EPA Contract No. 68-D7-0068
Work Assignment No. 2-09
ERG No. 0101-01-009

ESTIMATING PARTICULATE MATTER EMISSIONS FROM CONSTRUCTION OPERATIONS

FINAL REPORT

Prepared for:

Emission Factor and Inventory Group
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Prepared by:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

Under Subcontract to:

Eastern Research Group, Inc.
1600 Perimeter Park
P.O. Box 2010
Morrisville, North Carolina 27560

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Preface

This report was prepared by Midwest Research Institute (MRI) for the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards under Purchase Order No. EFIG-0068 from Eastern Research Group (ERG). Mr. Garry Brooks was the Work Assignment Leader for ERG. This work was performed under EPA Prime Contract No. 68-D7-0068 with ERG.

The report summarizes the methods that have been used to develop inventories of fugitive dust and exhaust particulate matter (PM) emissions from construction activities, identifies surrogate data sources for PM emission calculations, and proposes a preferred methodology to estimate county level emissions. Mrs. Mary Ann Grelinger was the MRI Project Leader for this assignment. Dr. Chatten Cowherd and Dr. Greg Muleski served as technical consultants on this project. This report was prepared by Mrs. Grelinger, Ms. Courtney Kies, and Dr. Cowherd.

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Section 1. Introduction

This report was prepared as part of a study to develop an improved method for estimating particulate matter (PM) emissions from construction operations.

A new methodology is needed to improve emission estimates on a national county-by-county basis for the National Emission Trends (NET) inventory. Construction operations can substantially impact local air quality from suspended dust, equipment exhaust, and burning emissions. The majority of PM emissions originates from sources that suspend dust from soil and construction materials, especially from equipment travel. PM emissions are released into ambient air from the following construction activities:

- Equipment movement on unpaved surfaces (suspended dust and exhaust emissions)
- Earthmoving (cut and fill operations, and excavation activities)
- Material transfer operations, including loading/unloading activities
- Material alterations, including drilling, crushing, screening, cutting, blasting, and surface cleaning activities
- Portable plant crushing and screening
- Track-out of dirt to nearby paved roads for subsequent dust resuspension by traffic
- Land clearing, including demolition/burning of existing structures and vegetative residues
- Wind erosion of soil exposed by construction activities

The activities performed in this study included:

- Identification of readily available national and regional information sources that can be used to prepare an inventory of PM emissions from construction activity
- Identification of categories of construction that can be expected to have different emission characteristics (e.g., highway, commercial, housing)
- Characterization of factors that impact construction emissions (e.g., meteorological parameters, regional differences in construction, soil types, economic conditions)
- Development of a methodology to estimate county-level emissions of fugitive dust from construction activities

This report is organized as follows. Section 2 provides information on the calculation of PM_{10} and $PM_{2.5}$ components of fugitive dust and exhaust emissions generated during construction operations. Section 3 identifies the categories of construction that are believed to have different dust emitting characteristics and levels of activity and in turn produce different amounts of PM emissions. Section 4 presents existing methodologies used to calculate PM_{10} emissions from construction activities. Section 5 presents an assessment of the California methodology and the NET methodology, recommended changes to the Trends procedure, an updated methodology for calculating emissions for the county-level on a national basis, and a review of the data sources needed to develop such an inventory.

Section 2.
PM Emissions from Construction Activities

Particulate matter emissions from construction activities are produced from equipment exhaust (primarily from diesel-fueled engines), equipment travel and activity on unpaved surfaces, on-site material handling operations (e.g., temporary on-site crushing/screening), and track-out of dirt onto adjacent paved roads with subsequent resuspension by traffic. Equipment exhaust emissions consist of finer, combustion aerosols, while fugitive dust emissions consist mostly of coarser crustal particles.

Conditions that influence construction PM emissions include equipment type, size, and travel speed; engine type, size, and load; soil type and moisture content; and wind conditions. For example, exhaust emissions are high when excavating soil and engines are under load; fugitive dust emissions are high when dry surface dust is disturbed and suspended by construction equipment travel.

A wide variety of equipment classes, sizes, and engine types are used in construction activities. Construction equipment includes motor graders, trucks, scrapers, and other equipment types. General construction equipment is outlined in Table 2-1.

Table 2-1. Types of Construction Equipment

Motor graders	Trucks	Scrapers
Loaders (track- and wheel-type)	Tractors (track- and wheel-type)	Excavators (track- and wheel-type)
Road wideners	Compactors (pneumatic and vibratory)	Road reclaimers/ Soil stabilizers
Windrow elevators	Cold planers	Power shovels

2.1 Information Sources—Construction Activity Levels

Many data sources are available that provide construction statistics for the national, regional, state, and county levels. This study identified information sources that can be used to develop a county-by-county inventory of PM emissions associated with construction activities. The available information sources determine the form of methodology that is used to develop the inventory.

Due to variations in the type of data that local governmental agencies can provide (construction permits and/or compiled local construction data), methods for determining construction activity levels differ by area. Many areas have high quality measures of construction activity levels resulting from local government requirements for construction permitting; however, only lower quality (less resolved) data may be available for other areas.

Two widely used references for national construction statistics are the F.W. Dodge Reports published by McGraw Hill, Inc. and the U.S. Bureau of Census, Construction Statistics Division. The F.W. Dodge Group publishes the monthly Dodge Construction Potentials Bulletin, and the Dodge Local Construction Potentials Bulletin providing the dollar value spent on various types of construction and also the number of buildings constructed. Annual reports and other supporting databases are also available from F.W. Dodge. All information is provided for a fee. The U.S. Bureau of Census publishes yearly the Statistical Abstract of the United States. This publication includes statistics on various aspects of construction. The Census of Construction Industries Division produces monthly statistics on construction activities including the number of housing starts. Most information from the F.W. Dodge group and the U.S. Census Bureau is available on a state basis.

Transportation statistics are published yearly by the Federal Highway Administration (FHWA) in *Highway Statistics*. The publication includes roadway characteristics and extent along with other roadway statistics. The data provided by the FHWA is useful in determining the new miles of roadway constructed on a yearly basis.

2.2 Information Sources—Construction Emission Factors

Two chapters of the U.S. EPA handbook, "Compilation of Air Emission Factors" [AP-42][1] apply to particulate matter emissions from construction activities. Chapter 7 relates to emissions from the mineral products industry, including construction aggregate processing and crushed stone processing. Chapter 13 contains relevant emission factors for prescribed burning, unpaved road traffic, aggregate handling and storage piles, industrial wind erosion, abrasive blasting, and explosives detonation. Section 13.2.3, "Heavy Construction Operations," contains PM emission factors specifically for emissions from heavy construction. Exhaust emissions contains emission factors from diesel-fueled construction equipment are separately estimated using EPA's NONROAD model.

2.3 Emission Calculations

Emissions from construction operations are related to three phases of a project. Demolition and debris removal includes removal of old structures or brush collection and transport/burning. Site preparation involves cut-and-fill, grading, and compaction activities (i.e., all earthmoving operations). General construction includes material handling operations for construction of structures and roads. Under some local PM estimation methodologies, construction equipment activity is allocated to road construction, building construction, and miscellaneous land-moving operations. Emissions are calculated for specific periods and time intervals. Inventories can be developed for annual, seasonal, monthly, and for worst-case, twenty-four hour periods.

Estimates of PM_{10} and $PM_{2.5}$[a] emissions from construction activities are developed using emission factors, activity level (source extent) data[b], and control efficiencies (if applicable). Historically, the primary emission factor for construction activities has been:

$$e = 1.2 \text{ tons/acre/month of activity}$$

This factor was based on early (i.e., 1970's) upwind/downwind tests of construction site impacts on ambient particulate levels. It refers to total suspended particulate (TSP) matter emissions represented by particles no greater than 30 μm in aerodynamic diameter.

Additional emission factors for earthmoving and other activities associated with construction operations can be borrowed from other AP-42 chapters, but certain differences exist between construction operation emissions and emissions from other fugitive dust sources. These additional factors were derived from field testing using the MRI exposure (plume) profiling method that determines the downwind transport of PM flux. Consequently, these emission factors combine exhaust with fugitive dust emissions. PM emission factors for fugitive dust are available in AP-42 Chapters 7 and 13 and are related to soil silt and moisture contents.

Emission factors for PM from construction equipment exhaust are available in the NONROAD model produced by EPA, Office of Mobile Sources (OMS), and are related to engine type, size, and load. The EPA OMS has developed a second draft of the NONROAD Emission Inventory Model. The NONROAD model calculates emissions of criteria and HAP pollutants, including PM emissions.

Control efficiency data for construction equipment engines is built into the NONROAD model for future diesel engine rules that will affect PM emissions. Control efficiencies for fugitive dust are published in AP-42 and are primarily related to watering or chemical suppression of surface soils at construction sites.

2.4 Factors Influencing Construction Emissions

The factors that influence construction emissions represent meteorological parameters, regional construction differences (e.g., basement/no basement for residential housing), soil types, and economic growth. Construction activity is related to climate, terrain, and economic conditions. For example, residential foundations differ between northern and southern states in the U.S. (e.g., fewer basements are excavated in southern states). Regional terrain and soil variations are also important (e.g., highway construction in mountains, or rocky vs. silty soils).

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[a] PM_{10} and $PM_{2.5}$ refer to particulate matter no greater than 10 μm and 2.5 μm in aerodynamic diameter, respectively.

[b] In most cases emissions are proportional to activity level.

Regional economic cycles in the construction industry impact construction PM emission inventories. The factors that will cause the highest activity levels for construction are low real interest rates, increasing economic growth, and some need for housing and commercial structures (population growth is a strong predictor of need). A prediction of future emissions must rely on economic and demographic forecasts for the inventoried area.

Construction activity also varies temporally according to meteorology (rainfall stops work), climate (unfavorable winter conditions impact work schedules), soil characterization (compacted, rocky areas slow construction), workforce availability (labor disputes halt construction), and economic conditions (effective demand).

Effective demand is defined as the combination of need for structures and roads, and affordable resources (capital). Several socioeconomic forces affect the need for construction, and are likely to impact regions and sub-regions unequally. Residential construction is driven by localized population growth, low interest rates, and the quality of current housing; on the other hand industrial construction is driven largely by economic growth. In turn, highway construction is frequently driven by new residential and commercial/industrial construction.

Section 3.
Categories of Construction

Construction activities can be distinguished by three classes: (1) road construction, (2) residential construction, and (3) nonresidential construction. Each is discussed below to show the variations in emission producing activities.

3.1 Road Construction

Road construction includes the building of new roadways from all the functional classes. The FHWA divides roads by purpose, lane width, number of lanes, surface type, location (including urban, rural, state), and other roadway characteristics. The characteristics of roadways vary depending on the type of roadway being constructed.

The road characteristics along with the new miles of roadway built on an annual basis are used to determine the land area that is affected by construction for the type of road being built. The three primary functional classes, arterials, collectors, and local roads, vary in width, lanes, and may have further variations depending on whether the road is located in an urban or rural area. Four divisions of roadways were made by functional class and demographic type in order to group the roads by similar characteristics.

3.2 Residential Construction

The construction of houses and apartment buildings is included as a separate category than other building construction primarily because of the statistics available for residential construction. Statistics are available for the number of housing units constructed and also the value of the construction.

