Noncatalytic low emitting" wood stoves are those having no catalyst and meeting EPA certification standards.

Pellet fired stoves are fueled with pellets of sawdust, wood products and other biomass materials pressed into manageable shape and size. These

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stoves have a specially designed or modified grate to accommodate this type of fuel.

Catalytic stoves are equipped with a ceramic or metal honeycomb material, called a combustor or converter that is coated with a noble metal such as platinum or palladium. The catalyst material reduces the ignition temperature of the unburned hydrocarbons and carbon monoxide in the exhaust gases, thus augmenting their ignition and combustion at normal stove operating temperatures. As these components of the gases burn, the temperature inside the catalyst increases to a point where the ignition of the gases is essentially self-sustaining.

Waste Oil. Approximately 1.1 billion gallons of waste oil are generated annually in the United States. This used oil is produced by a range of sources such as repair shops, service stations, airports, shipyards, and recycling centers. Additionally, spill cleanup and tank cleaning contribute to waste oil generation. A major portion of this waste oil, 400 to 660 million gallons, is burned in boilers, kilns, diesel engines, and waste oil heaters. Ninety-two percent of the oil that is burned is burned in boilers. Combustion represents the largest single use of waste oil, with the remainder being re-refined, used as dust suppressants, landfilled, or dumped.<sup>2</sup>

The major concern about using waste oil as fuel is related to increased emissions of air toxics, as a result of contamination of the oil. Available literature indicates that air emissions are dependent on the type of combustion unit, the waste oil composition, operating parameters, and the type of air pollution controls in place.

Oil-fired boilers consuming waste oil include small residential boilers, intermediate commercial and institutional boilers, and large industrial boilers. Typically, industrial boilers are larger in size and achieve high combustion efficiency at higher burner temperatures; the factors that affect the quality of combustion are not as carefully controlled in smaller boilers. These conditions impose a tremendous

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variability in the level of metal emissions from boilers, the average metal emissions ranging from 31 to 75 percent of the original metal feed. However, to be on the conservative side, a 100 percent emission rate for metals could be assumed.

Methods for estimating emissions of air toxics from industrial, commercial, institutional, and residential area source burning of coal, virgin oil, wood, and natural gas are discussed in Sections 3.1 through 3.3. An approach for estimating emissions from waste oil combustion is described in Section 3.4.

A method for estimating the quantities of fuel burned by stationary area sources (activity levels) has been documented by GCA Technologies, Inc.<sup>3</sup> Portions of that document are incorporated directly into this manual (with approval from Dale Pahl, the EPA Project Officer). Secondary references cited in Reference 3 have been cited in this manual, as well, so that the reader can obtain additional information if needed.

Emission factors have been compiled for each heating category, along with example calculations to demonstrate the application of activity levels and emission factors to estimate countywide pollutant loads. In addition, thermal equivalents for various fuels and densities of fuels are presented in Tables 3-1 and 3-2, respectively, to help in conversions in estimating emissions.

The EPA has developed a VOC and particulate speciation manual<sup>4</sup> which contains factors for a number of point and area source categories, including heating, that can be used to supplement factors provided in this manual. Many of those factors may be incorporated, with minor revisions, into future versions of this manual.

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Table 3-1 Thermal Equivalents for Various Fuels

Type of fuel	BTU (gross)	kcal
Solid fuels		
Bituminous coal	$(21.0 \text{ to } 28.0) \times 10^6/\text{ton}$	$(5.8 \text{ to } 7.8) \times 10^6/\text{MT}$
Anthracite coal	$25.3 \times 10^6/\text{ton}$	$7.03 \times 10^6/\text{MT}$
Wood	$21.0 \times 10^6/\text{cord}$	$1.47 \times 10^6/\text{m}^3$
Liquid fuels		
Residual fuel oil	$6.3 \times 10^6/\text{bbl}$	$10 \times 10^3/\text{liter}$
Distillate fuel oil	$5.9 \times 10^6/\text{bbl}$	$9.35 \times 10^3/\text{liter}$
Gaseous fuels		
Natural gas	$1,050/\text{ft}^3$	$9,350/\text{m}^3$

Source: Reference 1.

Table 3-2 Densities of Selected Fuels

Fuel	Density	
<hr/>		
Fuels		
Crude oil	874 kg/m <sup>3</sup>	7.30 lb/gal
Residual oil	944 kg/m <sup>3</sup>	7.88 lb/gal
Distillate oil	845 kg/m <sup>3</sup>	7.05 lb/gal
Gasoline	739 kg/m <sup>3</sup>	6.17 lb/gal
Natural gas	673 kg/m <sup>3</sup>	1.00 lb/23.8 ft <sup>3</sup>
Wood <sup>a</sup>	600 kg/m <sup>3</sup>	38.00 lb/ft <sup>3</sup>

<sup>a</sup>Average of 10 wood types

Source: Reference 1.



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3.2 Industrial Heating

This category encompasses all industrial stationary combustion sources that are not typically included as point sources. Traditionally, boilers larger than 26 GJ/hr are treated in inventories as point sources. Combustion equipment in this category is used for energy and steam generation, along with space heating.

Small industrial boilers generally use the following types of fuel: anthracite coal, bituminous coal, industrial coke, distillate oil and natural gas.

(1) Activity Levels for Industrial Heating. Walden<sup>5</sup> developed a procedure for the estimation of state industrial area source consumption of bituminous coal, distillate oil, residual oil, natural gas, and liquid petroleum gas (LPG). NEDS' estimates of countywide fuel consumption are calculated using these procedures and can be used in combination with emission factors to estimate countywide emissions.

(2) Emission Factors for Industrial Heating. Emission factors to estimate air toxics emissions from industrial area source heating are presented in Table 3-3. Emissions can be calculated by multiplying the activity for each area source by the appropriate emission factor.

Most of the emission factors were taken from Reference 6. It was conservatively assumed that no controls are in place and that technologies common to small units typical of area sources (such as coal stokers) were used. Emissions of POMs were estimated based on information provided by ORD, who defined POMs as the benzene extractable portion of particulate matter. For each source category e.g. industrial coal, residential oil, ORD provided a percent of particulate that is considered to be POMs for that category.<sup>7</sup>

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Table 3-3 Emission Factors for Industrial Area Source Heating

Fuel type	Pollutant	Emission factor	Reference	Comment
Anthracite	Arsenic	482 pg/J ( $2.6 \times 10^{-2}$ lb/ton)	6	Stoker (uncontrolled)
	Benzo(a)pyrene	0.06 pg/J ( $3.3 \times 10^{-6}$ lb/ton)	6	
	Beryllium	0.005 pg/J ( $9.5 \times 10^{-4}$ lb/ton)		Stoker
	Cadmium	17.9 pg/J ( $9.4 \times 10^{-4}$ lb/ton)	6	Stoker
	Chromium	38.3 pg/J ( $2.1 \times 10^{-3}$ lb/ton)	6	Stoker
	Formaldehyde	537 pg/J ( $3 \times 10^{-2}$ lb/ton)	6	
	Lead	4.1 pg/J ( $2.3 \times 10^{-4}$ lb/ton)	6	Stoker
	Nickel	68.4 pg/J ( $3.8 \times 10^{-3}$ lb/ton)	6	Stoker
	POMS	343 pg/J ( $1.8 \times 10^{-2}$ lb/ton)	7, 1	Assumed POMS are 0.2% of TSP for Anthracite stoker
	Vanadium	58.1 pg/J ( $3.2 \times 10^{-3}$ lb/ton)	6	
Bituminous Coal	Arsenic	482 pg/J ( $2.7 \times 10^{-2}$ lb/ton)	6	Stoker (uncontrolled)
	Benzo(a)pyrene	0.06 pg/J ( $3.5 \times 10^{-6}$ lb/ton)	6	
	Beryllium	18.1 pg/J ( $1.0 \times 10^{-3}$ lb/ton)	6	Stoker (uncontrolled)
	Cadmium	17.9 pg/J ( $1.0 \times 10^{-3}$ lb/ton)	6	Stoker
	Chromium	38.3 pg/J ( $2.2 \times 10^{-3}$ lb/ton)	6	Stoker
	Formaldehyde	537.0 pg/J ( $3 \times 10^{-2}$ lb/ton)	6	
	Lead	4.1 pg/J ( $2.4 \times 10^{-4}$ lb/ton)	6	Stoker
	Nickel	68.4 pg/J ( $4.0 \times 10^{-3}$ lb/ton)	6	Stoker
	POMS	537 pg/J ( $3.0 \times 10^{-2}$ lb/ton)	7, 1	Assumed POMS are 0.2% of TSP for Bituminous stoker
	Vanadium	58.1 pg/J ( $3.4 \times 10^{-3}$ lb/ton)	6	
Residual oil	Arsenic	47.3 pg/J ( $1.6 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	Benzo(a)pyrene	0.13 pg/J ( $4.52 \times 10^{-5}$ lb/1,000 gal)	6	Tangential
		0.2 pg/J ( $7.0 \times 10^{-5}$ lb/1,000 gal)	6	Wall
	Beryllium	1.9 pg/J ( $6.6 \times 10^{-4}$ lb/1,000 gal)	6	Tangential, Wall
	Cadmium	71.3 pg/J ( $2.5 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	Chromium	28.6 pg/J ( $1.0 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	Formaldehyde	94.4 gh/J ( $3.3 \times 10^{-2}$ lb/1,000 gal)	6	
	Lead	4.1 pg/J ( $1.42 \times 10^{-3}$ lb/1,000 gal)	6	Tangential, Wall
	Nickel	31.4 pg/J ( $1.0 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	POMS	207 pg/J ( $7.0 \times 10^{-2}$ lb/1,000 gal)	7, 1	Assumed POMS are 0.7% of TSP
	Vanadium	1000 pg/J ( $3.5 \times 10^{-1}$ lb/1,000 gal)	6	Tangential, Wall

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 3-3 (Continued)

Fuel type	Pollutant	Emission factor	Reference	Comment
Distillate oil	Arsenic	47.3 pg/J ( $1.53 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	Benzo(a)pyrene	0.13 pg/J ( $4.23 \times 10^{-5}$ lb/1,000 gal)	6	Tangential
		0.2 pg/J ( $6.5 \times 10^{-5}$ lb/1,000 gal)	6	Wall
	Beryllium	1.9 pg/J ( $6.2 \times 10^{-4}$ lb/1,000 gal)	6	Tangential, Wall
	Cadmium	71.3 pg/J ( $2.3 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	Chromium	28.6 pg/J ( $9.3 \times 10^{-3}$ lb/1,000 gal)	6	Tangential, Wall
	Formaldehyde	94.4 pg/J ( $3.3 \times 10^{-2}$ lb/1,000 gal)	6	
	Lead	4.1 pg/J ( $1.33 \times 10^{-3}$ lb/1,000 gal)	6	Tangential, Wall
	Nickel	31.4 pg/J ( $1.02 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	POMS	43.3 pg/J ( $1.4 \times 10^{-2}$ lb/1,000 gal)	7, 1	Assumed POMS are 0.7% of TSP
	Vanadium	1000 pg/J ( $3.2 \times 10^{-1}$ lb/1,000 gal)	6	Tangential, Wall
Natural Gas	Formaldehyde	$2.0 \times 10^0$ lb/million cubic feet	16	

Note: pg/J indicates picograms per joule.

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3.3 Commercial and Institutional Heating

The commercial and institutional heating source category includes all stationary fuel combustion sources that are not included under residential sources, industrial sources, power plants, or commercial point sources. Major commercial/institutional area sources include hospitals, hotels, laundries, schools, and universities.

Activity levels for commercial/institutional heating. Quantities of fuels burned by industry are estimated for anthracite coal, bituminous coal, distillate oil, residual oil, and natural gas using the methodology described by Walden.<sup>5</sup> The NEDS data base estimates commercial/institutional fuel consumption by fuel type, using these procedures. These values can be multiplied by the appropriate emission factor listed in Table 3-4 to estimate emissions.

A methodology for estimating waste oil consumption in residential, institutional, and commercial (RIC) and industrial boilers can be found in Section 3.4. It is estimated that 23 percent of the waste oil that is burned in the United States is burned in RIC boilers.

Emission factors for commercial/institutional heating. Emission factors for commercial and institutional heating are presented in Table 3-4. Emissions can be calculated by multiplying the activity for each area source by the appropriate emission factor.

Most of the emission factors were taken from Reference 6. It was conservatively assumed that no controls are in place and that technologies common to small units typical of area sources (such as coal stokers) were used. Emissions of POMs were estimated based on information provided by ORD, who defined POMs as the benzene extractable portion of particulate matter. For each source category e.g. industrial coal, residential oil, ORD provided a percent of particulate that is considered to be POMs for that category.<sup>7</sup>

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Table 3-4 Emission Factors for Commercial/Institutional Area Source Heating

Fuel type	Pollutant	Emission factor	Reference	Comment
Anthracite coal	Arsenic	482 pg/J ( $2.7 \times 10^{-2}$ lb/ton)	6	Stoker
	Benzo(a)pyrene	4.7 pg/J ( $2.6 \times 10^{-4}$ lb/ton)	6	Stoker
	Beryllium	18.1 pg/J ( $9.5 \times 10^{-4}$ lb/ton)	6	Stoker
	Cadmium	12.9 pg/J ( $7.1 \times 10^{-3}$ lb/ton)	6	Stoker
	Chromium	38.3 pg/J ( $2.1 \times 10^{-3}$ lb/ton)	6	Stoker
	Formaldehyde	567 pg/J ( $3 \times 10^{-2}$ lb/ton)		
	Lead	4.1 pg/J ( $2.3 \times 10^{-4}$ lb/ton)	6	Stoker
	Nickel	68.4 pg/J ( $3.8 \times 10^{-3}$ lb/ton)	6	Stoker
	POMS	1486 pg/J ( $7.8 \times 10^{-2}$ lb/ton)	7, 1	Assumed POMS are 0.2% of TSP
	Vanadium	51.8 pg/J ( $2.8 \times 10^{-3}$ lb/ton)	6	Stoker
Bituminous coal	Arsenic	482 pg/J ( $2.8 \times 10^{-2}$ lb/ton)	6	Stoker
	Benzo(a)pyrene	4.7 pg/J ( $2.7 \times 10^{-4}$ lb/ton)	6	Stoker
	Beryllium	18.1 pg/J ( $1.0 \times 10^{-3}$ lb/ton)	6	Stoker
	Cadmium	12.9 pg/J ( $7.5 \times 10^{-4}$ lb/ton)	6	Stoker
	Chromium	38.3 pg/J ( $2.2 \times 10^{-3}$ lb/ton)	6	Stoker
	Formaldehyde	537.0 pg/J ( $3.0 \times 10^{-2}$ lb/ton)	6	
	Lead	4.1 pg/J ( $2.4 \times 10^{-4}$ lb/ton)	6	Stoker
	Nickel	68.4 pg/J ( $4.0 \times 10^{-3}$ lb/ton)	6	Stoker
	POMS	543 pg/J ( $3 \times 10^{-2}$ lb/ton)	7, 1	Assumed POMS are 0.2% of TSP
	Vanadium	51.8 pg/J ( $3.0 \times 10^{-3}$ lb/ton)	6	Stoker
Residual oil	Arsenic	47.3 pg/J ( $1.6 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	Benzo(a)Pyrene	0.4 pg/J ( $1.4 \times 10^{-4}$ lb/1,000 gal)	6	Tangential, Wall
	Beryllium	0.1 pg/J ( $3.5 \times 10^{-5}$ lb/1,000 gal)	6	Tangential, Wall
	Cadmium	71.8 pg/J ( $2.5 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	Chromium	50.0 pg/J ( $1.7 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	Formaldehyde	94.4 pg/J ( $3.3 \times 10^{-2}$ lb/1,000 gal)	6	
	Lead	4.1 pg/J ( $1.4 \times 10^{-3}$ lb/1,000 gal)	6	Tangential, Wall
	Nickel	804 pg/J ( $2.7 \times 10^{-1}$ lb/1,000 gal)	6	Tangential, Wall
	POMS	40 pg/J ( $1.4 \times 10^{-2}$ lb/1,000 gal)	7, 1	Assumed POMS are 0.7% of TSP
	Vanadium	3660 pg/J (1.2 lb/1,000 gal)	6	Tangential, Wall

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Table 3-4 (Continued)

Fuel type	Pollutant	Emission factor	Reference	Comment
Distillate oil	Arsenic	47.3 pg/J ( $1.5 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	Benzo(a)Pyrene	0.4 pg/J ( $1.3 \times 10^{-4}$ lb/1,000 gal)	6	Tangential, Wall
	Beryllium	0.1 pg/J ( $3.3 \times 10^{-5}$ lb/1,000 gal)	6	Tangential, Wall
	Cadmium	71.8 pg/J ( $2.3 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	Chromium	50.0 pg/J ( $1.6 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	Formaldehyde	94.4 pg/J ( $3.3 \times 10^{-2}$ lb/1,000 gal)	6	
	Lead	4.1 pg/J ( $1.3 \times 10^{-3}$ lb/1,000 gal)	6	Tangential, Wall
	Nickel	112 pg/J ( $3.6 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
	POMS	44 pg/J ( $1.4 \times 10^{-2}$ lb/1,000 gal)	7, 1	Assumed POMS are 0.7% of TSP
	Vanadium	30 pg/J ( $9.8 \times 10^{-2}$ lb/1,000 gal)	6	Tangential, Wall
Natural Gas	Formaldehyde	$6.3 \times 10^{-1}$ lb/million cubic feet	8	

Note: pg/J indicates picograms per joule

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3.4    Residential Heating

The residential heating category includes emissions for residential activities that use fuel for water heating, space heating, and cooking. Emissions contributed by residential fuel consumption are broken down into six categories according to the type of fuel. Fuel types included are anthracite coal, bituminous coal, distillate oil, residual oil, natural gas, and wood. For each of the listed fuel types, activity levels measured by fuel quantity consumed in weight or volume units are multiplied by emission factors listed in Table 3-5 to obtain emissions estimates. Methodologies for activity levels follow.

Activity levels for residential heating. Total county residential consumptions of coal, oil, and natural gas are calculated based on algorithms derived by Walden.<sup>5</sup> It should be noted that residential residual oil consumption is assumed to be negligible.<sup>9</sup> Residential wood consumption provided in NEDS also are based on Estimates of U.S. Wood Energy Consumption,<sup>10</sup> updated annually using regional data from the Annual Housing Survey.<sup>9</sup> The NEDS data base provides estimates of consumption based on these procedures.

Emission factors for residential heating. Air toxic emission factors are presented in Table 3-5. Emissions can be estimated by multiplying the appropriate factor from Table 3-5 by the activity for the area of concern.

Most of the emission factors were taken from Reference 6. It was conservatively assumed that no controls are in place and that technologies common to small units typical of area sources (such as coal stokers) were used. Emissions of POMs were estimated based on information provided by ORD, who defined POMs as the benzene extractable portion of particulate matter. For each source category e.g. industrial coal, residential oil, ORD provided a percent of particulate that is considered to be POMs for that category.<sup>7</sup>

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 3-5 Emission Factors for Residential Area Source Heating

Fuel type	Pollutant	Emission factor	Reference	Comment
Bituminous coal	Arsenic	717 pg/J ( $4.2 \times 10^{-2}$ lb/ton)	6	
	Benzo(a)pyrene	108 pg/J ( $6.0 \times 10^{-3}$ lb/ton)	6	
	Beryllium	7.2 pg/J ( $4.2 \times 10^{-4}$ lb/ton)	6	
	Cadmium	17.9 pg/J ( $1.0 \times 10^{-3}$ lb/ton)	6	
	Chromium	71.3 pg/J ( $4.1 \times 10^{-3}$ lb/ton)	6	
	Formaldehyde	43.0 pg/J ( $2.4 \times 10^{-3}$ lb/ton)	6	
	Lead	359 pg/J ( $2.1 \times 10^{-2}$ lb/ton)	6	
	Nickel	71.8 pg/J ( $4.2 \times 10^{-3}$ lb/ton)	6	
	POMS	221,960 pg/J (12.4 lb/ton)	7, 1	Assumed POMS are 83% of TSP
	Vanadium	71.8 pg/J ( $4.2 \times 10^{-3}$ lb/ton)	6	
Anthracite coal	Arsenic	166 pg/J ( $9.86 \times 10^{-3}$ lb/ton)	6	
	Benzo(a)pyrene	106 pg/J ( $6.2 \times 10^{-3}$ lb/ton)	6	
	Beryllium	6.6 pg/J ( $3.9 \times 10^{-4}$ lb/ton)	6	
	Cadmium	6.6 pg/J ( $3.9 \times 10^{-4}$ lb/ton)	6	
	Chromium	56.2 pg/J ( $3.3 \times 10^{-3}$ lb/ton)	6	
	Lead	265 pg/J ( $1.6 \times 10^{-2}$ lb/ton)	6	
	Nickel	66.2 pg/J ( $3.9 \times 10^{-3}$ lb/ton)	6	
	Formaldehyde	40.9 pg/J ( $2.4 \times 10^{-3}$ lb/ton)	6	Assumed same as Bituminous
	POMS	141,351 pg/J (8.3 lb/ton)	7, 1	Assumed POMS are 83% of TSP
	Vanadium	56.2 pg/J ( $3.3 \times 10^{-3}$ lb/ton)	6	
Distillate oil	Arsenic	1.5 pg/J ( $5.1 \times 10^{-4}$ lb/1,000 gal)	6	
	Benzo(a)pyrene	0.1 pg/J ( $3.4 \times 10^{-5}$ lb/1,000 gal)	6	
	Beryllium	1.9 pg/J ( $6.4 \times 10^{-4}$ lb/1,000 gal)	6	
	Cadmium	11 pg/J ( $3.7 \times 10^{-3}$ lb/1,000 gal)	6	
	Chromium	1.1 pg/J ( $3.7 \times 10^{-4}$ lb/1,000 gal)	6	
	Formaldehyde	94.4 pg/J ( $3.3 \times 10^{-2}$ lb/1,000 gal)	6	Assumed same as commercial distillate
	Lead	9.5 pg/J ( $3.2 \times 10^{-3}$ lb/1,000 gal)	6	
	Nickel	103 pg/J ( $3.5 \times 10^{-2}$ lb/1,000 gal)	6	
	POMS	2,451 pg/J ( $8.2 \times 10^{-1}$ lb/1,000 gal)	7, 1	Assumed POMS are 33% of TSP
	Vanadium	10.1 pg/J ( $3.4 \times 10^{-3}$ lb/1,000 gal)	6	



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Table 3-5 (Continued)

Fuel type	Pollutant	Emission factor	Reference	Comment
Wood-woodstoves	Acetaldehyde	0.24 lb/ton	10	
	Acrolein	$7.3 \times 10^{-2}$ lb/ton	11	
	Arsenic	$3.6 \times 10^{-4}$ lb/ton	10	
	Benzo(a)pyrene	$3.4 \times 10^{-6}$ lb/ton	11	Average catalytic and noncatalytic.
	Beryllium	$2.9 \times 10^{-7}$ lb/ton	10	Assumed max cured pine, noncatalytic
	Formaldehyde	0.48 lb/ton	6	
	Nickel	$6.0 \times 10^{-5}$ lb/ton	11	Assumed max cured oak, noncatalytic
	POMS	$3.4 \times 10^1$ lb/ton	7, 1	Assumed POMS are 83% of TSP for conventional non-catalytic
Wood-fireplaces	Acetaldehyde	1.4 lb/ton	6	
	Acrolein	$7.3 \times 10^{-2}$ lb/ton	11	Assumed same as woodstoves
	Arsenic	$2.6 \times 10^{-4}$ lb/ton	10	
	Benzo(a)pyrene	$3.0 \times 10^{-6}$ lb/ton	11	
	Beryllium	$2.9 \times 10^{-7}$ lb/ton	10	
	Cadmium	$7.1 \times 10^{-5}$ lb/ton	10	
	Formaldehyde	3.0 lb/ton	6	
	Nickel	$3.3 \times 10^{-3}$ lb/ton	10	
	POMS	$2.3 \times 10^1$ lb/ton	7, 1	Assumed POMS are 83% of TSP
Natural Gas	Formaldehyde	6.2 lb/ton million cubic feet	8	

Note: pg/J indicates picograms per joule.

