MIDWEST RESEARCH INSTITUTE

MRI REPORT

# STUDY OF CONSTRUCTION RELATED MUD/DIRT CARRYOUT

FINAL REPORT
July 26, 1983

EPA Contract No. 68-02-3177, Work Assignment 21
MRI Project No. 4862-L(21)

Prepared for:

U.S. Environmental Protection Agency
Air Programs Branch - Region V
230 South Dearborn
Chicago, Illinois 60604

Attn: Lino Castanares

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# STUDY OF CONSTRUCTION RELATED MUD/DIRT CARRYOUT

by

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Midwest Research Institute

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# PREFACE

This report was prepared by Midwest Research Institute (MRI) under Work Assignment 21 of Contract No. 68-02-3177 from the U.S. Environmental Protection Agency. Mr. Lino Castanares was the EPA Project Officer. Work conducted in this project was performed in MRI's Air Quality Assessment Section under the overall direction of Dr. Chatten Cowherd, Jr. The principal author of the report was Mr. Phillip Englehart. Mr. John Kinsey was the project leader and an author of this report. Messrs. D. Griffin and S. Cummins contributed to the collection and analysis of field samples.

MRI would like to express its gratitude to Mr. Mike Connolly of the Minnesota Pollution Control Agency who lent his valuable assistance during site selection and who participated in the actual collection of the samples in the field.

Approved for:

MIDWEST RESEARCH INSTITUTE

M. P. Schrag, Director
Environmental Systems Department

July 26, 1983

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# 1.0 INTRODUCTION

Several recent studies have identified traffic entrained dust from paved roads as both a major source of total suspended particulate (TSP) in urban areas and a leading contributor to exceedances of the ambient air quality standards.[1] Though not directly comparable because of differences in methodology and intrinsic study area characteristics, all of these studies arrived at similar conclusions. That is: reentrained dust from paved roadways has an annual impact of 10 to 30 $\mu g/m^3$ at most urban TSP sampling sites and constitutes 10 to 50% of the particulate emissions in these areas.

Despite these findings, relatively little attention has been focused directly on the problem of controlling paved roadway fugitive emissions. The existing literature does suggest that the most realistic approach would involve reducing the amount of street surface material available for reentrainment. This strategy is based on the results of extensive work conducted by Midwest Research Institute (MRI) in the quantification of paved roadway dust emissions, which indicates that the rate of dust reentrainment (and thus, fugitive emissions attributable to the roadway) is positively related to the amount of silt-sized material (< 75 μm physical diameter) on the traveled portions of the streets.[2]

Order of magnitude estimates for the processes important in the deposition and removal of dust on paved roads (Table 1.1) indicate that mud/dirt carryout is the primary contributor to material reentrained from paved surfaces.[3]

In this study MRI evaluated the secondary air quality impacts associated with mud carryout from eight active construction sites in the Minneapolis/St. Paul metropolitan area. The overall goals of this research were to define the extent of construction related mud/dirt carryout and to establish the physical and technical bases necessary to develop appropriate control strategies for this source.

The following sections describe the field sampling activities and results of the mud carryout determination conducted under this program. The sampling portion of the study was performed in two phases with the first phase consisting of sampling at three sites with three sets of data, and the second phase consisting of sampling at five additional sites with two sets of data. Phase I was funded under a project sponsored by the Minnesota Pollution Control Agency (MPCA), and Phase II constituted Work Assignment No. 21 of EPA Contract No. 68-02-3177. The data collected during the MPCA program was combined with that gathered in the follow-on EPA study to relate mud/dirt carryout (and resulting traffic entrained dust emissions) to physical parameters which characterized the level of construction activity.