Another variation is the level of activity that occurs at a residential construction site as compared to other forms of building construction. Housing construction does not normally require a large amount of earthmoving and occurs during a shorter time period, producing less emissions per unit area than would be seen at a nonresidential construction site. Apartment building construction lasts longer than housing construction.

3.3 Nonresidential Construction

Office buildings, warehouses, manufacturing facilities, schools, public works, and hospitals are all included in nonresidential construction. Construction on nonresidential sites is normally more involved and lasts longer than housing construction. It varies in the amount of earthmoving that takes place but most nonresidential construction impacts a similar amount of land on a per dollar basis.

3.4 Other Construction

Almost all construction activity can be included in either road, residential, or nonresidential construction. Public projects in which a large amount of earthmoving and building activity occurs (e.g., an expansive project such as a stadium or airport), should be considered separately and emissions should be estimated using detailed construction data from the engineering plans.

Section 4.
Existing Methodologies for Estimating Construction Emissions

Many methodologies have been developed to calculate PM emissions from construction activity. The basic limitations to developing a construction emissions methodology are how to estimate the level of activity that occurs at a construction site and what emission factor is appropriate to use to calculate PM emissions.

Two basic approaches are used in collecting data for the development of emission inventories: (a) "top down" methodology; and (b) "bottom up" methodology. The "top down" method uses national and state data resources to estimate activity levels that are multiplied by general emission factors to calculate emissions for a large region. The calculated emissions are then apportioned to more resolved areas, such as county and sub-county levels using surrogate activity level data, such as population or affected land area. The "top down" method for estimating construction operation emissions uses a single-valued, composite emission factor of 1.2 tons TSP/acre/month, multiplied by estimated acres of construction (derived from construction cost data) and an average duration for construction. The "top down" method is cost-effective, but does not usually provide an accurate reflection of emissions when broken down into the county and subcounty levels.

The "bottom up" methodology may use multiple emission factors (for specific construction phases and activities) and local activity data to calculate emissions. Local data includes equipment population levels, construction permit information, and specific factors that affect construction activity for that area, including construction equipment usage. "Bottom up" methods more accurately reflect the actual construction emissions than is represented using a "top down" method, but are labor-intensive and costly. A "bottom up" emission inventory is preferred for spatial and temporal allocation needed by modeling applications.

Existing methodologies for estimating PM emissions from construction activities are described below and are mostly "top down" methods. Their advantages and limitations are also explained.

4.1 Methodology 1: General "Top-Down" Emission Inventory

Most "top down" emission inventories of PM emissions from construction activities have utilized the current composite AP-42 emission factor as follows:

$$EF_{PM\text{-}k} = k \times EF_{TSP}$$

where: k = fraction of TSP that is PM-k
EF = emission factor, 1.2 tons TSP/acre/month

This emission factor requires only that the activity level (acres of construction and duration of the construction activity) be known for each type of construction. If construction activities are controlled, a fractional control efficiency is utilized:

$$\text{PM-k emissions} = EF_{PM\text{-}k} \times \text{acres of construction} \times \text{months of activity} \times (1 - CE)$$

where: CE = fractional control efficiency

The acres of construction are determined, usually from a published relationship of construction cost to acres disturbed. PM-k emissions are calculated by multiplying the TSP emission factor of 1.2 tons/acre/month by the PM-k/TSP ratio, the total acres disturbed by the construction activity and the months of activity. A control efficiency may be applied to reduce emissions.

For example, the PM_{10} emissions inventory for the Southern California Air Quality Management District's (SCAQMD) 1991 and subsequent 1994 Air Quality Management Plan used a PM_{10} emission factor of 0.31 tons/acre/month. This factor was based on the TSP emission factor of 1.2 tons/acre/month, a PM_{10} /TSP ratio of 0.52 (SCAQMD, 1991 and 1994), and a 50% emission reduction to account for watering as a dust control measure.[2]

The ratios of PM_{10} /TSP and $PM_{2.5}/PM_{10}$ are important because of their use to project PM_{10} and $PM_{2.5}$ emissions from TSP estimates. A typical ratio of 0.30 is used for PM_{10} /TSP. The *Criteria Document for Particulate Matter* (USEPA, 1996)[3] indicates a ratio for $PM_{2.5}/PM_{10}$ of approximately 0.15 for construction sites in Fresno, California. Other laboratory and field tests have indicated ratios of crustal $PM_{2.5}$ to PM_{10} in the range of 0.05 to 0.20, and are documented by Cowherd and Kuykendal.[4] They recommended a $PM_{2.5}/PM_{10}$ ratio of 0.15 for construction operations because of the typical dominance of unpaved road emissions.

The information on the acres of land disturbed by construction activity can be obtained from local government agencies and regional planning councils. Building permits usually specify the area of land and/or the cost of the construction. Permits are typically issued by city or county governments and require different levels of activity information.

The duration for an individual construction activity is likely to be identified in the building permit. An average duration can also be estimated using the MRI-developed values of 6 months for residential, 11 months for nonresidential, and 18 months for non-building construction.[5] Construction activity information can also be obtained from two major national sources, the U.S. Bureau of Census and from the McGraw-Hill Construction Information Group's *Dodge Construction Analysis System*, an on-line service that provides monthly-updated construction data for a fee.

The disturbed area can be determined by using the cost of the construction activity and published conversion factors for several construction types. This simple method uses the aggregated cost of construction in an area which is available from the U.S. Bureau of Census, Construction Statistics Division or from the U.S. Census Bureau's annual publication, *Privately Owned Construction Authorized by Building Permits.* The dollars-to-acres conversion factors are presented in Table 4-1 and are from the MRI report, *Emissions Inventory of Agricultural Tilling, Unpaved Roads and Airstrips, and Construction Sites.*[5]

Table 4-1. Construction Dollars-To-Acres Conversion Factors (MRI, 1974)[5]

SIC code	SIC description	Factor (acres/$\$10^6$)
1521	General Contractors-Single-Family Houses	5
1522	General Contractors-Residential Buildings, Other Than Single-Family	5
1531	Commercial, Institutional, Manufacturing, and Industrial Buildings	5
1541	General Contractors- Industrial Buildings and Warehouses	5
1542	General Contractors- Nonresidential Buildings, Other than Industrial Buildings	5
1611	Highway and Street Construction, Except Elevated Highways	25
1622	Bridge, Tunnel, and Elevated Highway Construction	25
1623	Water, Sewer, Pipeline, and Communications and Power Line Construction	5
1629	Heavy Construction; Non-building Structures Construction	150

Reference: Cowherd, Chatten, Christine Guenther, and Dennis Wallace. *Emissions Inventory of Agricultural Tilling, Unpaved Roads and Airstrips, and Construction Sites.* EPA-450/3-74-085, U.S. Environmental Protection Agency, Research Triangle Park, NC, November 1974.

Acres under construction, if obtained from construction cost data, are usually temporally resolvable only to a monthly level. It is possible to extrapolate to a daily emission estimate by dividing either annual or monthly emission estimates by the appropriate number of workdays in a month.

Table 4-2 identifies the original data resources used by MRI for the estimation of construction activity variables to support the methodology developed in 1974 for estimating county-by-county construction activity levels and emissions. Annual TSP emissions were estimated by MRI by determining the average construction duration (in months) for each type of construction and multiplying by the monthly emission estimate.

Table 4-2. Estimation of Construction Emissions—National Inventory by MRI

Variable	Data resource
Statewide dollars spent on construction	U.S. Bureau of Census, *Census of Construction 1972.*
Dollars-to-acres conversion factors	Developed by MRI using *Census of Construction 1972.*
County acres under construction	U.S. Bureau of Census, *Census of Construction 1972,* construction employment data.
Average duration of construction	Developed by MRI economists; 6 months for residential, 11 months for nonresidential, and 18 months for nonbuilding construction.

Reference: Cowherd, Chatten, Christine Guenther, and Dennis Wallace. *Emissions Inventory of Agricultural Tilling, Unpaved Roads and Airstrips, and Construction Sites.* EPA-450/3-74-085, U.S. Environmental Protection Agency, Research Triangle Park, NC, November 1974.

Summary. Using a composite emission factor of 1.2 tons TSP/acre/month is believed to overestimate PM_{10} emissions from construction activities. The emission factor assumes all construction produces emissions at the same level on a per acre basis. The indicator for the level of activity that occurs at construction sites, dollar value of construction, is a good indicator of activity but conversion factors may not be accurate for converting dollar value to acres for all types of construction. The emission factor and the conversion factors were developed in 1974 and require changes to reflect current construction activity and economic factors.

4.2 Methodology 2: NET Inventory

E.H. Pechan and Associates based the National Emission Trends (NET) inventory methodology on the general methodology developed by MRI in 1974 for a national inventory to estimate construction PM_{10} emissions. The activity level is acres under construction and is estimated using construction expenditures by SIC code. The NET methodology is described below, and differences from the MRI method (described in Section 4.1) are identified.

Section 4.8.2.7.1, "Construction Activities," of the *National Air Pollution Emission Trends Procedures Document for 1900-1996*[6] gives the calculation methodologies for PM_{10} emissions from construction activities for the years 1985 through 1996 and includes $PM_{2.5}$ emissions for 1990 through 1996. In a manner patterned after Methodology 1, emissions were calculated from the AP-42 composite emission factor, an estimate of the acres of land under construction, and the average duration of construction activity. The acres of land under construction were estimated from the dollars spent on construction.

The 1985 through 1989 emission calculation procedure incorporated the general AP-42 emission factor for determining PM_{10} emissions for construction activities during that time period:

$$E = T \times \$ \times f \times m \times P$$

where E = PM_{10} emissions
T = TSP emission factor (1.2 tons/acre)
$ = Dollars spent on construction ($ million)
F = Factor for converting dollars spent on construction to acres of construction (varies by types of construction, acres/$ million)
M = Months of activity (varies by type of construction)
P = Dimensionless PM_{10}/TSP ratio (0.22)

The 1990 through 1995 emission calculation procedure used the same basic equation but also accounts for a control efficiency level and calculates both PM_{10} and $PM_{2.5}$ emissions:

$$E = P \times \$ \times f \times m \times (1\text{-}CE)$$

where E = PM emissions
P = PM emission factor (tons/acre of construction/month of activity) (PM_{10} = 0.11; $PM_{2.5}$ = 0.022)
$ = Dollars spent on construction ($ million)
F = Factor for converting dollars spent on construction to acres of construction (varies by type of construction, acres/$ million)
M = Months of activity (varies by type of construction)
CE = Fractional control efficiency

Estimates for the dollars spent on various types of construction by EPA region for 1987 were obtained from the Census Bureau. The fraction of the total U.S. dollars spent in 1987 for each region for each construction type was calculated. Since the values from the Census Bureau are only available every five years, the Census dollars spent for the United States for construction were normalized using estimates of the dollars spent on construction for the United States as estimated by the F.W. Dodge Corporation for other years. This normalized Census value was distributed by region and construction type using the previously calculated fractions.

