Chapter 3. Construction and Demolition

3.1 Characterization of Source Emissions

Heavy construction is a source of dust emissions that may have a substantial temporary impact on local air quality. Building and road construction are two examples of construction activities with high emissions potential. Emissions during the construction of a building or road can be associated with land clearing, drilling and blasting, ground excavation, cut and fill operations (i.e., earth moving), and construction of a particular building or road. Dust emissions often vary substantially from day to day, depending on the level of activity, the specific operations, and the prevailing meteorological conditions. A large portion of the emissions results from construction vehicle traffic over temporary roads at the construction site.

The temporary nature of construction differentiates it from other fugitive dust sources as to estimation and control of emissions. Construction consists of a series of different operations, each with its own duration and potential for dust generation. In other words, emissions from any single construction site can be expected (1) to have a definable beginning and an end, and (2) to vary substantially over different phases of the construction process. This is in contrast to most other fugitive dust sources where emissions are either relatively steady or follow a discernable annual cycle. Furthermore, there is often a need to estimate areawide construction emissions without regard to the actual plans of any individual construction project. For these reasons, methods by which either areawide or site-specific emissions may be estimated are presented below.

The quantity of dust emissions from construction operations is proportional to the area of land being worked and to the level of construction activity. By analogy to the parameter dependence observed for other similar fugitive dust sources, one can expect emissions from construction operations to be positively correlated with the silt content of the soil (i.e., particles smaller than 75 micrometers [μm] in diameter), as well as with the speed and weight of the construction vehicle, and to be negatively correlated with the soil moisture content.

Table 3-1 displays the dust sources involved with construction. In addition to the on-site activities shown in Table 3-1, substantial emissions are possible because of material tracked out from the site and deposited on adjacent paved streets. Because all traffic passing the site (i.e., not just that associated with the construction) can resuspend the deposited material, this "secondary" source of emissions may be far more important than all the dust sources located within the construction site. Furthermore, this secondary source will be present during all construction operations. Persons developing construction site emission estimates must consider the potential for increased adjacent emissions from off-site paved roadways (see Chapter 5). High wind events also can lead to emissions from cleared land and material stockpiles. Chapters 8 and 9 present estimation methodologies that can be used for such sources at construction sites.

Table 3-1. Emission Sources for Construction Operations

Construction phase	Dust-generating activities
I. Demolition and debris removal	1. Demolition of buildings or other (natural) obstacles such as trees, boulders, etc. a. Mechanical dismemberment ("headache ball") of existing structures b. Implosion of existing structures c. Drilling and blasting of soil d. General land clearing 2. Loading of debris into trucks 3. Truck transport of debris 4. Truck unloading of debris
II. Site Preparation (earth moving)	1. Bulldozing 2. Scrapers unloading topsoil 3. Scrapers in travel 4. Scrapers removing topsoil 5. Loading of excavated material into trucks 6. Truck dumping of fill material, road base, or other materials 7. Compacting 8. Motor grading
III. General Construction	1. Vehicular Traffic 2. Portable plants a. Crushing b. Screening c. Material transfers 3. Other operations

3.2 Emissions Estimation: Primary Methodology[1-6]

This section was adapted from: Estimating Particulate Matter Emissions from Construction Operations, report prepared for USEPA by Midwest Research Institute dated September 15, 1999.[1]

Note that AP-42 Section 13.2.3, "Heavy Construction Operations," was not adopted for the primary emission estimation methodology because it relies on a single-valued emission factor for TSP of 1.2 tons/acre-month based on only one set of field tests.[2]

3.2.1 PM Emissions from 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. A general emission factor for all types of construction activity is 0.11 tons PM10/acre-month and is based on a 1996 BACM study conducted by Midwest Research (MRI) Institute for the California South Coast Air Quality Management District (SCAQMD).[3] The single composite factor of 0.11 tons PM10/acre-month assumes that all construction activity produces the same amount of dust on a per acre basis. In other words, 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 activity. A second assumption is that land affected by construction activity does not involve large-scale cut and fill operations. Factors for the conversion of dollars spent on construction to acreage disturbed, along with the estimates for the duration of construction activity, were originally developed by MRI in 1974.[4]

Separate emission factors segregated by type of construction activity provide better estimates of PM10 emissions that are more accurate estimate than are obtained using a general emission factor. The factors from the 1996 MRI BACM study[3] are summarized in Table 3-2. Specific emission factors and activity levels for residential, nonresidential, and road construction activities are described below.

Table 3-2. Recommended PM10 Emission Factors for Construction Operations[1]

Basis for emission factor	Recommended PM10 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."

3.2.2 Residential Construction

Residential construction emissions can be calculated for three basic types of residential construction:

- Single-family houses
- Two-family houses
- Apartment buildings

Housing construction emissions are calculated using an emission factor of 0.032 tons PM10/acre-month. Also required are: 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:

$$\text{Emissions} = (0.032 \text{ tons PM10/acre-month})\ B \times f \times m$$

where, B = the number of houses constructed
f = building to acres conversion factor
m = the duration of construction activity in months

Following the California methodology, residential construction acreage is based on the number of housing units constructed rather than the dollar value of construction.

An alternative methodology 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 (www. fwdodge.com/newdodgenews.asp) give the total square footage of homes for both single-family and two-family homes. These values can be used to estimate the volume in cubic yards of dirt moved. Multiplying the total square footage of the homes by an average basement depth of 8 ft, and adding 10% additional volume to account for peripheral dirt removed for footings, space around the footings, and other backfilled areas adjacent to the basement, produces an estimate of the total volume in cubic yards of earth moved during residential construction.