TABLE 1-1. ESTIMATED DEPOSITION AND REMOVAL RATES[a]

| Deposition process | Typical rate (lb/curb-mile/day) | Removal process | Typical rate (lb/curb-mile/day) |
|---|---|---|---|
| Mud and dirt carryout | 100 | Reentrainment | 100 |
| Litter | 40 | Displacement | 40 |
| Biological debris | 20 | Wind erosion | 20 |
| Ice control compounds | 10 | Rainfall runoff | 50 |
| Dustfall | 10 | Sweeping | 35 |
| Pavement wear and decomposition | 10 | | |
| Vehicle-related (including tire wear) | 17 | | |
| Spills | < 2 | | |
| Erosion from adjacent areas | 20 | | |

[a] Source: Reference 3.

# 2.0 FIELD SAMPLING PROGRAM

## 2.1 DESCRIPTION OF SAMPLING SITES

Three separate sites were selected for sampling during Phase I. Site No. 1 was a project involving the construction of a large commercial office building on a 10-acre site. Samples were collected after a large portion of the building had already been erected. The on-site traffic consisted mostly of workers entering and leaving the project with some delivery of building materials such as concrete and steel.

Site No. 2 was a large subdivision consisting of the construction of 91 single-family dwellings. Mud carryout samples were taken early in the project during the laying of utilities with some on-site grading taking place. Traffic in and out of the subdivision consisted of passenger vehicles and light-duty trucks of the construction workers.

Site No. 3 was a small subdivision of multi-family dwellings (condominiums) located on a cul-de-sac. Most of the buildings had already been erected when sampling began but a significant amount of building material was still being delivered. Toward the end of the study period, final grading was performed preparatory to the paving of curbs and streets. Traffic entering and leaving the site generally consisted of on-site residents, construction workers, and heavy trucks and other construction vehicles.

In Phase II, five additional sites were selected for mud carryout sampling. Site No. 4 involved the construction of a large industrial park on approximately 150 acres. Samples were collected during the installation of the underground utilities with some concrete work also occurring on-site. Because of the diffuse nature of the project, there were numerous points of access being used by the vehicular traffic entering and leaving the site. Traffic in and out of the project consisted of both light- and heavy-duty vehicles.

Site No. 5 was a project consisting of the construction of a 13-story office building with an associated 4-deck parking garage. Activities occurring on-site during sample collection included minor excavation work, pile driving, and the pouring of concrete pile caps. The two main points of access to the site for vehicular traffic included both an employee entrance and a delivery entrance, although a number of other points were also used as well. Vehicular traffic entering and leaving the site consisted mostly of passenger vehicles and light trucks with some delivery of construction material by medium and heavy-duty trucks.

Site No. 6 involved the construction of a commercial office building and associated paved city street on a 5-acre site. The only traffic into and out of the site were heavy-duty trucks delivering building materials.

The construction workers themselves parked their vehicles along the existing paved road (North Service Drive) instead of on the site. A major portion of the mud carryout associated with Site 6 was generated during excavation work for a new city sewer line along the north perimeter of the North Service Drive.

Site No. 7 was a 15-acre subdivision of 22 single and multifamily residences. During sampling, earthmoving for the installation of underground utilities was occurring. Traffic in and out of the site consisted mainly of construction workers along with some miscellaneous heavy vehicles.

The final site sampled (No. 8) was a construction project involving a small commercial office building on a 2-acre site. During sampling, some grading and earthmoving was being performed on-site along with the pouring of concrete footings. Traffic entering and leaving the site consisted of construction workers along with the delivery of concrete.

Figure 2-1 shows the location of each of the sampling sites; a general summary of their physical characteristics is provided in Table 2-1.

## 2.2 SAMPLING AND ANALYSIS PROCEDURES

During Phase I, samples of the street surface loadings were collected at specific locations relative to the site point(s) of access with the adjacent paved road as shown in Figure 2-2. Two samples (A, C) were obtained from the immediate access between the construction site and adjoining paved roadway with two additional samples (B, D) collected approximately 320 m (~ 0.2 miles) in either direction along the paved road. It should be noted that some of the B-D sample pairs were composited prior to analysis for silt content. A total of three sets of samples were collected at each mud carryout site.

In Phase II, two additional points were sampled as shown in Figure 2-3. These additional samples were collected to better define the spacial distribution of the silt and surface loading along the adjacent paved road. As with Phase I, some of the C-F sample pairs were composited prior to analysis for silt content. Due to inclement weather in the Twin Cities, only two sets of samples were collected at each site during Phase II.