Construction acres were calculated using the proportionality developed by MRI between the number of acres and the dollars spent on that type of construction.[5] This information (proportioned to constant dollars using the method developed by Heisler)[7] was utilized along with total construction receipts to determine the total number of acres affected by each type of construction type. Estimates of the duration (in months) for each type construction were derived by MRI, from its 1974 report.[5]

The PM_{10}/TSP ratio for construction activities was derived from MRI research studies. Pechan used PM_{10}/TSP ratios for 19 test sites for three different construction activities presented in Table 9, "Net Particle Concentrations and Ratios" from the MRI Report "Gap Filling PM_{10} Emission Factors for Selected Open Area Dust Sources."[8] This report suggests averaging the ratios for the construction activity of interest. Since Pechan was looking at total construction emissions, the average PM_{10}/TSP ratios for all test sites were calculated and used for the

PM_{10}/TSP ratio. The PM_{10} emission factor 0.11 tons/acre/month is from the Best Available Control Method (BACM) Report, *Improvement of Specific Emission Factors.*[9] A particle size adjustment of 0.2 was used to convert PM_{10} to $PM_{2.5}$ emissions, after a review of $PM_{2.5}/PM_{10}$ ratios between EPA, Pechan, and MRI.[6] For the 1995 and 1996 NET inventories, the control efficiencies used for PM_{10} and $PM_{2.5}$ were 62.5 and 37.5 percent, respectively. No detail was provided on the rationale for the control efficiencies. [Note: MRI has reviewed past test data and found that the efficiency of watering, as a dust control method, is not related to the particle size fraction (i.e., the control efficiency should be the same for both PM_{10} and for $PM_{2.5}$).]

For the 1996 NET inventory, construction fugitive dust emissions were calculated from the composite TSP emission factor prepared by MRI for EPA, with default EPA correction parameters and 1996 Bureau of Census data. Controls were applied.[10] The total emissions are then allocated to the county level by county construction payrolls to develop a county-level inventory. Table 4-3 summarizes the Pechan methodology to develop NET emissions from construction activity.

Table 4-3. Estimation of Construction Emissions—EPA National Emission Trends Analysis by E.H. Pechan and Associates

Variable	Data resource
Statewide dollars spent on construction	U.S. Bureau of the Census, *Census of Construction Industries,* 1987, and F.W. Dodge/McGraw Hill, Inc. construction data (published annually).
Dollars-to-acres conversion factors	Midwest Research Institute, *Emissions Inventory of Agricultural Tilling, Unpaved Roads and Airstrips, and Construction Sites,* November 1974.
Average duration of construction	Midwest Research Institute, *Emissions Inventory of Agricultural Tilling, Unpaved Roads and Airstrips, and Construction Sites,* November 1974.

Reference: Barnard, William R., Allan Dean, and Patricia M. Carlson. *Evaluation of Fugitive Dust Emission Data, Draft Report,* E.H. Pechan & Associates, October 11, 1992.

Summary. The NET Inventory uses a "top-down" methodology and uses dollar value of construction as an indicator of activity level. The dollar value is found for nine EPA regions, and then emissions are allocated to the county level using county construction employment payrolls. The allocation does not give a good estimate for the actual county construction emissions because total emissions for the nine regions are divided among over 3,000 counties. The dollars-to-acres conversion factors based on 1972 dollars have been changed to reflect current dollar value and give a better estimate of acres disturbed. The 1996 NET Inventory uses an updated emission factor for construction activity and provides a better estimate of total PM_{10} emissions.

4.3 Methodology 3: California Emission Inventory Procedure

The methodology used in the *Emission Inventory Procedural Manual, Volume III, Methods for Assessing Area Source Emissions*[11] by the California Air Resources Board (CARB) is similar to the NET methodology, but calculates residential acreage by unit rather than cost and estimates for cost and number of units are from county sources.

The California manual's Section 7.7, "Building Construction Dust" presents a methodology for calculating construction emissions from fugitive dust using the same emission factor as used in the NET method plus a worst-case emission factor for heavy construction areas. The emission factors used are from a 1996 MRI report[9] in which an emission factor was developed using field test observations from eight construction sites in Las Vegas and California. The factors account for both exhaust emissions and fugitive dust emissions and do not account for any control measures, as is standard for all AP-42 construction emission factors.

Because acres under construction are not readily available for a geographic region, it must be estimated from either the value of construction or the units under construction. The CARB methodology uses an acreage per dollar conversion factor and an acreage per unit conversion factor to estimate total acres under construction. Residential construction acres are estimated on an acres/unit basis with single-unit residential construction having a factor of 1/5 acre/unit in rural areas and 1/7 acre/unit in urban areas. The factor for multi-unit residential construction is estimated at 1/20 acre/living unit. Commercial construction is estimated to affect 3.7 acres for every $1 million valuation. Likewise, industrial construction has a factor of 4.0 acres/$1 million valuation, and institutional construction a factor of 4.4 acres/$1 million valuation. The California methodology assumes that the emission factor includes the effects of typical control measures[11] even though the MRI report lists the factors as uncontrolled.[9] The procedure manual assumes a 50% control efficiency and recommends doubling the factor for areas in which watering is not used to control fugitive dust. Table 4-4 provides the estimates for the activity variables used in the California methodology.

Table 4-4. Estimation of Construction Emissions—California Methodology

Variable	Data resource
Residential construction acres	Uses default for acres/residential unit: 1/7 acre for single-unit residences in urban areas, 1/5 acre for single-unit residences in rural areas, and 1/20 acre/unit for multi-unit residences.
Nonresidential construction acres	Uses default values for acres/$1 million of construction. The factors for commercial, industrial, and institutional are 3.7, 4.0, and 4.4 acres/$1 million, respectively.
Construction duration	Uses default value of 6 months for single or multiple residential units and 11 months for commercial, industrial, and institutional construction.

Reference: Countess, Richard and Susan. PM_{10} Fugitive Dust Integration Project. South Coast AQMD Contract 96091, July 1996.

The California emission inventory includes a second section for calculating emissions from road construction. Section 7.8, "Road Construction Dust," uses the same emission factors from the BACM Report but uses different activity level indicators to find acreage disturbed. Road construction is divided into freeways, state highways, and city and county roads. The area affected is calculated from the miles of road built and the number of lanes, lane width, and shoulder width. The number of lanes, width per lane, and shoulder width are estimated for each type of roadway and from these estimates an area per mile factor is determined. The values determined in the California procedure are 12.1 acres per mile for freeways, 9.2 acres per mile for highways, and 7.8 acres per mile for city and county roads. All road construction is assumed to last 18 months.

The CARB uses a new computerized model, OFFROAD, to develop emission inventories of PM from construction equipment exhaust activities.

Summary. The CARB methodology uses housing units as an indicator of activity level for residential construction and dollar value for nonresidential construction. The dividing of the construction types and the conversion factors used in the California methodology give a higher level of accuracy to the estimate for the acres of land disturbed by construction. The CARB methodology indicates that the emissions calculated are for fugitive dust only and the OFFROAD model is used to estimate the construction equipment exhaust component. However, the emission factors used in the California methodology were derived from site testing, which includes both exhaust and fugitive dust. Thus the total PM emissions calculated by CARB for construction may be too high if both the Area Source Methodology and the OFFROAD model are used.

4.4 Methodology 4: National Particulate Inventory—Phase I

A national, county-level emission inventory of primary particulate (PM_{10} and $PM_{2.5}$) was prepared by E.H. Pechan and Associates under direction of EPA's Office of Policy, Planning, and Evaluation (OPPE). The National Particulate Inventory (NPI) projected emissions to the Year 2005 and utilized a methodology based largely on the methods used to develop the 1990 Interim Inventory, the NET inventory, and the 1985 NAPAP inventory.[12] Details of the methods were documented in a report to OPPE[13] and summarized in a paper presented at the 1997 A&WMA annual meeting.[12]

The methodology to estimate emissions from construction activities used the composite TSP factor of 1.2 tons/acre/month combined with ratios of PM_{10}/TSP and $PM_{2.5}/PM_{10}$. The ratios were stated to be derived from averages measured for three different construction activities at 19 sites.[12]

The activity level associated with the TSP factor is acres of land affected by the construction activities. Activity level data for development of the NPI, in acres, were obtained for states in each EPA Region from construction cost in the regional states. Construction cost date was used to find acres disturbed by using the same methodology as the NET Inventory.

State level emissions were allocated to county levels using construction payrolls from the *County Business Patterns* database, which provides county, state, and national level business data for 1977 to 1995. Statistics include number of establishments, payroll (annual and quarter), number of employees, and number of establishments by size class for 2-digit SIC industry groupings. The construction payroll data are collected annually by the Bureau of the Census.

Summary. The National Particulate Inventory follows the same methodology as the NET inventory and uses interim inventories to make future projections up to the Year 2005 for the emissions produced by construction activity.

4.5 Methodology 5: Regional Emission Inventories

The AP-42 Section 13.2.3, "Heavy Construction," provides emission factors for estimating site-specific construction emissions for specific construction phases (demolition, site preparation, etc.). This effort requires knowledge of the type and duration of construction phases that occur at each individual site. Examples of regional emission inventories of construction activities are presented below, as originally prepared for the MRI 1993 report, *Activity Levels of PM_{10} Area Source Categories Methodology Assessment and Improvement.*[14] These approaches demonstrate the use of local sources of construction activity level data.

4.5.1 San Joaquin Valley (SJV)

Activity levels could not be evaluated from the emission inventory report to the San Joaquin Valley Unified Air Pollution Control District PM_{10} Nonattainment Area Plan, prepared by Aerovironment, Inc., Monrovia, California, November 1991. The documentation of activity levels was not included in the report. Section 3 of the report presents results from a 1990 emission inventory, citing that calculations were performed by the CARB. Appendix A of that report presents the data from the CARB-developed emission inventory for the San Joaquin Valley. Appendix C of the report presents the only description of methodology, saying "the documentation of CARB methodology used for emissions inventory calculations was inadvertently omitted from the appendices attached to the 1991 PM_{10} Attainment Plan and accompanying this document. ARB has determined appropriate procedures for calculating each emissions inventory category." The SJV activity levels estimates are shown in Table 4-5.

Table 4-5. Estimation of Construction Emissions—SJV Methodology

Variable	Data resource
Areas under construction	CARB methodology was specified, but data sources not indicated.

Reference: San Joaquin Valley Unified Air Pollution Control District PM_{10} Nonattainment Area Plan, Aerovironment, Inc., Monrovia, CA, November 1991.

4.5.2 South Coast Air Quality Management District (SCAQMD)

The SCAQMD used the composite AP-42 TSP emission factor for construction activities in southern California. Activity data were presented in an MRI document[15] that determined total disturbed acres using the CARB methodology. Section 7-3, "Building Construction," presents ratios of construction units or valuation to acres of construction for residential, commercial, industrial, and institutional categories.

The number of construction units and value of construction were determined from the U.S. Census Bureau's annual publication, *Privately-Owned Construction Authorized by Building Permits*. It should be noted that U.S. Census Bureau data applies only to private construction. Public construction works such as a city convention center, airport, or similar public works are not included. The SCAQMD methodology is summarized in Table 4-6.

Table 4-6. Estimation of Construction Emissions—SCAQMD Methodology

Variable	Data resource
Units constructed and Value of construction	U.S. Census Bureau, *Privately Owned Construction Authorized by Building Permits* (an annual publication).
Acres under construction	CARB Area Source Methodology, Section 7-3 Building Construction; ratios of units or valuation to acres under construction.
Construction duration	Used CARB defaults for months of construction.