The information needed to determine activity levels of residential construction may be based either on the dollar value of construction or the number of housing units constructed. Construction costs vary throughout the United States. The average home cost can vary from the low to upper $100,000s depending on where the home is located in the United States. Because residential construction characteristics do not show as much variance as the cost does, 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. The number of housing units for the three types of residential construction (single family, two-family, and apartments) for a county or state are available from the F.W. Dodge's "Dodge Local Construction Potentials Bulletin."

A single-family house is estimated to occupy 1/4 acre. The "building to acres" conversion factor for a single-family house 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 2,000 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. The "building to acres" conversion factor 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 (approximately 3,500 sq. ft.) and the land affected beyond the base of the house, about 4 times the base for two-family residences.

For comparison purposes, residential construction emission factor calculations are calculated below for BACM Level 1 and Level 2 scenarios. The PM10 construction emission factor for one single-family home is based on typical parameters for a single-family home:

- area of land disturbed 1/4 acre
- area of home 2,000 sq. ft.
- duration 6 months
- basement depth 8 ft.
- moisture level 6%
- silt content 8%

The BACM Level 1 emission calculation is estimated as follows:

0.032 tons PM10/acre-month x 1/4 acre x 6 months = 0.048 tons PM10 = 96 lb PM10

The BACM Level 2 emission calculation is estimated as follows:

Cubic yards of dirt moved = 2,000 ft^2 x 8 ft. x 110% = 17,600 ft^3 = 652 yd^3
PM10 = (0.011 tons/acre-month x 1/4 acre x 6 months) + (0.059 tons/1000 yd^3 dirt x 652 yd^3 dirt)
= 0.016 tons + 0.038 tons = 0.0545 tons PM10 = 109 lb PM10

The emission factor recommended for the construction of apartment buildings is 0.11 tons PM10/acre-month because apartment construction does not normally involve a large amount of cut-and-fill operations. Apartment buildings vary in size, number of units, square footage per unit, floors, and many other characteristics. Because of these variations and the fact that 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” conversion factor. An estimate of 1.5 acres/$\$10^6$ (in 2004 dollar value) is recommended to determine the acres of land disturbed by the construction of apartments. This “dollars-to-acres” conversion factor is based on updating previous conversion factors developed by MRI[4, 5] using cost of living adjustment factors.

3.2.3 Nonresidential Construction

Nonresidential construction includes building construction (commercial, industrial, institutional, governmental) and also public works. The emissions produced from the construction of nonresidential buildings are calculated using the dollar value of the construction. The formula for calculating the emissions from nonresidential construction is:

$$\text{PM10 Emissions} = (0.19 \text{ tons PM10/acre-month}) \times \$ \times f \times m$$

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

The emission factor of 0.19 tons PM10/acre-month was developed by MRI in 1999 using a method similar to a procedure originated by Clark County, Nevada and the emission factors recommended in the 1996 MRI BACM Report.[3] A quarter of all nonresidential construction is assumed to involve active earthmoving in which the recommended emission factor is 0.42 tons PM10/acre-month. The 0.19 tons PM10/acre-month was calculated by taking 1/4 of the heavy emission factor, (0.42 tons PM10/acre-month) 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 PM10 emissions.[6] The proposed emission factor of 0.19 tons/acre-month for nonresidential building construction resulted in a total uncontrolled PM10 emissions estimate that was within 25% of that based on a detailed unit operation emissions inventory using detailed engineering plans and "unit-operation" emission factors.

Extensive earthmoving activities will produce higher amounts of PM10 emissions than the average construction project. Thus, a worst-case BACM "heavy construction emission factor" of 0.42 tons PM10/acre-month should provide a better emissions estimate for areas in which a significant amount of earth is disturbed.

The dollar amount spent on nonresidential construction is available from the U.S. Census Bureau (www.census.gov/prod/www/abs/cons-hou), and the Dodge Construction Potentials Bulletin (www. fwdodge.com/newdodgenews.asp). Census data are delineated by SIC Code, whereas the Potentials Bulletin divides activity by the types of building being constructed rather than by SIC Code. It is estimated that for every million dollars spent on construction (in 2004 dollars), 1.5 acres of land are impacted. The "dollars to acres" 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. The estimate for the duration of nonresidential construction is 11 months.

3.2.4 Road Construction

Road construction emissions are highly correlated with the amount of earthmoving that occurs at a site. Almost all roadway construction involves extensive earthmoving and heavy construction vehicle travel, causing emissions to be higher than found for other construction projects. The PM10 emissions produced by road construction are calculated using the BACM recommended emission factor for heavy construction[1] and the miles of new roadway constructed. The formula used for calculating roadway construction emissions is:

$$\text{PM10 Emissions} = (0.42 \text{ tons PM10/acre-month}) \times M \times f \times d$$

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

The BACM worst case scenario 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.

The miles of new roadway constructed are available at the state level from the *Highway Statistics* book published yearly by the Federal Highway Administration (FHWA; www.fhwa.dot.gov/ohim/hs97/hm50.pdf) 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 performed by estimating the overall width of the roadway, then multiplying the width by a mile to determine the acres affected by one mile of roadway construction. The California "miles to acres disturbed" conversion factors are available for freeway, highway and city/county roads. In the Highway Statistics book, roadways are divided into separate functional classes. MRI developed a "miles-to-acres" conversion factor in 1999[1] 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 occupy 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 3-3 shows the data used to calculate the acres per mile of road constructed.

Table 3-3. Conversion of Road Miles to Acres Disturbed

	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	105	81	65
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).

The amount of new roadway constructed is available on a yearly basis and 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 the fact that construction of roads normally lasts longer than a year. The duration of construction of a new roadway is estimated at 12 to 18 months.

3.3 Emission Estimation: Alternate Methodology for Building Construction

This section was adapted from Section 7.7 of CARB's Emission Inventory Methodology. Section 7.7 was last updated in September 2002.