Samples of the mud/dirt found on the paved roadway surface were generally collected from a 3.2 m x 2.6 m (10.5 ft x 8.5 ft) area in the travel lane used by traffic entering and leaving the site. A portable vacuum cleaner was used to collect the samples from the road. The attached brush on the collection inlet was used to slightly abrade surface compacted material, and to remove dust from the crevices of the road surface. Vacuuming was preceded by broom sweeping if a large amount of material or large aggregates were present. The field data forms used for mud carryout sampling are shown in Appendix A for Phases I and II, respectively.

The characteristics of the vehicular traffic entering and leaving the site, and on the adjacent paved road, were determined by both automatic and manual means. The vehicular characteristics included: (a) total traffic


Figure 2-1. Sampling site locations.

TABLE 2-1. PHYSICAL CHARACTERISTICS OF MUD CARRYOUT SAMPLING SITES

| Site number | Location of site | Type of construction | Construction activity during sampling | Size of construction site (acres) | No. of access points | No. of vehicles entering/leaving site (vehicles/day) | No. of travel lanes on adjacent paved road | Speed limit on paved road (mph) | ADT on adjacent paved road(s) (vehicles/day) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | County Road B-2 and Snelling Avenue | Commercial office building | Building construction | 10 | 1 | > 100 | 4 | 40 | 4,300[b] |
| 2 | Carsgrove Meadows-970 County Road C | Single family residential | Installation of underground utilities | 42 | 1 | 25-50 | 2 | 35 | 1,300 |
| 3 | Lower Afton Road and Morningside Drive | Multifamily residential | Installation of streets, curbs, and gutters | 4 | 1 | > 100 | 2 | 50 | 3,200[b] |
| 4 | Energy Park Drive | Industrial park | Installation of underground utilities | 10[a] | Multiple | > 100 | 2 | 30 | 3,300[b] |
| 5 | Norman Center Drive - 84th and Normandale | Commercial office building | Building excavation and pile driving | 4 | 3 | < 25 | 4 | 30 | 2,600[b] |
| 6 | Hwy 36 North Service Drive (Hoffman Elec.) | Commercial office building | Installation of underground utilities and curbs | 5 | 2 | 25-50 | 2 | 30 | 750 |
| 7 | Hilloway Road, Cloverly Way | Single/multi-family residential | Grading and installation of underground utilities | 15 | 2 | < 25 | 2 | 20 | 640 |
| 8 | County Road 61 and North Hwy 12 Frontage Road | Commercial office building | Earthmoving and pile driving | 2 | 3 | < 25 | 2 | 30 | 3,700 |

[a] Approximate area of the site active at the time of sampling. Actual site is much larger (~ 150 acres).

[b] Represent average of ADT counts supplied by MPCA as well as counts taken by MRI.