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Table 3-6 Apportionment of Residential Wood Consumption  
Between Fireplaces (FP) and Wood Stoves (WS) for the Year 1976

State		FP	WS
Alabama	AL	.08	.92
Alaska	AK	.14	.86
Arizona	AZ	.57	.43
Arkansas	AR	.17	.83
California	CA	.57	.43
Colorado	CO	.40	.60
Connecticut	CT	.26	.74
Delaware	DE	.28	.72
District of Columbia	DC	.29	.71
Florida	FL	.30	.70
Georgia	GA	.17	.83
Hawaii	HI	.57	.43
Idaho	ID	.39	.61
Illinois	IL	.32	.68
Indiana	IN	.33	.67
Iowa	IA	.32	.68
Kansas	KS	.32	.68
Kentucky	KY	.16	.84
Louisiana	LA	.29	.71
Maine	ME	.04	.96
Maryland	MD	.29	.71
Massachusetts	MA	.25	.75
Michigan	MI	.19	.81
Minnesota	MN	.11	.89
Mississippi	MS	.16	.84
Missouri	MO	.19	.81
Montana	MT	.40	.60
Nebraska	NE	.32	.68
Nevada	NV	.56	.44
New Hampshire	NH	.04	.96
New Jersey	NJ	.40	.60
New Mexico	NM	.73	.27
New York	NY	.25	.75
North Carolina	NC	.30	.70
North Dakota	ND	.33	.67
Ohio	OH	.32	.68
Oklahoma	OK	.45	.55
Oregon	OR	.13	.87
Pennsylvania	PA	.40	.60

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Table 3-6 (Continued)

State		FP	WS
Rhode Island	RI	.40	.60
South Carolina	SC	.30	.70
South Dakota	SD	.30	.70
Tennessee	TN	.05	.95
Texas	TX	.29	.71
Utah	UT	.42	.58
Vermont	VT	.04	.96
Virginia	VA	.30	.70
Washington	WA	.13	.87
West Virginia	WV	.30	.70
Wisconsin	WI	.19	.81
Wyoming	WY	<u>.40</u>	<u>.60</u>
		.24	.76

Source: Reference 10.

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3.5 Waste Oil Combustion

As mentioned earlier, between 400 million and 660 million gallons of waste oil is burned in boilers, kilns, diesel engines, and waste oil heaters. Ninety-two percent of the oil that is burned is burned in boilers, with 77 percent burned in industrial boilers and 23 percent burned in RIC units. Table 3-7 presents a rough estimate of state-by-state waste oil consumption.

A number of studies have been performed to characterize the contaminant concentrations in waste oil. Franklin Associates<sup>12</sup> has provided a detailed analysis of the typical contaminant concentrations in waste oil. Extensive sampling was carried out as a part of the study for each source of oil and its end-use application. The range of contaminant concentrations determined in the study varied from virtually zero to very high for most contaminants. In general, this large variation in contaminant concentration occurs because of (1) the numerous and varied processes and mechanism that originally contaminated the oil, (2) the different types of oil, and (3) the various additives that are used to enhance the performance characteristics of the oil.

Waste oil is often pretreated prior to burning. The pretreatment includes (1) reprocessing of the waste oil, (2) re-refining of the waste oil, and (3) blending of virgin or clean fuel oil with the waste oil. It has been estimated that approximately 44 percent of the total waste oil generated in 1982 underwent some form of processing.<sup>12</sup>

Median concentrations of metals and organics in waste oil, the fraction emitted, and emissions factors based on population and fuel usage are presented in Table 3-8.

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Table 3-7 Waste Oil Consumption by State

State	Waste oil burned (gallons)	State	Waste oil burned (gallons)
Alabama	6,678,000	Nebraska	5,362,000
Alaska	374,000	Nevada	1,069,000
Arizona	5,130,000	New Hampshire	855,000
California	36,053,000	New Mexico	2,563,000
Colorado	6,080,000	New York	16,503,000
Connecticut	3,610,000	North Carolina	9,856,000
Delaware	1,606,000	North Dakota	665,000
Florida	10,640,000	Ohio	9,405,000
Georgia	8,542,000	Oklahoma	12,806,000
Hawaii	608,000	Oregon	5,653,000
Idaho	570,000	Pennsylvania	32,797,000
Illinois	19,419,000	Rhode Island	2,166,000
Indiana	6,707,000	South Carolina	4,367,000
Iowa	4,151,000	South Dakota	739,000
Kansas	8,220,000	Tennessee	10,947,000
Kentucky	4,075,000	Texas	43,698,000
Louisiana	17,233,000	Utah	2,660,000
Maine	2,098,000	Vermont	470,000
Maryland	6,287,000	Virginia	7,429,000
Massachusetts	8,550,000	Washington, DC	556,000
Michigan	24,397,000	Washington	9,063,000
Minnesota	7,373,000	West Virginia	4,932,000
Mississippi	4,431,000	Wisconsin	5,013,000
Missouri	13,590,000	Wyoming	1,461,000
Montana	969,000		
Total - 429,014,000 gallons			

Source: Communication between Hope Pillsbury, IEMD, EPA, and Eric Males, OSW, EPA, cited in Reference 13.

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Table 3-8 Waste Oil Characteristics and Combustion Emission Factors

Constituent	Conc. (ppm) <sup>a</sup>	Fuel consumption		Based emission factor (kg/1000 gal of waste oil burned)	Reference et
		Fraction emitted	Per capita emission factor (kg/1000 persons)		
Arsenic	5	0.70	$3.6 \times 10^{-2}$	$1.3 \times 10^{-2}$	12
Barium	94.3	0.58	$5.6 \times 10^{-1}$	$2.1 \times 10^{-1}$	12
Beryllium	NR	NR	$9.1 \times 10^{-3}$	$3.4 \times 10^{-3}$	12
Benzene	9	0.01	$9.0 \times 10^{-4}$	$3.4 \times 10^{-4}$	12
Benzo(a)anthracene	16	0.01	$1.6 \times 10^{-3}$	$6.1 \times 10^{-4}$	12
Benzo(a)pyrene	10	0.01	$1.0 \times 10^{-3}$	$3.8 \times 10^{-4}$	12
Cadmium	1.3	0.40	$5.3 \times 10^{-3}$	$1.9 \times 10^{-3}$	12
Chloroform	NR	NR	$3.7 \times 10^{-2}$	$1.36 \times 10^{-3}$	$2.4 \times 10^{-1}$
Chlorobenzene	0.252 <sup>b</sup>	0.000019	$4.9 \times 10^{-8}$	$1.8 \times 10^{-8}$	13
Chromium (total)	8	0.31	$2.5 \times 10^{-2}$	$9.4 \times 10^{-3}$	12
Hexavalent chromium	NR	NR	$7.5 \times 10^{-5}$	$2.8 \times 10^{-5}$	12
Dichlorodifluoromethane	20	0.01	$2.1 \times 10^{-3}$	$7.6 \times 10^{-4}$	12
Dichloroethane	NR	NR	$5.6 \times 10^{-3}$	$2.1 \times 10^{-2}$	6
Ethylene dibromide	NR	NR	$4.6 \times 10^{-2}$	$1.7 \times 10^{-2}$	6
Formaldehyde	NR	NR	0.40	0.15	6
Lead	1,470	0.64	9.6	3.6	12
Manganese	NR	NR	$9.1 \times 10^{-3}$	$3.4 \times 10^{-3}$	6
Mercury	NR	NR	2.0 - 3.8	$7.6 \times 10^{-1}$	6
Methylene chloride	NR	NR	$3.8 \times 10^{-2}$	$1.4 \times 10^{-2}$	6
Nickel	NR	NR	0.97	0.36**	6
PCBs	39	0.01	$4.0 \times 10^{-3}$	$1.5 \times 10^{-3}$	12
Perchloroethylene	8.6	0.01	$9.0 \times 10^{-4}$	$3.3 \times 10^{-4}$	12
Toluene	190	0.01	$1.9 \times 10^{-2}$	$7.2 \times 10^{-3}$	12
Trichloroethane	6	0.01	$6.2 \times 10^{-4}$	$2.3 \times 10^{-4}$	12
Trichloroethylene	5	0.01	$5.1 \times 10^{-4}$	$1.9 \times 10^{-4}$	12
Trichlorotrifluoroethane	160	0.01	$1.6 \times 10^{-2}$	$6.1 \times 10^{-3}$	12
Vanadium	NR	NR	$3.8 \times 10^{-2}$	$1.4 \times 10^{-2c}$	6
Zinc	1,000	0.75	7.7	2.8	12

NR - Not Reported

<sup>a</sup>Median concentrations as reported in Reference 2, except as noted.

<sup>b</sup>Average value selected from reported range of 4-500 mg/l.

<sup>c</sup>Based on #6 residual oil.

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Test data indicate destruction efficiencies for organics ranging from 97 to 99.99 percent. Higher combustion temperatures in industrial boilers dictate higher destruction efficiencies. Hence, a 99.9 percent destruction efficiency for organics in industrial boilers is a reasonable estimate. In residential, institutional and commercial (RIC) boilers, where the units tend to be less efficient, a 99 percent destruction efficiency for organics is assumed to be representative.

Because the boilers using waste oil as a fuel vastly differ in their characteristics, simple quantification of boiler population, fuel blending, or oil consumption is not practical. OSW has estimated that about 100 million gallons of waste oil are burned in RIC boilers (23 percent) and about 330 million gallons are burned in industrial boilers (77 percent). It has also been indicated that waste oil is more likely to be burned at facilities that currently burn residual oil than at those that burn distillate oil.<sup>14</sup>

Methodology Options. Toxic emissions that result from the combustion of waste oil can be estimated when one of the following is known or can be estimated:

- The quantity of waste oil burned in the study area;
- The population of a particular county, state, or region; or
- The quantity of waste oil burned for a particular state, county, or region can be estimated.

Method 1: Estimates based on fuel consumption data

This approach is preferred when data on countywide consumption are available or can be collected by surveying users or distributors. Once data on the quantity of waste oil burned in the county or state are known, the estimation of emissions is straightforward. The emission

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factor (Table 3-8) that relates the quantities of emissions emitted per 1,000 gallons of waste oil burned is multiplied by the quantity of waste oil burned in the county or state. For example, if the county burns 74,290 gallons of waste oil annually and the emission factor from Table 2.2-8 is 3.6 kg Pb/1,000 gallons of waste oil burned/year, then the amount of lead emitted can be estimated as follows:

$$\text{Pb emitted} = 74.290 \text{ (thousand gallons of waste oil burned)} \frac{3.6 \text{ kg Pb}}{1000 \text{ gallons waste oil burned per year}}$$

$$\text{Pb emitted} = 267 \text{ kg/yr}$$

Method 2: Estimates based on population (per capita estimates).

Population data can be collected from the U.S. Census Bureau. Air toxic emissions can be estimated by applying the per capita emission factors from Table 3-8 which relate the quantity emitted per 1,000 persons. For example, to estimate the quantity of arsenic emitted in a county of 180,375 persons, use the emission factor from Table 3-8 to estimate the amount of arsenic emitted annually.

$$\text{As emitted} = 180.4 \text{ (1,000persons)} \times 3.5 \times 10^{-2} \text{ kg As/1,000 persons/yr}$$

$$\text{As emitted} = 6.3 \text{ kg/yr.}$$

Method 3: Estimates based on virgin oil consumption

This method assumes that quantities of waste oil burned in a given area is directly proportional to the quantity of residual oil that is burned.

STEP 1: Determine from NEDS or other sources state and county quantities of residual oil burned in RIC and industrial boilers.



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STEP 2: Determine quantity of waste oil burned in each county, assuming that the quantity of waste oil burned in the county is directly proportional to the quantity of residual oil burned in the county.

$$WOC = \frac{(CR + CI + CCI) \times WOS}{SR + SI + SCI}$$

where

WOC = annual waste oil burned in the county  
CR = annual countywide residential residual oil consumption  
CI = annual countywide industrial residual oil consumption  
CCI = annual countywide commercial/institutional residual oil consumption  
SR = annual state-wide residential residual oil consumption  
SI = annual state-wide industrial residual oil consumption  
SCI = annual state-wide commercial/institutional residual oil consumption  
WOS = annual state-wide waste oil consumption (from Table 3-7).

STEP 3: Calculate the quantity of waste oil burned in residential, commercial and industrial boilers assuming that 23% of the waste oil that is burned is burned in RIC boilers, and 77% is burned in industrial boilers.

$$WOR = WOC \times 0.23 \times \frac{CR}{CCI + CR}$$

$$WOCI = WOC \times 0.23 \times \frac{CCI}{CCI + CR}$$

$$WOI = WOC \times 0.77$$

where

WOR = waste oil burned in residential boilers  
WOCI = waste oil burned in commercial/institutional boilers  
WOI = waste oil burned in industrial boilers

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STEP 4: Obtain the emission factor from Table 3-8 for the contaminant in question. (Note: this factor should relate kg/1,000 gallons waste oil burned.)

STEP 5: Compute metal or organic emission by multiplying the quantity of waste oil burned in the county by the emission factor obtained in Step 4.

$$E_p (WO_I + WO_{CI} + WO_R) \times EF_p$$

where

$E_p$  = annual emission of pollutant p kg/yr

$EF_p$  = emission factor for pollutant p from Table 3-8.

### 3.6 Example Calculations

Example calculations for estimating toxic emissions from virgin fuel combustion are shown below. Examples of waste oil emission calculations are contained in Section 3.4.

#### Example Calculation 1

The following calculation estimates the area source emission of formaldehyde from burning distillate oil in commercial/industrial boilers. The consumption of commercial/institutional distillate oil for a particular county in one year is reported as 12,270,000 gallons (12,270 thousand gallons/year). The emission factor for formaldehyde for distillate oil from Table 3-4 is 0.033 lb/1,000 gallons.

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The calculation is as follows:

$$\frac{12,270 \text{ thousand gallons}}{\text{year}} \times \frac{0.033 \text{ lb Formaldehyde}}{\text{thousand gallons}} = 405 \text{ lb/year}$$

For the county in question, the estimated formaldehyde emission from commercial/institutional boilers burning distillate oil is 405 lb/yr.

Other pollutants in Table 3-4 can be estimated in a similar manner for commercial/institutional boilers. Emissions from the burning of other fossil fuels in residential, industrial, and commercial/institutional can be estimated using a similar methodology as well.

Example Calculation 2

This example illustrates the calculation of acetaldehyde emissions due to burning of wood in woodstoves and fireplaces in a county in Maryland. The residential wood consumption in this county for one year is 1,000 tons. The woodstove/fireplace apportionment from Table 3-6 for Maryland is 0.71 for woodstoves and 0.29 for fireplaces (i.e., 71% of the wood consumed is burned in woodstoves and 29% in fireplaces). The acetaldehyde emission factors from Table 3-5 are 0.24 lb/ton for woodstoves and 1.4 lb/ton for fireplaces.

The calculations are as follows:

Woodstoves

$$\frac{1,000 \text{ ton}}{\text{year}} \times 0.71 \times \frac{0.24 \text{ lb}}{\text{ton}} = 170 \text{ lb/yr}$$

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Fireplaces

$$\frac{1,000 \text{ ton}}{\text{year}} \times 0.29 \times \frac{1.4 \text{ lb}}{\text{ton}} = 406 \text{ lb/yr}$$

The estimated acetaldehyde emissions for the county in question are 170 lb/yr from woodstoves and 406 lb/yr for fireplaces. Other pollutants in Table 3-5 can be estimated in a similar manner.

3.7 Methods to Apportion Countywide Emissions from Heating

As described in Section 1.0 and Appendix A, when performing air dispersion modeling, it is generally recommended that countywide emissions be distributed within the study area into rectangular area source grid cells reflecting spatial variations in activity and emissions. Similarly, temporal in activities can be factored into the modeling to reflect seasonal or diurnal fluctuations in emissions. Modeling results would then reflect on-going activities in that portion of the county, e.g., residential heating in the winter, commercial solvent usage during working hours on weekdays.

There are three alternative approaches that can be used in spatially distributing emission: (1) population, i.e., the magnitude of emissions within a grid are directly proportional to the population living in the grid, (2) land area, i.e., emissions from a countywide area source are assumed to be uniform throughout the county and are distributed based on the size of the area source grid, and (3) landuse patterns that assume that certain area source activities, most likely to occur in certain areas of the county, e.g., commercial, residential, or industrial.

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In apportioning emissions from heating any of these methods may be appropriate. Land area and population data can be readily obtained and applied as described in Appendix A. Land use data, available from the U.S. Geological survey and other sources can be used in combination with the spatial resolution for heating to distribute emissions based on the type of activity being performed, as shown in Table 3-9.

Estimated seasonal, daily, and hourly temporal resolution for heating are also included in Table 3-9, and can be used with the annual countywide emissions data to estimate temporal variations.

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Table 3-9 Spatial and Temporal Resolution  
for Heating and Waste Oil Combustion

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## Fuel Combustion, Industrial<sup>15</sup>

### Spatial Resolution

Surrogate indicator: industrial areas (codes 13 and 15)  
Information source(s): land use map

### Temporal Resolution

Seasonal: uniform through the year  
Daily: Monday through Saturday  
Hourly: 80 percent from 0700 to 1800 and 20  
percent from 1800 to 2400, otherwise  
zero

## Fuel Combustion, Commercial/Institutional<sup>15</sup>

### Spatial Resolution

Surrogate indicator: industrial areas (codes 12 and 15)  
Information source(s): land use map and Reference 16

### Temporal Resolution

Seasonal: 25 percent uniform through the year and  
75 percent uniform during the months  
that have an average temperature of  
688°F or less  
Daily: 95 percent Monday through Saturday  
Hourly: 90 percent from 0600 to 2400 and 10  
percent from 2400 to 0600

## Fuel Combustion, Residential<sup>15</sup>

### Spatial Resolution

Surrogate indicator: residential area (codes 11, 16, and  
17); dwelling units  
Information source(s): land use map

### Temporal Resolution

Seasonal: 10 percent uniform through the year and  
90 percent uniform during the months  
that have an average temperature of  
688°F or less  
Daily: uniform through the week  
Hourly: uniform through the day

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Table 3-9 (Continued)

## Waste Oil Combustion (Industrial)

### Spatial Resolution

Surrogate indicator: industrial areas (codes 13 and 15)  
Information source(s): land use map

### Temporal Resolution

Seasonal: uniform through the year  
Daily: uniform Monday through Saturday  
Hourly: 80 percent from 0700 to 1800, 20  
percent from 1800 to 2400, otherwise  
zero

## Waste Oil Combustion (Residential/Institutional/Commercial)

### Spatial Resolution

Surrogate indicator: residential, institutional, and  
commercial areas (land use codes 11,  
12, 15, 16, 17)  
Information source(s): land use maps

### Temporal Resolution

Seasonal: 25 percent uniform through the year and  
75 percent uniform during the months  
that have an average temperature of  
688°F or less  
Daily: 95 percent Monday through Saturday  
Hourly: 90 percent from 0600 to 2400, 10  
percent from 2400 to 0600

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### 4. ROAD VEHICLES

#### 4.1 General

Road vehicles are a major source of organic and inorganic air toxics in urban areas. The Six Month Study<sup>1</sup> which estimated cancer risks from exposure to selected toxic air pollutants identified mobile sources as contributing a large portion of the national cancer incidence. Specific pollutants and pollutant categories which are emitted by road vehicles include diesel particulates, formaldehyde, benzene, gas phase organics, organics associated with non-diesel particulates, asbestos, and metals. Sources include exhaust and evaporative emissions tire wear, and (in the case of asbestos) emissions from the wearing away of brake linings.

The composition of road vehicle emissions varies depending on numerous factors including the age, model, and condition of the vehicle; the type of fuel used (i.e., leaded or unleaded gasoline, diesel); the composition of the gasoline including any additives; driving patterns and speed; and any pollution controls (catalytic or noncatalytic). Because of the large number of parameters that can affect emissions, it is necessary to apply "typical" vehicular emissions rates to predict pollutant loadings in a geographic area. These typical factors are by vehicular class (e.g., light duty gas, heavy duty diesel) and reflect the age, accrued mileage, etc., typical of the fleet.

#### 4.2 Factors

Table 4-1 provides toxic pollutant factors. Factors that can be used with NEDS data are provided on an average VMT basis and on a percent of hydrocarbon emissions. Many of the factors in Table 4-1 were taken directly from Carey (1987)<sup>4</sup>; that report should be accessed for additional information. POM Emissions were estimated based on information provided by ORD<sup>12</sup> and are defined as the benzene exhaustable portion of particulates emitted in road vehicle exhaust.

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Table 4-1 Road Vehicle Emission Factors

Pollutant/Emission Type	Percent Hydrocarbons		Vehicle Miles Traveled (MI/1000 VMT)			Comments
	Exhaust	Evaporative	Exhaust	Evaporative	Other	
Formaldehyde						
LDGV	1.3 <sup>a</sup>	---	3.32 x 10 <sup>-5</sup> b	---	---	Assumed 7 HC for all gasoline vehicles The factors in the "other" column are from tire wear.
LDGT-1	1.3 <sup>a</sup>	---	6.18 x 10 <sup>-5</sup> b	---	---	
LDGT-2	1.3 <sup>a</sup>	---	7.40 x 10 <sup>-5</sup> b	---	---	
LDDV	4.1 <sup>a</sup>	---	3.58 x 10 <sup>-5</sup> b	---	---	
LDDT	4.1 <sup>a</sup>	---	5.45 x 10 <sup>-5</sup> b	---	---	
HGV	3.1 <sup>a</sup>	---	1.89 x 10 <sup>-4</sup> b	---	---	
HDDV Truck	3.0 <sup>a</sup>	---	1.29 x 10 <sup>-4</sup> b	---	---	
HDDV Bus	10.0 <sup>a</sup>	---	3.49 x 10 <sup>-4</sup> b	---	---	
1,3-Butadiene						
LDGV	0.94 <sup>a</sup>	---	2.4 x 10 <sup>-5</sup> b	---	1.0 x 10 <sup>-8</sup> j	
LDGT-1	0.94 <sup>a</sup>	---	4.47 x 10 <sup>-5</sup> b	---	1.0 x 10 <sup>-8</sup> j	
LDGT-2	0.94 <sup>a</sup>	---	5.35 x 10 <sup>-5</sup> b	---	1.0 x 10 <sup>-8</sup> j	
LDDV	---	---	---	---	1.0 x 10 <sup>-8</sup> j	
LDDT	---	---	---	---	1.0 x 10 <sup>-8</sup> j	
HGV	0.94 <sup>a</sup>	---	5.72 x 10 <sup>-4</sup> b	---	1.0 x 10 <sup>-8</sup> j	
HDDV-Truck	---	---	---	---	1.0 x 10 <sup>-8</sup> j	
HDDV-Bus	---	---	---	---	1.0 x 10 <sup>-8</sup> j	
Benzene						
LDGV	4.98 <sup>a</sup>	1.11 to 1.53 <sup>*,**</sup> 0.35 to 0.46	1.27 x 10 <sup>-4</sup> b	1.13 x 10 <sup>-5</sup> to 1.56 x 10 <sup>-5</sup> j 3.57 x 10 <sup>-6</sup> to 4.69 x 10 <sup>-6</sup> j 1.84 x 10 <sup>-5</sup> b 2.78 x 10 <sup>-5</sup> b	Assumed all catalysts were 3-way catalysts; the mix is 88% catalyst and 12% no catalyst	Assumed HDGV is 100% no catalyst. Assumed the two HDDV categories were the same
LDGT-1	3.24 <sup>a</sup>	1.17 <sup>a</sup>	1.54 x 10 <sup>-4</sup> b	---	---	
LDGT-2	3.24 <sup>a</sup>	1.1 <sup>a</sup>	1.84 x 10 <sup>-4</sup> b	---	---	
LDDV	2.4 <sup>a</sup>	---	2.1 x 10 <sup>-5</sup> b	---	---	
LDDT	2.4 <sup>a</sup>	---	3.19 x 10 <sup>-5</sup> b	---	---	
HGV	3.48 <sup>a</sup>	1.1 <sup>a</sup>	2.12 x 10 <sup>-4</sup> b	6.44 x 10 <sup>-5</sup> b	---	
HDDV-Truck	1.1 <sup>a</sup>	---	4.73 x 10 <sup>-5</sup> b	---	---	
HDDV-Bus	1.1 <sup>a</sup>	---	4.73 x 10 <sup>-5</sup> b	---	---	

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 4-1 (Continued)

Pollutant/Emission Type	Percent Hydrocarbons		Vehicle Miles Traveled (MI/1000 VMI)			Comments
	Exhaust	Evaporative	Exhaust	Evaporative	Other	
Benzo(a)pyrene						
LDGV	---	---	$4.57 \times 10^{-9} a$	---	---	Assumed the three LDGV categories were the same; Assumed 88% unleaded fuel +12% leaded. Assumed both LDDV categories were the same; Assumed HDGV is 100% unleaded. Assumed both HDDV categories were the same
LDGT-1	---	---	$4.57 \times 10^{-9} a$	---	---	
LDGT-2	---	---	$4.57 \times 10^{-9} a$	---	---	
LDDV	---	---	$4.5 \times 10^{-9} a$	---	---	
LDDT	---	---	$4.5 \times 10^{-9} a$	---	---	
HDGV	---	---	$3.95 \times 10^{-8} a$	---	---	
HDDV Truck	---	---	$2.3 \times 10^{-9} a$	---	---	
HDDV Bus	---	---	$2.3 \times 10^{-9} a$	---	---	
Lead						
LDGV	---	---	$1.28 \times 10^{-6} a$	---	---	Assumed three LDGV categories were the same; Assumed 88% unleaded fuel +12% leaded
LDGT-1	---	---	$1.24 \times 10^{-6} a$	---	---	
LDGT-2	---	---	$1.24 \times 10^{-6} a$	---	---	
LDDV	---	---	---	---	---	
LDDT	---	---	---	---	---	
HDGV	---	---	$8.0 \times 10^{-6} a$	---	---	
HDDV Truck	---	---	---	---	---	
HDDV Bus	---	---	.	---	---	
Cadmium						
LDGV	---	---	$1.9 \times 10^{-9} a$	---	$4.85 \times 10^{-9} i$	Assumed three LDGV categories were the same; Assumed 88% unleaded fuel +12% leaded. Assumed both LDDV categories were the same. The factors in the "other" column are due to tire wear. Assumed both HDDV categories were the same.
LDGT-1	---	---	$1.9 \times 10^{-9} a$	---	$4.85 \times 10^{-9} i$	
LDGT-2	---	---	$1.9 \times 10^{-9} a$	---	$4.85 \times 10^{-9} i$	
LDDV	---	---	$1.79 \times 10^{-9} h$	---	$4.85 \times 10^{-9} i$	
LDDT	---	---	$1.79 \times 10^{-9} h$	---	$4.85 \times 10^{-9} i$	
HDGV	---	---	$1.6 \times 10^{-8} a$	---	$4.85 \times 10^{-9} i$	
HDDV Truck	---	---	$7.09 \times 10^{-8} b$	---	$4.85 \times 10^{-9} i$	
HDDV Bus	---	---	$7.09 \times 10^{-8} b$	---	$4.85 \times 10^{-9} i$	