The building construction dust source category provides estimates of the fugitive dust particulate matter caused by construction activities associated with building residential, commercial, industrial, institutional, or governmental structures. The emissions result predominantly from site preparation work, which may include scraping, grading, loading, digging, compacting, light-duty vehicle travel, and other operations. Dust emissions from construction operations are computed by using a PM10 emission factor developed by MRI during 1996.[3] The emission factor is based on observations of construction operations in California and Las Vegas. Activity data for construction is expressed in terms of acre-months of construction. Acre-months are based on estimates of the acres disturbed for residential construction, and project valuation for other non-residential construction.

3.3.1 Emission Estimation Methodology

Emission Factor. The PM10 emission factor used for estimating geologic dust emissions from building construction activities is based on work performed by MRI[3] under contract to the PM10 Best Available Control Measure (BACM) working group. For most parts of the state, the emission factor used is 0.11 tons PM10/acre-month of activity. This emission factor is based on MRI's observation of the types, quantity, and duration of operations at eight construction sites (three in Las Vegas and five in California). The bulk of the operations observed were site preparation-related activities. The observed activity data were then combined with operation-specific emission factors provided in AP-42[2] to produce site emissions estimates. These site estimates were then combined to produce the overall average emission factor of 0.11 tons PM10/acre-month. The PM2.5/PM10 ratio for fugitive dust from construction and demolition activities is 0.1 based on the analysis conducted by MRI on behalf of WRAP.[7]

The construction emission factor is assumed to include the effects of typical control measures such as routine watering. A dust control effectiveness of 50% is assumed from these measures, which is based on the estimated control effectiveness of watering.[8] Therefore, if this emission factor is used for construction activities where watering is not used, it should be doubled to more accurately reflect the actual emissions. The MRI document[3] lists their average emission factor values as uncontrolled. However, it can be argued that the activities observed and the emission estimates do include the residual effects of control. All of the test sites observed were actual operations that used watering controls as part of their standard industry practice in California and Las Vegas. So, even if in some cases watering was not performed during MRI's actual site visits, the residual decreases in emissions from the watering controls and raising the soil moisture are included in the MRI estimates.

The 1996 MRI report[3] also includes an emission factor for worst-case emissions of 0.42 tons PM10/acre-month. This emission factor is appropriate for large-scale construction operations, which involve substantial earthmoving operations. The South Coast Air Quality Management District (SCAQMD) estimated that 25% of their construction projects involve these types of operations. For the remainder of the state, such detailed information is not readily available, so the average emission factor of 0.11 tons PM10/acre-month is used by CARB for these other areas of California..

Activity Data. For the purpose of estimating emissions, it is assumed that the fugitive dust emissions are related to the acreage affected by construction. Because regionwide estimates of the acreage under construction may not be directly available, other construction activity data can be used to derive acreage estimates. Activity data are estimated separately for residential construction and the other types of construction (commercial, industrial, institutional, and governmental).

For residential construction, the number of new housing units estimated by the California Department of Finance[9] are used to estimate acreage disturbed. It is estimated that single family houses are built on 1/7 of an acre in heavily populated counties, and 1/5 of an acre in less populated counties.[10-12] It is also estimated that multiple living units such as apartments occupy 1/20 of an acre per living unit. For all of these residential construction activities, a project duration of 6 months is assumed.[10] Applying these factors to the reported number of new units in each county results in an estimate of acre-months of construction. This estimate of acre-months of construction combined with the construction emission factor is used to estimate residential construction particulate emissions.

For commercial, industrial, and institutional building construction, construction acreage is based on project valuations. Project valuations for additions and alterations are not included. According to the Construction Industry Research Board,[13] most additions and alterations would be modifications within the existing structure and normally would not include the use of large earthmoving equipment. Most horizontal additions would usually be issued a new building permit. The valuations are 3.7, 4.0 and 4.4 acres per million dollars of valuation for the respective construction types listed.[12] Valuations were corrected from 1999 values to 1977 values using the Annual Average Consumer Price Index (CPI-U-RS) provided by the U.S. Census Bureau.[14] The Census Bureau uses the Bureau of Labor Statistics' experimental Consumer Price Index (CPI-U-RS) for 1977 through 2000.[15] Valuations were corrected from 1999 values to 1977 values because the acres per dollar valuation values are based on 1977 valuations. For example, the CPI-U-RS for 1999 is 244.1 and the CPI-U-RS for 1977 is 100.0. The ratio of 1977 to 1999 dollars is 100.0/244.1 or 0.41. Inflation from 1999 to 2004 is estimated to be 12%. Thus, updating the 1977 valuation results to 2004 dollars produces a ratio of 1977 to 2004 dollars of 0.41/1.12 or 0.37. CARB assumes that each acre is under construction for 11 months for each project type.[10]

3.3.2 Assumptions and Limitations

1. The current methodology assumes that all construction operations in all parts of the state emit the same levels of PM10 on a per acre basis.
2. It is assumed that watering techniques are used statewide, reducing emissions by 50% and making it valid to apply the MRI emission factor without correction.
3. The methodology assumes that valuation is proportional to acreage disturbed, even for high-rise type building construction.
4. The methodology assumes that construction dust emissions are directly proportional to the number of acres disturbed during construction.
5. The estimates of acreage disturbed are limited in their accuracy. New housing units and project valuations do not provide direct estimates of actual acreage disturbed by construction operations in each county.
6. The methodology assumes that the Consumer Price Index (CPI-U-RS) provides an accurate estimate of 1977 and current values.

3.3.3 Temporal Activity

The temporal activity is assumed to occur five days a week between the hours of 8:00 AM and 4:00 PM. The table below shows the percentage of construction activity that is estimated to occur during each month. The monthly activity increases during the spring and summer months. Some districts may use a different profile that has a larger peak during the summer months.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
6.4	6.4	8.3	9.2	9.2	9.2	9.2	9.2	9.2	8.3	8.3	7.3

3.4 Emission Estimation: Alternate Methodology for Road Construction

This section was adapted from Section 7.8 of CARB's Emission Inventory Methodology. Section 7.8 was last updated in August 1997.