Reference: Phil J. Englehart and Gregory E. Muleski. *Open Fugitive Dust PM_{10} Control Strategies Study*, Midwest Research Institute: Kansas City, MO, October 12, 1990.

Data are available for SIC 47457-residential; 47365-commercial; 47373-industrial; and 54551-institutional construction.

A revised and more comprehensive emission inventory of SCAQMD construction sources was prepared by Richard and Susan Countess in their 1996 report, *PM-10 Fugitive Dust Integration Project*.[2] This report presented two useful tables for preparation of emission inventories. Table 4-7 shows a breakdown of construction activities and recommended that individual AP-42 emission factors be used when the required activity levels are known—rather than using the composite AP-42 TSP emission factor of 1.2 tons/acre/month. The recommended emission factors account for silt and moisture content, average wind speed, average vehicle speed, the number of vehicles, and climate.

Table 4-7. AP-42 Recommended PM_{10} Emission Factors for Construction Operations

Phase	Activity	AP-42 recommended emission factor reference	PM_{10} emission factor[1] (uncontrolled emissions)	Units
1. Demolition and debris removal	2. Demolition of buildings and natural obstacles			
	Mechanical dismemberment	NA	NA	
	Implosion of structure	NA	NA	
	Drilling/blasting soil	Drilling Factor in Table 11.9-4	1.3	lb/hole
	General land clearing	Dozer Equation (overburden) in Tables 11.9-1 and 11.9-2	$0.75\ (s)^{1.5}/(M)^{1.4}$	lb/hr
	3. Loading and unloading of debris into trucks	Material Handling Factor in Sec. 13.2.2	$0.0011(U/5)^{1.3}/(M/2)^{1.4}$	lb/ton
	4. Truck transport of debris			
	3a. Unpaved road travel	Unpaved Road emission factor in Sec. 13.2.2	$2.1(s/12)(S/30)(W/3)^{0.7}(w/4)^{0.5}(365\text{-}p/365)$	lb/VMT
	3b. Paved road travel	Paved Road emission factor in Sec. 13.2.2	$0.016(sL/2)^{0.65}(W/3)^{1.5}$	lb/VMT
2. Site Preparation	1. Bulldozing	Dozer Equation in Tables 11.9-1 and 11.9-2	$0.75(s)^{1.5}/(M)^{1.4}$	lb/hr
	2. Scrapers unloading topsoil	Scraper unloading factor in Table 11.9-4	0.04	lb/ton
	3. Scrapers in travel	Scraper (travel mode) expression in Tables 11.9-1 and 11.9-2	$0.0000037(s)^{1.4}/(M)^{2.5}$	lb/VMT
	4. Scrapers removing topsoil	5.7 kg/vehicle kilometer traveled (VKT)	20.2	lb/VMT
	5. Loading/unloading trucks	Material Handling Factor in Sec. 13.2.2	$0.0011(U/5)^{1.3}/(M/2)^{1.4}$	lb/ton
	6. Compacting	Dozer Equation in Tables 11.9-1 and 11.9-2	$0.75(s)^{1.5}/(M)^{1.4}$	lb/hr
	7. Motor grading	Grading Equation in Tables 11.9-1 and 11.9-2	$0.031(S)^2$	lb/VMT
3. General Construction	1a. Travel on unpaved roads	Unpaved Road emission factor in Sec. 13.2.2	$2.1(s/12)(S/30)(W/3)^{0.7}(w/4)^{0.5}(365\text{-}p/365)$	lb/VMT
	1b. Travel on paved roads	Paved Road emission factor in Sec. 13.2.2	$0.0126(sL/2)^{0.65}(W/3)^{1.5}$	lb/VMT

Table 4-7 (Continued)

Phase	Activity	AP-42 recommended emission factor reference	PM_{10} emission factor[1] (uncontrolled emissions)	Units
	2a. Portable plants crushing and screening	Factors for similar material/operations in Section 11 of AP-42	Factors for similar material/operations in Section 11 of AP-42	
	2b. Material transfers	Material Handling Factor in Sec. 13.2.2	$0.0011(U/5)^{1.3}/(M/2)^{1.4}$	lb/ton
	3. Other operations	Factors for similar material/operations in Section 11 of AP-42	Factors for similar material/operations in Section 11 of AP-42	

Note: s = silt content, %; M = moisture content, %; U = mean wind speed, mph; S = mean vehicle speed, mph; W = mean vehicle weight, tons; w = mean number of wheels/vehicle; sL = silt loading, g/m^2, and p = number of days with at least 0.01" of precipitation.

Because the composite AP-42 emission factor for TSP can provide only a rough estimate of PM_{10} emissions, MRI in their report to SCAQMD recommended alternative emission factors based on four different levels of construction activity knowledge, as seen in Table 4-8 from the report.

Table 4-8. Recommended PM_{10} Emission Factors for Construction Operations[c]

Basis for emission factor	Recommended PM_{10} emission factor
Level 1 Only area and duration known	0.11 ton/acre/month (average conditions) 0.42 ton/acre/month (worst-case conditions)[a]
Level 2 Amount of earth moving known, in addition to total project area and duration	0.011 ton/acre/month for general construction (for each month of construction activity) plus 0.059 ton/1,000 cubic yards for on-site cut/fill[b] 0.22 ton/1,000 cubic yards for off-site cut/fill[b]
Level 3 More detailed information available on duration of earth moving and other material movement	0.13 lb/acre-work hr for general construction plus 49 lb/scraper-hr for on-site haulage[c] 94 lb/hr for off-site haulage[d]
Level 4 Detailed information on number of units and travel distances available	0.13 lb/acre-work hr for general construction plus 0.21 lb/ton-mile for on-site haulage 0.62 lb/ton-mile for off-site haulage[c]

[a] Worst-case refers to construction sites with active large-scale earth moving operations.
[b] These values are based on assumptions that one scraper can move 70,000 cubic yards of earth in one month and one truck can move 35,000 cubic yards of material in one month. If the on-site/off-site fraction is not known, assume 100% on-site.
[c] If the number of scrapers in use is not knows, MRI recommends that a default value of 4 be used. In addition, if the actual capacity of earth moving units is known, the user is directed to use the following emission rates in units of lb/scraper-hour for different capacity scrapers: 19 for 10 yd^3 scraper, 45 for 20 yd^3 scraper, 49 for 30 yd^3 scraper, and 84 for 45 yd^3 scraper.
[d] Factor for use with over-the-road trucks. If "off-highway" or "haul" trucks are used, haulage should be considered "on-site".

[c] Some emission factors were revised by Countess based on median rather than mean values.

4.5.3 Phoenix

Construction activity levels for the Maricopa planning area were determined from the document, *PM_{10} Emissions Inventory Data for the Maricopa and Pima Planning Areas.*[16] The Maricopa County Air Pollution Bureau provided information on construction and earth moving permits, allowing location and area size to be tabulated. Information on permits is variable since each local governmental entity in the Phoenix metropolitan area establishes the information needed.

The Maricopa County Bureau of Air Pollution Control prepared a listing with addresses of approximately 1,500 earthmoving permits issued over a one-year period. Using a street atlas, each address for an earthmoving permit was manually located on a map of the inventoried area. Individual earthmoving permits listed the areas of disturbed earth and the lineal feet of trenching. A 20-ft width for each trench was assumed to allow calculation of area (acres for each disturbed site. All construction projects were assumed to have a 4-month duration so that a tons/acre/month inventory could be developed. An emission factor of 900 lb PM_{10}/acre was used, and appeared to be derived from the composite AP-42 TSP emission factor. The Phoenix methodology is summarized in Table 4-9.

Table 4-9. Estimation of Construction Emissions—Phoenix Methodology

Variable	Data resource
Acres under construction	Earthmoving permits from the Maricopa County Bureau of Air Pollution Control and the Pima County Air Quality Control District. Street addresses on permits were used to geographically map construction areas; approximately 1,500 permits had to be addressed. The permits listed acres of disturbed land and lineal feet of trenching; it was assumed that the disturbed width of trenches was 20 ft.
Construction duration	All construction projects were assumed to have a 4-month duration so that a tons/acre/month emission rate could be developed.

Reference: Donald R. Holtz. PM_{10} Emissions Inventory Data for the Maricopa and Pima Planning Areas, Engineering-Science; Pasadena, CA, January 1987.

4.5.4 Power/Bannock Counties

Construction-related emissions in an Idaho PM-10 nonattainment area were divided into (1) residential and commercial construction, and (2) road construction by Moore and Balakrishna.[17] They used AP-42 emission factors for construction activities, but devised unique ways to apportion emissions to smaller county areas (grid cells) for modeling purposes.

Residential and commercial construction activities were allocated to specific cells using U.S. Census tract data. Households were divided into low-, medium-, and high-growth areas, excluding urban areas. The numbers of households in each growth area were totaled and then divided by the total number in all three growth areas to obtain the percentage of households in each area. It was assumed that this percentage also applied to the number of construction events, and subsequently the percentage of emissions from construction. The calculated emissions for each growth area were divided equally among the total number of cells in each growth area.

Road construction activities were divided into (1) graveling, (2) rebuilding, (3) paving, and (4) sealing. Each activity was defined in terms of actual "road miles of construction" and "width" of the roads under construction. Road miles were multiplied by the road width that resulted in total acres of road being constructed. For road paving and sealing, the emission rate [factor] was reduced to half that of road graveling and rebuilding.

4.5.5 Las Vegas (Clark County, Nevada)

4.5.5.1 1991 Methodology

The 1991 emission inventory methodology began with the composite AP-42 TSP emission factor for construction activity. Activity levels for the Las Vegas, Nevada, nonattainment area were determined using the methodology presented in the document *Air Quality Implementation Plan for the Las Vegas Valley Particulate Matter PM_{10}*.[18] The primary piece of information was the total acres of construction, which was obtained from Topsoil Disturbance Permits from the Clark County Health District. Clark County requires Topsoil Disturbance Permits for land development activities affecting areas of 1/4 acre or more in size. These data are entered into the Clark County Geographic Information System (GIS) to calculate the total number of acres impacted by construction activities. There was no distinction between types of construction for the Las Vegas Valley.

PM_{10} emissions for Clark County were calculated using two components: (a) acres of construction, and (b) an emission factor of 654 lb PM_{10} per acre. A surrogate activity level factor was 1,000 gal diesel fuel/acre of construction, and resulted in a surrogate emission factor of 21.9 lb PM_{10} per 1,000 gal diesel fuel. These factors were "taken from research activities conducted in Arizona," and were not referenced or discussed further in the reviewed document. The 1991 Las Vegas methodology is summarized in Table 4-10.

Table 4-10. Estimation of Construction Emissions 1991 Las Vegas Methodology

Variable	Data resource
Gallons of diesel fuel	Estimate of 1,000 gallons of diesel fuel used in construction per acre of construction impacted land. This estimate was developed from a literature review that was referenced, but not discussed in the document.
Acres under construction	Clark County Health District Top Soil Disturbance Permits issued. Permits are required for any land development activity affecting more than one quarter of an acre. Permit data is entered into Clark County GIS for spatial distribution to each of 16 planning grids.

Reference: Clark County Department of Comprehensive Planning. Air Quality Implementation Plan for the Las Vegas Valley: Particulate Matter PM_{10}, Las Vegas, Nevada, November 5, 1991.