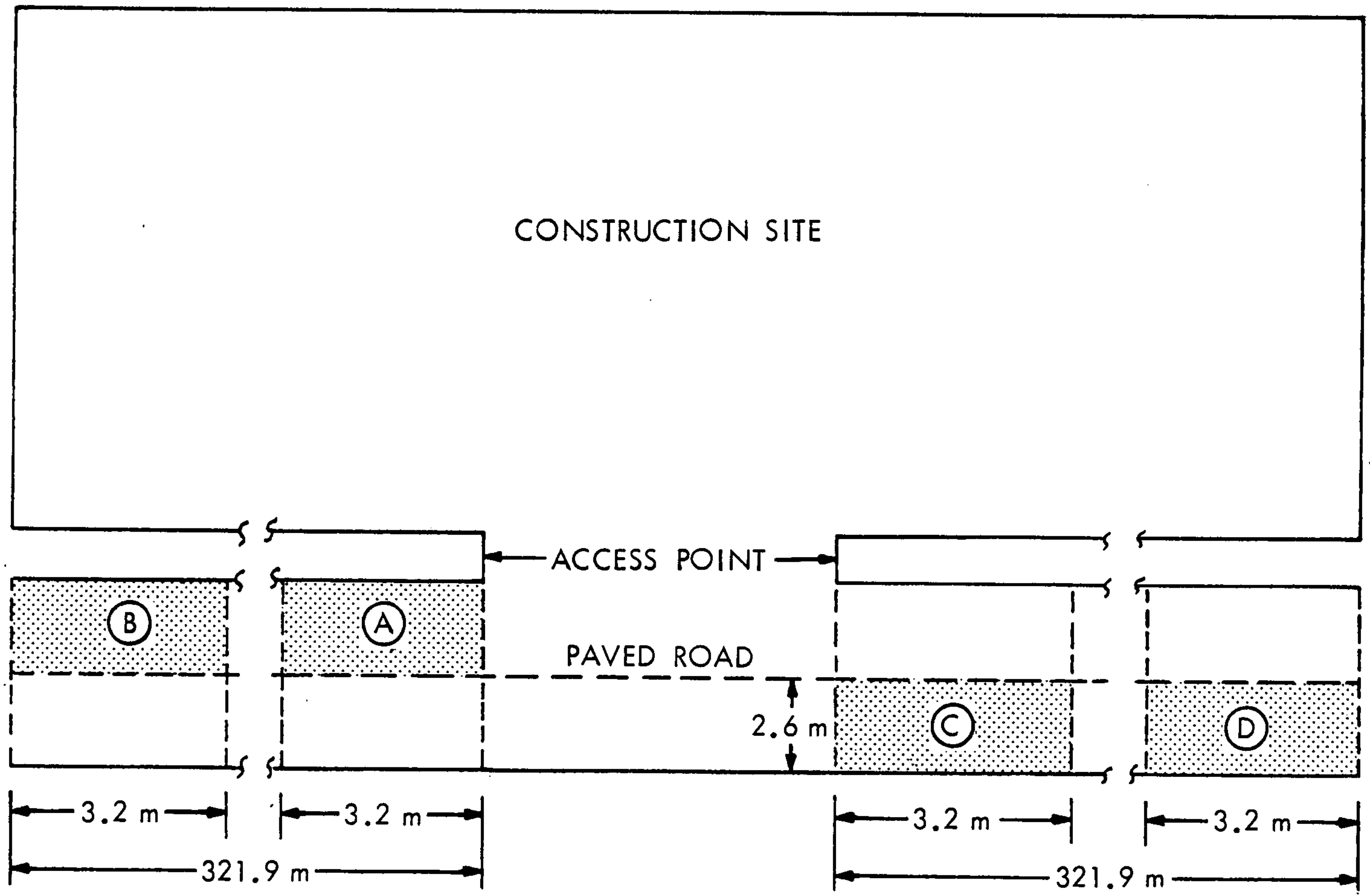



Figure 2-2. Sampling locations for Phase I.