The road construction dust source category provides estimates of the fugitive dust particulate matter due to construction activities while building roads. The emissions result from site preparation work that may include scraping, grading, loading, digging, compacting, light-duty vehicle travel, and other operations. Dust emissions from road construction operations are computed by using a PM10 emission factor developed by MRI.[3] The emission factor is based on observations of construction operations in California and Las Vegas. Activity data for road construction is expressed in terms of acre-months of construction. Acre-months are based on estimates of the acres disturbed for road construction. The acres disturbed are computed based on: estimates of the annual difference in road mileage; estimates of road width (to compute acres disturbed); and an assumption of 18 months as the typical project duration.

3.4.1 Emissions Estimation Methodology

Emission Factor. The PM10 emission factor used for estimating geologic dust emissions from road construction activities is based on work performed by MRI under contract to the PM10 Best Available Control Measure working group.[3] For most parts of the State, the emission factor used is 0.11 tons PM10/acre-month of activity. This emission factor is based on MRI's observation of the types, quantity, and duration of operations at eight construction sites (three in Las Vegas, and five in California). The bulk of the operations observed were site preparation related activities. The observed activity data were then combined with operation specific emission factors provided in U.S. EPA's AP-42 (5th Edition)[2] document to produce site emissions estimates. These site estimates were then combined to produce the overall average emission factor of 0.11 tons PM10/acre-month. The PM2.5/PM10 ratio for fugitive dust from construction and demolition activities is 0.1 based on the analysis conducted by MRI on behalf of WRAP.[7]

The construction emission factor is assumed to include the effects of routine dust suppression measures such as watering. A dust control effectiveness of 50% is assumed from these measures, which is based on the estimated control effectiveness of watering.[8] Therefore, if this emission factor is used for road construction activities where watering is not used, it should be doubled to more accurately reflect the actual emissions. The MRI document[3] lists their average emission factor values as uncontrolled. However, it can be argued that the activities do include the effects of controls. All of the test sites were actual operations that used watering controls, even if in some cases they were not used during the actual site visits. It is believed that the residual effects of controls are reflected in the MRI emission estimates.

The MRI report[3] also includes an emission factor for worst-case construction emissions of 0.42 tons of PM10/acre-month. This emission factor is appropriate for large scale construction operations that involve substantial earthmoving operations. The South Coast Air Quality Management District (SCAQMD) estimated that a percentage of their construction projects involve these types of operations, and applied the larger emission factor to these activities. For the remainder of the state, such detailed information is not readily available, so the average emission factor of 0.11 tons PM10 per acre-month is used by CARB.

Activity Data. For the purpose of estimating emissions, it is assumed that the fugitive dust emissions are related to the acreage affected by construction. Regionwide estimates of the acreage disturbed by roadway construction may not be directly available. Therefore, the miles of road built and the acreage disturbed per mile of construction can be used to estimate the overall acreage disturbed.

The miles of road built are based on the annual difference in the road mileage. These data, from the California Department of Finance[9] and Caltrans[16], are split for each county into freeways, state highways, and city and county road. The acreage of land disturbed per mile of road construction is based on the number of lanes, lane width, and shoulder width for each listed road type. The assumptions used are provided in Table 3-4. Because most projects will probably also disturb land outside of the immediate roadway corridor, these acreage estimates are somewhat conservative.

The final parameter needed is project duration, which is assumed to be an average of 18 months.[10] Multiplying the road mileage built by the acres per mile and the months of construction provides the acre-months of activity for road building construction. This, multiplied by the emission factor, provides the emissions estimate.

Table 3-4. Roadway Acres per Mile of Construction Estimates

Road Type	Freeway	Highway	City & County
Number of Lanes	*5*	5	2
Width per Lane (feet)	12	12	12
Shoulder Width (feet)	10'x4 = 40'	20'x2 = 40'	20'x2 = 40'
Roadway Width* (feet)	100	76	64
Roadway Width* (miles)	0.019	0.014	0.012
Area per Mile** (acres)	12.1	9.2	7.8

*Roadway Width (miles) = [(Lanes x Width per Lane) + Shoulder Width] x (1 mile/5,280 feet)
**Area per Mile (acres) = Length x Width = 1 Mile x Width x 640 acres/mile^2

3.4.2 Temporal Activity

Temporal activity is assumed to occur five days a week between the hours of 8 AM and 4 PM. The table below shows the percentage of construction activity that is estimated to occur during each month. The monthly activity increases during the spring and summer months as shown below. Some districts use a slightly different profile that has a larger peak during the summer months.

ALL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
100	7.7	7.7	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	7.7

3.4.3 Assumptions and Limitations

1. The current methodology assumes that all construction operations in all parts of the state emit the same levels of PM10 on a per acre basis.
2. It is assumed that watering techniques are used statewide, reducing emissions by 50% and making it valid to apply the MRI emission factor without correction.
3. The methodology assumes that the acreage disturbed per mile for road building is similar statewide, and the overall disturbed acreage is approximately the same as the finished roadway's footprint.
4. The methodology assumes that construction dust emissions are directly proportional to the number of acres disturbed during construction.

3.5 Supplemental Emission Factors

AP-42 lists uncontrolled TSP emission factors for specific activities at construction sites.[2] These TSP emission factors as well as references to the relevant chapters of this handbook that provide PM10 and/or TSP emission factors for similar activities are presented in Table 3-5.