4.5.5.2 1998 Methodology[19]

The 1998 methodology to estimate annual PM_{10} emissions for the year 1995 was improved by staff from Clark County and considered three different sources of emissions during construction operations. "Construction activities" included grading, trenching, crushing, screening, on-site vehicle traffic, blasting, and demolition. A modified BACM[9] Level 1 methodology was used to estimate PM_{10} emissions, and required only the amount of land involved and the duration of the project, as separated into "large" and "remaining" projects. The average time to complete construction projects was defined as the number of months from initial ground breaking to final landscaping and paving.

A recommended BACM emission factor of 0.42 tons/acre/month was used for general construction sites that included cut and fill areas, large-scale earthmoving operations, or heavy traffic volumes. The BACM report also recommended an uncontrolled emission factor of 0.11 tons/acre/month for general construction sites that did not include any cut and fill areas, large-scale earthmoving operations, or heavy traffic volumes. Clark County judged that "remaining" projects (i.e., commercial, public parks, public buildings, residential homes, and miscellaneous) sometimes included cut and fill areas, large-scale earthmoving activities, and/or heavy traffic volumes.[19] Consequently, an average emission factor of 0.265 tons/acre/month [(0.42 + 0.11) / 2] was used for all construction projects other than "large" projects.

A control efficiency of 50 percent was applied because of local watering regulations, and using the control efficiency described in MRI's 1988 study for U.S. EPA OAQPS, "Control of Open Fugitive Dust Sources."[20] The control efficiency was then decreased by the percentage of construction sites implementing dust control, as estimated by air quality compliance officers.

"Track-out" dealt with *increased* paved road dust emissions due to dirt track-out from the construction site onto the adjacent paved street network. Track-out emissions were estimated for each type of construction using an estimated number of access points and vehicle traffic volumes on adjacent paved roadways. The number of access points ranged from 1 per 10 acres to 1 per 30 acres. Traffic that exited the access points was estimated at greater than 25 vehicles per day and corresponded to the associated emission factor. PM_{10} emissions from track-out were based on 13 grams/vehicle times the number of vehicle passes per day on the adjacent paved road, as recommended in the 1988 MRI report for EPA, "Control of Open Fugitive Dust Sources."[20] Traffic on adjacent paved roadways was estimated at 2,157 trips per day and was determined to match those from collector streets. This resulted in PM_{10} emissions of 0.0309 ton/day (except for public parks), from each track-out/access point. A control efficiency of 75 percent was stated to be determined from compliance rates for street sweeping and watering.

"Wind erosion" emissions from land exposed by construction activities were separately estimated. The methodology was based on geometric mean hourly emission rates from disturbed soils within the Las Vegas Valley, as reported in 1996 by David James, "Estimation of PM_{10} Emissions from Vacant Lands in the Las Vegas Valley." Wind speed dependent emission rates in tons/acre/hr were developed for nine wind speed classes (> 15 mph). These rates were adjusted for vegetative cover and for loss of loose surface material in an initial wind "spike." The annual number of hours of wind in each wind speed category for the year was then multiplied by the emission factor in tons/acre/hour of wind. This calculation produced a PM_{10} emission factor of 0.4472 tons/acre for 1995, and was applied to the permitted acres of construction in Las Vegas during that same year.

Summary. Regional emission inventories use more detailed information than is normally available at a national level for estimating county-level construction emissions. The methodologies do provide estimates that can be compared to estimates found using a composite emission factor to determine county-level emissions.

4.6 Methodology 6: Major Construction Project Inventory

A general conformity analysis of construction emissions associated with a major construction project provides a detailed and systematic procedure for inventorying fugitive dust PM_{10} emissions.[21] This large project [presumably for enlargement of an Arizona airport] consisted of seven construction phases: (1) first building; (2) second building; (3) parking lot; (4) fire station; (5) fuel storage facility; (6) maintenance hangar; and (7) large pavement project.

The inventory team used a spreadsheet to organize input data and calculate emission estimates. Data that were available to estimate PM_{10} emissions from the large construction project included:

- Project timelines and activity schedules
- Area and access points to the construction site
- Types of construction equipment
- Characterization of construction activities
- Quantities of material to be moved, crushed, and screened
- Precipitation and wind data
- Equipment speed and miles traveled
- Soil silt fraction and moisture content

The authors of the general conformity analysis stated that "Exhaust emissions associated with the construction activities have not been included." While this is true for generators and other stationary equipment, it is not true for AP-42 emission factors for PM from construction equipment activity. The emission factors for fugitive dust from construction equipment represent both exhaust and fugitive dust emissions because of the source profiling test method used by MRI to develop the AP-42 factors.

Direct PM emissions were estimated from demolition, site preparation, general construction, truck transport of debris, bulldozing, compacting, etc. Indirect emissions from transport and unloading of material to/from the construction site were also estimated. This included VMT estimates for paved road travel both on-site and off-site. Track-out emissions and wind erosion emissions from unpaved surfaces were also estimated. Wet suppression of fugitive dust sources was incorporated into the emission calculations using a control efficiency of 80 percent.

Summary. The detailed inventory done based on "unit-operation" emission factors is useful in determining the accuracy of emissions calculated for different types of construction activity using an emission factor for a specific type of construction and in determining which types of construction activity produce what amounts of emissions.

4.7 Methodology 7: U.S. EPA NONROAD Model

The U.S. EPA Office of Mobile Sources, Assessment and Modeling Division has developed a model for estimating non-road engine exhaust emissions. A second draft version of the NONROAD model was announced May 21, 1999 with the signing of the Tier 2/ Gasoline Sulfur Notice of Proposed Rulemaking. The model is available at http://www.epa.gov/oms/nonrdmdl.htm.

Construction equipment exhaust emissions are calculated using national or state engine population for each equipment/engine type. The engine populations are obtained from the PartsLink database available from Power Systems Research (a commercial source of data), and multiplied by the average power, activity, and emission factors to obtain pollutant emissions. The NONROAD model estimates exhaust emissions under "load" and "no load" conditions. Engine load is related to soil density, cycle time (distance/speed), and pull required (rolling resistance + grade resistance.) The following equation shows how NONROAD calculates emissions.

$$\text{Emissions} = (\text{Pop})(\text{Power})(\text{LF})(\text{UL})(\text{EF})$$

where:
- Pop = Engine population
- Power = Average power of equipment type (hp)
- LF = Load Factor (fraction of available power)
- UL = Usage level (hrs/yr)
- EF = Exhaust emission factor (g/hp-hr)

This equation shows that the NONROAD model uses a multi-parameter activity level combining engine population number with average power, load factor, and usage level. The primary element is the number of engines in an area, distributed by age, power, fuel type, and application. Each equipment/engine type is characterized for usage by horsepower-hours per year, and adjusted for a power load factor. Nationally-averaged horsepower-hours and the relative fraction of maximum available power are used.

The most important data for construction activity levels that are input to the NONROAD model originate from the 1996 PSR equipment population data (PartsLink), and revised population allocation data using the F.W. Dodge construction valuation data. Engine populations are divided into several discreet power levels rather than one average power level for each equipment application. Equipment populations are adjusted using the F.W. Dodge construction valuation data. An engine scrappage rate is assumed and the level of activity is a function of equipment age. The model is flexible and allows a "bottom up" approach with locally-derived estimates for all variables to estimate and allocate emissions from state to counties and sub-counties.

NONROAD input files are integral to the model and provide basic data by state and county that are required to calculate emissions: exhaust emission factors, base year equipment population, activity levels, load factor, average lifetimes, scrappage rates, growth estimates, and geographic and temporal allocation algorithms. Default values are provided in these input files, but the user can replace the default data with better information, either from EPA for national defaults or from local sources for locality-specific data. The input files can also be modified to test control strategies.

The NONROAD model can estimate current year emissions for a specified geographic area as well as project future year emissions and backcast past year emissions. Emissions can also be calculated for time periods—an entire year, one of the four seasons, or any particular month. The emissions are then temporally and geographically allocated using appropriate allocation factors.

One of the current shortfalls of the NONROAD model to predict emission estimates for construction activities is that the model accounts for only exhaust emissions from construction equipment. A simple correlation of fugitive dust emissions with exhaust emissions is not possible. For example, construction equipment will be under load at the earth cutting location and will emit high levels of exhaust emissions, but little fugitive dust will be generated because of typical sub-grade high moisture content. As the loaded equipment travels to the fill location, high levels of fugitive dust will be emitted from the exposed ground but the equipment may not emit high levels of exhaust emissions.

An EEA report of 1997 developed data on construction employees to scale equipment population as a function of construction employees, but this method did not include all types of construction activity. Sierra Research, SAI, ENVIRON, and the Texas Transportation Institute also have examined and used survey methods for obtaining information on construction equipment usage for input to the NONROAD model. Survey data of current construction projects were needed to provide location-specific data on a daily level.

The EPA model, PART5, was developed by the Office of Mobile Sources (OMS) to estimate PM emissions from only onroad vehicles, and is discussed here for background information and comparison of vehicle emission estimation methodologies. The name indicates consistency with the MOBILE5 model used to calculate emissions of other pollutants from onroad vehicles.

PART5 uses PM emission factors for direct and indirect sulfate, and carbon (soluble organic fraction and remaining carbon portion) to calculate exhaust emissions. Road dust, tire wear, and brake wear emissions are also calculated. The PART5 program uses VMT to calculate PM emissions in gram/mile. VMT data are obtained using onroad travel statistics available from local survey information maintained by state and local transportation agencies and assembled by the FHWA. VMT data are not collected for non-road sources, such as construction equipment.

Summary. The NONROAD model estimates PM emissions only from construction equipment exhaust. The model is useful to determine the exhaust emission component of the total emissions calculated using the AP-42 emission factor that includes both suspended dust and exhaust PM. The PART5 model does not apply to construction activities because it estimates vehicle exhaust emissions from onroad vehicles only.

Methodologies 1 through 6 are summarized in Table 4-11.