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 4-1 (Continued)

Pollutant/Emission Type	Percent Hydrocarbons		Vehicle Miles Traveled (MI/1000 VMI)			Comments
	Exhaust	Evaporative	Exhaust	Evaporative	Other	
Chromium-1						
LDGV	---	---	$6.1 \times 10^{-4} \text{ c}$	---	---	Assumed three LDGV categories were the same and were based on heavy duty gas vehicle factors and average mpg
LDGT-1	---	---	$6.1 \times 10^{-4} \text{ c}$	---	---	
LDGT-2	---	---	$6.1 \times 10^{-4} \text{ c}$	---	---	
LDGV	---	---	ND	---	---	
LDGT	---	---	ND	---	---	
HDDV	---	---	$2.6 \times 10^{-7} \text{ c}$	---	---	Assumed HC for three LDGV categories were the same. Reference 12 suggests that EDC emissions are 10 times Ethylene dibromide emissions (provided in Reference 13).
HDDV-Truck	---	---	ND	---	---	
HDDV-Bus	---	---	ND	---	---	
Ethylene dichloride						
LDGV	$0.03 \text{ e}$	$0.015 \text{ e}$	$7.65 \times 10^{-7} \text{ e}$	$1.53 \times 10^{-7} \text{ e}$	---	Assumed three LDGV categories were the same. Reference 12 suggests that EDC emissions are 10 times Ethylene dibromide emissions (provided in Reference 13).
LDGT-1	$0.03 \text{ e}$	$0.015 \text{ e}$	$1.43 \times 10^{-6} \text{ e}$	$2.51 \times 10^{-6} \text{ e}$	---	
LDGT-2	$0.03 \text{ e}$	$0.015 \text{ e}$	$1.71 \times 10^{-6} \text{ e}$	$3.80 \times 10^{-6} \text{ e}$	---	
LDGV	---	---	---	---	---	
LDGT	---	---	---	---	---	
HDDV	$0.051 \text{ e}$	$0.015 \text{ e}$	$3.1 \times 10^{-6} \text{ e}$	$8.78 \times 10^{-7} \text{ e}$	---	Assumed three LDGV categories were the same. Assumed the LDGV categories were the same. Assumed the HDDV categories were the same.
HDDV-Truck	---	---	---	---	---	
HDDV-Bus	---	---	---	---	---	
Acetaldehyde						
LDGV	---	---	$4.8 \times 10^{-7} \text{ c}$	---	---	Assumed three LDGV categories were the same. Assumed the LDGV categories were the same. Assumed the HDDV categories were the same.
LDGT-1	---	---	$4.8 \times 10^{-7} \text{ c}$	---	---	
LDGT-2	---	---	$4.8 \times 10^{-7} \text{ c}$	---	---	
LDGV	---	---	$3.1 \times 10^{-5}$	---	---	
LDGT	---	---	$3.1 \times 10^{-5}$	---	---	
HDDV	---	---	$2.1 \times 10^{-5}$	---	---	Assumed three LDGV categories were the same. Assumed the HDDV categories were the same.
HDDV-Truck	---	---	$3.1 \times 10^{-5}$	---	---	
HDDV-Bus	---	---	$3.1 \times 10^{-5}$	---	---	

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 4-1 (Continued)

Pollutant/Emission Type	Percent Hydrocarbons		Vehicle Miles Traveled (MI/1000 VMI)			Comments
	Exhaust	Evaporative	Exhaust	Evaporative	Other	
Asbestos						
LDGV	---	---	---	---	$2.05 \times 10^{-9}$ d	These emission factors are under the "other" column but they are asbestos particles from brake linings. Emissions factors are averages of emission rates provided in Reference 7.
LDGT-1	---	---	---	---	$4.99 \times 10^{-9}$ d	
LDGT-2	---	---	---	---	$4.99 \times 10^{-9}$ d	
HGGV	---	---	---	---	$3.5 \times 10^{-8}$ d	
LDDV	---	---	---	---	$2.05 \times 10^{-9}$ d	
LDDT	---	---	---	---	$4.99 \times 10^{-9}$ d	
HDDV-Truck	---	---	---	---	$3.5 \times 10^{-8}$ d	
HDDV-Bus	---	---	---	---	$1.3 \times 10^{-8}$ d	
POM:						
LDGV	---	---	$3.92 \times 10^{-6}$ f	---	---	Assumed the three LDGV categories were the same. Assumed the two LDDV categories were the same. Assumed the two HDDV categories were the same.
LDGT-1	---	---	$3.92 \times 10^{-6}$ f	---	---	
LDGT-2	---	---	$3.92 \times 10^{-6}$ f	---	---	
HGGV	---	---	$3.76 \times 10^{-5}$ f	---	---	
LDDV	---	---	$6.00 \times 10^{-5}$ f	---	---	
LDDT	---	---	$6.00 \times 10^{-5}$ f	---	---	
HDDV-Truck	---	---	$4.95 \times 10^{-4}$ f	---	---	
HDDV-Bus	---	---	$4.95 \times 10^{-4}$ f	---	---	
Total Hydrocarbons						
LDGV	---	---	$2.55 \times 10^{-3}$ g	$1.02 \times 10^{-3}$ g	---	
LDGT-1	---	---	$4.75 \times 10^{-3}$ g	$1.67 \times 10^{-3}$ g	---	
LDGT-2	---	---	$5.69 \times 10^{-3}$ g	$2.53 \times 10^{-3}$ g	---	
LDDV	---	---	$8.73 \times 10^{-4}$ g	---	---	
LDDT	---	---	$1.33 \times 10^{-3}$ g	---	---	
HGGV	---	---	$6.09 \times 10^{-3}$ g	$5.85 \times 10^{-3}$ g	---	
HDDV-Truck	---	---	$4.30 \times 10^{-3}$ g	---	---	
HDDV-Bus	---	---	$3.49 \times 10^{-3}$ g	---	---	

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 4-1 (Cont inued)

Pollutant/Emission Type	Percent Hydrocarbons		Vehicle Miles Traveled (MT/1000 VMT)			Comments
	Exhaust	Evaporative	Exhaust	Evaporative	Other	
LDGV	---	---	$3.92 \times 10^{-5} \text{ g}$	---		Assumed the three LDGV categories were the same. Assumed the two LDDV categories were the same. Assumed the HDDV categories were the same
LDGT-1	---	---	$3.92 \times 10^{-5} \text{ g}$	---		
LDGT-2	---	---	$3.92 \times 10^{-5} \text{ g}$	---		
LDDV	---	---	$3.00 \times 10^{-4} \text{ g}$	---		
LDDT	---	---	$3.00 \times 10^{-4} \text{ g}$	---		
HDDV	---	---	$3.76 \times 10^{-4} \text{ g}$	---		
HDDV-Truck	---	---	$1.65 \times 10^{-3} \text{ g}$	---		
HDDV-Bus	---	---	$1.65 \times 10^{-3} \text{ g}$	---		

## Notes:

- = Not Applicable
- ND = No Data Available
- LDGV = Light duty vehicles
- LDGT-1 = Light duty gas trucks (6000-8500 lbs)
- LDGT-2 = Light duty gas trucks (8501-10,000 lbs)
- LDDV = Light duty diesel vehicles
- HDDV-Truck = Heavy duty diesel trucks
- HDDV-Bus = Heavy duty diesel buses

## Sources:

- <sup>a</sup>Reference 4.
- <sup>b</sup>Calculated from Reference 4 and estimates of HC/VMT from Reference 2
- <sup>c</sup>Reference 6.
- <sup>d</sup>Reference 7.
- <sup>e</sup>Calculated from Reference 12 and 13 estimates of HC/VMT from Reference 2.
- <sup>f</sup>Calculated from Reference 2 and Reference 5.
- <sup>g</sup>Reference 2
- <sup>h</sup>Reference 8.
- <sup>i</sup>Reference 9.
- <sup>j</sup>Reference 10.
- <sup>k</sup>Reference 11.
- <sup>\*</sup>Carburetted LDGV.
- <sup>\*\*</sup>Fuel Injected LDGV.

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4.3 Methodology Options

Emission factors can be based on vehicle miles traveled (VMT) and/or emissions of criteria pollutants, particularly hydrocarbons. When used in conjunction with NEDS' VMT data or EPA's MOBILE3 (Mobile Source Emission Model) both of which predict emissions of criteria pollutants, apportionment factors can be applied to predict toxic pollutant emissions.

In NEDS, road vehicles can be disaggregated into five categories on the basis of use and gross vehicle weight for the purpose of calculating emissions. Light duty gasoline vehicles are defined as gasoline powered passenger vehicles weighing 8500 pounds or less; similarly light duty diesel vehicles. Light duty gasoline Trucks I include gasoline cargo vehicles weighing 6000 pounds or less. Light duty gasoline Trucks II include gasoline cargo vehicles weighing 6001 pounds to 8500 pounds. Heavy duty vehicle categories separate diesel and gasoline powered trucks and buses weighing more than 8500 pounds. Motorcycles, light duty diesel vehicles and light duty diesel trucks are assumed to contribute little emissions relative to the above four categories.

Fuel consumption and average fuel efficiencies are used to determine vehicle miles traveled (VMT) for four classes of average speed to reflect road usage, namely, limited access roads (55 mph), rural roads (45 mph), suburban roads (35 mph), and urban roads (19.6 mph). At the present time, NEDS calculates criteria pollutant emissions for limited access roads, rural roads and urban road types. Each speed class includes the following road types.<sup>5</sup>

Limited Access Roads  
(55 mph)

Rural and Urban Interstate  
Rural and Urban Other Principal Arterials  
Other Freeways and Expressways  
Rural and Urban Minor Arterials



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Rural (45 mph)	Rural Major Collector Rural Minor Collector Rural Local
Urban (19.6 mph)	Urban Collector Urban Local

For highway vehicles, NEDS contains data on fuel consumption ( $10^3$  gallons) by fuel type for each vehicle type and speed class specific annual vehicle miles traveled (VMT), along with estimated emissions of criteria pollutants.

MOBILE3, on the otherhand, is a computer model that calculates emissions of hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen ( $\text{NO}_x$ ) from highway motor vehicles using emission factors contained in AP-42, Volume II.<sup>2</sup> MOBILE3 estimates depend on various ambient, vehicle usage, and local conditions such as temperature, speed, and mileage accumulation, and accrual distributions. MOBILE3 will estimate emissions for any calendar year between 1970 and 2020, inclusive. The twenty most recent vehicle model years are considered in operation during each calendar year. Additional information on MOBILE3 can be obtained in Reference 3.

MOBILE3 differentiates between evaporative and exhaust emissions. A recent EPA study, (Carey 1987)<sup>4</sup> compiled emission factors that can be used with MOBILE3 to estimate road vehicle related emissions (as well as exposure and risk); this report is the basis for many of the road vehicle emission factors that are listed in this manual.

#### 4.4 Example Calculations

The following examples demonstrate the approach for estimating emissions from onroad vehicles.

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Example Calculation 1

This example illustrates the calculation of road vehicle emissions for heavy duty gasoline vehicles (HDGV) using data contained in the NEDS area source report. NEDS gives estimated total hydrocarbon emissions in the three-county study area. Then, using emission factors in terms of percent of total hydrocarbons, the emissions of each pollutant can be determined.

<u>County</u>	<u>HDGV total hydrocarbons (THC)</u> <u>(MT/yr)</u>
A	56.21
B	32.85
C	79.57

Using the emission factors in terms of percent of hydrocarbons from Table 4-1 the emissions from heavy duty gasoline vehicles in the study area of concern can be calculated as follows:

County A

Formaldehyde:

$$\text{Exhaust: } 0.031 \times \frac{56.21 \text{ MT THC}}{\text{yr}} = 1.74 \text{ MT/yr}$$

Evaporative: Not Applicable

1,3 Butadiene

$$\text{Exhaust: } 0.0094 \times \frac{56.21 \text{ MT THC}}{\text{yr}} = 0.53 \text{ MT/yr}$$

Evaporative: Not Applicable

Benzene

$$\text{Exhaust: } 0.0348 \times \frac{56.21 \text{ MT THC}}{\text{yr}} = 1.96 \text{ MT/yr}$$

$$\text{Evaporative: } 0.011 \times \frac{56.21 \text{ MT THC}}{\text{yr}} = 0.62 \text{ MT/yr}$$

Ethylene dichloride

$$\text{Exhaust: } 0.00051 \times \frac{56.21 \text{ MT THC}}{\text{yr}} = 0.029 \text{ MT/yr}$$

$$\text{Evaporative } 0.00015 \times \frac{56.21 \text{ MT THC}}{\text{yr}} = 0.0084 \text{ MT/yr}$$

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County B

Formaldehyde

$$\text{Exhaust: } 0.031 \times \frac{32.85 \text{ MT THC}}{\text{yr}} = 1.02 \text{ MT/yr}$$

Evaporative: Not Applicable

1,3 Butadiene

$$\text{Exhaust: } 0.0094 \times \frac{32.85 \text{ MT THC}}{\text{yr}} = 0.31 \text{ MT/yr}$$

Evaporative: Not Applicable

Benzene

$$\text{Exhaust: } 0.0348 \times \frac{32.85 \text{ MT THC}}{\text{yr}} = 1.14 \text{ MT/yr}$$

$$\text{Evaporative: } 0.011 \times \frac{32.85 \text{ MT THC}}{\text{yr}} = 0.36 \text{ MT/yr}$$

Ethylene dichloride

$$\text{Exhaust: } 0.00051 \times \frac{32.85 \text{ MT THC}}{\text{yr}} = 0.017 \text{ MT/yr}$$

$$\text{Evaporative: } 0.00015 \times \frac{32.85 \text{ MT THC}}{\text{yr}} = 0.0049 \text{ MT/yr}$$

County C

Formaldehyde

$$\text{Exhaust: } 0.031 \times \frac{79.57 \text{ MT THC}}{\text{yr}} = 2.47 \text{ MT/yr}$$

Evaporative: Not Applicable

1,3 Butadiene

$$\text{Exhaust: } 0.0094 \times \frac{79.57 \text{ MT THC}}{\text{yr}} = 0.75 \text{ MT/yr}$$

Evaporative: Not Applicable

Benzene

$$\text{Exhaust: } 0.0348 \times \frac{79.57 \text{ MT THC}}{\text{yr}} = 2.77 \text{ MT/yr}$$

$$\text{Evaporative: } 0.011 \times \frac{79.57 \text{ MT THC}}{\text{yr}} = 0.87 \text{ MT/yr}$$

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Ethylene dichloride

$$\text{Exhaust: } 0.00051 \times \frac{79.57 \text{ MT THC}}{\text{yr}} = 0.041 \text{ MT/yr}$$

$$\text{Evaporative: } 0.00015 \times \frac{79.57 \text{ MT THC}}{\text{yr}} = 0.012 \text{ MT/yr}$$

For metals and semi-volatiles the emissions must be calculated using estimates of VMT as in Example Calculation 2. Summing the emission over all the counties will give the total emissions for the study area.

[In a similar manner, emissions from other classes of vehicles can be calculated based on NEDS data.]

Example Calculation 2

This example demonstrates the calculation of emissions from light duty gasoline vehicles (LDGV) using data on vehicle miles traveled (VMT) and emission factors in terms of VMT.

We will assume the study area consists of one county. The annual VMT for that county is 356,177,000.

Using the emission factors in terms of VMT from Table 4-1 the emissions are calculated as follows:

County A

Formaldehyde

$$\text{Exhaust: } \frac{3.32 \times 10^{-5} \text{ MT}}{1,000 \text{ VMT}} \times \frac{356,177 (1,000 \text{ VMT})}{\text{yr}} = 11.82 \text{ MT/yr}$$

Evaporative: Not Applicable

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1,3 Butadiene

$$\text{Exhaust: } \frac{2.4 \times 10^{-5} \text{ MT} \times 356,177 (1,000 \text{ VMT})}{1,000 \text{ VMT}} = 8055 \text{ MT/yr}$$

Evaporative: Not Applicable

$$\text{Tire Wear: } \frac{1.0 \times 10^{-8} \text{ MT} \times 356,177 (1,000 \text{ VMT})}{1,000 \text{ VMT}} = 0.0036 \text{ MT/yr}$$

Benzene

$$\text{Exhaust: } \frac{1.27 \times 10^{-4} \text{ MT} \times 356,177 (1,000 \text{ VMT})}{1,000 \text{ VMT}} = 45.23 \text{ MT/yr}$$

Evaporative\*: Not Applicable

Benzo(a)pyrene

$$\text{Exhaust: } \frac{4.57 \times 10^{-8} \text{ MT} \times 356,177 (1,000 \text{ VMT})}{1,000 \text{ VMT}} = 0.0016 \text{ MT/yr}$$

Evaporative: Not Applicable

Lead

$$\text{Exhaust: } \frac{1.28 \times 10^{-6} \text{ MT} \times 356,177 (1,000 \text{ VMT})}{1,000 \text{ VMT}} = 0.46 \text{ MT/yr}$$

Evaporative: Not Applicable

Cadmium

$$\text{Exhaust: } \frac{1.9 \times 10^{-9} \text{ MT} \times 356,177 (1,000 \text{ VMT})}{1,000 \text{ VMT}} = 0.00068 \text{ MT/yr}$$

Evaporative: Not Applicable

$$\text{Tire Wear: } \frac{4.85 \times 10^{-9} \text{ MT} \times 356,177 (1,000 \text{ VMT})}{1,000 \text{ VMT}} = 0.0017 \text{ MT/yr}$$

Chromium

$$\text{Exhaust: } \frac{6.1 \times 10^{-4} \text{ MT} \times 356,177 (1,000 \text{ VMT})}{1,000 \text{ VMT}} = 217.27 \text{ MT/yr}$$

Evaporative: Not Applicable

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\*The evaporative emissions factor for benzene is given as a range. To calculate the emissions in this example, we assumed the emission factor was the midpoint of the range.

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Ethylene dichloride

$$\text{Exhaust: } \frac{7.65 \times 10^{-7} \text{ MT} \times 356,177}{1,000 \text{ VMT}} \frac{(1,000 \text{ VMT})}{\text{yr}} = 0.27 \text{ MT/yr}$$

$$\text{Evaporative: } \frac{1.53 \times 10^{-7} \text{ MT} \times 356,177}{1,000 \text{ VMT}} \frac{(1,000 \text{ VMT})}{\text{yr}} = 0.054 \text{ MT/yr}$$

Acetaldehyde

$$\text{Exhaust: } \frac{4.8 \times 10^{-7} \text{ MT} \times 356,177}{1,000 \text{ VMT}} \frac{(1,000 \text{ VMT})}{\text{yr}} = 0.17 \text{ MT/yr}$$

Evaporative: Not Applicable

Asbestos

Exhaust: Not Applicable

Evaporative: Not Applicable

$$\text{Brake Linings: } \frac{2.05 \times 10^{-9} \text{ MT} \times 356,177}{1,000 \text{ VMT}} \frac{(1,000 \text{ VMT})}{\text{yr}} = 0.00073 \text{ MT/yr}$$

Polycyclic Organic Matter

$$\text{Exhaust: } \frac{3.92 \times 10^{-6} \text{ MT} \times 356,177}{1,000 \text{ VMT}} \frac{(1,000 \text{ VMT})}{\text{yr}} = 1.40 \text{ MT/yr}$$

Evaporative: Not Applicable

Summing the type of emission for each pollutant will give the total emission from LDGV for the study area.

[In a similar manner, emissions from other classes of onroad vehicles can be calculated.]

#### 4.5 Methods to Apportion Countywide Emissions from Road Vehicles

As described in Section 1.0 and Appendix A when performing air dispersion modeling, it is generally recommended that countywide emissions be distributed within the study area into rectangular area source grid cells reflecting spatial variations in activity and

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emissions. Similarly temporal in activities can be factored into the modeling to reflect seasonal or diurnal fluctuations in emissions. Modeling results would then reflect ongoing activities in that portion of the county, e.g., residential heating in the winter, commercial solvent usage during working hours on weekdays.

There are three alternative approaches that can be used in spatially distributing emission: (1) population, i.e., the magnitude of emissions within a grid are directly proportional to the population living in the grid; (2) land area, i.e., emissions from a countywide area source are assumed to be uniform throughout the county and are distributed based on the size of the area source grid; and (3) land use patterns, that assume that certain area source activities, most likely occur in certain areas of the county, e.g., commercial, residential or industrial.

In apportioning emissions from onroad vehicles any of these methods may be appropriate. Land area and population data can be readily obtained, and applied as described in Appendix A. Land use data, available from the U.S. Geological Survey and other sources can be used in combination with the spatial resolution for onroad vehicles, to distribute emissions based on the type of activity being performed, as shown in Table 4-2.

Estimated seasonal, daily and hourly temporal resolution for onroad vehicles are also included in Table 4-2, and can be used with the annual countywide emissions data to estimate temporal variations.

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Table 4-2 Spatial and Temporal Resolution for Road Vehicles

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<u>Spatial Resolution</u>	
Surrogate Indicator:	traffic volume
Information source(s)	zonal traffic statistics
<u>Temporal Resolution</u>	
Seasonal:	uniform through the year
Daily:	uniform through the week
Hourly:	75 percent from 0600 to 1800, 25 percent from 1800 to 0600

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PROCEDURES FOR ESTIMATING AND ALLOCATING  
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## PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

### 5. AIRCRAFT

#### 5.1 General

Aircraft exhaust contains an assortment of toxic compounds, including formaldehyde, benzene, metals, and semivolatiles. Ambient monitoring in areas adjacent to large municipal and military airports indicate that these levels may at times be significant. Unfortunately, little data are available on which to base emission factors, since emissions vary according to engine type, landing and takeoff patterns, etc. At this time, VOC speciation factors are the only factors available to predict aircraft exhaust emissions on an area-wide basis. While data are available on levels of other pollutants emitted by planes, the information was inadequate to develop factors representative of all aircraft.

#### 5.2 Factors

Emission factors are available for total hydrocarbons (HC) and particulates. An approach for estimating criteria pollutant emissions is presented below. The methodology described in detail in AP-42, Volume II<sup>1</sup>, and used in NEDS to estimate criteria pollutant emissions can be used in combination with speciation factors provided in Air Emissions Species Manual<sup>2</sup> to estimate emissions of air toxics. These data may be used to apportion VOCs and particulates based on activities at the airport such as takeoffs and landings and are provided in Tables 5-1, 5-2 and 5-3.