Table 3-5. TSP Emission Factors for Specific Construction Site Activities

Construction Phase	Activity	TSP Emission Factor*
Demolition and Debris Removal	Drilling soil	1.3 lb/hole
	Land clearing with bulldozer	$5.7\ (s)^{1.2} / M^{1.3}$ lb/hr
	Loading debris into trucks and subsequent unloading	See Chapter 4
	Truck transport of debris on paved or unpaved roads	See Chapters 5 and 6
Site Preparation (earth moving)	Bulldozing and compacting	$5.7\ (s)^{1.2} / M^{1.3}$ lb/hr
	Scrapers unloading topsoil	0.04 lb/ton
	Scrapers in travel mode	See Chapter 6
	Scrapers removing topsoil	20.2 lb/mile
	Grading	$0.040\ (S)^{2.5}$ lb/mile
	Loading excavated material into trucks and subsequent unloading	See Chapter 4
General Construction	Vehicular traffic	See Chapters 5 and 6
	Crushing and screening aggregate	See Chapter 11
	Material transfer	See Chapter 4

* Symbols for equations: M = material moisture content (%), s = material silt content (%), S = mean vehicle speed (mph).

3.6 Demonstrated Control Techniques

Because of the relatively short-term nature of construction activities, some control measures are more cost-effective than others. Frank Elswick of Midwest Industrial Supply Inc. presented an extensive summary of control measures for construction activities and their associated costs at a WRAP sponsored fugitive dust workshop in Palm Springs, CA in May 2005.[17] Elswick concluded that dust suppressant methods fall into the following six categories:

1. **Watering**

* Watering works by agglomerating surface particles together.
* No negative environmental impacts from using water.
* Normally readily available.
* Evaporates quickly, therefore typically only effective for short periods of time.
* Frequency of application depends on temperature and humidity.
* Generally labor intensive due to frequent application.
* Costs associated with pre-watering and as needed watering are $55 to $80/hour.

2. **Chemical Stabilizers**

(a) Water absorbing products (e.g., calcium chloride brine or flakes, magnesium chloride brine, sodium chloride)

* These products work by significantly increasing surface tension of water between dust particles, helping to slow evaporation and further tighten compacted soil.
* Products ability to absorb water from the air is a function of temperature and humidity.
* These products work best in low humidity environments.
* Frequent re-application in dry climates.
* Must be watered to activate during dry months.
* Potential costly environmental impacts to fresh water aquatic life, plants and water quality
* Corrosive to metal and steel.
* Not suitable for non-traffic areas.
* Costs associated with traffic area program are $.03 - $.05 per square foot.

(b) Organic Petroleum Products (e.g. asphalt emulsions, cut/liquid asphalt, dust oils, petroleum resins)

* These products work by binding and/or agglomerating surface particles together because of asphalt adhesive properties.
* Potentially costly environmental due to presence of polycyclic aromatic hydrocarbons that are "hazardous air and water pollutants" that may be subject to reporting requirements.
* Can fragment under traffic conditions.
* Not suitable for non-traffic areas.
* Costs associated with traffic area program are $.05 - $.075 per square foot.

(c) Organic Non-Petroleum Products (e.g., ligninsulfonates, tall oil emulsions, vegetable oils)

* These products work by binding and/or agglomerating surface particles together.
* Surface binding for these product may be reduced or destroyed by rains.
* Generally limited availability of non-petroleum products.
* Ligninsulfonates can impact freshwater aquatic life due to high B.O.D. and C.O.D.
* Not suitable for non-traffic areas.
* Costs associated with traffic area program are $.04 - $.08 square foot.

(d) Polymer Products (e.g., polyvinyl acetates, vinyl acrylics)

* These products work by binding soil particles together because of the polymer's adhesive properties.
* Polymers also increase the load-bearing strength of all types of soils.
* Polymers are non-toxic, non-corrosive, and do not pollute ground water.
* Polymers dry virtually clear to create an aesthetically pleasing result.
* Polymers create a tough yet flexible crust to prevent wind and water erosion.
* Costs associated with traffic areas are $.05 - $.08 per square foot.
* Costs associated with disturbed non-traffic areas are $300 - $800 per acre depending on longevity desired.

* Costs associated with slopes and inactive stockpiles are $500 to $1,000 per acre.

(e) Synthetic Products (e.g., iso-alkane compounds)
* Synthetic fluids work as a dust suppressing ballasting mechanism, while also acting as a durable re-workable binder.
* Formulated with safe and environmentally friendly synthetic fluids; non-hazardous per OSHA, EPA and US DOT; contains no asphalt, oil or PAH's.
* Easy application; no water required.
* Costs associated with traffic area program are $.05 - $.10 per square foot.

3. **Sand Fences**
* Fabric on chain link fence.
* Redwood slat fence.
* Mylar sand fence.
* Most effective when used in conjunction with chemical stabilizers.

4. **Perimeter Sprinklers**
* Most effective when used in conjunction with other methods.

5. **Tire Cleaning Systems at Site Exit**
* Rumble strips to prevent track-out from site onto pavement.
* Washed rock 100' prior to exit onto pavement.

6. **On- Site Speed Control**
* Limiting on-site vehicle speed to 15mph.

Wet suppression and wind speed reduction are the two most common methods used to control open dust sources at construction sites because a source of water and material for wind barriers tend to be readily available on a construction site. However, several other forms of dust control are available. Table 3-6 displays each of the preferred control measures by dust source.[18, 19]

Table 3-6. Control Options for General Construction Sources of PM10

Emission source	Recommended control methods(s)
Debris handling	Wind speed reduction; wet suppression[a]
Truck transport[b]	Wet suppression; paving; chemical stabilization[c]
Bulldozers	Wet suppression[d]
Pan scrapers	Wet suppression of travel routes
Cut/fill material handling	Wind speed reduction; wet suppression
Cut/fill haulage	Wet suppression; paving; chemical stabilization
General construction	Wind speed reduction; wet suppression; early paving of permanent roads

[a] Dust control plans should contain precautions against watering programs that confound trackout problems.
[b] Loads could be covered to avoid loss of material in transport, especially if material is transported offsite.
[c] Chemical stabilization is usually cost-effective for relatively long-term or semipermanent unpaved roads.
[d] Excavated materials may already be moist and not require additional wetting. Furthermore, most soils are associated with an "optimum moisture" for compaction.