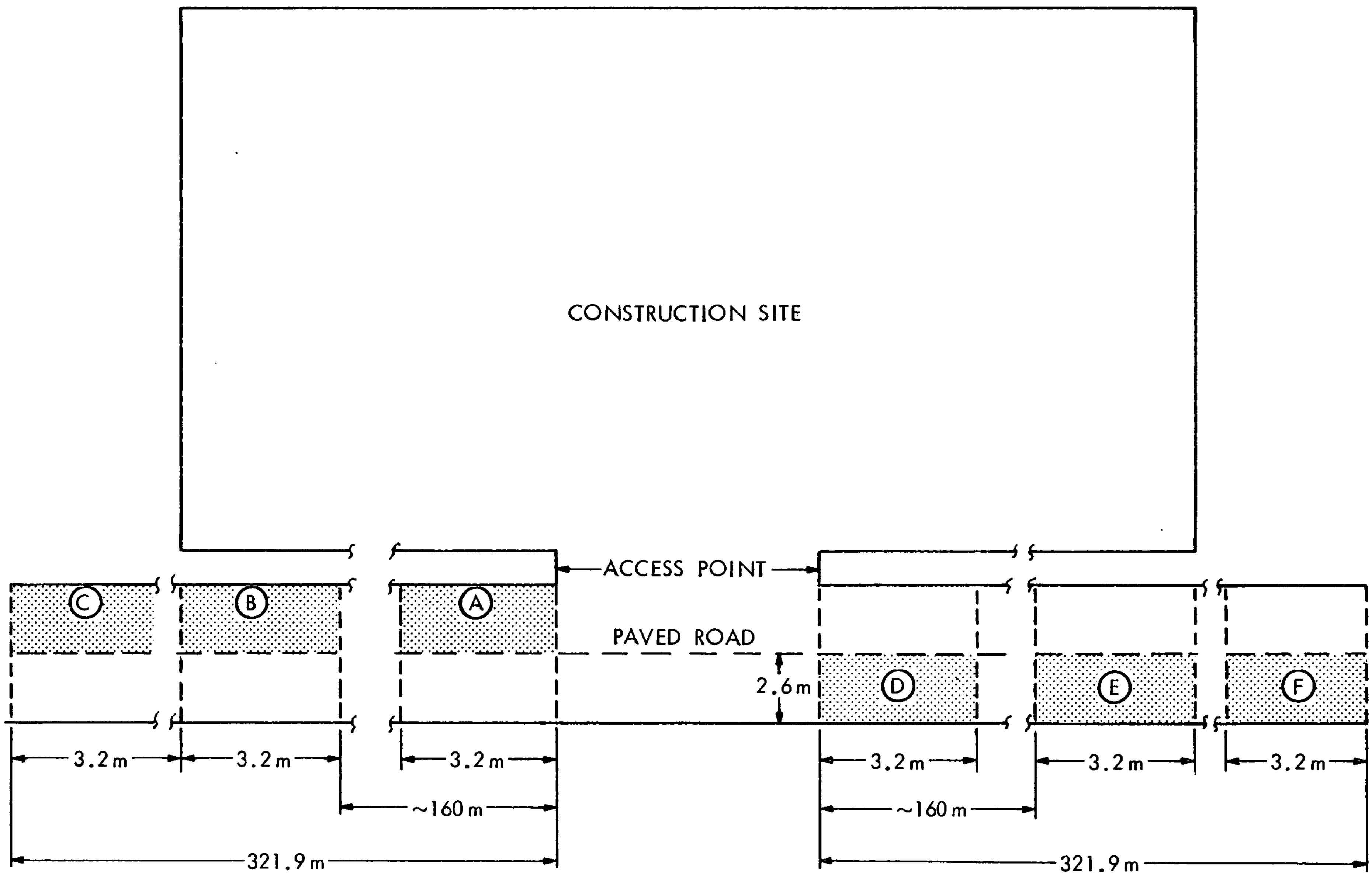



Figure 2-3. Sampling locations for Phase II.

count, (b) mean traffic speed, and (c) vehicle mix. Total vehicle count on the adjacent paved road was determined by using pneumatic-tube counters or was obtained from local transportation agencies. In order to convert the traffic counts taken at the access point to equivalent light-duty (2-axle) vehicles, vehicle mix summaries were tabulated through interviews with construction personnel and by observing the vehicles parked on-site. The vehicle mix summaries recorded the percentage of each vehicle type in each major category. From this information, the total counts were corrected to the total number of light-duty vehicles passing through the point of access to the construction site.

The speed of the traveling vehicles was taken to be the posted speed limits of the roadway adjacent to the construction project. As a check, speeds of the vehicles were determined through visual estimate. Typical weights of the various types of vehicles were estimated by consulting (a) automobile literature concerning curb weights of vehicles and (b) distributors of medium duty and semitrailer type trucks as to their curb weights.

On-site construction activity was determined by interviews with construction personnel. Information collected in this manner included: duration of construction, percentage of completion, types of activities occurring on-site (i.e., grading, etc.), estimate of source extent (i.e., cubic yards of material moved), number and type of vehicles entering and leaving the site, and control measures employed (if any). A special form was developed for this purpose, a copy of which is included in Appendix A.