#### 5.3 Methodology Options

NEDS uses the AP-42<sup>1</sup> methodology to estimate LTO's and emissions of criteria pollutants, including total hydrocarbons for commercial, civil, and military aircraft. In that methodology emissions of criteria

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 5-1 Military Aircraft

Species Name	Percent Weight
Isomers of Dodecane	0.19
Isomers of Tetradecane	0.20
Isomers of Pentadecane	0.18
Isomers of Pentene	0.76
C16 Branched Alkane	0.16
C7-C16	0.32
Methane	9.37
Ethane	0.91
Ethylene	18.36
Propane	0.19
Propene	5.44
Acetylene	4.41
Butene	2.06
cis-2-Butene	0.50
1,3-Butadiene	1.89
N-Pentane	0.22
1-Pentene	0.89
2-Methyl-2-Butene	0.21
Methylpentane	0.41
Heptane	0.07
Octane	0.05
Nonane	0.13
N-Decane	0.44
N-Undecane	0.54
1-Hexene	0.86
N-Dodecane	1.07
N-Tridecane	0.67
N-Tetradecane	0.59
N-Pentadecane	0.26
Heptene	0.54
Octene	0.30
1-Nonene	0.26
Formaldehyde	15.47
Acetaldehyde	4.83
Propionaldehyde	0.98
Acrolein	2.38
Butyraldehyde	1.24
Hexanal	0.22
Glyoxal	2.18
Methyl Glyoxal	2.06

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 5-1 (Continued)

Species Name	Percent Weight
Crotonaldehyde	0.00
Acetone	2.41
Benzene	2.02
Toluene	0.55
Ethylbenzene	0.18
O-Xylene	0.20
Styrene	0.41
Pentyl Benzene	0.21
Butyl Benzene	0.26
Phenol	0.26
Benzaldehyde	0.57
Napthalene	0.60
Methyl Naphthalenes	0.52
M-Xylene and P-Xylene	0.30
1-Decene	0.17
C6H1803SI3	6.96
C8H2404SI4	2.37
Hexadecane	0.12
N-Heptadecane	0.01

Note: Composite profile developed from data for CFM-36 jet engine fired with JP-5 fuel at idle, 30% thrust and 80% thrust. Data collected by GC/MS and DNPH analyses were combined according to average LTO cycle times obtained from AP-42 (4th. Edition) for military aircraft

Source: Reference 2

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 5-2 Civil Aircraft

Species Name	Percent Weight
Isomers of Dodecane	0.16
Isomers of Tetradecane	0.17
Isomers of Pentadecane	0.15
Isomers of Pentene	0.64
C16 Branched Alkane	0.13
C7-C16	0.27
Methane	10.95
Ethane	0.92
Ethylene	15.48
Propane	0.20
Propene	4.59
Acetylene	3.69
Butene	1.79
cis-2-Butene	0.45
1,3-Butadiene	1.57
N-Pentane	0.19
1-Pentene	0.75
2-Methyl-2-Butene	0.18
Methylpentane	0.35
Heptane	0.06
Octane	0.04
Nonane	0.15
N-Decane	0.42
N-Undecane	0.52
1-Hexene	0.76
N-Dodecane	1.21
N-Tridecane	0.66
N-Tetradecane	0.59
N-Pentadecane	0.27
Heptene	0.52
Octene	0.25
1-Nonene	0.22
Formaldehyde	14.14
Acetaldehyde	4.32
Propionaldehyde	0.90
Acrolein	2.06
Butyraldehyde	1.19
Hexanal	0.20
Glyoxal	2.53
Methyl Glyoxal	1.81

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 5-2 (Continued)

Species Name	Percent Weight
Crotonaldehyde	0.00
Acetone	2.93
Benzene	1.79
Toluene	0.49
Ethylbenzene	0.13
O-Xylene	0.19
Styrene	0.37
Pentyl Benzene	0.17
Butyl Benzene	0.22
Phenol	0.22
Benzaldehyde	0.53
Napthalene	0.51
Methyl Naphthalenes	0.44
M-Xylene and P-Xylene	0.25
1-Decene	0.15
C6H18O3SI3	11.77
C8H24O4SI4	4.20
Hexadecane	0.14
N-Heptadecane	0.01

Note: Composite profile developed from data for CFM-36 jet engine fired with JP-5 fuel at idle, 30% thrust and 80% thrust. Data collected by GC/MS and DNPH analyses were combined according to average LTO cycle times obtained from AP-42 (4th. Edition) for general aviation.

Source: Reference 2

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 5-3 Commercial Aircraft

Species Name	Percent Weight
Isomers of Dodecane	0.18
Isomers of Tetradecane	0.19
Isomers of Pentadecane	0.17
Isomers of Pentene	0.73
C16 Branched Alkane	0.14
C7-C16	0.30
Methane	9.56
Ethane	0.88
Ethylene	17.42
Propane	0.18
Propene	5.15
Acetylene	4.17
Butene	1.97
cis-2-Butene	0.48
1,3-Butadiene	1.80
N-Pentane	0.21
1-Pentene	0.84
2-Methyl-2-Butene	0.20
Methylpentane	0.39
Heptane	0.06
Octane	0.05
Nonane	0.13
N-Decane	0.42
N-Undecane	0.53
1-Hexene	0.82
N-Dodecane	1.07
N-Tridecane	0.66
N-Tetradecane	0.58
N-Pentadecane	0.26
Heptene	0.54
Octene	0.28
1-Nonene	0.24
Formaldehyde	15.00
Acetaldehyde	4.65
Propionaldehyde	0.95
Acrolein	2.27
Butyraldehyde	1.20
Hexanal	0.21
Glyoxal	2.54
Methyl Glyoxal	1.97



# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 5-3 (Continued)

Species Name	Percent Weight
Crotonaldehyde	0.00
Acetone	2.45
Benzene	1.94
Toluene	0.52
Ethylbenzene	0.17
O-Xylene	0.19
Styrene	0.39
Pentyl Benzene	0.19
Butyl Benzene	0.24
Phenol	0.24
Benzaldehyde	0.55
Napthalene	0.57
Methyl Napthalenes	0.49
M-Xylene and P-Xylene	0.29
1-Decene	0.17
C6H18O3S13	9.10
C8H24O4S14	2.92
Hexadecane	0.12
N-Heptadecane	0.01

Note: Composite profile developed from data for CFM-36 jet engine fired with JP-5 fuel at idle, 30% thrust and 80% thrust. Data collected by GC/MS and DNPH analyses were combined according to average LTO cycle times obtained from AP-42 (4th. Edition) for commercial aircraft.

Source: Reference 2

## PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

pollutants are estimated based on aircraft takeoffs and landings. The general approach is to first estimate the number of landing and takeoff (LTO) cycles per aircraft type for a specified period of time at each airport facility. An LTO cycle incorporates all of the normal flight and around operation modes (at their respective times-in-mode), including descent/approach from approximately 3000 feet (915 meters) above ground level (AGL), touchdown, landing run, taxi in, idle and shutdown, startup and idle, checkout, taxi out, takeoff, and climbout to 3000 feet (915 meters) AGL. It is during this cycle that most compound emissions that affect the subsequent ground-level concentrations of concern are released. The LTO estimates are multiplied by aircraft and specific emission factors, and the results are summed to provide an estimate of particulate and organic compound emissions for the inventory period and location of interest.

Alternative, more labor intensive, approaches are available to estimate LTOs. One possible approach, for example, is to obtain information directly from each airport. Airports often have detailed information on their operations that can be very helpful.

### 5.4 Example Calculation

#### Example Calculation

The example below demonstrates a methodology for estimating total annual airport emissions of three pollutants: 1,3 butadiene, formaldehyde, and benzene.

#### Step 1. Obtain VOC Data.

The emission factors are given by percentage of VOC for three types of aircraft: military, civil, and commercial. NEDS gives estimates of countywide VOC estimates for these aircraft categories. Data for a hypothetical county is given below.

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<u>Aircraft Type</u>	<u>VOC Emissions (kkq/yr)</u>
Military	384
Civil	40
Commercial	1,357

Step 2. Multiply VOC estimates by pollutant specific emission factors.

Table 5-1, 5-2, and 5-3 provide speciation factors for the three compounds. The emissions of three pollutants of concern (1,3 butadene, formaldehyde, and benzene) are calculated as follows.

Military

1,3 butadene:  $\frac{384 \text{ Metric tons}}{\text{year}} \times 0.0189 = 7.3 \text{ Metric tons/yr}$

formaldehyde:  $\frac{384 \text{ Metric tons}}{\text{year}} \times 0.1547 = 59.40 \text{ Metric tons/yr}$

benzene:  $\frac{384 \text{ Metric tons}}{\text{year}} \times 0.0202 = 7.75 \text{ Metric tons/yr}$

Civil

1,3 butadene:  $\frac{40 \text{ Metric tons}}{\text{year}} \times 0.0157 = 0.6 \text{ Metric tons/yr}$

formaldehyde:  $\frac{40 \text{ Metric tons}}{\text{year}} \times 0.1414 = 5.7 \text{ Metric tons/yr}$

benzene:  $\frac{40 \text{ Metric tons}}{\text{year}} \times 0.0179 = 0.7 \text{ Metric tons/yr}$

Commercial

1,3 butadene:  $\frac{1,357 \text{ Metric tons}}{\text{year}} \times 0.0180 = 24.4 \text{ Metric tons/yr}$

formaldehyde:  $\frac{1,357 \text{ Metric tons}}{\text{year}} \times 0.1500 = 203.6 \text{ Metric tons/yr}$

benzene:  $\frac{1,357 \text{ Metric tons}}{\text{year}} \times 0.0194 = 26.3 \text{ Metric tons/yr}$

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5.5 Methods to Apportion Countywide Emissions from Aircraft

As described in Section 1.0 and Appendix A when performing air dispersion modeling, it is generally recommended that countywide emissions be distributed within the study area into rectangular area source grid cells reflecting spatial variations in activity and emissions. Similarly temporal in activities can be factored into the modeling to reflect seasonal or diurnal fluctuations in emissions. Modeling results would then reflect ongoing activities in that portion of the county, e.g., residential heating in the winter, commercial solvent usage during working hours of weekdays.

In apportioning emissions from aircraft the U.S. Geological Survey and other sources can be used in combination with the spatial resolution for aircraft, to distribute emissions based on the type of activity being performed, as shown in Table 5-4.

The best approach for estimating spatial distribution is to identify airports on U.S. Geological Survey land use maps, contacting local airport authorities, and surveying U.S. Department of Transportation data on airport activities, as noted in Table 5-4. Spatial, temporal variations on activity and emissions tend to be unique for each airport; airport authorities usually have detailed information on variations in activity.

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 5-4  
Spatial and Temporal Resolution for Aircraft

## Aircraft, General<sup>3</sup>

### Spatial Resolution

Surrogate indicator:	airport area (code 14)
Information source(s):	land use map, local airport authority, and Reference 4

### Temporal Resolution

Seasonal:	uniform through the year
Daily:	40 percent of operations occur on weekends and 60 percent on weekdays
Hourly:	uniform from 0700 to 2100, otherwise zero

## Aircraft, Commercial<sup>3</sup>

### Spatial Resolution

Surrogate indicator:	airport area by airport (code 14)
Information source(s):	land use map, local airport authority, and References 5 and 6

### Temporal Resolution

Seasonal, daily, and hourly:	Since the temporal profiles of commercial airports vary widely, the respective airport managers should be contacted. The airport managers usually have very detailed temporal information.
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## Aircraft, Military<sup>3</sup>

### Spatial Resolution

Surrogate indicator:	airport area (code 14)
Information source(s):	land use map, local airport authority, and Reference 7

### Temporal Resolution

Seasonal, daily, and hourly:	Estimate on individual basis. Contact local airport authorities and appropriate military agencies.
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REFERENCES

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6. COMFORT AND INDUSTRIAL COOLING TOWERS

6.1 General<sup>1</sup>

Chromium, in the form of chromates, is commonly added to cooling tower water as a corrosion inhibitor. Water droplets and the dissolved solids, including chromates, that they contain are entrained in the air and are emitted from the cooling tower stack. Because this cooling tower "drift" will also presumably contain chromates, it follows that cooling towers are potentially an important source of hexavalent chromium air emissions.

There are two types of cooling towers, comfort and industrial. Comfort cooling towers are used to maintain a specified environment or refrigeration system. Industrial process cooling towers are used to control the temperatures of process fluids in industrial production units.

Chromium emission rates vary depending on the type of cooling tower. It is estimated that national baseline emissions of hexavalent chromium from comfort cooling towers are between 7.2 and 206 metric tons annually, and national baseline emissions from industrial cooling towers (for the four major industries that make up the majority of industrial towers) are 795 metric tons per year.

Warm water is cooled by cooling towers when it contacts ambient air that is drawn or forced through the tower. For most cooling towers, about 80 percent of the cooling occurs through evaporation of water, as the air flowing through the tower contacts the water flowing from the top to the bottom of the tower. Most tower systems are designed with recirculating water systems to conserve water resources or reduce the cost of purchasing water. The major cooling tower components are the fan(s), fill material, water distribution deck or header, drift

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eliminator, structural frame, and cold water basin. Other components that affect tower operation include the pumps and pipes necessary to circulate the cooling water through the tower and heat exchanger loops.

Cooling towers are designed with mechanically induced-, mechanically forced-, or natural-draft airflow. Induced-draft airflow is provided by a propeller-type fan located in the stack at the top of the tower. Forced-draft towers are usually smaller than induced-draft towers and have either centrifugal fans located at the base of the tower or axial fans located on the side of the tower. Natural-draft airflow relies on the buoyancy created by differences in temperature between the air in the tower and the atmosphere. When the cooling demands are minimal and the air temperature is low enough, water can be circulated through the tower and can be cooled sufficiently without using the fans. In these instances, a natural draft is created in a mechanical draft tower. The direction of airflow in a mechanical-draft tower is either crossflow or counterflow. Crossflow refers to horizontal airflow through the fill; counterflow refers to upward vertical airflow.

Drift eliminators can be installed at the exit of the fill sections to reduce the drift in the exiting airflow. The drift removal efficiency is a function of the drift eliminator design, of which there are four major types: blade-type, waveform, cellular, and herringbone. (Herringbone is similar to blade-type, but the blades in one row are offset from the blades in the next row.) Typically, herringbone and blade-type units are the least efficient, waveform units are moderately efficient, and cellular units are the most efficient. Drift eliminators are constructed of wood, PVC, metal, asbestos-cement, polystyrene, or cellulose.

Comfort cooling towers.<sup>1</sup> Comfort cooling towers are used in all states in the U.S., primarily in urban areas. Major users of comfort cooling towers with heating, ventilating, and air conditioning (HVAC) systems include hospitals, hotels, educational facilities, office



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buildings, and shopping malls. Refrigeration systems that may operate with comfort cooling towers include ice skating rinks, cold storage (food) warehouses, and other commercial operations. Estimates from the two largest manufacturers of cooling towers indicate that the nationwide population of comfort cooling towers is between 200,000 and 300,000.<sup>2,3</sup>

Water treatment vendors estimated that 10 to 25 percent of comfort cooling towers use chromium-based water treatment chemicals.<sup>4,5,6</sup> For analysis purposes, it is assumed that the nationwide population of comfort cooling towers is 250,000 units and that 15 percent of them (about 37,500) use chromium-based water treatment chemicals. Hexavalent chromium use in comfort cooling towers appears to be distributed randomly across the country.

Typically, comfort cooling towers are open recirculating systems with either forced- or induced-draft airflow (natural-draft airflow is not used for comfort cooling towers) and are designed with crossflow air direction.

Industrial cooling towers.<sup>7</sup> The industrial cooling tower category includes all cooling towers that are used to remove heat from an industrial process or chemical reaction. Towers that are used to cool both industrial processes and HVAC and refrigeration systems are also included in this category. Only towers devoted exclusively to cooling HVAC and refrigeration systems are defined as comfort cooling towers.

Major users of industrial cooling towers are chemical manufacturing, petroleum refining, primary metals, and numerous miscellaneous industries. The industries in the U.S. using chromium-based water treatment chemicals include approximately 190 petroleum refineries, 1,800 chemical manufacturing plants, 1,000 primary metals plants (including 775 foundries), and 750 plants in five miscellaneous industries (textiles, tobacco products, tire and rubber products, glass

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products, and utilities). It was assumed that chromates are not used in miscellaneous industries other than the five referred to above. Approximately 8,800 industrial cooling towers are estimated to be operating in all eight industries. It is further estimated that the percentage of towers using chromium-based chemicals is 73 percent at petroleum refineries, 40 percent at chemical manufacturing plants, 21 percent at primary metals facilities, and 15 percent in the miscellaneous industries, except for utilities where only two are reported to use chromates. These percentages result in a total of about 2,800 industrial cooling towers using chromium-based water treatment chemicals.

In a typical industrial cooling system, cooling water is pumped from the cooling tower basin to the heat exchanger(s) being served by the tower, and the heated water flows back to the cooling tower water distribution system. The cooling water loop may include numerous separate heat exchangers of various designs. Heat exchangers are designed to transfer heat from one fluid to another. The transfer can occur directly by mixing the hot and cold materials or indirectly through a device separating the hot and cold materials. Indirect heat exchanger types include shell-and-tube, flat plate, and spiral designs. In most industries, heat transfer is accomplished with shell-and-tube heat exchangers.

## 6.2 Factors

Comfort cooling towers.<sup>1</sup> Chromium emission factors have been developed based on EPA-sponsored tests performed on industrial cooling towers equipped with lower efficiency drift eliminators, which are similar to comfort cooling towers. These emission factors relate chromium emissions to the chromium concentration in the recirculation water. Data on chromate concentrations in comfort cooling tower water indicate that concentrations vary from less than 1 ppm to 20 ppm chromate.<sup>8,9,10</sup> Although a large amount of data has

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shown that the average concentration of chromate in industrial process cooling towers is 13 ppm, there are insufficient data on comfort cooling towers to justify using a concentration other than the midpoint of the observed range.<sup>11-19</sup> Therefore, the chromate concentration is assumed to be 10 ppm, or 4.48 ppm hexavalent chromium.

The lowest emission factor is thought to underestimate emissions because some of the hexavalent chromium in the samples was retained on the walls of the beakers used to concentrate the samples. Errors are not, expected to account for most of the difference between the lowest and highest emission factors, however. The wide differences among emission factors indicate that emissions may vary substantially with time for an individual tower as well as from tower to tower.

The above results were used to develop emission factors on a per capita basis. The total number of comfort cooling towers was apportioned (by size groups) by state based on state population. The chromium emissions for individual towers in each state are dependent on the utilization rate for the state. The utilization rate is the percentage of the number of days that the tower operates annually. The utilization rate depends on the climate at the cooling tower site. It was assumed (as a rough approximation) that the tower is not used on days when the average temperature is below 60°F

The annual chromium emissions from individual towers in each state were estimated by calculating annual emissions based on the factors cited above. The estimated individual emission rates for the six tower sizes in each state were then multiplied by the respective number of comfort cooling towers of that size in the state to obtain the statewide chromium emission. The average emission rate per person for each state was estimated by dividing the total chromium emission rate for the state by the population of the state. The resulting emission factors are provided

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in Table 6-1. The factors are presented as ranges because they were calculated from the highest and lowest emission factors from the EPA-sponsored study. Therefore, the lower value carries the same uncertainty as the Agency's lowest emission factor because of the problem of the chromium retention in the beaker during the test.

Industrial cooling towers.<sup>7</sup> An estimated national average emission factor for chromium releases from industrial cooling towers was determined based on four industries: petroleum refining, chemical manufacturing, primary metals, and miscellaneous industries (including the textiles, tire and rubber, tobacco, glass manufacturing, and utilities industries), as well as four different sizes of cooling towers in each industry.

Data compiled from the petroleum refinery industry indicate that the average chromate concentration in industrial cooling towers is approximately 13 ppm. Data from the Chemical Manufacturers Association also indicate an average of 13 ppm chromate in the chemical manufacturing industry. (These two categories account for the majority of the industrial cooling towers.) In the absence of data for other industries, 13 ppm chromates was assumed for all industry categories. Thirteen ppm chromates translates into 5.82 ppm hexavalent chromium.

A chromium emission factor was developed from EPA-sponsored tests performed on industrial cooling towers equipped with low efficiency drift eliminators. The emission factor relates chromium emissions to recirculation rate and chromium concentration in the water. Testing was done for crossflow towers, the most common type of comfort cooling tower in use. Information from a cooling tower vendor indicates that crossflow towers are more likely to have higher drift rates than the other type of tower, counterflow towers, because crossflow towers have higher velocities at the outlet.

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Table 6-1 Lower- and Upper-Bound Estimates of  
Annual Cr<sup>+6</sup> Emissions Per Person By State

State	Utilization (percent)	Hexavalent Chromium Emissions (kg/yr per person)	Hexavalent Chromium Emissions (lb/yr per person)
Alabama	59	4.13E-05-1.17E-03	9.11E-05-2.59E-03
Alaska <sup>a</sup>	0	0.00E+00-0.00E+00	0-00E+00-0.00E+00
Arizona	55	3.85E-05-1.09E-03	8.49E-05-2.41E-03
Arkansas	56	3.92E-05-1.11E-03	8.64E-05-2.45E-03
California	54	3.78E-05-1.07E-03	8.33E-05-2.37E-03
Colorado	29	2.03E-05-5.76E-04	4.48E-05-1.27E-03
Connecticut	33	2.31E-05-6.56E-04	5.09E-05-1.45E-03
Delaware	33	2.31E-05-6.56E-04	5.09E-05-1.45E-03
Florida	89	6.23E-05-1.77E-03	1.37E-05-3.90E-03
Georgia	59	4.13E-05-1.17E-03	9.11E-05-2.59E-03
Hawaii	100	7.00E-05-1.99E-03	1.54E-04-4.38E-03
Idaho	21	1.47E-05-4.17E-04	3.24E-05-9.20E-04
Illinois	42	2.94E-05-8.35E-04	6.48E-05-1.84E-03
Indiana	42	2.94E-05-8.35E-04	6.48E-05-1.84E-03
Iowa	38	2.66E-05-7.55E-04	5.86E-05-1.67E-03
Kansas	42	2.94E-05-8.35E-04	6.48E-05-1.67E-03
Kentucky	42	2.94E-05-8.35E-04	6.48E-05-1.84E-03
Louisiana	65	4.55E-05-1.29E-03	1.00E-04-2.85E-03
Maine	21	1.47E-05-4.17E-04	3.24E-05-9.20E-04
Maryland	46	3.22E-05-9.14E-04	7.10E-05-2.02E-03
Massachusetts	33	2.31E-05-6.56E-04	5.09E-05-1.45E-03
Michigan	33	2.31E-05-6.56E-04	5.09E-05-1.45E-03
Minnesota	29	2.03E-05-5.76E-04	4.48E-05-1.27E-03
Mississippi	59	4.13E-05-1.17E-03	9.11E-05-2.59E-03
Missouri	42	2.94E-05-8.35E-04	6.48E-05-1.84E-03

<sup>a</sup>Alaska was assumed to have no comfort cooling towers because, on average, there are no days when the mean temperature exceeds 60°F.

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Table 6-1 (Continued)

State	Utilization (percent)	Hexavalent Chromium Emissions (kg/yr per person)	Hexavalent Chromium Emissions (lb/yr per person)
Montana	25	1.75E-05-4.97E-04	3.86E-05-1.10E-03
Nebraska	42	2.66E-05-7.55E-04	5.86E-05-1.67E-03
Nevada	39	2.73E-05-7.75E-04	6.02E-05-1.71E-03
New Hampshire	27	1.89E-05-5.37E-04	4.17E-05-1.18E-03
New Jersey	42	2.94E-05-8.35E-04	6.48E-05-1.84E-03
New Mexico	39	2.73E-05-7.75E-04	6.02E-05-1.71E-03
New York	33	2.31E-05-6.56E-04	5.09E-05-1.45E-03
North Carolina	53	3.71E-05-1.05E-03	8.18E-05-2.32E-03
North Dakota	25	1.75E-05-4.97E-04	3.86E-05-1.10E-03
Ohio	39	2.73E-05-7.75E-04	6.02E-05-1.71E-03
Oklahoma	54	3.78E-05-1.07E-03	8.33E-05-2.37E-03
Oregon	23	1.61E-05-4.57E-04	3.55E-05-1.01E-03
Pennsylvania	39	2.73E-05-7.75E-04	6.02E-05-1.71E-03
Rhode Island	33	2.31E-05-6.56E-04	5.09E-05-1.45E-03
South Carolina	59	4.13E-05-1.17E-03	9.11E-05-2.59E-03
South Dakota	33	2.31E-05-6.56E-04	5.09E-05-1.45E-03
Tennessee	50	3.50E-05-9.94E-04	7.72E-05-2.19E-03
Texas	63	4.41E-05-1.25E-03	9.72E-05-2.76E-03
Utah	31	2.17E-05-6.16E-04	4.78E-05-1.36E-03
Vermont	25	1.75E-05-4.97E-04	2.86E-05-1.10E-03
Virginia	42	2.94E-05-8.35E-04	6.48E-05-1.84E-03
Washington	20	1.40E-05-3.98E-04	3.09E-05-8.76E-04
West Virginia	42	2.94E-05-8.35E-04	6.48E-05-1.84E-03
Wisconsin	31	2.17E-05-6.16E-04	4.78E-05-1.36E-03
Wyoming	25	1.75E-05-4.97E-04	3.86E-05-1.10E-03
Washington, D.C.	50	3.50E-05-9.95E-04	7.72E-05-2.19E-03

Source: Reference 1

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Table 6-2 lists the emission factors for counterflow, crossflow, and the national average baseline. The emissions are given as amount of hexavalent chromium emitted per hexavalent chromium concentration in the cooling water. Hexavalent chromium emissions can be estimated by multiplying the emission factor by the concentration of chromium and the recirculation rate.

Emission factors have also been calculated to relate hexavalent chromium emissions to the number of employees in the study area for the industries that contribute the most to industrial cooling tower emissions. The Background Information Document for Industrial Cooling Towers<sup>7</sup> contains data on national emissions of hexavalent chromium for the petroleum refining, chemical manufacturing, primary metals, textile finishing, tobacco, tire and rubber, and glass manufacturing industries as well as for utilities.

County Business Patterns<sup>20</sup> was used to determine the number of employees nationally for each of the SIC codes listed in Table 6-3. The number of employees (by SIC code) was summed for each industry. The national hexavalent chromium emission for that industry was then divided by the national number of employees for that industry, giving the emission factor as kg/yr/employee (lb/yr/employee). Table 6-4 presents these emission factors.