One of the dustiest construction operations is cutting and filling using scrapers, with the highest emissions occurring during scraper transit. In a 1999 MRI field study,[5] it was found that watering can provide a high level of PM10 control efficiency for scraper transit emissions. Average control efficiency remained above 75% approximately 2 hours after watering. The average PM10 efficiency decay rate for water was found to vary from approximately 3% to 14% hour. The decay rate depended upon relative humidity in a manner consistent with the effect of humidity on the rate of evaporation. Test results for watered scraper transit routes showed a steep increase in control efficiency with a doubling of surface moisture and little additional control efficiency at higher moisture levels. This is in keeping with past studies that found that control efficiency data can be successfully fitted by a bilinear function. In another recent MRI field study (MRI, 2001),[20] tests of mud and dirt trackout indicated that a 10% soil moisture content represents a reasonable first estimate of the point at which watering becomes counter productive. The control efficiencies afforded by graveling or paving of a 7.6 m (25 ft) access apron were in the range of 40% to 50%.

Table 3-7 summarizes tested control measures and reported control efficiencies for dust control measures applied to construction and demolition operation.

Table 3-7. Control Efficiencies for Control Measures for Construction/Demolition[20, 21]

Control measure	Source component	PM10 control efficiency	References/Comments
Apply water every 4 hrs within 100 feet of a structure being demolished	Active demolition and debris removal	36%	MRI, April 2001, test series 701. 4-hour watering interval (Scenario: lot remains vacant 6 mo after demolition)
Gravel apron, 25" long by road width	Trackout	46%	MRI, April 2001
Apply dust suppressants (e.g., polymer emulsion)	Post-demolition stabilization	84%	CARB April 2002; for actively disturbed areas
Apply water to disturbed soils after demolition is completed or at the end of each day of cleanup	Demolition Activities	10%	MRI, April 2001, test series 701. 14-hour watering interval.
Prohibit demolition activities when wind speeds exceed 25 mph	Demolition Activities	98%	Estimated for high wind days in absence of soil disturbance activities
Apply water at various intervals to disturbed areas within construction site	Construction Activities	61%	MRI, April 2001, test series 701. 3.2-hour watering interval
		74%	MRI, April 2001, test series 701. 2.1-hour watering interval
Require minimum soil moisture of 12% for earthmoving	Scraper loading and unloading	69%	AP-42 emission factor equation for materials handling due to increasing soil moisture from 1.4% to 12%
Limit on-site vehicle speeds to 15 mph (Scenario: radar enforcement)	Construction traffic	57%	Assume linear relationship between PM10 emissions and uncontrolled vehicle speed of 35 mph

3.7 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Regulatory formats specify the threshold source size that triggers the need for control application. Example regulatory formats downloaded from the Internet for several local air quality agencies in the WRAP region are presented in Table 3-8. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/envsvc/air/ruledsc.asp

3.8 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations (e.g., whether an unpaved road has been paved, graveled, or treated; whether haul truck beds are covered ; whether water trucks are being used during construction activities). An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 3-9 summarizes the compliance tools that are applicable to construction and demolition.

Table 3-8. Example Regulatory Formats for Construction and Demolition

Source	Control measure	Goal	Threshold	Agency
Paved Roads-Public and Private Track-out and Carryout	Install track-out ctrl device	Prevent/remove track-out from haul trucks and tires	Paved roads within construction sites, where haul trucks traverse; with disturbed surface area >2 acres, with 100 cubic yards of bulk material hauled	Maricopa County Rule 310 04/07/2004
	Either immediately cleanup track-out (>50ft) and nightly clean-up of rest; install grizzly/wheel wash system; install gravel pad--30ftx50ft, 6" deep; pave intersection--100ftx20ft; route traffic over track-out ctrl devices; limit access to unprotected routes; pave construction roadways ASAP	Control track-out on paved construction roads	Immediate track-out clean-up after 50ft, at end of workday for less; gravel pad standards are min; paved intersection also min and must be accessible to public; limit access to unprotected routes with barriers	Maricopa County Rule 310 04/07/2004
	Track-out control device must be installed at all access points to public roads and there must be mud/dirt removal from interior paved roads with sufficient frequency	Allow mud/dirt to drop off before leaving site and prevent track-out	For sites greater than 5 acres or those with more than 100 yd3 of daily import/export	SJVAPCD Rule 8041 11/15/2001
	Removal of track-out within one hour or selecting a track-out prevention option and removing track-out at the end of the day		For sites greater than 5 acres or those with more than 100 yd3 of daily import/export and track-out is less than 50ft	SCAQMD Rule 403 12/11/1998
	Removing track-out ASAP		Track-out greater than 50 ft	SCAQMD Rule 403 12/11/1998
	Require road surface paved or chemically stabilized from point of intersection with a public paved road to distance of at least 100 ft by 20 ft or installation of track-out control device from point of intersection with a public paved road to a distance of at least 25 ft by 20 ft	Prohibits material from extending more than 25 ft from a site entrance	For sites greater than 5 acres or those with more than 100 yd3 of daily import/export	SCAQMD Rule 403 12/11/1998
Bulk Materials Transport	Establishes speed limits. Requires at least 6" freeboard when crossing paved public road, water applied to top of load. Haul trucks need tarp or suitable cover and truck interior must be cleaned before leaving site	Limit visible dust emissions to 20% opacity and prevent spillage from holes	Trucks entering paved public roads (6" freeboard); leaving work site; specific haul trucks need covering	SJVAPCD Rule 8031 11/15/2001
	Requires covering haul trucks or to use bottom-dumping if possible and maintain minimum 6" freeboard (in high winds)			SCAQMD Rule 403 12/11/1998
	Freeboard at least 3"; prevent spillage from holes; install track-out ctrl devices	Prevent/remove track-out onto paved roads	Within the work site; removes possible track-out from tires, exterior of trucks that traverse work site	Maricopa County Rule 310 04/07/2004
Construction and Demolition Earthmoving	Require water and chemical stabilizers (dust suppressants) be applied, in conjunction with optional wind barrier	Limit visible dust emissions to 20% opacity		SJVAPCD Rule 8021 11/15/2001
	Specifies Dust Control Plan must be submitted	Limit visible dust emissions to 20% opacity	For areas 40 acres or larger where earth movement of 2500 yd3 or more on at least 3 days is intended	SJVAPCD Rule 8021 11/15/2001