## 2.3 LABORATORY ANALYSES AND RESULTS

The samples collected in the field were transported back to MRI for silt analysis. The procedure followed was generally the same as that used in previous MRI studies but was abbreviated slightly due to the large number of samples to be analyzed. The actual procedure used for the analysis of silt content ($\% < 74\ \mu m$) is shown in Appendix A.

Table 2-2 and 2-3 present the road surface loadings determined under Phases I and II of the field sampling program. At least one measurable precipitation event occurred between each set of samples collected. All the information from both studies was combined into one data set for analysis as discussed in Section 3.

TABLE 2-2. ROAD SURFACE LOADINGS - PHASE I

| Site No. | Sample set No. | Date sample collected | Sampling location A: Total surface loading ($g/m^2$)[a] | Sampling location A: Silt content[b] (weight %) | Sampling location B: Total surface loading ($g/m^2$)[a] | Sampling location B: Silt content[b] (weight %) | Sampling location C: Total surface loading ($g/m^2$)[a] | Sampling location C: Silt content[b] (weight %) | Sampling location D: Total surface loading ($g/m^2$)[a] | Sampling location D: Silt content[b] (weight %) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 7/20/82 | 120 | 11 | 3.0 | 7.3 | 1,300 | 11 | 32 | 2.2 |
| | 2 | 8/3/82 | 1,000 | 8.5 | 2.4 | 6.5 | 1,200 | 14 | 13 | 2.2 |
| | 3 | 8/18/82 | 81 | 1.2 | 2.3 | 6.7 | 24 | 10 | 8.3 | 1.9 |
| 2 | 1 | 7/21/82 | 510 | 12 | 2.7 | 8.3[c] | 1,100 | 7.2 | 7.0 | 8.3[c] |
| | 2 | 8/2/82 | 750 | 11 | 5.3 | 5.0[c] | 160 | 6.3 | 6.9 | 5.0[c] |
| | 3 | 8/17/82 | 110 | 7.8 | 1.5 | 9.5[c] | 47 | 7.2 | 11 | 9.5[c] |
| 3 | 1 | 7/21/82 | 2,000[d] | 9.3[e] | 0.8 | 14[c] | 19 | 12 | 0.8 | 14[c] |
| | 2 | 8/2/82 | 740[d] | 11[e] | 1.4 | 7.9[c] | 31 | 2.2 | 0.8 | 7.9[c] |
| | 3 | 8/17/82 | 620[d] | 4.6[e] | 0.7 | 9.3[c] | 12 | 3.0 | 0.7 | 9.3[c] |

[a] Rounded to two significant figures.

[b] Percent < 200 mesh (74 μm). Results rounded to two significant figures.

[c] Silt content of a combined sample obtained from locations B and D.

[d] Includes bicycle lane sample adjacent to sampling location A.

[e] Weighted average silt content of the samples collected from the bicycle lane and traveled portion of the roadway.