Table 4-11. Emission Inventory Methodologies

Emission Calculation Parameters			
Inventory	Emission Factor	Activity Level Source	Notes
MRI National Inventory, 1974	1.2 tons/acre/month (TSP) AP-42	Construction Dollars and dollars to acres conversion factors(MRI developed factors,1972)	MRI durations of construction: 6 months residential, 11 months nonresidential, 18 months nonbuilding
National Emission Trends	1.2 tons/acre/month (TSP) AP-42 adjusted to PM_{10} and $PM_{2.5}$ PM_{10} = .26	Construction Dollars and dollars to acres conversion factors(MRI factors, adjusted using Heisler's method)	MRI durations: 6 months residential, 11 months nonresidential, 18 months nonbuilding
National Particulate Inventory	1.2 tons/acre/month(TSP), AP-42; used PM_{10}/TSP and $PM_{2.5}$/PM_{10} ratios derived from EPA "Gap Filling PM_{10} Emission Factors for Selected Area Dust Sources"	Emissions and methods derived from 1993 National Emission Trends Inventory	
California Air Resources Board (CARB)	1.2 tons/acre/month (TSP) AP-42 adjusted to PM_{10} and $PM_{2.5}$	Construction Dollars or Number of Units Constructed; CARB conversion factors for dollars to acres and units to acres	CARB Default Values: 6 months residential, 11 months commercial, industrial, and institutional
South Coast Air Quality Management District	0.31 tons PM_{10}/acre/month (based on AP-42 TSP emission factor)	CARB Methodology	CARB Defaults for Construction Duration
San Joaquin Valley	CARB Methodology	CARB Methodology	CARB Methodology
Las Vegas (Clark Co., NV) 1991	654 lb PM_{10}/acre (activity) plus 21.9 lb PM_{10}/1000 gal diesel fuel (equipment)	Top Soil Disturbance Permits for acres disturbed	Conversion of 1 acre of construction impacted land to 1000 gal. of diesel fuel
Las Vegas (Clark Co., NV) 1997	Heavy Construction—0.42 tons/acre/mo.; Other Construction—0.265 tons/acre/mo.; Track-Out—0.0309 ton/day/access pt. (based on traffic volume of 2,157 trips/day) Wind Erosion—0.4472 ton/acre, dependent on 1995 windspeeds	Topsoil Disturbance Permits for acres disturbed; other local data from air quality and metropolitan agencies	See text
Phoenix	900 lb PM_{10}/acre	Earth Moving Permits for acres disturbed	4 months for all construction projects
Power/ Bannock, 1996	1.2 tons/acre/month (TSP) AP-42 recommended emission factor		

Section 5.
Recommended Methodologies and Data Sources

This section presents an improved emission inventory procedure that calculates both exhaust and fugitive dust emissions from construction activities. The recommended procedure provides a balance between a "top-down" inventory and "bottom-up" inventory methodology. PM emissions at the county level are more accurately estimated for different types of construction operations using improved indicators of activity levels.

5.1 Assumptions and Limitations of Current Methodologies

The NET procedure and the CARB methodology both make assumptions and also use estimates that may no longer be applicable because of the date of their development. The NET methodology uses a single, composite emission factor for all types of construction based only on the dollar amount spent on construction. The first assumption is that all construction activity produces the same amount of dust on a per acre basis. The amount of dust produced is not dependent on the type of construction but merely on the area of land being disturbed by the construction. A second assumption is that land affected by construction activity is always affected the same amount, i.e., the methodologies do not account adequately for large scale cut and fill operations. Also, the methodologies are limited in that the conversion factors used to convert dollars spent on construction to acreage disturbed, along with the estimates for the duration of construction activity, were developed by MRI in 1974 and may result in a loss in reliability in calculating emissions.

5.2 Recommended Changes to the NET Methodology

MRI recommends the following changes to the current NET methodology. Following the California methodology, residential construction acreage should be based on the number of units constructed rather than the dollar value of construction. Accounting for the construction of foundations is also seen as a necessary change because of the difference in the amount of dirt moved when constructing a slab foundation as compared to a basement. Highway construction with significant cut and fill operations should be based on the new miles of highway constructed in each county. The control efficiency used in the 1996 Trends inventory for PM_{10} was 62.5% and was 37.5% for $PM_{2.5}$. MRI recommends using a control efficiency of 50% for both PM_{10} and $PM_{2.5}$ for areas in which dust control measures are used. The estimates for the duration of construction activity levels also need to be revised for each construction category.

increase factor to account for sig cut + fill

5.3 General Emission Factor for Construction

Construction emissions can be estimated when two basic construction parameters are known, the acres of land disturbed by the construction activity and the duration of the activity. As a general emission factor for all types of construction activity, MRI recommends using 0.11 tons PM_{10}/acre/month that is based on a 1996 BACM study by MRI prepared for the California South Coast Air Quality Management District (SCAQMD).[9] However, separate emission factors segregated by type of construction activity provide better estimates of PM_{10} emissions and give a more accurate estimate than could be obtained using a general emission factor. Specific emission factors and activity levels for residential, nonresidential, and road construction are described below.

5.4 Residential Construction Emissions

Residential construction emissions are calculated for three basic types of residential construction:

- Single-Family Houses
- Two-Family Houses
- Apartment Buildings

5.4.1 Emission Calculation Procedure

Emissions for housing construction activities are estimated using emission factors from the MRI BACM report.[9] Housing construction emissions are calculated using an emission factor of 0.032 tons PM_{10}/acre/month, (as recommended by the SCAQMD[2]), the number of housing units created, a units-to-acres conversion factor, and the duration of construction activity. The formula for calculating emissions from residential construction is:

$$\text{Emissions} = (0.032 \text{ tons } PM_{10}/\text{acre/month}) \times B \times f \times m$$

where: B = the number of houses constructed
f = buildings-to-acres conversion factor
m= the duration of construction activity in months

Figure 5-1 illustrates the calculation of residential construction emissions.

Residential Construction

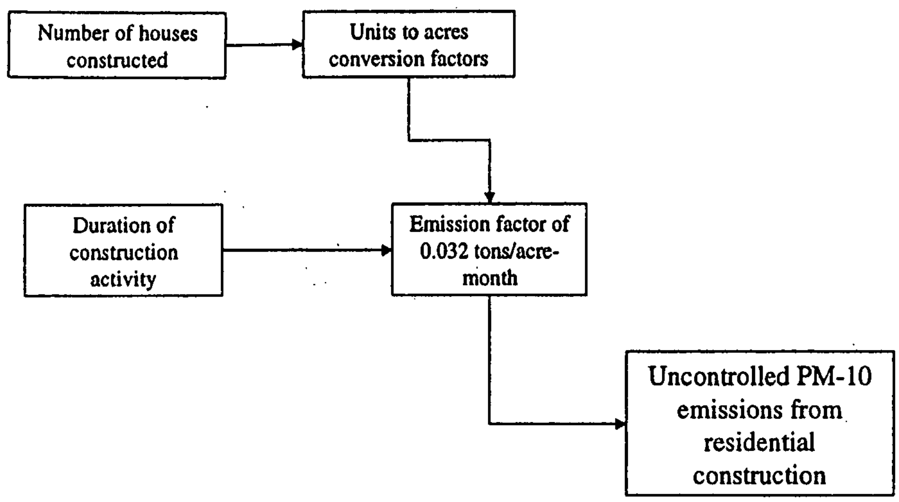

Figure 5-1. Residential Construction Emissions Flowchart

Apartment buildings vary in size, number of units, square footage per unit, floors, and many other characteristics. Since these variations exist and most apartment buildings occupy a variable amount of space, a dollars-to-acres conversion is recommended for apartment building construction rather than a building-to-acres factor. The estimate of 2.0 acres/$\$10^6$ (in 1992 constant dollar value) is recommended to determine the acres of land disturbed by the construction of apartments. The dollars-to-acres conversion factor was updated to a 1992 constant dollar value using the Construction Cost Index found in the annual edition of Statistical Abstract of the United States. A new estimate for the acres under construction per million dollars was developed using the difference in the 1992 index value and an estimated 1974 value. The approximately 40% difference led to an updated factor of 2 acres/$\$10^6$ derived from the original 5 acres/$\$10^6$ developed by MRI in 1974, The emission factor recommended for the construction of apartment buildings is 0.11 tons PM_{10}/acre/month because apartment construction does not normally involve a large amount of cut-and-fill operations.

An alternative formula is recommended for residential construction in areas in which basements are constructed or the amount of dirt moved at a residential construction site is known. The F.W. Dodge reports give the total square footage of homes for both single-family and two-family homes. This value can be used to estimate the cubic yards of dirt moved. Multiplying the total square feet by an average basement depth of 8 ft. and adding in 10% of the cubic feet calculated for peripheral dirt removed produces an estimate of the cubic yards of earth moved during residential construction. The added 10% accounts for the footings, space around the footings, and other backfilled areas adjacent to the basement. The cubic yards of earth moved along with the number of houses constructed can be used with the BACM Level 2 equation (emission factor of 0.011 tons PM_{10}/ acre/month plus 0.059 tons PM_{10}/1000 cubic yards of on-site cut/fill) to calculate emissions for regions in which basements are constructed or a large amount of dirt is moved during most residential construction. The Level 2 equation produces a slightly higher estimate of PM_{10} emissions than would be estimated using the residential construction emission equation.

5.4.2 Data Sources and Assumptions

The information available to determine activity level of residential construction is the dollar value of construction put in place and the number of units constructed. Construction costs vary throughout the United States and residential construction characteristics do not show as much variance as the cost does, so the number of units constructed is a better indicator of activity level. The amount of land impacted by residential construction is determined to be about the same on a per house basis rather than a per dollar basis. The average 2000 sq. ft. home can vary from the low to upper $100,000s depending on where the home is located in the United States. Incorporating a dollars-to-acres conversion factor would give a larger estimate for the acreage of land disturbed even though the construction affects the same amount of land as an area with a lower dollar value for residential construction and vice versa.

The number of housing units constructed by a county or state are available from the F.W. Dodge's "Dodge Local Construction Potentials Bulletin." Housing units are available for the three types of residential construction previously mentioned.

The conversion for single-family housing is estimated to be 1/4 acre per house. The conversion factor was determined by finding the area of the base of a home and estimating the area of land affected by grading and other construction activities beyond the "footprint" of the house. The average home is around 2000 sq. ft. Using a conversion factor of 1/4 acre/house indicates that five times the base of the house is affected by the construction of the home. This estimate is reasonable when considering the amount of grading, cut and fill, and transportion of materials on the property that occurs during residential construction.

The conversion for two-family housing was found to be 1/3 acre per building. The 1/3 acre was derived from the average square footage of a two-family home, around 3500 sq. ft., and the land affected beyond the base of the house, about 4 times the base for two-family residences.

5.4.3 Example Emission Calculation

Table 5-1 presents an example calculation of county-level emissions for residential construction.

Table 5-1. Example Annual PM_{10} Emissions from Residential Construction in a Hypothetical County

Residential type	No. of buildings	Acreage per building	Total Acres disturbed	Duration of construction	Emission factor (tonsPM_{10}/ acre/month)	Uncontrolled PM_{10} (tons)	PM_{10} control efficiency (%)	Controlled PM_{10} (tons)
Single-family	2422	1/4	606	6	0.032	116	0	116
Two-family	48	1/3	16	6	0.032	3.1	0	3.1
Apartment	59	1/2	30	12	~~0.032~~ 0.11	11.3	0	11.3
Total						130		130

A comparison of emission calculations using unit-operation emission factors, the residential construction emission equation, and the BACM Level 2 calculation shows that the Level 2 equation provides a higher estimate of emissions than using the general residential emission factor. The unit-operation emission calculation for bulldozing and grading produces an estimate similar to that from the Level 2 equation. The general residential emission factor calculates PM_{10} emissions from the construction of one single-family home to be 96 lbs/house. The Level 2 equation for a single-family home with a basement produces emissions of 109 lb PM_{10}/house. The emission calculation for bulldozing and grading estimates emissions to 112 lb/house PM_{10} (assuming 10 days of operation, 8% silt content, and 6% moisture content).