Table 3-8. Example Regulatory Formats for Construction and Demolition (Continued)

Source	Control measure	Goal	Threshold	Agency
	Requires implementation of Best Available Control Measures (BACM)	Prohibit visible dust emissions beyond property line and limit an upwind/downwind PM10 differential to 50 ug/m3. Limit visible dust emissions to 100 ft from origin		SCAQMD Rule 403 12/11/1998
Construction and Demolition Demolition	Application of dust suppressants	Limit visible dust emissions to 20% opacity		SJVAPCD Rule 8021 11/15/2001
	Application of best available control measures (BACM)	Prohibits visible dust emissions beyond property line. Limits downwind PM10 levels to 50 ug/m3	For projects greater than 5 acres or 100 yd3 of daily import/export	SCAQMD Rule 403 12/11/1998
Construction and Demolition Grading Operations	Requires pre-watering and phasing of work	Limit VDE to 20% opacity		SJVAPCD Rule 8021 11/15/2001
	Requires water application and chemical stabilizers	Increase moisture content to proposed cut	For graded areas where construction will not begin for more than 60 days after grading	SCAQMD Rule 403 12/11/1998
	Preapplication of water to depth of proposed cuts and reapplication of water as necessary. Also stabilization of soils once earth-moving is complete	Ensure visible emissions do not extend more than 100 ft from sources		SCAQMD Rule 403 12/11/1998

Table 3-9. Compliance Tools for Construction and Demolition

Record keeping	Site inspection/monitoring
Site map; description of work practices; duration of project activities; locations and methods for demolition activities; locations and amounts of all earthmoving and material (types) handling operations; dust suppression equipment (types) and maintenance; frequencies, amounts, times, and rates of watering or dust suppressant application; mud/dirt carryout prevention and remediation requirements; wind shelters; meteorological log.	Observation of earthmoving and demolition activities, considering timeframe of project; observation of operation of dust suppression systems, vehicle/ equipment operation and disturbance areas; surface material sampling and analysis for silt and moisture contents; observation of truck spillage onto adjacent paved roads; mud/dirt carryout prevention and remediation; inspection of wind sheltering; real-time portable monitoring of PM; observation of dust plume opacity exceeding a standard.

3.9 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for construction and demolition. A sample cost-effectiveness calculation is presented below for a specific control measure (gravel apron at trackout egress points) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for construction and demolition, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Construction and Demolition
(Mud/Dirt Egress Points)

Step 1. Determine source activity and control application parameters.

Egress traffic rate (veh/day)	100
Number of egress points	2
Duration of construction activity (month)	24
Wet days/year	10
Number of workdays/year	260
Number of emission days/yr (workdays without rain)	250

Control Measure	Gravel apron 25 ft long by road width
Economic Life of Control System (yr)	2
Control Efficiency	46%
Reference	MRI, 2001[20]

The number of vehicles per day, wet days per year, workdays per year, and the economic life of the control are determined from climatic and industrial records. The number of emission days per year are calculated by subtracting the number of annual wet days from the number of annual workdays as follows:

Number of workdays/year – Wet days/year = 260 – 10 = 250

Gravel aprons at the two construction site egress points have been chosen as the applied control measure. The control efficiency was obtained from MRI, 2001.[19]

Step 2. Obtain PM10 Emission Factor. The PM10 emission factor for construction and demolition dust is 6 g/vehicle.[22]

Step 3. Calculate Uncontrolled PM Emissions. The PM10 emission factor, EF, (given in Step 2) is multiplied by the number of vehicles per day and by the number of emission days per year (both under activity data) and divided by 454 grams/lb and 2000 lb/ton to compute the annual PM10 emissions, as follows:

Annual PM10 emissions = (EF x Veh/day x Emission days/year)/(454 x 2,000)
Annual PM10 emissions = (6 x 100 x 250) / (454 x 2,000) = 0.165 tons/year

Annual PM2.5 emissions = 0.1 x PM10 emissions[7]
Annual PM2.5 emissions = (0.1 x 0.165 tons/year) = 0.0165 tons/year

Step 4. Calculate Controlled PM Emissions. The controlled PM emissions (i.e., the PM emissions remaining after control) are equal to the uncontrolled emissions (calculated above in Step 3) multiplied by the percentage that uncontrolled emissions are reduced, as follows:

Controlled emissions = Uncontrolled emissions x (1 – Control Efficiency).

For this example, we have selected gravel aprons at egress points as our control measure. Based on a control efficiency estimate of 46% for a gravel apron, the annual PM emissions are calculated to be:

Annual Controlled PM10 emissions = (0.165 tons/yr) x (1 – 0.46) = 0.089 tons/yr
Annual Controlled PM2.5 emissions = (0.0165 tons/yr) x (1 – 0.46) = 0.0089 tons/yr

Step 5. Determine Annual Cost to Control PM Emissions.