### 6.3 Methodology Options

Comfort Cooling Towers. To estimate area source emissions of hexavalent chromium from comfort cooling towers, the following steps are recommended:

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Table 6-2 Industrial Cooling Tower Emission Factors

mg Cr <sup>+6</sup> /ppm Cr <sup>+6</sup> /1 H <sub>2</sub> O	Emission factor	
	lb Cr <sup>+6</sup> /ppm Cr <sup>+6</sup> /gal H <sub>2</sub> O	
0.0003	2.49 x 10 <sup>-9</sup>	

Source: Reference 2.

Table 6-3 SIC Codes Included in Industry-Specific Emission Factors

Industry	SIC Codes
Petroleum Refining	291
Chemical Manufacturing	281, 282, 286, 287
Primary Metals	331, 332, 333
Textile Finishing	223, 226
Tobacco	211, 212, 213
Tire and Rubber	301, 302, 304, 306
Glass Manufacturing	321, 322
Utilities	491

Source: Reference 7.



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Table 6-4 Industrial Cooling Tower Hexavalent Chromium  
Employee-Based Emission Factors

Industry	Emission factor	
	kg/yr/employee	lb/yr/employee
Petroleum Refining	0.35	0.75
Chemical Manufacturing	0.19	0.42
Primary Metals	0.02	0.045
Textile Finishing	0.09	0.20
Tobacco	0.018	0.044
Tire and Rubber	0.0037	0.008
Glass Manufacturing	0.005	0.011
Utilities	0.002	0.005

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- Determine the population of the study area. This information can be obtained from population reports published by the U.S. Department of Commerce, Bureau of the Census.
- Multiply the emission factor for the state in which the study area lies by the population of the study area to give an estimate of the study-wide area emission of hexavalent chromium from comfort cooling towers.

Industrial cooling towers. The easiest method for estimating area source emissions of hexavalent chromium is to determine the number of employees in industries likely to use hexavalent chromium in cooling towers, and to apply the emission factors in Table 6-5, as follows:

- Determine, for each industry listed in Table 6-5, the number of employees in the study area. This information is available from County Business Patterns,<sup>21</sup> which gives the number of employees for each SIC code by county.
- For each industry, multiply the emission factor by the number of employees in the study area to give an estimate of the area source emissions for that industry.
- Sum the emissions over all industries in the study area to obtain an estimate of the total area source emissions of hexavalent chromium from industrial cooling towers in the study area.

Alternately, area source emissions of hexavalent chromium from industrial cooling towers can be estimated using the following approach:

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- Determine, by surveying the facilities in the study area, which facilities have cooling towers that use chromate-based water treatment, and what the annual recirculation rate is for each of the towers under consideration.
- Sum the recirculation rates to determine the total recirculation rate of chromium-containing cooling water in the study area.
- Multiply the national average baseline emission factor by the concentration of hexavalent chromium (assumed to be 4.48 ppm) and by the total recirculation rate in the study area to give an estimation of the study-wide area emission of hexavalent chromium by industrial cooling towers.

### 6.4 Example Calculations

#### Example Calculation 1

Hexavalent chromium emissions can be calculated on a per capita basis as shown in the following example.

The emission is calculated on a per capita basis. Assuming the study area is in Alabama and the study area population is 150,000, the per capita emission factor for Alabama from Table 6-1 is multiplied by the study area population of 150,000:

$$\begin{aligned} 1.17 \times 10^{-3} \text{ kg/yr/person} \times 150,000 \text{ people} &= 175.5 \text{ kg/yr} \\ 2.59 \times 10^{-3} \text{ lb/yr/person} \times 150,000 \text{ people} &= 388.5 \text{ lb/yr.} \end{aligned}$$

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Example Calculation 2

A method for estimating hexavalent chromium emissions from industrial cooling towers is demonstrated in the following example.

One can assume that there are 15 industrial cooling towers in a study area that use chromates for corrosion control and that summing the recirculation rate for all 15 of these towers yields a total recirculation rate of  $6.8 \times 10^7$  l/hr ( $1.8 \times 10^7$  gal/hr). Multiplying this value by the national average baseline emission factor will give the emission of hexavalent chromium from industrial cooling towers in the study area:

$$(6.8 \times 10^7 \text{ l/hr}) \times (4.48 \text{ ppm}) \times (0.0016 \text{ mg Cr/ppm Cr/l H}_2\text{O}) = 4.88 \times 10^5 \text{ mg/hr}$$

$$(1.8 \times 10^7 \text{ gal/hr}) \times (4.48 \text{ ppm}) \times (1.33 \times 10^{-8} \text{ lbCr/ppm Cr/gal H}_2\text{O}) = 1.07 \text{ lb/hr.}$$

Alternatively, the emissions can be calculated based on number of employees of the major industries in the study area. Assuming the study area is Allegheny County, Pennsylvania, the number of employees by SIC code can be determined from County Business Patterns (Pennsylvania).<sup>21</sup> The number of employees for Allegheny County for each SIC Code of concern is as follows:

<u>Industry</u>	<u>SIC Code</u>	<u>No. of employees</u>
Petroleum Refining	291	0
	Total	0
Chemical Manufacturing	281	468
	282	1,679
	286	250-499 (assume average of 375)
	287	0
	Total	2,522
Primary Metals	331	38,68
	332	2,622
	333	0
	Total	41,311

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<u>Industry</u>	No. of <u>SIC Code</u>	<u>employees</u>
Textile Finishing	223	0
	226	0
	Total	0
Tobacco	211	0
	212	0
	213	0
	Total	0
Tire and Rubber	301	0
	302	0
	304	0
	306	20-99 (assume average of 60)
	Total	60
Glass Manufacturing	321	0
	322	877
	Total	877
Utilities	491	250-499 (assume average of 375)
	Total	375

The next step is to multiply the emission factor for each industry by the total number of employees for that industry

<u>Industry</u>	<u>Emission factor (lb/yr/employee)</u>	<u>No. of employees</u>	<u>Emissions Cr-6 (lb/yr)</u>
Petroleum Refining	4.03	0	0
Chemical Manufacturing	2.27	2,522	5,725
Primary Metals	0.24	41,311	9,915
Textile Finishing	1.06	0	0
Tobacco	0.21	0	0
Tire and Rubber	0.044	60	3
Glass Manufacturing	0.06	877	53
Utilities	0.029	375	11

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Finally, summing the chromium emissions over all the industries will give an estimate of the hexavalent chromium emissions from industrial cooling towers in the study area:

$$5,725 + 9,915 + 3 + 53 + 11 = 15,707 \text{ lb/yr.}$$

6.5 Methods to Apportion Countywide Emissions from Cooling Towers

As described in Section 1.0 and Appendix A when performing air dispersion modeling, it is generally recommended that countywide emissions be distributed within the study area into rectangular area source grid cells reflecting spatial variations in activity and emissions. Similarly temporal variations in activities can be factored into the modeling to reflect seasonal or diurnal fluctuations in emissions. Modeling results would then reflect on-going activities in that portion of the county, e.g., residential heating in the winter, commercial solvent usage during working hours on weekdays.

There are three alternative approaches that can be used in spatially distributing emissions: (1) population, i.e., the magnitude of emissions within a grid are directly proportional to the population living in the grid, (2) land area, i.e., emissions from a countywide area source are assumed to be uniform throughout the county and are distributed based on the size of the area source grid, and (3) land use patterns, that assume that certain area source activities, most likely occur in certain areas of the county, e.g., commercial, residential or industrial.

In apportioning emissions from commercial and industrial cooling towers, any of these methods may be appropriate. Land area and population data can be readily obtained, and applied as described in Appendix A. Land use data, available from the U.S. Geological Survey and other sources can

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be used in combination with the spatial resolution for both categories of cooling towers, to distribute emissions based on the type of activity being performed, as shown in Table 6-5.

Estimated seasonal, daily and hourly temporal resolution for industrial and comfort cooling towers are also included in Table 2-5, and can be used with the annual countywide emissions data to estimate temporal variations.

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Table 6-5 Temporal and Spatial Desolution for Industrial and  
Comfort Cooling Towers

## Industrial Cooling Towers

### Spatial Resolution

Surrogate indicator:	industrial areas (codes 13 and 15)
Information source:	land use maps

### Temporal Resolution

Seasonal:	uniform through the year
Daily:	uniform through the week
Hourly:	80 percent from 0700 to 1900, 20 percent from 1900 to 2400, otherwise zero

## Comfort Cooling Towers (Residential/Commercial/Institutional)

### Spatial Resolution

Surrogate indicator:	residential areas (land use codes 11, 16, and 17) and commercial areas (land use codes 12 and 15)
Information source(s):	land use maps

### Temporal Resolution

Seasonal:	25 percent uniform through year and 75 percent uniform during months that have an average temperature of 68° or more
Daily:	90 percent Monday through Saturday 10 percent Sunday
Hourly:	75 percent 0800 through 2000 25 percent 0100 through 0800

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### 7. FOREST FIRES AND AGRICULTURAL BURNING

#### 7.1 General

Open burning (e.g., forest wildfires, managed burning, and agricultural burning) is a source of a number of air toxics, most notably, products of incomplete combustion such as polycyclic organic matter (POM). A forest "wildfire" is a large-scale natural combustion process that consumes various ages, sizes, and types of botanical specimens growing outdoors in a defined geographical area. Managed burning activities include slash burning and prescribed burning. Slash burning practices are used to burn wastes from logging operations under controlled conditions, whereas prescribed burning is used as a forest management practice to establish favorable seedbeds, remove competing underbrush, and produce to other ecological benefits. Agricultural burning is practiced routinely to clear and/or prepare land for planting.<sup>1</sup>

#### 7.2 Factors

Emissions from wildfires and controlled burning in areas can be significant despite the relatively short duration of the burn. The size and intensity of these fires are dependent on such variables as meteorological conditions, species of vegetation and their moisture content, and the weight of consumable fuel per acre.

Limited data are available to characterize air toxics emissions from wildfires, managed burning, and agricultural burning. It has been hypothesized (but not proved) that the nature and amounts of air pollutant emissions are directly related to the intensity and direction (relative to the wind) of the wildfire and are indirectly related to the rate at which the fire spreads. The factors the rate of spread are (1) weather (wind velocity, ambient temperature, relative humidity, and

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precipitation); (2) fuels (type, bed array, moisture content, and size); and (3) topography (slope and profile). However, logistical problems (such as size of the burning area) and the difficulties involved in safely situating personnel and equipment near the fire have prevented the collection of reliable experimental emission data on actual wildfires. Thus, it is presently impossible to verify or disprove the above hypothesis. Until such measurements are made, therefore, the only available information is that obtained from burning experiments in the laboratory. Although existing emission factors are adequate for laboratory-scale emissions estimates, substantial errors may result if they are used to calculate actual wildfire emissions.<sup>1</sup> Emission factors that can be used to estimate air toxics emitted from forest fires, managed burning, and agricultural burning are presented in Tables 7-1, 7-2, and 7-3.

### 7.3 Methodology Options

For each type of burning or burning operation, the quantity of air toxics emitted can be estimated by multiplying the number of acres burned in each county by a fuel loading factor and the emission factor for each pollutant. The acreage burned can be obtained from NEDS, along with the estimated VOC emissions. Emission estimates of semivolatiles can be obtained either directly by using the emission factors provided in Table 7-1. Emissions for a subset of volatile organic compounds (VOC's), by the data contained in Tables 7-2 and 7-3.

Alternatively, instead of relying on NEDS data, Table 7-2 identifies the percentage by weight of various VOC's emitted from ponderosa logging slash materials collected from the San Bernadino National Forest and burned under controlled laboratory conditions.<sup>2</sup> Table 7-3 is a summary of total hydrocarbon emission factors for forest wildfires as a function of geographical area. Wildfire emissions of a compound listed

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Table 7-1 Emission Factors Used to Estimate Emissions from  
Wildfires, Managed Burning, and Agricultural Burning

Air toxic	Emission factor (kg/MT dry fuel)	Emission factor (lb/ton dry fuel)
Anthracene	$2.5 \times 10^{-3}$	$5.0 \times 10^{-3}$
Benzo(a)anthracene	$3.1 \times 10^{-3}$	$6.2 \times 10^{-3}$
Benzo(a)fluoranthene	$1.3 \times 10^{-3}$	$2.6 \times 10^{-3}$
Benzo(k)fluoranthene	$1.3 \times 10^{-3}$	$2.6 \times 10^{-3}$
Benzo(ghi)perylene	$2.5 \times 10^{-3}$	$5.0 \times 10^{-3}$
Benzo(a)pyrene	$7.4 \times 10^{-4}$	$1.5 \times 10^{-3}$
Chrysene	$3.1 \times 10^{-3}$	$6.2 \times 10^{-3}$
Fluoranthene	$5.5 \times 10^{-3}$	$1.1 \times 10^{-2}$
Indeno(1,2,3-cd)pyrene	$1.7 \times 10^{-3}$	$2.4 \times 10^{-3}$
Phenanthrene	$2.5 \times 10^{-3}$	$5.0 \times 10^{-3}$
Pyrene	$4.6 \times 10^{-3}$	$9.2 \times 10^{-3}$

Source: Reference 4.

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Table 7-2 Summary of Hydrocarbon Emission Factors  
for Forest Wildfires<sup>a</sup>

<u>Emission factors, kg/hectare</u>	
Geographic area <sup>b</sup>	Hydrocarbons
Rocky Mountain group	996
Northern,	
Region 1	1,620
Rocky Mountain,	
Region 2	808
Southwestern,	
Region 3	269
Intermountain,	
Region 4	215
Pacific group	512
California,	
Region 5	485
Alaska,	
Region 10	431
Pacific N.W.,	
Region 6	1,620
Southern group	242
Southern,	
Region 8	242
North Central group	296
Eastern, Region 9	296
(Both groups are in Region 9)	
Eastern group	296
(With Region 9)	
Total United States	458

<sup>a</sup>Areas consumed by wildfire and emissions are for 1971.

<sup>b</sup>Geographic areas are defined in Figure 7-1

Source: Reference 1.

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Table 7-3 Volatile Organic Species Profile  
from Typical Forest Wildfires

Chemical name	Percent weight
Isomers of pentane	15
Propane	.35
N-Butane	.24
Isobutane	.11
Isomers of butene	.92
Ethylene	19.11
Propylene	3.93
Butene	.81
1,3-Butadiene	.52
3-Methyl-1-butene	.17
Unidentified hydrocarbons	44.59
Acetylene	8.40
Methylacetylene	.41
Methane	9.82
Ethane	10.47

Source: Reference 3

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in Table 7-2 can be estimated by simply (1) multiplying the "percent weight" term for that compound by the hydrocarbon emission factor corresponding to the geographical area of interest and (2) multiplying that product by the estimated acreage of the wildfire. This procedure is illustrated in Example 2 in this section.

As noted earlier, NEDS lists the acreage, tons of growth burned per acre, and VOC emissions. In most cases these data are adequate.

For forest "wildfires," estimates of the quantity and types of growth burned in a given area can also be obtained from the U.S. Forest Service's state forestry or agricultural department, or from local fire protection agencies. For localities where estimates are not available, the U.S. Forest Service annually publishes Wildfire Statistics,<sup>3</sup> which gives the total acreage burned in each state. Although this document does not include data for each county, local fire and forestry officials can usually provide county-specific estimates. If sufficient information cannot be obtained from local officials, the state total from Wild Fire Statistics should be apportioned to counties according to forest acreage per county.

Determination of tons of growth burned per acre ("fuel loading") is equally important, and local officials should be contacted for this information. The emissions in the study area are then obtained by multiplying the appropriate emission factor by the fuel loading factor, then multiplying this product by the amount of forest acreage burned.

Average fuel loadings for the various U.S. Forest Service regions are presented in Table 7-4.

Slash Burning and Agricultural Field Burning. Wastes from logging operations are often burned under controlled conditions to reduce



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Table 7-4 Summary of Estimated Fuel Consumed  
by Forest Fires

Area and region <sup>a</sup>	Estimated average fuel loading	
	MT/hectare	ton/acre
Rocky Mountain group	83	37
Region 1: Northern	135	60
Region 2: Rocky Mountain	67	30
Region 3: Southwestern	22	10
Region 4: Intermountain	40	8
Pacific group	43	19
Region 5: California	40	18
Region 6: Pacific Northwest	135	60
Region 10: Alaska	36	16
Coastal	135	60
Interior	25	11
Southern group	20	9
Region 8: Southern	20	9
Eastern group	25	11
North Central group	25	11
Region 9: Conifers	22	10
Hardwoods	27	12

<sup>a</sup> Geographical areas are defined in Figure 7-1.

Source: Reference 1

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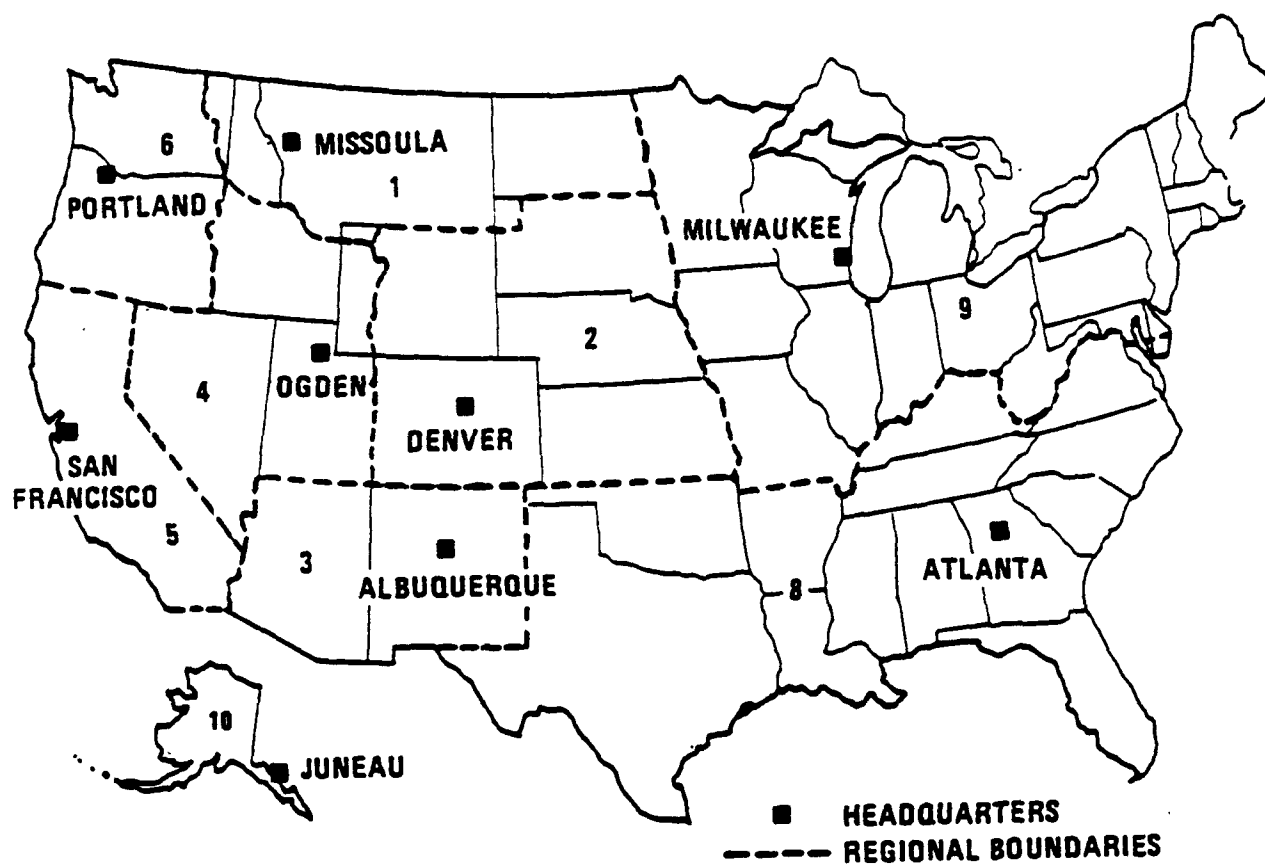


Figure 7-1 Forest Area and U.S. Forest Service Regions

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the potential fire hazard in forests and to remove brush that can serve as host for destructive insects. As with forest fires, NEDS provides data on the acreage and tons of growth burned per acre, and the estimated VOC emissions. If NEDS data are not used, Officials of the U.S. Forest Service or the state forestry department can be contacted for estimates of the area burned and quantity of slash burned per acre. If an estimate of the quantity of slash burned per acre cannot be obtained from other sources, a rough value of 75 tons per acre can be used.

Also included in this source category are agricultural field burning operations such as stubble burning and burning of land-clearing refuse. Little published information is available on this subject, so burning activity estimates must be determined through state agriculture departments or extension services.

Acreage and average fuel loadings should be estimated. The U.S. Soil Conservation Service should be able to provide some of this information. Average fuel loadings and organic emission factors for various wastes are provided in Section 2.4 of Reference 1. In some cases, agricultural burning may be reported under residential open burning.

#### 7.4 Example Calculations

##### Example Calculation 1

By assuming that a wildfire in a county located in the Pacific Northwest consumes 1,735 hectares, one can estimate the quantity of Benzo[a]anthracene (BaA) emitted. Using Table 7-1, the total quantity emitted can be calculated as follows:

$$\begin{aligned} \text{Total BaA} &= \frac{3.1 \times 10^{-3} \text{ kg BaA}}{\text{MT dry fuel}} \times 1,735 \text{ hectares} \times \frac{60 \text{ MT fuel}^*}{\text{hectare}} \\ \text{Total BaA} &= 3.2 \times 10^2 \text{ kg BaA emitted.} \end{aligned}$$

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\* From Table 7-4

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In a similar manner, emissions can be estimated for the other pollutants shown in Table 7-1, as follows:

Anthracene	260 kg = 0.3 MT
Benzo(a)fluoranthene	135 kg = 0.1 MT
Benzo(k)fluoranthene	135 kg = 0.1 MT
Benzo(ghi)perylene	229 kg = 0.2 MT
Benzo(a)pyrene	770 kg = 0.8 MT
Chrysene	323 kg = 0.3 MT
Fluoranthene	572 kg = 0.6 MT
Indeno(1,2,3-cd)Pyrene	177 kg = 0.2 MT
Phenanthrene	260 kg = 0.3 MT
Pyrene	479 kg = 0.5 MT

Example Calculation 2

NEDS reports that a wildfire in a county in Alaska produces 1,208 tons of VOC emissions annually; one can estimate the quantity of 1,3-butadiene using the speciation factor provided in Table 7-2.

$$\begin{aligned}\text{Total 1,3-Butadiene} &= (1208 \text{ tons/yr}) (907 \text{ kg/ton}) (0.0052 \text{ kg/kg of VOC})^* \\ &= 5.7\end{aligned}$$

In a similar manner, emissions can be estimated for the other pollutants in cited Table 7-2, as follows:

Isomers of pentane	$1.6 \times 10^3$ kg
Propane	$3.8 \times 10^3$ kg
N-Butane	$2.6 \times 10^3$ kg
Isobutane	$1.2 \times 10^3$ kg
Isomers of butene	$1.0 \times 10^4$ kg
Ethylene	$2.1 \times 10^5$ kg
Propylene	$4.3 \times 10^4$ kg
Butene	$8.9 \times 10^3$ kg

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\* From Table 7-2.

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3-Methyl-1-butene	$1.9 \times 10^3$ kg
Acetylene	$9.2 \times 10^4$ kg
Methy acetylene	$4.5 \times 10^3$ kg
Methane	$1.1 \times 10^5$ kg
Ethane	$1.2 \times 10^5$ kg
Unidentified hydrocarbons	$4.9 \times 10^5$ kg

7.5 Methods to Apportion Countywide Emissions from Forest Fires and Agricultural Burning

As described in Section 1.0 and Appendix A when performing air dispersion modeling, it is generally recommended that countywide emissions be distributed within the study area into rectangular area source grid cells reflecting spatial variations in factored into the modeling to reflect seasonal or diurnal fluctuations in emissions. Modeling results would then reflect on-going activities in that portion of the county, e.g., residential heating in the winter, commercial solvent usage during working hours on weekdays.

There are three alternative approaches that can be used in spatially distributing emission: (1) population, i.e., the magnitude of emissions within a grid are directly proportional to the population living in the grid, (2) land area, i.e., emissions from a countywide area source are assumed to be uniform throughout the county and are distributed based on the size of the area source grid, and (3) land use patterns that assume that certain area source activities, most likely to occur in certain areas of the county, e.g., commercial, residential or industrial.

In apportioning emissions from agricultural burning, and of these methods may be appropriate. Land area and population data can be readily obtained, and applied as described in Appendix A. Land use data, available from the U.S. Geological Survey and other sources can be used

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in combination with the spatial distribution for agricultural burning, to distribute emissions based on the type of activity being performed, as shown in Table 7-5.

Seasonal, daily, and hour temporal resolution are also included in Table 7-5, and can be used with the annual countywide emissions data to estimate temporal variations.