The comparison of residential construction emission methods for one single-family home were based on typical parameters for a single-family home:

- area of land disturbed 1/4 acre
- area of home 2000 sq. ft.
- duration 6 months
- basement depth 8 ft.
- moisture level 6%
- silt content 8%

Residential construction emission factor calculations are shown below. The general residential calculation is:

$$0.032 \text{ tons } PM_{10}/\text{acre/month} \times 1/4 \text{ acre} \times 6 \text{ months} = 0.048 \text{ tons or } 96 \text{ lb } PM_{10}$$

The BACM Level 2 emission calculation is:

Cubic yards of dirt moved: 2000 ft^2 x 8 ft. x 110% = 17600 ft^3 = 652 yd^3

(0.011 tons PM_{10}/acre/month x 1/4 acre x 6 months)+
(0.059 tons PM_{10}/1000 yd^3 dirt x 652 yd^3 dirt) =
0.016 +0.038 = 0.0545 tons or 109 lb PM_{10}
33 +76

The Unit Operation Emissions (Bulldozing) calculation from AP-42 is:

$PM10 = 0.75\ (s)^{1.5}/(M)^{1.4} = 0.75\ (8)^{1.5}/(6)^{1.4}$
= 1.4 lb PM_{10}/hr x 10 days x 8 hours = 112 lb PM_{10}

5.5 Nonresidential Construction Emissions

Nonresidential construction includes building construction (commercial, industrial, institutional, governmental) and also public works.

5.5.1 Emission Calculation Procedure

The emissions produced from the construction of nonresidential buildings are calculated using the value of the construction put in place. The formula for calculating the emissions from nonresidential construction is:

Emissions = (0.19 tons PM_{10}/acre/month) x \$ x f x m

where: \$ = dollars spent on nonresidential construction in millions
f = dollars-to-acres conversion factor
m = duration of construction activity in months

Figure 5-2 illustrates the calculation of PM_{10} emissions from non residential construction.

The emission factor of 0.19 tons PM_{10}/acre/month was developed using a method similar to a procedure originated by Clark County, NV (Las Vegas) and the emission factors recommended in the MRI BACM Report.[9] A quarter of all nonresidential construction is assumed to involve active earthmoving in which the recommended emission factor is 0.42 tons PM_{10}/acre/month. The 0.19 tons PM_{10}/acre/month was calculated by taking 1/4 of the heavy construction emission factor, 0.42, plus 3/4 of the general emission factor 0.11 tons/acre/month. The 1/4:3/4 apportionment is based on a detailed analysis of a Phoenix airport construction where specific unit operations had been investigated for PM_{10} emissions[21].

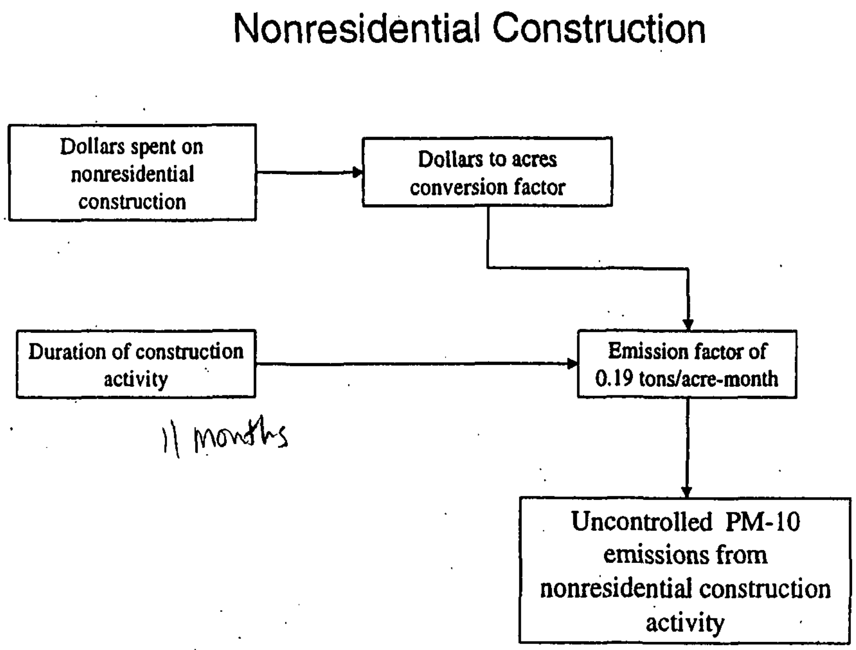

Figure 5-2. Nonresidential Construction Emissions Flowchart

Regions known to have extensive earthmoving activities will produce higher amounts of PM_{10} emissions. Since this larger amount would not be accounted for in building construction, the BACM "heavy construction emission factor" of 0.42 tons PM_{10}/acre/month may provide a better estimate for areas in which a significant amount of earth is disturbed.

An emission inventory for a 114-acre airport project[21] provides a comparison of detailed PM_{10} emissions as contrasted with the new recommended PM_{10} emission factor of 0.19 tons/acre/month. The results show total uncontrolled PM_{10} emissions using the detailed unit operation emission inventory methodology is 210 tons PM_{10} for the duration of the construction. The proposed emission factor results in total uncontrolled PM_{10} emissions of 260 tons PM_{10}. The new factor along with the acres under construction as an indicator of activity level provides an estimate of PM_{10} emissions from nonresidential construction within 25% of the emissions calculated using detailed engineering plans and "unit-operation" emission factors.

5.5.2 Data Sources and Assumptions

The dollar amount spent on nonresidential construction is available from the U.S. Census Bureau, Census of Construction Industries and the Dodge Construction Potentials Bulletin. Census data are divided by SIC Code whereas the Potentials Bulletin divides activity by the types of building being constructed rather than by SIC Code.

MRI has determined that the previous 1974 dollars-to-acres conversion factors can be updated to a single factor for nonresidential, nonroad construction. It is estimated that for every million dollars spent on construction, in 1992 constant dollars, 2 acres of land are impacted. The conversion factor reflects the current dollar value using the Price and Cost Indices for Construction that are available from the Statistical Abstract of the United States, published yearly. For example, the 1997 dollars-to-acres conversion factor would be 2/(118.7%) or 1.7 acres/ $ 10^6. The estimate for the duration of nonresidential construction is 11 months.

5.5.3 Example Emission Calculation

Table 5-2 presents an example calculation of 1992 PM_{10} emissions from nonresidential, nonroad construction for a hypothetical county.

Table 5-2. Example 1992 PM_{10} Emissions for Nonresidential Construction in a Hypothetical County

Construction put in place ($\$10^6$)	1992 ($ to acres)	Acres disturbed	Duration of activities	PM_{10} emissions factor (tons/acre/month)	Uncontrolled PM_{10} (tons)
57.7	2 acres/$\$10^6$	115	11	0.19	240

5.6 Roadway Construction Emissions

Roadway construction emissions are highly correlated with the amount of earthmoving that occurs at a site. Almost all roadway construction involves extensive earthmoving and equipment travel, causing emissions to be higher than found for other construction types.

5.6.1 Emission Calculation Procedure

The PM_{10} emissions produced by road construction are calculated using the BACM recommended emission factor for heavy construction and the miles of new roadway constructed. The formula used for calculating roadway construction emissions is:

$$\text{Emissions} = (0.42 \text{ tons } PM_{10}/\text{acre/month}) \times M \times f \times d$$

where: M = miles of new roadway constructed
f = miles-to-acres conversion factors
d = duration of roadway construction activity in months

The emission factor of 0.42 tons/acre/month is used to account for the large amount of dirt moved during the construction of roadways. Since most road construction consists of grading and leveling the land, the higher emission factor more accurately reflects the high level of cut and fill activity that occurs at road construction sites. Figure 5-3 illustrates the calculation of road construction emissions of PM_{10}.

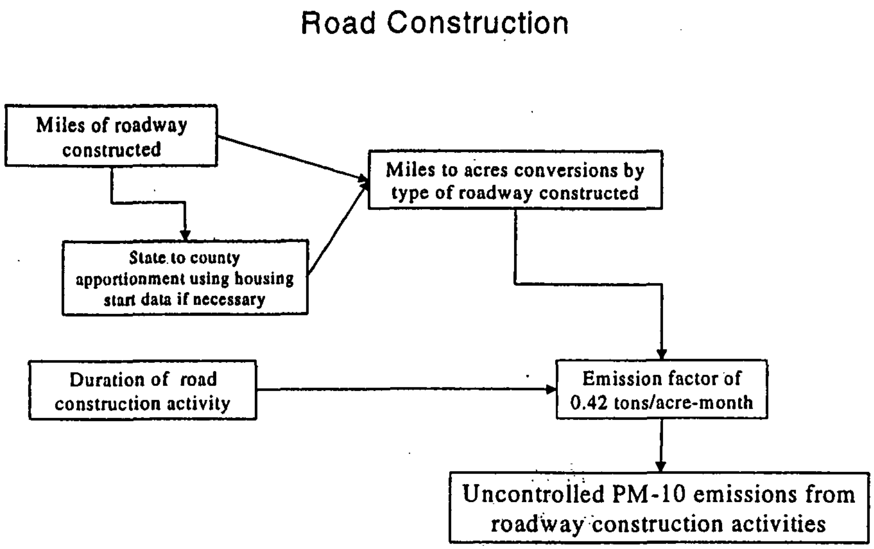

Figure 5-3. Road Construction Emissions Flowchart

5.6.2 Data Sources and Assumptions

The miles of new roadway constructed are available at the state level from the *Highway Statistics* book published yearly by the Federal Highway Administration and the Bureau of Census' Statistical Abstract of the United States. The miles of new roadway constructed can be found by determining the change in the miles of roadway from the previous year to the current year. The amount of roadway constructed is apportioned from the state to the county level using housing start data that is a good indicator of the need for new roads.

The conversion of miles of roadway constructed to the acres of land disturbed is based on a method developed by the California Air Resources Board. This calculation is done by estimating the roadway width, then multiplying by a mile to determine the acres affected by one mile of roadway construction. The California conversion factors are for freeway, highway and city/county roads. In the *Highway Statistics* book, roadways are divided into separate functional classes. MRI developed the miles-to-acres conversion according to the roadway types found in the "Public Road Length, Miles by Functional System" table of the annual *Highway Statistics*. The functional classes are divided into four groups. Group 1 includes Interstates and Other Principal Arterial roads and is estimated to have a conversion factor of 15.2 acres/mile. Group 2 includes Other Freeways and Expressways (Urban) and Minor Arterial Roads and is estimated at 12.7 acres/mile. Group 3 has Major Collectors (Rural) and Collectors (Urban) and a conversion factor of 9.8 acres/mile. Minor Collectors (Rural) and Local roads are included in Group 4 and converted at 7.9 acres/mile. Table 5-3 shows the data used to calculate the acres per mile of road constructed.

Table 5-3. Road Miles-to-Acres Conversion Calculation

	Group 1	Group 2	Group 3	Group 4
Lane Width (feet)	12	12	12	12
Number of Lanes	5	5	3	2
Average Shoulder Width (feet)	10	10	10	8
Number of Shoulders	4	2	2	2
Roadway Width* (feet)	100	80	56	40
Area affected beyond road width	25	25	25	25
Width Affected (feet)	125.0	105.0	81.0	65.0
Acres Affected per Mile of New Roadway	15.2	12.7	9.8	7.9

*Roadway Width= (Lane Width x # of Lanes) + (Shoulder Width x # of Shoulders)

Since the amount of new roadway constructed is available on a yearly basis, the duration of the construction activity is determined to be 12 months. The duration accounts for the amount of land affected during that time period and also reflects that construction of roads normally lasts longer than a year. The estimate for the duration of construction to find the total emissions produced by the construction over the length of the activity is 18 months.