Capital costs ($)	500
Annual Operating/Maintenance costs ($)	3,150
Annual Interest Rate	5%
Capital Recovery Factor	0.54
Annualized Cost ($/year)	3,419

The capital costs, annual operating and maintenance costs, and annual interest rate (AIR) are assumed values for illustrative purposes. The Capital Recovery Factor (CRF) is calculated as follows:

Capital Recovery Factor = AIR x $(1+\text{AIR})^{\text{Economic life}} / (1+\text{AIR})^{\text{Economic life}} - 1$
Capital Recovery Factor = 5% x $(1+5\%)^2 / (1+5\%)^2 - 1 = 0.54$

The Annualized Cost is calculated by adding the product of the Capital Recovery Factor and the Capital costs to the annual Operating and Maintenance costs:

Annualized Cost = (CRF x Capital costs) + Annual Operating and Maintenance costs
Annualized Cost = (0.54 x $500) + $3,150 = $3,419

Step 6. Calculate Cost Effectiveness. Cost effectiveness is calculated by dividing the annualized cost by the emissions reduction. The emissions reduction is determined by subtracting the controlled emissions from the uncontrolled emissions:

Cost effectiveness = Annualized Cost / (Uncontrolled emissions – Controlled emissions)

Cost effectiveness for PM10 emissions = $3,420 / (0.165 - 0.089) = $44,991/ton
Cost effectiveness for PM2.5 emissions = $3,420 / (0.0165 - 0.0089) = $449,908/ton

3.10 References

1. Midwest Research Institute, 1999. *Estimating Particulate Matter Emissions From Construction Operations*, Kansas City, Missouri, September.

2. U.S. EPA, 1995. *Compilation of Air Pollutant Emission Factors.* AP-42. Fifth Edition, Research Triangle Park, NC, September.

3. Muleski, G., 1996. *Improvement of Specific Emission Factors (BACM Project No. 1), Final Report*. Midwest Research Institute, March.

4. Cowherd, C. Jr., Axtell, K. Jr., Maxwell, C.M., Jutze, G.A., 1974. *Development of Emission Factors for Fugitive Dust Sources*, EPA Publication No. EPA-450/3-74-037, NTIS Publication No. PB-238 262.

5. Muleski, G. E., Cowherd, C., 1999. *Emission Measurements of Particle Mass and Size Emission Profiles From Construction Activities,* EPA-600/R-99-091 (NTIS PB2000-101-11), U.S. Environmental Protection Agency, Research Triangle Park, NC.

6. Anderson, C.L., Brady, M.J. 1998. *General Conformity Analysis for Major Construction Projects: An Example Analysis of Fugitive PM10 Emissions*. Paper 98-MP4B.06 presented at the Annual Meeting of the Air & Waste Management Association, June 1998.

7. MRI, 2006. Background Document for Revisions to Fine Fraction Ratios Used for AP-42 Fugitive Emission Factors, prepared for the WRAP by Midwest Research Institute, Project No. 110397, February 1.

8. PEDCo Environmental Specialists, 1973. *Investigation of Fugitive Dust Sources – Emissions and Control*, prepared for the Environmental Protection Agency, OAQPS, contract No. 68-02-0044, May.

9. California Department of Finance, California Statistical Abstract - 2000, Section I, Construction, Economic Research Unit, (916) 322-2263. (www.dof.ca.gov)

10. Midwest Research Institute, 1974. *Inventory of Agricultural Tilling, Unpaved Roads and Airstrips and Construction Sites*, prepared for the U.S. Environmental Protection Agency, PB 238-929, Contract 68-02-1437, November.
11. South Coast Air Quality Management District, 1977. *Emissions from Construction/Demolition*, Emission Programs Unit, December.
12. Taback, J.J., et al, 1980. *Inventory of Emissions from Non-Automotive Vehicular Sources*, Final Report, KVB.
13. Personal Communication between CARB and Ben Bartolotto, Research Director of the Construction Industry Research Board, (818) 841-8210 (August 2002).
14. U.S. Census Bureau, Income 2000, Supplemental Information: Annual Average Consumer Price Index (CPI-U-RS); (www.census.gov/hhes/income/income00.cpiur).
15. U.S. Department of Labor, Bureau of Labor Statistics, Consumer Price Indexes, CPI Research Series Using Current Labor Methods (CPI-U-RS), (www.bls.gov/cpi/cpirsdc).
16. California Department of Transportation, Highway System Engineering Branch.
17. Elswick, F., 2005. *Emission Control Methods for the Construction Industry,* WRAP Fugitive Dust Control Workshop, Palm Springs, CA, May 10-11.
18. MRI, 1993. *Background Documentation For AP-42 Section 11.2.4, Heavy Construction Operations*, EPA Contract No. 69-D0-0123, Midwest Research Institute, Kansas City, MO, April.
19. C. Cowherd, et al., 1988. *Control Of Open Fugitive Dust Sources*, EPA-450/3-88-008, U.S. Environmental Protection Agency, Research Triangle Park, NC, September.
20. Muleski, G. E., Cowherd, C., 2001. *Particulate Emissions From Controlled Construction Activities,* EPA-600/R-01-031 (NTIS PB2001-107255), U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, April.
21. CARB April 2002. *Evaluation of Air Quality Performance Claims for Soil-Sement Dust Suppressant*.
22. Muleski, G.E., Page, A., Cowherd, C. Jr., 2003. *Characterization of Particulate Emissions from Controlled Construction Activities: Mud/Dirt Carryout*, EPA-600/R-03-007. Research Triangle Park, NC: U.S. Environmental Protection Agency, February.