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 7-5 Spatial and Temporal Resolutions  
for Agricultural Burning

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## Spatial Resolution

Surrogate indicator:	areas where these activities occur
Information source(s):	U.S. Forest Service, state forestry departments, state agricultural department, extension services, citrus grove operations, and land use map

## Temporal Resolution

Seasonal, and Daily:	Base on local regulations and on data collected from information sources.
Hourly:	N/A

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REFERENCES

1. U.S. Environmental Protection Agency. Compilation of Air Pollution Emission Factors. Volume I: Stationary Point and Area Sources (AP-42) Fourth Edition. EPA-460/3-81-005. Office of Air Quality Planning and Standards. Research Triangle Park, NC. 1985.
2. U.S. Environmental Protection Agency. Volatile Organic Compound (VOC) Species Data Manual. Second Edition. EPA-450/3-81-005. Office of Air Quality Planning and Standards. Research Triangle Park, NC. 1980.
3. U.S. Department of Agriculture, Forest Service. Wildfire Statistics (Annual). Washington, DC.
4. Arthur D. Little, Inc. An Exposure and Risk Assessment for Benzo[a]pyrene and Other Polycyclic Aromatic Hydrocarbons, Volume IV, Benzo[a]pyrene, Acenaphthylene, Benz[a]anthracene, Benzo[b]fluoranthene, Benzo[b]fluoranthene, Benzo[k]fluoranthene, Benzo[g,h,i]perylene, Chrysene, Dibenz[a,h]anthracene, and Ideno[1,2,3-c,d]pyrene. U.S. EPA Contract No. 68-01-6160. U.S. Environmental Protection Agency, Office of Water Regulations and Standards. Washington, D.C. 1982.
5. U.S. Environmental Protection Agency. Guidelines for the Preparation of Emission Inventories for Volatile Organic Compounds Volume II: Emission Inventory Requirements for Photochemical Air Quality Simulation Models. EPA-450/4-78-018. U.S. Office of Air Quality Planning and Standards. Research Triangle Park, NC. September 1979.



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8. GASOLINE SERVICE STATIONS (GASOLINE MARKETING)

8.1 General

Air toxics are emitted from gasoline stations as a result of (1) underground storage tank filling, (2) underground storage tank breathing, and (3) vehicle refueling. The quantity of gasoline vapor released from each of these sources is affected by the method and rate of tank filling, tank geometry, and quantity of gasoline added. The amount of any one toxic chemical released with the vapor depends on such factors as the initial concentration of the chemical in the gasoline, the vapor-liquid equilibrium of the system, and the temperature within the tank.

Gasoline is generally transported to retail sales outlets in 8,000-gallon tank trucks. When these trucks unload the gasoline into underground storage tanks, gasoline vapor in the storage tank is displaced by the liquid gasoline and vented to the atmosphere. The underground storage tank may be filled by either a splash or a submerged method.

With the splash filling method, the fill pipe ends above the level of the gasoline in the tank so that, as gasoline enters the tank, it splashes into the liquid already in the tank, causing turbulent mixing and additional vaporization of volatiles. The displaced vapors are then lost through the hatch.

Submerged filling lessens the amount of vaporization because the fill pipe extends below the liquid level. Although this method avoids the turbulent splattering of the splash method, emissions of displaced vapors are still not controlled.

One control method that avoids this problem is a vapor balance system

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wherein gasoline vapors are returned to the tank truck and the underground tank is equipped with a pressure relief vent. This method of submerged filling is 93 to 100 percent efficient at controlling vapor emissions.

In 1980, an estimated 70 to 95 percent of the service stations used submerged filling techniques, with the balance using splash filling. Only a very small number used the vapor balance method. Recent trends show a move toward submerged and vapor balanced methods and away from the splash technique. Current local data on the filling techniques and control methods should be used whenever possible.

Underground storage tank breathing losses result from daily changes in temperature and barometric pressure, which change the vapor-liquid equilibrium of the system and cause expansion and contraction of the vapors. Expansion forces vapors out of the tank and into the atmosphere. When the vapor in the tank contracts, however, fresh air is drawn into the tank, and volatilization increases until equilibrium is again reached. This cycle repeats with daily environmental changes. The quantity of fresh air introduced into the tank when gasoline is withdrawn also increases the amount of evaporation and, thus, breathing losses.

Vehicle refueling also results in the emission of vapors to the atmosphere because the vapors present in the automobile gas tank are displaced by gasoline and because gasoline spilled during refueling evaporates. Emissions of displaced vapors can be controlled by conveying the displaced vapors back to the underground storage tank through a specially-designed hose and nozzle. This conveyance can either be caused by a natural pressure differential established during gasoline transfer (as with the vapor balanced storage tank fill method) or by a vacuum-assisted method.<sup>1</sup>

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8.2 Factors

Emission factors relating the quantity of benzene, 1,2-dichloroethane, (ethylene dichloride), and ethylene dibromide (EDB) released from sources within gasoline service stations to the volume of gasoline flowing through the system are presented in Table 8-1. In this table apportionment factors have been applied, where appropriate, to the estimated quantity of gasoline vapors emitted from each source. In order for these factors to be useful, the quantity of gasoline flowing through the system must be known. This quantity can be approximated by using the quantity of gasoline sold within a given study area, as provided in NEDS or other data sources.

Estimates of VOC emissions can be speciated using factors being developed by OAQPS.<sup>2</sup> The speciation profile for gasoline marketing is presented in Table 8-2. It should be noted that the benzene speciation factor is approximately five times greater in Reference 2 than it is in Reference 1; this discrepancy is probably at least in part attributable to the large variation in gasoline compositions.

8.3 Methodology Options

As noted earlier, NEDS contains data on the quantities of gasoline marketed in a county (as well as estimated VOC emissions). In most cases, these data are considered to be adequate. However, if NEDS estimates are believed to be out of date, or unreliable for other reasons, the quantities of gasoline sold in a study area can be estimated using one of several methods described below (in order of preference):

Distributor Data. Data from the gasoline distributor provide the most accurate source of gasoline use figures because they are based on the actual quantity of gasoline passing through the system rather than on the amount sold. Unfortunately, these data are not usually available for all areas of the country.<sup>3</sup>

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 8-1 Selected Air Toxic Emissions from Gasoline Stations<sup>a</sup>

Emission source	Benzene emissions (g/l) <sup>b</sup> (lb/gal)	Ethylene dichloride emissions (g/l) <sup>c</sup> (lb/gal)	Ethylene dibromide emissions (g/l) (lb/gal)
Filling Underground Storage Tanks			
Submerged	$5.28 \times 10^{-3}$ ( $4.4 \times 10^{-5}$ )	$4.4 \times 10^{-4}$ ( $3.7 \times 10^{-6}$ )	$4.4 \times 10^{-5}$ ( $3.7 \times 10^{-7}$ )
Splash	$8.28 \times 10^{-3}$ ( $6.9 \times 10^{-5}$ )	$6.9 \times 10^{-4}$ ( $5.8 \times 10^{-6}$ )	$6.9 \times 10^{-5}$ ( $5.8 \times 10^{-7}$ )
Vapor balance (submerged)	$2.4 \times 10^{-4}$ ( $2.0 \times 10^{-6}$ )	$2.0 \times 10^{-5}$ ( $1.7 \times 10^{-7}$ )	$2.0 \times 10^{-6}$ ( $1.7 \times 10^{-8}$ )
Breathing Losses	$7.2 \times 10^{-4}$ ( $6.0 \times 10^{-6}$ )	$6.0 \times 10^{-5}$ ( $5.0 \times 10^{-3}$ )	$6.0 \times 10^{-6}$ ( $5.0 \times 10^{-8}$ )
Vehicle Refueling			
Uncontrolled displacement	$7.92 \times 10^{-3}$ ( $6.6 \times 10^{-5}$ )	$6.6 \times 10^{-4}$ ( $5.5 \times 10^{-6}$ )	$6.6 \times 10^{-5}$ ( $5.5 \times 10^{-7}$ )
Controlled displacement	$7.92 \times 10^{-4}$ ( $6.6 \times 10^{-6}$ )	$6.6 \times 10^{-5}$ ( $5.5 \times 10^{-3}$ )	$6.6 \times 10^{-6}$ ( $5.5 \times 10^{-8}$ )
Spillage	$4.8 \times 10^{-4}$ ( $4.0 \times 10^{-6}$ )	$4.0 \times 10^{-5}$ ( $3.3 \times 10^{-3}$ )	$4.0 \times 10^{-6}$ ( $3.3 \times 10^{-8}$ )

<sup>a</sup>Emission factors given in units of grams of toxic vapor released per liter of gasoline passing through the system.

<sup>b</sup>Based on the apportionment factor,  $6.0 \times 10^{-3}$  MT benzene/MT VOC (Reference 1 in conjunction with emission factors from AP-42. (Reference 4)

<sup>c</sup>Based on the apportionment factor,  $5.0 \times 10^{-4}$  MT ethylene dichloride/MT VOC (Reference 1), in conjunction with emission factors from AP-42. (Reference 4)

<sup>d</sup>Based on the apportionment factor,  $5.0 \times 10^{-5}$  MT ethylene dibromide/MT VOC (Reference 1), in conjunction with emission factors from AP-42. (Reference 4)

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 8-2 VOC Speciation Factors for Gasoline Marketing

Species Name	Percent Weight
Isomers of Hexane	0.10
Isomers of Decane	0.10
Isomers of Undecane	0.09
Isomers of Undecane	0.00
Isomers of Dodecane	0.00
Isomers of Dodecane	0.05
Isomers of Tetradecane	0.02
C-7 Cycloparaffins	0.05
C9 Olefins	0.08
C9 Olefins	0.01
C9 Olefins	0.01
C9 Olefins	0.00
C10 Olefins	0.04
C10 Olefins	0.00
C10 Paraffin	0.00
C10 Paraffin	0.00
C10 Paraffin	0.00
C9 Paraffin	0.48
C-8 Olefins	0.00
C-8 Olefins	0.21
C8 Paraffin	3.84
C7 Paraffin	0.04
C5 Olefin	1.91
C5 Paraffin	2.09
C5 Paraffin/Olefin	1.08
C11 Olefin	0.00
C11 Olefin	0.01
C11 Olefin	0.04
C9H16	0.00
C9H16	0.02
C9H16	0.00
C8H14	0.00
Butene	0.14
Hexane	3.91
Heptane	1.84
Cyclopentane	0.16
Methylcyclohexane	0.21
Methylcyclopentane	0.68
Heptene	0.03
Methylcyclopentene	0.45

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 8-2 (Continued)

Species Name	Percent Weight
Cyclohexene	0.04
Ethylcyclohexane	0.08
Cyclopentene	0.18
C7H12O	0.04
Dimethylcyclobutanone	0.05
Isomers of Butylbenzene	3.18
Isomers of Diethylbenzene	0.03
Isomers of Diethylbenzene	0.02
Trimethylbenzene	4.29
Isomers of Propylbenzene	0.76
C10H12	0.04
C10H10	0.00
C10H10	0.00
Benzene	3.25
Toluene	15.22
Ethylbenzene	4.07
O-Xylene	6.41
Cumene (Isopropyl Benzene)	0.33
Styrene	0.17
Methyl Styrene	0.05
Ethyltoluene	3.61
Propylbenzene	0.92
Ethyl dimethylbenzene	1.24
Tetramethylbenzene	1.03
C5-Alkylbenzene	0.35
C5-Alkylbenzene	0.02
C5-Alkylbenzene	0.04
C5-Alkylbenzene	0.05
C5-Alkylbenzene	0.83
C5-Alkylbenzene	0.05
C5-Alkylbenzene	0.09
C5-Alkylbenzene (Unsat.)	0.05
C6-Alkylbenzene	0.00
C6-Alkylbenzene	0.06
C6-Alkylbenzene	0.00
C6-Alkylbenzene	0.03
C6-Alkylbenzene	0.02
C6-Alkylbenzene	0.00
C4-Alkylstyrene	0.04
C4-Alkylstyrene	0.02
C4-Alkylstyrene	0.00
C4-Alkylstyrene	0.01

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 8-2 (Continued)

Species Name	Percent Weight
C7-Alkylbenzene	0.00
Benzaldehyde	0.00
Chlorobenzene	0.03
Dimethylnaphthyridine	0.01
Napthalene	0.80
Methyl Naphthalenes	0.64
C2-Alkylnapthalene	0.10
Methylindan	0.01
Methylindan	0.52
Methylindan	0.00
Methyldihydronapthalene	0.01
Dimethylindan	0.00
Dimethylindan	0.42
Dimethylindan	0.00
Dihydronapthalene	0.06
Dimethylindene	0.01
Ethylindan	0.04
Trimethylindan	0.06
M-Xylene and P-Xylene	15.28
Methylpropane	2.65
Methylpropene	0.14
Methylbutene	0.06
Methylbutadiene	0.01
Methylpentene	0.48
Methylpentene	0.41
Methylpentane	1.76
Methylcyclopentadiene	0.04
Methylhexane	1.68
Methylhexene	0.00
Methylhexene	0.03
Methylhexadiene	0.25
Methylcyclohexadiene	0.02
Methylhexanal	0.92
Methylheptyne	0.02
Methylheptane	0.35
Methylcyclohexene	0.14
Methylnonane	0.21
Methyldecane	0.12
Pentenyne	0.03
Hexene	0.40

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Table 8-2 (Continued)

Species Name	Percent Weight
Hexadienal	0.03
Heptadienal	0.02
Dimethylbutane	2.29
Dimethylbutene	0.30
Dimethylpentane	0.36
Dimethylpentene	0.02
Dimethylcyclopentane	0.15
Dimethylcyclopentene	0.22
Dimethylcyclopentene	0.09
Dimethylhexane	0.48
Dimethylhexane	0.28
Dimethylhexadiene	0.10
Dimethylethylcyclohexane	0.09
Dimethyloctane	0.04
Dimethyloctane	0.02
Dimethylundecane	0.00
Dimethyldecane	0.07
Ethylpentene	0.03
Ethylcyclopentene	0.06
Ethylmethylcyclopentane	0.12
Ethylhexane	0.24
Ethylmethylhexane	0.21
Ethylmethylcyclohexane	0.04
Ethylmethylcyclohexane	0.02
Ethylheptane	0.02
Ethylmethyloctane	0.02
Ethylbicycloheptane	0.01
Ethyltrimethylpentane	0.13
Tetramethylcyclobutene	0.04
Trimethylpentane	0.68
Trimethylpentadiene	0.05
Trimethylheptane	0.09
Trimethylheptane	0.05
Trimethylhexene	0.04
Trimethyloctane	0.07
Trimethyldecane	0.03
Octatriene	0.01
Nonene	0.03
Pentadiene	0.04
Methyloctane	0.55
Indane	0.44



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Table 8-2 (Continued)

Species Name	Percent Weight
Trimethylcyclopentane	0.09
Dimethylcyclohexane	0.10
Trimethylcyclohexane	0.02
Dimethylheptane	0.16
Unidentified	0.00

Source: Reference 2

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Fuel Tax Data. Fuel tax data, on the other hand, are readily available through state fuel tax offices. These data provide tax statistics for local political jurisdictions. Therefore, because tax is collected for each gallon sold, gasoline consumption can be back-calculated with the tax formulas from each jurisdiction. Care must be taken, however, that the local jurisdictions of interest have comparable tax bases. For instance, gasoline sold to government agencies, or for nonhighway use, may not be taxed in one jurisdiction, but may be taxed in another.<sup>3</sup>

Questionnaires. If the area sources of interest do not correspond directly with a local tax area, and if the sources are relatively few in number, direct questionnaires concerning gasoline volumes distributed may be useful. An example of a situation for which this method may be helpful is if the investigator is concerned only with emissions resulting from gasoline sales by convenience stores within a three-county area. Advantages of this type of data include the accuracy of the results and the flexibility to ask particular questions, such as emission control practices and number of employees. Obvious administrative and analytical difficulties limit the usefulness of this data source.

Publications. National publications also provide data on gasoline consumption and sales. The Federal Highway Authority publishes Highway Statistics,<sup>5</sup> containing state consumption data. These state data can be apportioned to local areas if the percent of state gasoline sales occurring within each jurisdiction can be determined. Other apportionment factors such as vehicle miles traveled, registered vehicles, or population within the local jurisdiction, can be used if

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they are more appropriate for a particular area. Countywide gasoline sales data are available in the Census of Retail Trade.<sup>3,6,7</sup>

8.4      Example Calculation

Analysis of fuel tax data for the county of concern showed that  $2.78 \times 10^9$  liters of gasoline were sold in that county in 1986. It was also determined that approximately 90 percent of the stations were equipped for submerged fueling of underground storage tanks, 5 percent used splash filling techniques, and 5 percent used a vapor balanced technique. In addition, only 10 percent of the stations were equipped with pump nozzles that controlled refueling losses. Benzene emissions from gasoline service stations in this county can be estimated as follows, based on emission factors provided in Table 8-1.

(1) Filling of underground storage tanks

(a) Submerged

$$\begin{aligned} & (5.28 \times 10^{-3} \text{ grams of benzene/liter}) \times (2.78 \times 10^9 \text{ liters}) \\ & \times 0.90 \\ & = 1.32 \times 10^7 \text{ grams of benzene/year} \end{aligned}$$

(b) Splash

$$\begin{aligned} & (8.28 \times 10^{-3}) \times (2.78 \times 10^9) \times 0.05 \\ & = 1.15 \times 10^6 \text{ grams of benzene/year} \end{aligned}$$

(c) Vapor Balanced

$$\begin{aligned} & (2.4 \times 10^{-4}) \times (2.78 \times 10^9) \times 0.05 \\ & = 3.34 \times 10^4 \text{ grams of benzene/year} \end{aligned}$$

(2) Breathing losses

$$(7.2 \times 10^{-4}) \times (2.78 \times 10^9)$$

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$$= 2.00 \times 10^6 \text{ grams of benzene/year}$$

(3) Vehicle refueling

(a) Uncontrolled

$$(7.92 \times 10^{-3}) \times (2.78 \times 10^9) \times 0.90$$

$$= 1.98 \times 10^7 \text{ grams of benzene/year}$$

(b) Controlled

$$(7.92 \times 10^{-4}) \times (2.78 \times 10^9) \times 0.10$$

$$= 1.98 \times 10^6 \text{ grams of benzene/year}$$

(4) Spillage

$$(4.8 \times 10^{-4}) \times (2.78 \times 10^9)$$

$$= 1.33 \times 10^6 \text{ grams of benzene/year.}$$

The total countywide emissions of benzene from gasoline service stations can be estimated by summing the component emissions as shown:

$$(1.32 \times 10^7) + (1.15 \times 10^6) + (3.34 \times 10^4) + (2.00 \times 10^6) + (1.98 \times 10^7) + (1.98 \times 10^6) + (1.33 \times 10^6)$$

$$= 3.95 \times 10^7 \text{ grams of benzene/year}$$

$$= 39.5 \text{ MT benzene/year.}$$

Similarly, emissions of 1,2 dichloroethane are estimated to be 3.3 MT/yr, and emissions of ethylene dibromide are estimated to be 0.3 MT/yr.

8.5 Methods to Apportion Countywide Emissions from Gasoline Marketing

As described in Section 1.0 and Appendix A when performing air dispersion modeling, it is generally recommended that countywide emissions be distributed within the study area into rectangular area source grid cells reflecting spatial variations in activity and emissions. Similarly temporal in activities can be factored into the modeling to reflect seasonal or diurnal fluctuations in emissions.

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Modeling results would then reflect on-going activities in that portion of the county, e.g., residential heating in winter, commercial solvent usage during working hours on weekdays.

There are three alternative approaches that can be used in spatially distributing emission: (1) population, i.e., the magnitude of emissions within a grid, (2) land area, i.e., emissions from a countywide area source are assumed to be uniform throughout the county and are distributed based on the size of the area source grid, and (3) land use patterns, assume that certain area source activities, most likely occur in certain areas of the county, e.g., commercial, residential or industrial.

In apportioning emissions from gasoline marketing, any of these methods may be appropriate. Land area and population data can be readily obtained, and applied as described in Appendix A. Land use data, available from the U.S. Geological Survey and other sources can be used in combination with the spatial resolution for gasoline marketing, to distribute emissions based on the type of activity being performed, as shown in Table 8-3.

Estimated seasonal, daily, and hourly temporal resolution for gasoline marketing are also included in Table 8-3, and can be used with the annual countywide emissions data to estimate temporal variations.

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table 8-3 Spatial and Temporal Resolutions  
for Gasoline Marketing<sup>8</sup>

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## Spatial Resolution

Surrogate indicator:	Industrial and commercial/institutional land use areas (Codes 12, 13, and 15)
Information source(s):	land use map and Reference 14

## Temporal Resolution

Seasonal:	uniform through the year
Daily:	Monday through Saturday
Hourly:	uniform from 0600 to 2000, otherwise zero

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9. CHROMIUM ELECTROPLATING

9.1 General

The chromium electroplating source category includes two distinct types of plating operations: hard and decorative. In hard plating, the substrate (usually steel) is plated with a relatively thick layer of chromium to provide wear resistance, low coefficient of friction, hardness, and corrosion resistance or to build up surfaces that have been eroded by use. Hard plating is used for items such as hydraulic cylinders and rods, industrial rolls, zinc die castings, plastic molds, engine components, and marine hardware. In decorative plating, the substrate (e.g., brass, steel, aluminum, or plastic) is plated with a layer of nickel followed by a relatively thin layer of chromium to provide a bright, tarnish-resistant surface. Decorative plating is used for items such as automotive trim, metal furniture, bicycles, hand tools, and plumbing fixtures. Although other types of operations performed at electroplating plants involve chromium in some form, this source category includes only those processes that use chromic acid in an electrolytic cell to deposit chromium metal on a product.

There are approximately 4,500<sup>1</sup> chromium electroplating operations in the country. Chromium electroplating is used in the manufacture of a wide variety of industrial and consumer items. In general, chromium plating operations are located at or near the industries they service, which are usually in centers of high population density. Plating operations range in size from small shops operating one tank for as few as 15 hours per week to large shops operating several tanks for as many as 130 hours per week. Most plating operations are "captive" processes performed within larger manufacturing facilities. Some operations are "job shops" that provide custom plating services for many different clients. Captive platers and job shops may perform either hard plating, decorative plating, or both.



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The actual chromium plating process is similar for hard and decorative plating, although pretreatment processes and operating parameters may differ somewhat. The plating process involves dipping the item to be plated in a tank containing chromic acid solution and a small amount of sulfuric acid as a catalyst. Electric current passed through the lead anodes causes chromium to deposit out of solution onto the substrate, which acts as the cathode. (In the case of plating a plastic substrate, the pretreatment process includes steps to render the surface conductive so that it can act as the electrical cathode.)

The chromium plating process is inefficient. Only 10 to 20 percent of the electric current supplied to the anodes is used to deposit chromium onto the item; the rest produces chemical reactions that generate hydrogen gas at the surface of the cathodes and oxygen gas at the surface of the anodes. Efficiency can be improved in some situations by using fluoride rather than sulfuric acid as the catalyst in the plating solution. Fluoride cannot be used in all types of plating solutions, however, and may cause "etching" or "burning" of exposed steel surfaces if used in hard plating solutions.

### 9.2 Factors

Hexavalent chromium is emitted during the chromium electroplating process. It can be seen as a yellow mist that is formed when hydrogen gas is released through the surface of the plating solution. Additionally, oxygen bubble formation and plating bath evaporation contribute to chromium emissions; however, their contribution is negligible when compared to emissions related to hydrogen gas generation.

The amount of mist generated and consequently the amount of hexavalent chromium emitted depends on several factors: (1) the magnitude of the current supplied to the anodes, (2) the surface area plated, (3) the duration of electrolysis, (4) the quantity of chromic

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acid consumed, and (5) the efficiency of any mist control systems. Emissions factors that can be used to estimate the quantity of hexavalent chromium emitted from uncontrolled hard and decorative plating operations are presented in Table 9-1. These factors were derived from EPA source tests conducted in Greenville, South Carolina, and Sterling Heights, Michigan.

9.3 Methodology Options

A reasonable method of estimating chromium emissions is based on population density, because chromium electroplating operations are used by many different industries and are usually located in centers of high population density. According to OAQPS 147,000 kg of hexavalent chromium are emitted by electroplaters. This estimate of 147,000 kg/yr of  $\text{Cr}^6$  was calculated by OAQPS based on the emission factors provided in Table 9-1, and assumed that hard platers had the following levels of control: scrubber (40%), fume suppressant (15%), mist eliminator (15%) and uncontrolled (30%). Decorative platers were assumed to have the following levels of controls: scrubbers (35%), fume suppressant (50%), and uncontrolled (15%). It was also assumed that scrubbers are 95 percent effective in reducing  $\text{Cr}^6$  emissions; mist eliminators are 85 percent effective; and fume suppressant, 90 percent effective.

Based on the United States population of  $2.265 \times 10^5$  thousand persons, the per capita quantity of chromium emitted annually can be calculated at  $6.5 \times 10^{-1}$  kg  $\text{Cr}^6$ /1000 persons ( $1.4 \times 10^{-1}$  lb  $\text{Cr}^6$ /1,000 persons). The population of a given county can be obtained from U.S. Census data and multiplied by this per capita emission factor to estimate the amount of  $\text{Cr}^6$  emitted from plating operations in the county.