TABLE 2-3. ROAD SURFACE LOADINGS - PHASE II

| Sampling location | Sample set No. | Date sample collected | Total surface loading (g/m²)[a] Site No. 4 | Site No. 5 | Site No. 6 | Site No. 7 | Site No. 8 | Silt content (weight %)[e] Site No. 4 | Site No. 5 | Site No. 6 | Site No. 7 | Site No. 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 09/20-09/21 | 560 | 320[c] | 540[c] | 310 | 80 | 6.0 | 11[c] | 11 | 12 | 23 |
| | 2 | 10/18-10/19 | 680 | 3,200[c,d] | 1,200 | 240 | 340 | 4.4 | 5.2[c] | 19 | 18 | 16 |
| B | 1 | 09/20-09/21 | -- | 190 | 24 | 3.7 | 2.5 | -- | 5.7 | 7.4 | 19 | 4.4 |
| | 2 | 10/18-10/19 | 5.9 | 280 | 35 | 32 | 94 | 29 | 19 | 13 | 17 | 17 |
| C | 1 | 09/20-09/21 | 3.1[b] | 2.5 | 24 | -- | 1.7 | 3.6[b] | 7.0 | 7.4 | -- | 7.3 |
| | 2 | 10/18-10/19 | 8.5[b] | 2.6 | -- | -- | 23 | 6.5[b] | 8.4 | -- | -- | 13 |
| D | 1 | 09/20-09/21 | 80 | 49 | 49 | 120 | 14 | 3.7 | 2.5 | 3.2 | 13 | 16 |
| | 2 | 10/18-10/19 | 28 | 60 | 660 | 160 | 130 | 9.4 | 4.9 | 12 | 11 | 12 |
| E | 1 | 09/20-09/21 | 11 | 33 | 23 | 2.5 | 21 | 2.5 | 1.1 | 1.2 | 18 | 11 |
| | 2 | 10/18-10/19 | 6.5 | 87 | 20 | 400 | 160 | 13 | 1.9 | 3.0 | 15 | 18 |
| F | 1 | 09/20-09/21 | 3.1[b] | -- | -- | 6.6 | -- | 3.6[b] | -- | -- | 16 | -- |
| | 2 | 10/18-10/19 | 8.5[b] | -- | 8.2 | 21 | -- | 6.5[b] | -- | 3.4 | 13 | -- |

[a] Rounded to two significant figures.

[b] Samples C and F composited prior to analysis.

[c] Average of A samples from two access points.

[d] Reflects mound of earth covering curb to provide access for heavy vehicles.

[e] Percent < 200 mesh (74 µm). Results rounded to two significant figures.

# 3.0 DATA ANALYSIS

## 3.1 INTRODUCTION

This study had three major objectives with regard to construction related mud/dirt carryout. These were:

1. To characterize paved road surface loadings associated with uncontrolled mud/dirt carryout from typical construction activities in the Twin Cities metropolitan area.

2. To estimate the increase in emissions due to mud/dirt carryout from active construction sites.

3. To develop a statistical model that relates traffic entrained dust emissions associated with mud/dirt carryout to physical parameters which characterize the level of construction activity and climatic conditions.

The following is a description of the analysis performed as related to the above objectives.

In interpreting the results of this study, it is important to bear in mind that the sampling and site characterizations were conducted at discrete widely separated intervals in time. Consequently, the surface loadings reflected the cumulative effects of sequential construction processes, most of which were not monitored. Despite this limitation it is felt that the program yielded valuable information, particularly with respect to Objectives 1 and 2.

## 3.2 OBJECTIVE 1 - CHARACTERIZATION OF MUD/DIRT CARRYOUT ASSOCIATED WITH CONSTRUCTION ACTIVITIES

As stated in Section 2, surface loading samples were collected at various distances from the access point of the construction project, depending upon site and roadway characteristics. The most common distances for sample collection were 10 m and 320 m in either direction from the point of access. Only during Phase II were samples collected at intermediate points at a distance of about 160 m from the site entrance.

Statistics based on the surface loading samples collected at 10 and 320 m are presented in Table 3-1, along with similar measurements from two previously compiled urban road data sets. The means for the other two data sets represent typical background values (~ 1 $g/m^2$) for urban areas. The data indicate that silt loadings found near construction site access points (10 m) are approximately 40 times greater than background. Silt loadings at 320 m from the access point are in the range of background, with 85% of the values less than 1 $g/m^2$. At distances ranging from 50 to 220 m from

TABLE 3-1. COMPARISON OF ROADWAY SURFACE SILT LOADINGS

| Data base | Number of samples (n) | Silt loading Mean ($g/m^2$) | Standard deviation ($g/m^2$) | Range ($g/m^2$) |
|---|---|---|---|---|
| Current study: | | | | |
| Samples collected 10 m from access point | 22 | 41.9 | 46.0 | 0.348-157 |
| Samples collected 320 m from access point | 21 | 0.387 | 0.650 | 0.0632-3.02 |
| Urban roads - 4 U.S. Cities[a] | 43 | 0.910 | 0.898 | 0.040-4.23 |
| Urban roads - 12 U.S. Cities[b,c] | 72 | 1.44 | 2.09 | 0.140-10.7 |

[a] Source: Reference 2.