5.6.3 Example Emission Calculation

Table 5-4 presents an example calculation of PM emissions from road construction. State miles are obtained from Table HM-50 in the annual report of the FHWA Report, *Highway Statistics*. State emissions are apportioned to the county level based on new housing statistics that are believed to be a good indicator for the construction of new road mileage.

Table 5-4 Example PM_{10} Emissions from Road Construction in a Hypothetical County

Road Type	State road mileage 1996	1997	New 1997 state road mileage	Miles to Acre factor	Affected state acres	Duration of construction (mo)	Emission factor (tons PM10/acre/ month)	State uncontrolled PM_{10}emissions (tons)	County X uncontrolled PM_{10} emissions (tons)*
1	2980	3030	50	15.2	760	12	0.42	3830	192
2	3470	3530	60	12.7	762	12	0.42	3840	192
3	4200	4400	200	9.8	1960	12	0.42	9878	494
4	11100	11500	300	7.9	2370	12	0.42	11945	597

*Based on 0.05 fraction of state housing constructed in County "X".

5.7 Correction Parameters

The regional variances in construction activity, as previously mentioned, cause PM emissions to vary even though the same level of activity may occur at construction sites. These differences are accounted for using correction parameters.

5.7.1 Control Efficiency

The first correction parameter accounts for the emission reductions afforded by dust control measures used at construction sites. At most large construction sites watering is used to control dust suspended by construction equipment activity and vehicle travel on unpaved roads. The recommended emission factors are representative of uncontrolled sites which is consistent with the AP-42 manual. The recommended control efficiency for PM emissions, including PM-10 and PM-2.5, is 50% based on data presented in Reference 20 and recent MRI unpaved road tests.

5.7.2 Soil Moisture Level and Silt Content

The emission factors developed in the BACM report were developed from test sites in the southwestern United States which have different moisture levels and silt contents than other areas in the country. To account for the differences in moisture level and silt content, adjustments are applied to the controlled PM emissions.

Soil moistures for the areas from which the emission factors were developed are typically much lower than other regions. Thornthwaite's Precipitation-Evaporation Index ranges from 7 to 41 and is shown in Figure 5-4. The average value for the test sites is 24. The adjustment for moisture is:

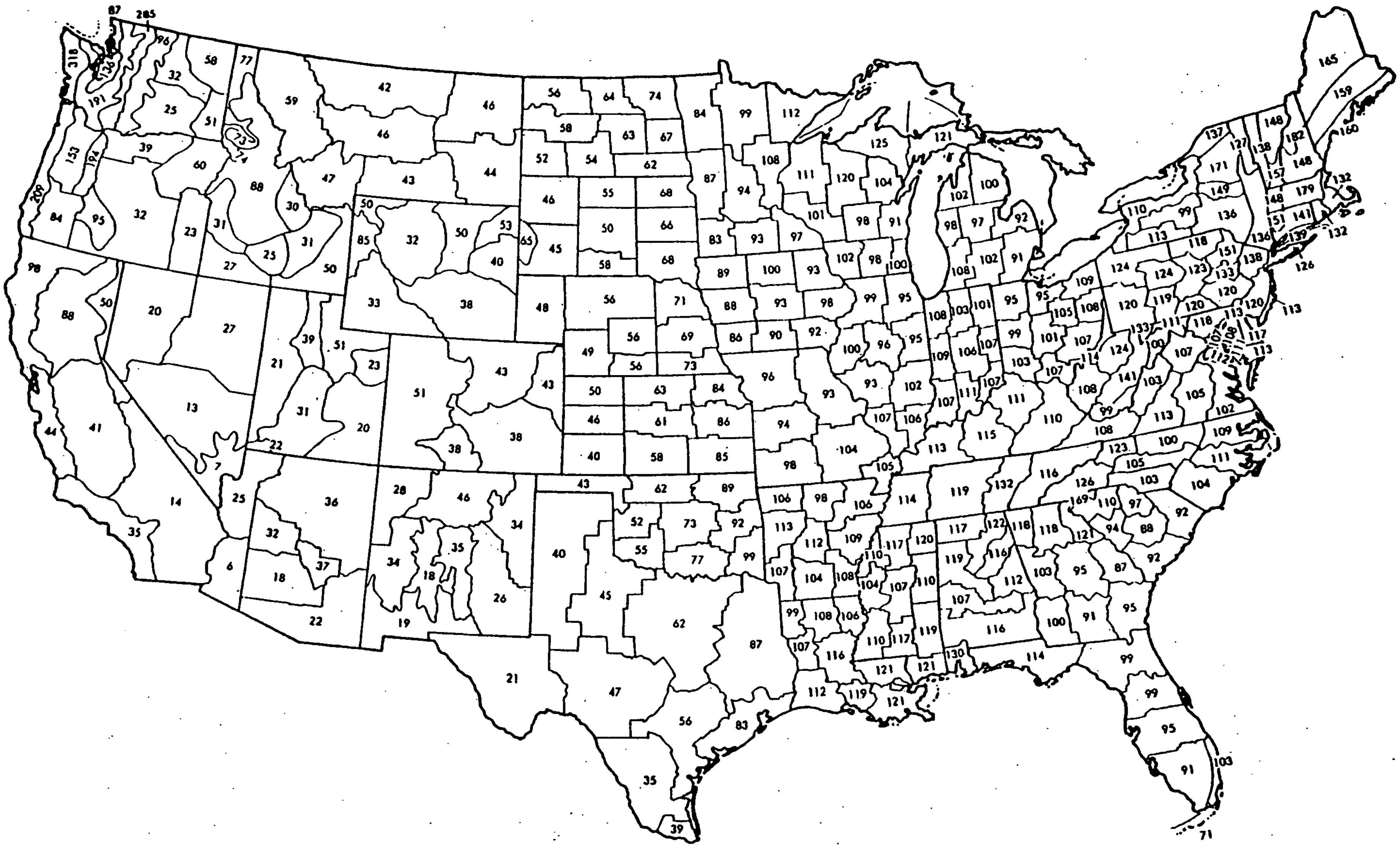

Figure 5-4. Map of PE Values for State Climatic Divisions

Moisture Level Corrected Emissions = Base Emissions x (24/PE)

where PE = the Precipitation-Evaporation value for the county being inventoried

The average dry silt content found for the test sites in the BACM report was 9%. To adjust for the level of silt content of surface soil in a particular county, a proportionality is used along with the base emissions. The equation to adjust for silt content is:

Silt Content Corrected Emissions = Base Emissions x (s / 9%)

where s = % dry silt content in soil for area being inventoried

The silt content of soil for a county can be found using the same procedure as in the NET Inventory. Section 4.8.2.2.1.1 in Reference 6 gives the methodology for determining the silt percentage of soils. The silt percentage is corrected using information from the California ARB which gives the conversion from a wet silt value to a dry silt value[23]. The dry silt percentage is used as a correction parameter for construction emissions. Typical silt contents for the various soil types are listed in Table 5-5, as reported in Reference 6.

Table 5-5. Dry Silt Content by Soil Type

Soil type	Silt content (%)
Silt Loam	52
Sandy Loam	33
Sand	12
Loamy Sand	12
Clay	29
Clay Loam	29
Organic Material	10-82
Loam	40

5.7.3 Emissions Adjustments

County level emissions of PM_{10} should be adjusted for dust control measures, precipitation/evaporation, and dry silt content of the soil. PM_{10} emissions can also be used to estimate $PM_{2.5}$ emissions using a $PM_{2.5}/PM_{10}$ ratio.

$PM_{2.5}$ Emissions = Uncontrolled PM_{10} Emissions x 50% x (24 / PE) x (s / 9%) x $PM_{2.5}/PM_{10}$

where: PE = PE value
s = % dry silt content
50% = 50% Control efficiency from periodic watering
$PM_{2.5}/PM_{10} = 0.15$

Table 5-6 presents the data sources, emission factors, and correction parameters for all three types of construction.

Table 5-6. Recommended Methodology

Construction activity type	Activity level data source	Emission factor	Control efficiency	Climatic factor	Soil factor
Residential	Houses: Number of housing units Apartments: Value of apartment construction (Statistical Abstract of the United States, published annually by the U.S. Census Bureau, or the F.W. Dodge Reports)	Houses: 0.032 tons PM_{10}/acre/month (Source: South Coast Air Quality Managment District $PM/_{10}$ Fugitive Dust Integration Project 1996) Apartments: 0.11 tons PM_{10}/acre/month	None	Precipitation/Evaporation Index	Dry Silt content as converted from wet silt
Nonresidential	Dollar Value of New Construction (Statistical Abstract of the United States or the F.W. Dodge Reports)	0.19 tons PM_{10}/acre/month (Source: SCAQMD, BACM Report No. 1, 1996, assumes 1/4 of all nonresidential construction activity is heavy construction	50%		
Road	New highway miles (Highway Statistics, FHWA annual publication)	0.42 tons PM_{10}/acre/month (Source: SCAQMD, BACM Report No. 1, 1996)			

5.8 PM_{10} Emissions from Combustion of Cleared Materials

Construction operations begin with general site preparation. This involves the clearing of trees, shrubs, and other vegetation that are usually burned. PM emissions are produced during the combustion of cleared materials.

The PM emissions from the combustion of cleared materials can be calculated using the emission factors from AP-42 Section 13.1, Wildfires and Prescribed Burning. The information needed to find PM emissions from burning are the acres affected by the construction activity and the tons of fuel per acre (available from Table 13.1- 1 of AP-42 by region). The total acres affected by construction can be found by using the conversion factors for units to acres, dollars to acres, and miles to acres for the three types of construction.

The emission factors used for the combustion of cleared materials come from Table 13.1-4 of AP-42 and are by region. Piled slash best represents vegetative residue cleared at a construction site and is typically 1/2 of the regional average emission factor for prescribed burning. The PM_{10} emission factor used for each region is 5 g PM_{10}/kg fuel for the Pacific Northwest, 6.5 g PM_{10}/kg fuel for the Pacific Southwest, 9.4 g PM_{10}/kg fuel for the Southeast, 6 g PM_{10}/kg fuel for the Rocky Mountain region, and 7 g PM_{10}/kg fuel for the North Central and Eastern Regions.

The equation for calculating PM_{10} emissions from the combustion of cleared materials is:

$$PM_{10} \text{ Emissions} = EF \times t \times a$$

where: EF = Regional emission factor for combustion in g/kg
t = conversion from acres to tons of available fuel (AP-42 Table 13.1-1)
a = total acres affected by construction

Table 5-7 gives the PM_{10} emission factors by region for the combustion of materials cleared from construction activities by region.

Table 5-7. Combustion of Cleared Materials Emission Factors by Region

Region	PM_{10} emission factor (g/kg of fuel)
Pacific Northwest	5.0
Pacific Southwest	6.5
Southeast	9.4
Rocky Mountain	6.0
North Central and Eastern	7.0

An example calculation of PM_{10}emissions from the burning of vegitative residues for a hypothetical county in the Rocky Mountain Region is shown in Table 5-8.

Table 5-8. Example Calculation of PM_{10} Emissions from the Burning of Vegetative Residues

Construction type	Acres affected	emission factor (g/kg)	Fuel loading per acre (ton/acre)	PM_{10} Emissions (tons)
Residential	652	6.0	60	234
Non-residential	115	6.0	60	41
Roads	293	6.0	60	105
Total				380

Section 6.
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