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Table 9-1 Uncontrolled Emission Factors Used to Estimate  
Emissions from Chromium Electroplating Operations

Type of operation	mg/Cr <sup>6</sup> /ampere hour	Basis
Hard	10	EPA source test at Carolina Plating--Roll Division plant in Greenville, South Carolina.
Decorative	2	EPA source test at C. S. Ohm Manufacturing Company plant in Sterling Heights, Michigan.

<sup>a</sup>Based on the assumption that the fume suppressant used during the test controlled 80 percent of the misting.

Source: Reference 2.

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9.4 Example Calculation

Given that a county has 33,345 residents, the chromium emission can be estimated as follows:

$$\begin{aligned}\text{Chromium emitted} &= 33.345 \text{ (thousand persons)} \times 1.4 \text{ lb of Cr}^{+6}/1000 \text{ persons} \\ &= 46.7 \text{ lb Cr}^{+6} \text{ emitted annually.}\end{aligned}$$

9.5 Methods to Apportion Countywide Emissions from Chromium Electroplating

As described in Section 1.0 and Appendix A when performing air dispersion modeling, it is generally recommended that countywide emissions be distributed within the study area into rectangular area source grid cells reflecting spatial variations in activity and emissions. Similarly temporal in activities can be factored into the modeling to reflect seasonal or diurnal fluctuations in emissions. Modeling results would then reflect on-going activities in that portion of the county, e.g., residential heating in the winter, commercial solvent usage during working hours on weekdays.

There are three alternative approaches that can be used in spatially distributing emission: (1) population, i.e., the magnitude of emissions within a grid are directly proportional to the population living in the grid, (2) land area, i.e., emissions from a countywide area source are assumed to be uniform throughout the county and are distributed based on the size of the area source grid, and (3) land use patterns, that assume that certain area source activities, most likely occur in certain areas of the county, e.g., commercial, residential or industrial.

In apportioning emissions from chromium electroplaters any of these methods may be appropriate. Land area and population data can be readily obtained, and applied as described in Appendix A. Land use data,

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available from the U.S. Geological Survey and other sources can be used in combination with the spatial resolution for chromium electroplaters, to distribute emissions based on the type of activity being performed, as shown in Table 9-2.

Estimated seasonal, daily and hourly temporal resolution for chromium electroplaters are also included in Table 9-2, and can be used with the countywide emissions data to estimate temporal variations.

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Table 9-2 Spatial and Temporal Resolution  
for Chromium Electroplaters

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## Spatial Resolution

Surrogate indicator:	commercial and industrial areas (codes 12, 13, and 15)
Information source(s):	land use maps

## Temporal Resolution:

Seasonal:	uniform through the year
Daily:	95 percent Monday through Friday, 5 percent Saturday
Hourly:	80 percent from 0700 to 1900, 20 percent from 1900 to 2400, otherwise zero

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10. HOSPITAL AND LABORATORY STERILIZERS

10.1 General

Ethylene oxide (EO) is a highly toxic compound that is widely used as a fumigant and sterilant. It has been estimated that there are 7,000 potential emitters and that U.S. hospitals alone emitted 400 to 450 metric tons of EO in 1976.<sup>1,2</sup> Research laboratories emitted an additional 275 to 444 metric tons.<sup>2</sup> Types of equipment that use ethylene oxide include vacuum chambers, atmospheric chambers, ampule/liner bags, and sterijet systems.

Vacuum chambers are pressure vessels, each with a vacuum pump that removes air from the chamber prior to sterilization and removes the EO/air mixture after sterilization. Units vary in size and design. For example, small countertop models are primarily used in health care and diagnostic facilities. Generally, these models have capacities of less than 0.1 m<sup>3</sup>. In hospitals, these units can be used in operating rooms. The EO is supplied to the unit by single dose cartridges or pressurized cylinders. Emissions occur when the EO is vented through a length of tubing directly to the atmosphere.<sup>2</sup>

Chambers from 0.1 m<sup>3</sup> to 2.8 m<sup>3</sup> are used primarily in hospital central supply facilities. Ethylene oxide is provided from pressurized cylinders. Emissions occur when the chamber is vented directly to the atmosphere. Also, emissions may be mixed with water and routed to a sewer drain.<sup>2</sup>

Since atmospheric chambers do not evacuate air before treatment, a longer sterilization time is usually required. Ethylene oxide is supplied as a gas mixture in a cartridge, and emissions occur when the units vent their contents directly into the workplace. Other units reduce emissions by manually pumping the chamber contents through a charcoal adsorbent.<sup>2</sup>



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Ampule/liner bags contribute to EO emissions. In this method, the article to be sterilized and a broken ampule of 100 percent EO are placed in a plastic liner bag. The bag is sealed and the EO escapes slowly into the atmosphere.<sup>2</sup>

The sterijet system is used in hospitals and is similar to the ampule/liner bag method. In this system the article to be sterilized is placed in a pouch. It is attached to a gas delivery nozzle that draws a slight vacuum on the pouch and then injects a premeasured amount of EO mixture. The pouch is heat sealed, and emissions to the atmosphere occur as EO diffuses through the pouch.<sup>2</sup>

Other important emitters of EO are research laboratories. It has been estimated that in 1976, research laboratories used between 275 and 444 metric tons of EO for sterilization.<sup>2</sup> Emissions would result as previously discussed for hospitals.

### 10.2 Emission Factors

Whenever possible, emissions of ethylene oxide from sterilizers should be treated as a point source. Many of the emission factors and procedures that are described in this section can be applied to a single laboratory or hospital. When activity coefficients are available on a point source basis, the preferred approach is to treat the source as a point source, rather than an area source. When facility-specific data are unavailable, the source can be incorporated into the area source inventory.

Hospitals. Emission factors for estimating ethylene oxide emissions from hospitals were developed based on the results of a study by Midwest Research Institute (MRI) to estimate chlorinated fluorocarbon (CFC) emissions that resulted from sterilization procedures at

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hospitals. Often, these sterilization processes use a mixture of 88 percent dichlorodifluoromethane (Freon<sup>®</sup>) and 12 percent ethylene oxide (EO). This mixture is referred to as "12/88."

MRI estimated Freon<sup>®</sup> emissions program to evaluate nationwide ethylene oxide emissions. Based on their findings, 12/88 hospital usage was divided into three categories:

(1) large hospitals (>500 beds), (2) medium hospitals (200 to 500 beds), and (3) small hospitals (<200 beds). Hospitals do not emit sterilant at the same rate, and a linear regression analysis indicated that for the data from the Section 114 responses, 12/88 emissions are most closely related to the number of beds at the hospital. The following ethylene oxide emission factors are presented on a per bed basis:

- |                   |                |
|-------------------|----------------|
| • Large hospital  | 1.8 lb/bed/yr  |
| • Medium hospital | 1.3 lb/bed/yr  |
| • Small hospital  | 1.7 lb/bed/yr. |

An alternative method of estimating ethylene oxide emissions uses a countywide per capita emission factor. Assuming that 425 metric tons of ethylene oxide are emitted nationally, and that there is a national population of  $2.265 \times 10^8$  people<sup>3</sup>, it is estimated that ethylene oxide is emitted from hospitals at an annual per capita rate of 1.9 kg/1000 persons (4.2 lb/1000 persons).

Research Laboratories. As noted, research laboratories used 275 to 444 metric tons of ethylene oxide for sterilization in 1976.<sup>2</sup> It may be difficult to determine the number of individual laboratories in a given county or city because they generally constitute a smaller operation in a large company or institution. For example, a pharmaceutical manufacturer may have a research laboratory associated with its production facilities, and a teaching hospital can have extensive research laboratory facilities.

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10.3 Methodology Options

Hospital Emissions. To estimate area source emissions of ethylene oxide resulting from hospital sterilization, the following steps are recommended:

- (1) Determine the number of hospitals in each county, and the number of beds in each hospital. This information can be located in the American Hospital Association Guide to the Health Care Field.<sup>4</sup>
- (2)(a) Estimate the annual quantity of ethylene oxide emitted by multiplying the emission factors times the number of beds in each hospital, or
- (b) Survey the individual hospitals in the receptor area to determine the amount of ethylene oxide that was purchased and used. Conservatively, it can be assumed that all EO used is emitted to the atmosphere. Emissions from hospitals could be treated as an area source and summed. Emissions from large hospitals can be treated as point sources for modeling purposes, if so desired.

Laboratory Emissions. Laboratories tend to be located in urban areas of high population density; a reasonable method of estimating area source emissions from these facilities is to use a per capita emissions factor.

Assuming a median value of 360 Mg of EO is consumed and emitted annually by research laboratories, and a national population of  $2.265 \times 10^5$  thousand persons, an annual emission factor can be calculated to be 1.6 kg/1000 persons/yr (3.5 lb/1000 persons).<sup>2,4</sup>

County and city population data can be obtained from the U.S. Bureau of Census. The population of a particular county or city can then be multiplied by the per capita emission factor to estimate a countywide emission of ethylene oxide from laboratories.

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10.4     Example Calculations

Example Calculation 1

EO emissions from hospitals are calculated as follows.

The study area has five hospitals. One is a large facility with 530 beds and a 75 percent annual occupancy. Another is a medium-sized facility of 450 beds and a 70 percent occupancy. The remaining three hospitals are small facilities having 125, 150, and 165 beds, with percent occupancies of 73, 78, and 82 percent, respectively.

Ethylene oxide emissions can be estimated for the large hospital as follows:

$$530 \text{ beds} \times 1.8 \text{ lb EO/bed/yr} = 954 \text{ lb EO/yr.}$$

Ethylene oxide emissions can be estimated for the medium hospital as follows:

$$450 \text{ beds} \times 1.3 \text{ lb EO/bed/yr} = 585 \text{ lb EO/yr.}$$

EO Emissions from the small hospitals can be estimated as follows:

$$\begin{aligned} 125 \times 1.7 \text{ lb EO/bed/yr} &= 213 \text{ lb/yr} \\ 150 \times 1.7 \text{ lb EO/bed/yr} &= 255 \text{ lb/yr} \\ 165 \times 1.7 \text{ lb EO/bed/yr} &= \underline{281 \text{ lb/yr}} \\ \text{Total} &= 749 \text{ lb/yr} \end{aligned}$$

The total EO emission can be determined by adding the quantity emitted by the large hospital, the quantity emitted by the medium hospital, and the total annual quantity of EO emitted by small hospitals,  $954 + 585 + 749$  or 2,288 lbs EO/yr.

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### Example Calculation 2

EO emissions from laboratories are calculated as demonstrated.

If a county has a population of 219,368 persons, the area source emission of EO from laboratories can be estimated as follows:

$$\begin{aligned}\text{EO Emissions} &= 219 \text{ (1,000 persons)} \times 1.6 \text{ kg EO/1000 persons/yr} \\ &= 350 \text{ kg EO/yr.}\end{aligned}$$

### 10.5 Methods to Apportion Countywide Emissions

As described in Section 1.0 and Appendix A when performing air dispersion modeling, it is generally recommended that countywide emissions be distributed within the study area into rectangular area source grid cells reflecting spatial variations in activity and emissions. Similarly temporal in activities can be factored into the modeling to reflect seasonal or diurnal fluctuations in emissions. Modeling results would then reflect on-going activities in that portion of the county, e.g., residential heating in the winter, commercial solvent usage during working hours on weekdays.

There are three alternative approaches that can be used in spatially distributing emission: (1) population, i.e., the magnitude of emissions within a grid are directly proportional to the population living in the grid, (2) land area, i.e., emissions from a countywide area source are assumed to be uniform throughout the county and are distributed based on the size of the area source grid, and (3) land use patterns that assume that certain area source activities, most likely occur in certain areas of the county, e.g., commercial, residential, or industrial.

In apportioning emissions from sterilizers, any of these methods may be appropriate. Land area and population data can be readily obtained, and applied as described in Appendix A. Land use data, available from the U.S. Geological survey and other sources can be used in combination with the spatial resolution for hospitals and laboratories to distribute emissions based on the type of activity being performed, as shown in

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Table 10-1; hospitals can, in fact, often be identified on topographical or street maps and may be treated as point sources in the inventory..

Estimated seasonal, daily, and hourly temporal resolution for both categories of sterilizers are also included in Table 10-1, and can be used with the annual countywide emissions data to estimate temporal variations.

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Table 10-1 Spatial and Temporal Resolution of Countywide  
Emissions Totals for Hospital and Laboratory Sterilizers

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## Hospital Sterilizers

### Spatial Resolution

Surrogate indicator:	identify hospitals on maps or commercial areas (code 12)
Information source(s):	land use map and U.S.G.S. topographical maps, street maps

### Temporal Resolution

Seasonal:	uniform through the year
Daily:	uniform through the week
Hourly:	uniform through the day

## Laboratory Sterilizers

### Spatial Resolution

Surrogate indicator:	commercial (code 12) and industrial and commercial complexes (code 15)
Information source(s):	land use maps

### Temporal Resolution

Seasonal:	uniform through the year
Daily:	90% Monday through Friday; 10% Saturday
Hourly:	uniform from 0800 to 2400; otherwise zero

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APPENDIX A

A. METHODS TO APPORTION COUNTYWIDE AREA SOURCE EMISSIONS

In order to perform air dispersion modeling, it is generally recommended that countywide area source emissions are distributed within the study area into rectangular area source grid cells and that spatial and temporal variations of area source emissions are defined within the grid. By spatially and temporally apportioning countywide area source emissions, modeling results will reflect on-going activities in that portion of the county, e.g., residential heating in the winter, or commercial solvent use on weekdays.

Note that methods used in selecting the area source grid boundaries are not addressed in this Appendix; it would suffice to say that the boundaries are somewhat subjective, and are established based on the level of detail in the inventory, the boundaries of the study area, the requirements of the air dispersion model and the resulting data analysis.

Two methods are commonly used to spatially distribute countywide emissions to area source grids. In some cases, the area source emissions can be determined directly from the area source activity within the grid cell. The most frequently used method, however, is to apportion the countywide emissions to the grid cell level by assuming that the distribution of the area sources behaves similarly to that of a surrogate indicator. Often these spatial apportionment factors are generic in nature, i.e., they are based on "typical" national data. Obviously, site-specific data are preferred, when available.

Temporal apportionment, on the other hand, is usually based on typical seasonal, weekly, and daily operating schedules.

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A.1 Direct Determination of Emissions within an Area Source Grid

This method is often used when data are available on the location of individual minor facilities that comprise an area source category. For example, a local gas company may have information on the quantity of natural gas consumed in every household or commercial facility, or a survey can identify the locations of commercial or industrial facilities such as dry cleaners or service stations. These data can be compiled by surveying facilities within an industrial category, using the telephone Yellow Pages, Dunn and Bradstreet's Electronic Yellow Pages<sup>1</sup>, zip code locations, the Thomas Registry<sup>2</sup>, or other sources. Emissions can then be calculated at the grid cell level, resulting in emission estimates that better reflect variations within the county.

A.2 Spatial Apportionment

The selection of apportionment factors for a given area source category depends on the spatial distribution of the emissions and on what other information is available. In most cases, data are not readily available to directly estimate area source emissions at the grid level. As a result, default or "surrogate" indicators can be identified that reflect activity and emission rates at the grid cell level. These surrogate indicators can then be used to apportion grid all emissions to the basic countywide inventory. Variables often used as surrogate indicators of area source activity include land area, land use parameters, employment in various industrial and commercial sectors and population. Appropriate surrogate indicators for each area source category (Sections 2.10) are presented in the appropriate section of the manual.

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Spatial Apportionment Based on Land Area

Land area (e.g., square mileage, acres) can be used as a surrogate indicator for those area source categories where the activity level is typically uniform across the study region. The step-by-step procedure, described below, is based on the assumption that source emissions are directly proportional to land area.

1. Estimate the area of the study region.

If the study region is a unique geographic entity (i.e., city or county) this information is often available from a local or state government agency. If the study region is not so easily defined, however, the areas must be estimated manually. A planimeter is a tool frequently used to accomplish this task.

2. Overlay the chosen grid system onto the study region and estimate the area of each grid cell.

A planimeter is again useful for this procedure. If the area grid cell extends beyond the study region, only the cell area that is within the study region should be considered in the apportionment process.

3. Apportion the area source emissions within the grid cell according to land area.

Because area source emission estimates are typically available on a county level, it is best to proceed with the allocation process on a county-by-county basis. The area source emissions within each grid cell are apportioned according to the percentage of the respective total county land area the grid cell occupies. (For example, if .05 percent of the land area of County A resides in a grid cell, then .05 percent of the area source emissions of County A are apportioned to the grid cell.) This relationship can be expressed mathematically as follows:

$$\frac{\text{Area Within Grid}}{\text{Grid Cell Area Source Emissions}} = \frac{\text{Country Area}}{\text{Total County Area Source Emissions.}}$$

This methodology is illustrated in Example Calculation #1, Section 3.5.1.

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The major advantage of this methodology is its simplicity. It is relatively easy to obtain all the information necessary to accomplish this method of apportionment. It should be noted, however, that the method assumes that emissions are uniform across the country or study region; in reality, even for source categories that are relatively uniform across a region there tends to be clustering at distinct geographical locations (i.e., gasoline stations are often found at intersections).

### Spatial Apportionment Based on Population Density

The spatial distribution of many area source emissions such as those from residential heating is proportional to population density within the study region. As a consequence, countywide area source emissions are frequently assigned to the grid cell level by using population density as a surrogate indicator. This methodology is described in the following steps:

1. Obtain population density information and a census tract identification map for the study region.

Population data statistics are assembled according to census tracts. The data and the census tract identification maps for the study region can be obtained from the U.S. Department of Commerce, Bureau of the Census or any current census almanac publication.

2. Overlay the chosen grid onto the census tract map and estimate the area of the census tracts and each grid cell.

A planimeter is frequently used to estimate these areas. At this point, it is important to closely identify those grid cells or portions thereof that lie within each county comprising the study area.

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3. Apportion population within a grid cell according to the percentage of the area of the respective census tract that the grid cell occupies. (For example, if the area of the grid cell occupies 50 percent of the area of a census tract, then it is assumed that 50 percent of the population of that census tract lies within the grid cell.)

Special attention is required when determining the population of those grid cells which overlap two or more population census tract. In those cases, the area of the grid cell that lies within each census tract and the corresponding population within that area must be computed separately. These population estimates must then be summed to estimate the total population of the grid cell.

4. Apportion the area source emissions for the study area by grid cell population density.

Because area source emission estimates are typically available on a county level, it is best to proceed with the allocation process on a county-by-county basis. The area source emissions within each grid cell are apportioned according to the percentage of the respective county population residing in the grid cell. (For example, if .05 percent of the population of County A resides in a grid cell, then .05 percent of the area source emissions of County A is apportioned to the grid cell.) This relationship can be expressed mathematically as follows:

$$\frac{\text{Population Within Grid}}{\text{Grid Cell Area Source Emission}} = \frac{\text{County Population}}{\text{Total County Area Source Emission.}}$$

This methodology is illustrated in Example Calculation #2, Section 3.5.2.

The obvious advantage of this approach lies in the simplicity of the methodology and the availability of the information needed to perform the procedure. This method is quite useful for those source categories such as residential heating that can be spatially related to population density. The primary weakness of this approach is the assumption that emissions are proportional to population. While this is true for many source categories, some categories such as degreasing or industrial heating, are not necessarily concentrated in the more densely populated

## PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

areas. Other categories such as forest fires may, in fact, be inversely proportional to population density. A second major disadvantage lies in the assumption that population density is uniform throughout the census tract.

### Spatial Apportionment Based on Land Use Patterns

Land use patterns can serve as a useful surrogate indicator of the spatial distribution of area source emissions because they provide a more accurate picture of the "real world" situation. Frequently, pollution sources are located in low population areas such as industrial parks. Local ordinances may dictate the location of certain types of industries or businesses. This clustering of area sources results in concentrations of certain types of sources in specific sections of a study area. For example, small dry cleaners, a source of perchloroethylene, are typically found in commercial areas, whereas domestic heating emissions are common to suburban and urban residential areas.

A prerequisite for using this approach is the availability of land use data. The U.S. Geological Survey (USGS) maintains a comprehensive, computerized data base of information on land use distributions throughout the country. One of the basic sources of land use compilation data for the USGS is the NASA high latitude U-2/RB-57 aerial photocoverage, usually at macroscales.<sup>3</sup> This land use and land cover data compilation is based upon the classification system of land use and cover shown in Table A-1.

State and local governments frequently compile land use maps for urban areas that are, in some instances, more current, more detailed, and less costly than the USGS survey land maps.

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Historically, land use data have been presented on topographical maps; however, much of these data have, in recent years, been computerized. USGS now compiles digital data, for many regions in the country, in terms of 200 meters x 200 meters (4 hectare) grid cells.

For ease of transfer and readability, USGS data files also are available in a character-coded format. These data files contain records of each individual grid cell and provide the following information:

- UTM zone number;
- UTM Easting value in meters;
- UTM Northing value in waters;
- Land use and land cover attribute code (see Table A.2-1);
- Political unit code;
- USGS hydrologic unit code;
- Census county subdivision or SMSA tract code;
- Federal land ownership agency code; and
- State land ownership code.

The standard character-coded grid cell data files will have only grid cell records for which at least one of the categories is coded. Apportionment of areawide emissions according to land use patterns requires the manipulation of enormous amounts of data. There are frequently 500,000 to 1,000,000 four-hectare grid cells in a study area. Data manipulation of such magnitude can be achieved only by using a computer.

Land use data are compiled at four Levels (I through IV) with increasing levels of detail. For environmental analyses, however, Levels I and II provide sufficient detail for categorizing pollution source distribution. A more complete description of USGS land use categories can be found in Reference 3.

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Table A-1 Land Use Categories

- |  |   |
|--|---|
| <p>1. URBAN OR BUILT-UP LAND</p> <p>11 Residential</p> <p>12 Commercial and Service</p> <p>13 Industrial</p> <p>14 Transportation, communications<br/>and services</p> <p>15 Industrial and<br/>commercial complexes</p> <p>16 Mixed urban or<br/>built-up land</p> <p>17 Other urban or built-up<br/>land</p> | <p>7. BARREN LAND</p> <p>71 Dry salt flats</p> <p>72 Beaches</p> <p>73 Sandy areas, other</p> <p>75 Strip mines, quarries,<br/>and gravel pits</p> <p>76 Transitional areas</p> <p>77 Mixed barren land</p> |
| <p>2. AGRICULTURAL LAND</p> <p>21 Cropland and pasture</p> <p>22 Orchards, groves, vineyards,<br/>nurseries, and ornamental<br/>horticultural groves</p> <p>23 Confined feeding operation</p> <p>24 Other agricultural land</p>  | <p>8. TUNDRA</p> <p>81 Shrub and brush tundra</p> <p>82 Herbaceous tundra</p> <p>83 Bare ground</p> <p>84 Wet tundra</p> <p>85 Mixed tundra</p>   |
| <p>3. RANGELAND</p> <p>31 Herbaceous rangeland</p> <p>32 Shrub and brush rangeland</p> <p>33 Mixed rangeland</p>   | <p>9. PERENNIAL SNOW OR ICE</p> <p>91 Perennial snow fields</p> <p>92 Glaciers</p>  |
| <p>4. FOREST LAND</p> <p>41 Deciduous forest land</p> <p>42 Evergreen forest land</p> <p>43 Mixed forest land</p>  |   |
| <p>5. WATER</p> <p>51 Streams and canals</p> <p>52 Lakes evergreen</p> <p>53 Reservoirs</p> <p>54 Bays and estuaries</p>   |   |
| <p>6. WETLAND</p> <p>61 Forested wetland</p> <p>62 Nonforested wetland</p>   |   |

Source: Reference 3

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PROCEDURES FOR ESTIMATING AND ALLOCATING  
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The basic steps to the apportionment procedure are as follows:

1. Compute or obtain county-specific area source emissions. This information can usually be obtained from local and state government agencies.
2. Identify the total number of land use grid cells in the county by land use category.
3. Identify the area grids lie within the county.
4. Compile a grid cell/area source grid matrix.

Land use fractions for each area grid are computed for the various land use categories. This information is then combined with the data assembled in steps 1 through 3 above and compiled into a matrix format. An example of this type of matrix is shown in Table A-2.

5. Allocate area source emission fractions into land use categories.

This step requires the compilation of a land use/area source matrix. Table A-3 is an example of this type of matrix. The creation of this matrix should be based upon source distributions found in the literature in combination with engineering judgment, as needed. Emissions from residential heating, for example, can be totally assigned to the residential land use category. Dry cleaning emissions, 90 percent of which come from coin-operated and commercial dry cleaners,<sup>4</sup> can be distributed proportionately to the commercial and services land use category. Surface coating emissions can be distributed between five urban categories, all of which paint and coat surfaces. A sixth urban category, "mixed urban," is typically redistributed equally among Categories 11, 12, 12, 14, 15, and 17. Site-specific characteristics, if available, should be used in the development of this matrix.

6. At the area source grid level in a county, for each area source category and each pollutant, multiply the county area source emission by the land use fraction of Step 4 and the emission fraction of Step 5 to obtain land use emissions.

The two matrices, when multiplied, are transformed into a product matrix that defines the fraction of the area source emissions is assigned to each area source grid. This fraction is then multiplied by each pollutant total in the countywide emission inventory to determine the apportionment of each pollutant to each area grid cell.

# PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

Table A-2 Example of Grid Cell/Area Source Grid Matrix

Land Use Category	Area 02	Area 06	Area 07	Area 11	County total
Residential	3774 53.6	820 11.7	1034 14.7	1409 20.0	7037
Com. & Services	797 63.8	82 6.6	159 12.7	212 17.0	1250
Industrial	276 59.2	119 25.5	44 9.4	27 5.8	466
Trans., Com., & Services	261 61.1	60 14.1	79 18.5	27 6.3	427
Ind. & Com. Complex	166 57.6	0 0.0	80 27.8	42 14.6	288
Mixed Urban	133 75.1	5 2.8	16 9.0	23 13.0	177
Other Urban	357 32.5	243 22.2	184 16.8	313 28.5	1097
Streams & Canals	100 68.5	46 31.5	0 0.0	0 0.0	146
Lakes	0 0.0	0 0.0	0 0.0	0 0.0	1
Reservoirs	48 76.2	9 14.3	5 7.9	1 1.6	63
Bays & Estuaries	0 0.0	0 0.0	0 0.0	0 0.0	1
All Other	15510 88.1	993 5.6	777 4.4	326 1.9	17606

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PROCEDURES FOR ESTIMATING AND ALLOCATING  
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Table A-3 Example of an Apportionment of Area Source Categories by  
Land Use Category (land use/area source matrix)

	Degreasing	Dry cleaning	Rubber & Plastics	Printing & Publishing	Surface Coating	Misc. Index SC	Misc. Non-Industrial	Residential Heating	Commercial & Institutional	Industrial Heating	Gasoline Marketing	Water
Residential (11)	-	-	-	-	0.20	-	.35	1.00	-	-	-	-
Commercial & Services (12)	0.15	0.90	-	0.50	0.20	-	.25	-	0.50	-	.80	-
Industrial (13)	0.30	0.05	0.50	-	0.30	0.50	-	-	-	1.00	-	-
Transportation & Communication (14)	0.25	-	-	-	0.05	0.10	.25	-	-	-	.20	-
Industrial & Commercial (15)	0.30	0.05	0.50	0.50	0.25	0.40	.15	-	0.50	-	-	-
Mixed Urban (16)	*	*	*	*	*	*	*	*	*	*	*	-
Other Urban (17)	-	-	-	-	-	-	-	-	-	-	-	-
Water (5)	-	-	-	-	-	-	-	-	-	-	-	-
All Others	-	-	-	-	-	-	-	-	-	-	-	-

\* 16.7% of the total mixed urban land area is included in land use categories 11, 12, 13, 14, 15, and 17 respectively.

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An example calculation using this procedure is presented as Example Calculation 3, Section A.5.

An alternative approach is based on extracting data directly from land use maps. In this approach, the surrogate indicator is the area in the study region devoted to each land use zone. Key assumptions in this methodology are that (1) area source activity is uniformly distributed throughout land use zones, and (2) the area of the grid cell devoted to a particular land use code is a true indication of the magnitude of the area source emissions within that grid cell. The basic steps in this alternative procedure are summarized below.

1. Identify the total countywide emissions of the area source categories under study. These estimates can usually be obtained from local and state governmental offices or can be estimated from available area source activity data.
2. Identify the land use code in which the activity of a particular area source category would be likely to occur. An example of this association is to assume that dry cleaning activities would be most likely to occur in a commercial land use zone.
3. Superimpose the grid system network on the land use map and estimate the area of each grid cell devoted to each land use code.
4. Estimate the emissions from each grid cell as a simple fraction of the total as follows:

$$E_i = E_t (S_i/S_t)$$

where

E = area source emissions;

S = surrogate indicator;

i = the value in grid cell; and

t = the total for the county or region

( $S_i/S_t$ ) is known as the "apportioning factor."

The units for the surrogate indicator(s) can be arbitrary (i.e., percent of grid cell, square kilometer, square mile).<sup>5</sup>

## PROCEDURES FOR ESTIMATING AND ALLOCATING AREA SOURCE EMISSIONS OF AIR TOXICS

An example of this apportionment method is shown in Example 4, Section A.5.

The discussion above is applicable for apportioning area source emissions based on a single land use surrogate indicator. In some cases, more than one indicator may be used for an area source emission apportionment. For example, miscellaneous solvent use can be associated with the two consumer (residential and commercial) land use categories (land use codes 11 and 12).

There are two principal ways to manage this type of apportionment. The first approach is to estimate solvent emission subtotals for the two types of land use involved; then each of these subtotals is apportioned according to the corresponding land use areas. This action creates two new emission subcategories where the countywide inventory may have had only one. For example, one-half of the miscellaneous solvent emissions could be assigned to multifamily residences (land use 11) and one-half to commercial and service use (land use 12). Hence, if countywide emissions from miscellaneous solvent use are 12 tons per day, 6 tons per day would be apportioned at the grid cell level for each of these subcategories, based on the distribution of the corresponding surrogate indicator. Alternatively, the relative intensity of solvent use in the two types of areas could be estimated. For example, it can be assumed that residential areas have one-third the emission rate per unit area of commercial and service areas. In this case, the apportioning factors would be calculated using an appropriate weighting factor for the two types of land use. This would be expressed, mathematically, by the equation:<sup>5</sup>

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$$f_{ik} = \frac{\sum_{j=1}^2 W_{jk} S_{ij}}{\sum_{i=1}^n \sum_{j=1}^2 W_{jk} S_{ij}}$$

where

$f_{ik}$  = apportioning factor

$W_{jk}$  = the weighting factor selected for land use type  $j$  in relation to source category  $k$ .

$S_{ij}$  = the value of the surrogate indicator (i.e., the area) of land use type  $j$  in cell  $i$ .

The summation term appearing in the numerator is essentially a composite surrogate indicator for the entire category. Consequently, if solvent emissions are weighted according to the previous suggestion ( $W_1 = 1$ ,  $W_2 = 3$ ) and the respective areas in a given grid cell are 0.6 and 0.4, then the value of the composite surrogate indicator for that cell is  $(0.6 \times 1) + (0.4 \times 3)$ , or 1.8. The countywide emission for the category is then apportioned based on this composite surrogate indicator.<sup>5</sup>

The above methodology can also be implemented using traffic zone-level demographic statistics.

State and local transportation planning agencies often compile data on employment and other demographic statistics for urban areas. These data, which are frequently aggregated at the zonal level, can be used in lieu of land use maps to define surrogate indicators for area source apportionment. These zonal statistics are usually much more detailed in data characterization than are land use data. For instance, zonal

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statistics in a particular urban area may typically be compiled for five or more commercial and industrial subcategories, whereas the corresponding land use maps may only identify generalized commercial and industrial land uses.

Reference 5 discusses this approach in greater detail.

### A.3 Mobile Source Apportionment

Several methods are currently available to apportion emissions from mobile sources. Each methodology is discussed below.

#### Apportionment Based on Vehicle Miles Traveled

Vehicle Miles Traveled (VMT) data can be effectively used as a surrogate indicator to allocate mobile VOC emissions to the grid cell level for modeling purposes. State and local traffic agencies usually compile VMT data disaggregated into traffic zones. In most cases, these data are readily available for most metropolitan areas. The basic steps in the allocation procedure are illustrated below: an example of this procedure is presented as Example Calculation #5; Section 3.5.5.

1. Obtain countywide or study area VMT and mobile VOC emissions data from state or local agencies. These data are typically compiled according to vehicle type and pollutant species. VOC emissions are also frequently categorized as either evaporative or exhaust and are emanating from either gasoline or diesel fuels.
2. Obtain traffic zone VMT data from local or state agencies and determine the total VMT for each grid cell. This is accomplished by summing the VMT data for all the traffic zones lying within each grid cell. If only a portion of a traffic zone lies within the grid cell, apportion VMT's within the cell in proportion to the area of the traffic zone lying within the grid cell (i.e., if 10 percent of the traffic zone lies within the cell apportion 10 percent of the traffic zone's total VMT to the grid cell). A planimeter can be used to estimate the area of the traffic zones. In some cases, area estimation can be done by sight.

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3. Determine the apportionment factor for each grid cell. The apportionment ( $A_i$ ) is defined by the following equation

$$A_i = \text{VMT}_i / \text{VMT}_t$$

where  $\text{VMT}_i$  is the VMT within the grid cell and  $\text{VMT}_t$  is the total VMT for the study area.

4. Apportion VOC emissions to each grid cell by multiplying the apportionment factor by the total county/study area mobile VOC emissions. The apportionment factor is further multiplied by each pollutant-specific subtotal of the county/study area mobile VOC emissions data to create a speciated VOC data base for each grid cell.

### Apportionment Based on MOBILE3

As mentioned in Section 4, MOBILE3 is a computer program that calculates emissions of hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen ( $\text{NO}_x$ ) from highway motor vehicles. MOBILE3 can be adapted to apportion the estimated emissions into designated area grids for modeling purposes. The best sources of data for input into the model (i.e., VMT distribution, driving patterns) are local and state transportation planning commissions and other related organizations. Emissions can then be each estimated for grid within a county. For further information on MOBILE3, the reader is directed to User's Guide to MOBILE3 (Mobile Source Emissions Model).<sup>7</sup>

The VMT approach to apportionment is an effective screening tool for mobile emission estimates; however, driving patterns and vehicle speed are not considered in estimating emissions, which is a major drawback. MOBILE4 estimates mobile emissions in a much more sophisticated manner taking into account both driving patterns and vehicle speed. Mobile emissions are categorized as evaporative or exhaust, resulting in a more real life representation of pollutant production. A second major advantage of MOBILE3 is that mobile emissions are directly apportioned into area source grids.



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The sophisticated nature of MOBILE3 demands that persons familiar with the program must conduct the modeling exercise. In addition, obtaining the extensive data needed as input into the model, if not readily available from a local or state transportation commission, can be time consuming and expensive. In contrast, the Vehicle Miles Traveled approach, while less accurate, can be performed more easily by individuals not familiar with the MOBILE3 model.

### A.4 Temporal Distribution of Countywide Emission Estimates

The countywide emission values used in the apportionment process above are typically available only as annual or perhaps seasonal estimates. In order to more effectively use the data for modeling purposes, it must be translated into hour-by-hour emission rates.

If only annual emission estimates are available, the first step in this process is to estimate the seasonal component of activity for each area source. For many sources, activity is fairly constant from season to season, whereas for some sources, a strong seasonal component will be evident. Degreaser operations is an example of the former category where activity is fairly constant throughout the year. Conversely, emissions from residential heating will occur primarily in the colder winter months.<sup>5</sup>

Once the seasonal component is known, the daily component should be determined. Again, some area source activities are relatively constant from day to day, thereby simplifying the estimation process. For example, gasoline storage losses and natural gas leaks can be assumed to be uniform over the week. On the other hand, many work-related area sources are more active on weekdays. Examples include dry cleaning

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plants and degreasing operations where activities are concentrated from Monday through Friday (or Saturday in some cases).<sup>5</sup> The seasonal activity for these sources should be distributed only to those days on which the source is active. For instance, if dry cleaning emissions for the county are 312 tons of solvent over a 92-day period from July to September, and most plants typically operate 6 days a week (for a total of 78 operating days), then daily emissions from dry cleaning would be 4 tons ( $312 \div 78$ ). This daily rate would not be applicable to a Sunday.<sup>5</sup>

After the daily activity level has been determined for each area source, the final step is to estimate hourly emissions. This is generally accomplished by applying a 24-hour operating pattern to the daily activity level. The 24-hour operating pattern can be obtained from onsite measurements, survey data, or engineering judgment. To illustrate, dry cleaning establishments generally operate from 7 a.m. to 5 p.m., Monday through Saturday, with uniform emissions throughout the period. Given a countywide daily emission rate of 4 tons, the hourly emission would be .36 tons ( $4 \div 11$ ).

Temporal resolution methodologies for various area source categories are presented in the manual in Sections 2 through 10.

### A.5 Example Calculations

Example calculations of selected area source apportionment methodologies are provided. The examples presented are somewhat simplistic to better illustrate the fundamental steps of each methodology.

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Example Calculation 1

Estimate area source spatial apportionment using land area as a surrogate indicator.

County A has an area of 1472 square miles. For purposes of air dispersion modeling, the county has been divided into two area source grids. Using a planimeter, the square mileage of the grid is estimated to be as follows:

	<u>Area</u>	<u>% of Area</u>
Grid 1	962 square miles	65
Grid 2	510 square miles	35

Emissions of benzene from gasoline marketing are estimated to be 11 MT/yr and emissions of formaldehyde from heating area sources is estimated to be 75 MT/yr.

The emissions are apportioned using the methodology described in Section A.2.1, as follows.

Benzene

Grid 1	$(11 \text{ MT/yr}) \times (.65) = 7 \text{ MT/yr}$
Grid 2	$(11 \text{ MT/yr}) \times (.35) = 4 \text{ MT/yr}$

Formaldehyde

Grid 1	$75 \text{ MT/yr} \times (.65) = 49 \text{ MT/yr}$
Grid 2	$75 \text{ MT/yr} \times (.35) = 26 \text{ MT/yr}$

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Example Calculation 2

Estimate area source spatial apportionment using population density as a surrogate indicator.

County A, USA has a population of 354,000 people. For purposes of modeling the county has been divided into three area source grids with the following populations estimated based on census tract data.

	<u>Population</u>	<u>% of County Population</u>
Grid 1	193,000	55
Grid 2	120,000	34
Grid 3	41,000	11

Total emissions from area sources of perchloroethylene from dry cleaners is estimated to be 73 MT/yr and trichloroethylene emissions from degreasers are 49 tons/yr.

The emissions are apportioned using the methodology described in Section A.2.2 as follows.

Perchloroethylene

Grid 1	$(73 \text{ MT/yr}) \times (.55) = 40 \text{ MT/yr}$
Grid 2	$(73 \text{ MT/yr}) \times (.34) = 25 \text{ MT/yr}$
Grid 3	$(73 \text{ MT/yr}) \times (.11) = 8 \text{ MT/yr}$

Trichloroethylene

Grid 1	$(49 \text{ MT/yr}) \times (.55) = 27 \text{ MT/yr}$
Grid 2	$(49 \text{ MT/yr}) \times (.34) = 17 \text{ MT/yr}$
Grid 3	$(49 \text{ MT/yr}) \times (.11) = 5 \text{ MT/yr}$

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Example Calculation 3

Sample calculations are provided below for apportioning emissions from dry cleaning operations in County A, USA, utilizing the surrogate land use matrix methodology. It is estimated that 162 MT/yr of perchloroethylene are emitted from area source dry cleaners.

Step 1

<u>Land Use Category</u>	<u>Number of Grid Cells in Land Use Category</u>
Residential	2,799
Commercial and Services	618
Industrial	78
Transportation, Communications, and Services	348
Industrial and Commercial Complexes	1
Mixed Urban*	3
Other Urban	128
Streams and Canals	233
Lakes	61
Reservoirs	519
Bays and Estuaries	652
All Other	53,480

Step 2

Area Grid Cells 22 and 23 lie within this county.

\* Mixed Urban grid cells in Area Source 22: 3  
Area Source 23: 0

The reallocation of the above grid cells will not change the county and area grid distributions.

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Step 3

<u>Land Use Category</u>	<u>Area Source 22 Grid Cells %</u>		<u>Area Source 23 Grid Cells %</u>		<u>County Total Grid Cells %</u>	
Residential	2107	75.3	692	24.7	2799	100
Commercial and Services	363	58.7	255	41.3	618	100
Industrial	75	96.2	3	3.8	78	100
Transportation, Communication, and Services	136	39.1	212	60.9	348	100
Industrial and Commercial Complexes	1	100	0	0	1	100
Other Urban	97	75.8	31	24.2	128	100
Streams and Canals	9	3.9	224	96.1	233	100
Lakes	24	39.3	37	60.7	61	100
Reservoirs	285	54.9	234	45.1	519	100
Bays and Estuaries	29	4.4	623	95.6	652	100
All Other	34584	64.7	18896	35.3	53480	100

Step 4

For dry cleaning, emission fractions from various land use categories are:

Commercial and Services: 90%  
Industrial: 5%  
Industrial and Commercial  
Complexes: 5%

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Step 5

Area Source Grid 22

Perchloroethylene

$$\begin{aligned}\text{Commercial and Services} &= 162 \text{ MT/yr} \times \frac{58.7}{100} \times \frac{90}{100} \\ &= 85.6 \text{ MT/yr.}\end{aligned}$$

$$\begin{aligned}\text{Industrial} &= 162 \text{ MT/yr} \times \frac{96.2}{100} \times \frac{5}{100} \\ &= 7.8 \text{ MT/yr}\end{aligned}$$

$$\begin{aligned}\text{Industrial and Commercial} \\ \text{Complexes} &= 162 \text{ M.T./yr} \times \frac{100}{100} \times \frac{5}{100} \\ &= 8.1 \text{ M.T./yr.}\end{aligned}$$

Therefore, total perchloroethylene emissions from Area Source Grid 22

$$= 85.6 + 7.8 + 8.1 = 101.5 \text{ MT/yr}$$

Similarly, in Area Source Grid 23,

$$\text{Perchloroethylene emissions} = 60.5 \text{ MT/yr.}$$

Example Calculation 4

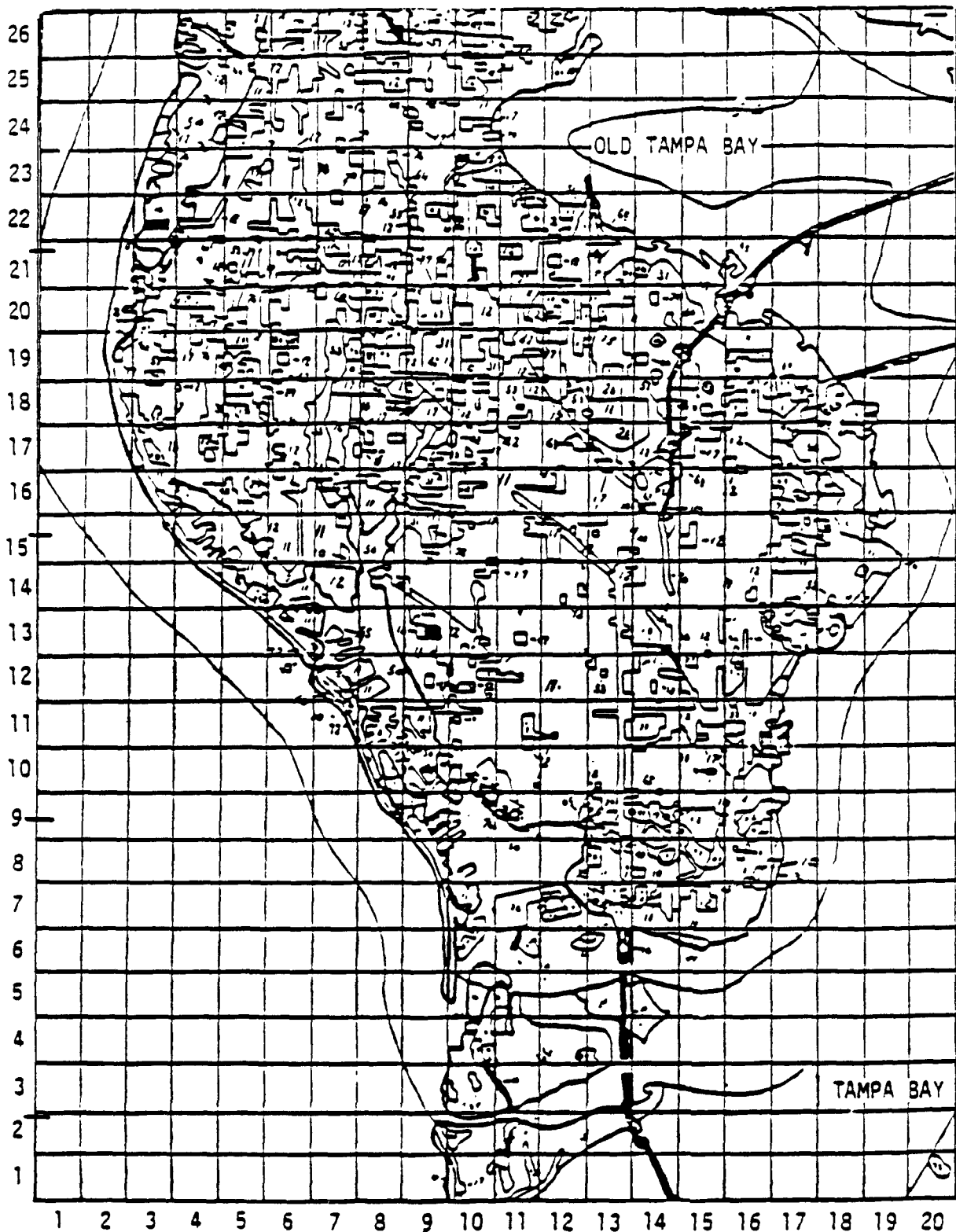
Example calculations are provided below for apportioning emissions from dry cleaning operations in County B, USA, utilizing an alternative surrogate land use methodology. It is estimated that 100 MT/yr of perchloroethylene are emitted by area source dry cleaners. Refer to Figure A-1.

Step 1 Surrogate Land Use Codes

12: Commercial

15: Industrial and Commercial Combined

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SOURCE: Reference 5

Figure A-1 LAND USE MAP



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Steps 2 and 3

For Grid Cell (15, 15)

$S_i$  = .20 grid cells (20 percent of the area  
is indicated as commercial/industrial)

$S_t$  = 26.3 grid cells

$(S_i/S_t)$  for grid cell (15, 15) = .0076

$E_i = E_t (S_i/S_t)$

$E_i = (100) (.0076) = .76 \text{ MT/yr}$

Example Calculation 5

A county is divided into two grid cells for air dispersion modeling. The following example apportions mobile emissions data resulting from gasoline consumption from light duty vehicles (cars and light trucks) in Grid Cells 931 and 932.

Total county emissions by pollutant (MT/yr), using the methodology provided in Section 4 are as follows:

Acetaldehyde	=	0.2
Asbestos	=	0.001
Benzene*	=	68.8
Benzo(a)pyrene	=	0.002
1,3-butadiene	=	11.7

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\*The benzene evaporative emissions factor on Table 4-1 is given as a range to calculate the total county emissions, we assumed the benzene evaporative factor was the mid-point of the range.

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Cadmium	=	0.003
Chromium	=	298.9
Ethylene dichloride	=	0.45
Formaldehyde	=	16.3
Lead	=	0.6
Polycyclic organic Matter	=	1.9

Traffic zone data provided is as follows:

<u>TRAFFIC ZONES</u>	<u>VMT/DAY</u>
1	75,827
2	513,601
3	386,399
4	150,132
5	56,013
6	80,537
7*	241,611

Step 1

Grid Cell 931 consists of traffic zones 1, 2, and 3.  
Grid Cell 932 consists of traffic zones 4, 5, and 6, as well as one-third of traffic zone 7.

Allocate VMT Data to Grid Cells 931 and 932.

Grid Cell 931:

$$75,827 + 51,3601 + 386,399 = 975,827$$

(Zone 1) (Zone 2) (Zone 3)

Grid Cell 932:

$$150,132 + 56,013 + 80,537 + (1/3 \times 241,611) = 367,219$$

(Zone 4) (Zone 5) (Zone 6) (1/3 Zone 7)

Step 2

Apportionment Factor ( $A_i = \text{VMT}_i / \text{VMT}_t$ )

$$\text{Grid Cell 931; } A = 975,827 / (975,827 + 1,342,506) = .70$$

$$\text{Grid Cell 932; } A = 367,219 / (975,827 + 1,342,506) = .30$$

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\*One-third of the area of zone 7 lies within Grid Cell 932.

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Step 3

To apportion emissions to Grid Cells 931 and 932, multiply results of Step 2 times countywide emissions

Light duty vehicle

Grid Cell 931

Acetaldehyde	0.2	x	0.70	=	0.2
Asbestos	0.001	x	0.70	=	0.0007
Benzene	68.8	x	0.70	=	48.2
Benzo(a)pyrene	0.002	x	0.70	=	0.002r
1,3-Butadiene	11.7	x	0.70	=	8.7
Cadmium	0.003	x	0.70	=	0.002
Chromium	298.9	x	0.70	=	209.2
Ethylene dibromide	0.5	x	0.70	=	0.3
Formaldehyde	16.3	x	0.70	=	11.4
Lead	0.6	x	0.70	=	0.4
Polycyclic organic Matter	1.9	x	0.70	=	1.3

Grid Cell 932

Acetaldehyde	0.2	x	0.30	=	0.07
Asbestos	0.001	x	0.30	=	0.0003
Benzene	68.8	x	0.30	=	20.6
Benzo(a)pyrene	0.002	x	0.30	=	0.0007
1,3-Butadiene	11.7	x	0.30	=	3.5
Cadmium	0.003	x	0.30	=	0.0001
Chromium	298.9	x	0.30	=	89.7
Ethylene dibromide	0.5	x	0.30	=	0.1
Formaldehyde	16.3	x	0.30	=	4.9
Lead	0.6	x	0.30	=	0.2
Polychclic organic matter	1.9	x	0.30	=	0.6

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