[b] In order to provide data comparable to that collected by MRI in the current study and in the paved road study (Ref. 2), two assumptions were made. The first assumption was that travel lanes contain 12% of total curb-to-curb loading, with the second being that average particle size distributions of road surface loading were applicable and could be used to obtain the silt fraction. Both assumptions are based on data contained in the survey report.

[c] Source: Reference 4.

the access point (Phase II sites), 75% of the silt loading values were greater than 1 $g/m^2$. This would suggest that significant carryout of material from construction sites is limited to less than 300 m from the site.

The light loadings at 320 m indicate that an appropriate background value, at least for the specific sites evaluated if not for the entire Twin Cities area, should be lower than that indicated by previous studies. The primary reason for the low loadings (at 320 m) probably involves the fact that the majority of the roads sampled were relatively new, and in good-to-excellent condition. Previous survey programs with samples obtained for a variety of pavement conditions, found that these roads (i.e., good to excellent condition) exhibit substantially lighter loadings than roads in fair to poor condition.

In order to estimate the increase in emissions due to mud/dirt carryout (Objective 2) it was necessary to define an operational background loading. Review of the sampling data (for 320 m) indicated that six samples with silt loading values ranging from 0.0632 to 0.279 $g/m^2$, could be considered as representative background values. These samples were designated as background based on their location relative to the source, as well as pavement and traffic conditions. The average of these samples, 0.104 $g/m^2$, provided the operational background value for the remainder of the data analysis. It should be noted that selection of a background level of 1 $g/m^2$ (i.e., factor of 10 higher) would only decrease the resulting emissions estimates by about 10% since they are most directly tied to the magnitude of the carryout immediately adjacent to the access point of the site.

## 3.3 OBJECTIVE 2 - ESTIMATING THE EMISSIONS INCREASE DUE TO CONSTRUCTION RELATED MUD/DIRT CARRYOUT

A two-step approach was used to estimate the increase in emissions due to mud/dirt carryout from the construction sites evaluated in this study. The first step involved fitting the data collected under Objective 1 to an exponential decay function of the form:

$$sL_x = A \exp(-bx) + (sL)_0 \qquad (1)$$

where: $sL_x$ = silt loading at distance x (mass/area);
$A$ = constant (mass/area);
$b$ = constant ($length^{-1}$);
$x$ = distance away from the site entrance (m);
$(sL)_0$ = background silt loading = 0.104 $g/m^2$

The estimated parameters (A, b, x*) for each sample pair are presented in Table 3-2.

The second step combined the results of the above procedure with the size-specific predictive emission factor equations developed by MRI to estimate the distance dependent increase in particulate emissions due to construction associated mud/dirt carryout.[2] More specifically, the increase in emissions ($\Delta E$) over a specific distance (x*) was evaluated by:

TABLE 3-2. ESTIMATED PARAMETERS FOR EXPONENTIAL FIT OF $sL_x = A\ \mathrm{Exp}(-bx)+(sL)_o$

| Site No./ sample pair | Sample set: Set 1 | | | Set 2 | | | Set 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | b | x*[a] | A | b | x* | A | b | x* |
| Site 1/ | | | | | | | | | |
| A-B | 14.9 | -0.015 | 348 | 110 | -0.024 | 305 | 0.950 | -0.0092 | 276 |
| C-D | 176 | -0.018 | 436 | 195 | -0.022 | 363 | 2.58 | -0.012 | 293 |
| Site 2/ | | | | | | | | | |
| A-B | 75.2 | -0.020 | 343 | 92.0 | -0.020 | 358 | 10.4 | -0.018 | 281 |
| C-D | 91.6 | -0.016 | 433 | 10.8 | -0.012 | 418 | 3.42 | -0.0040 | 944 |
| Site 3/ | | | | | | | | | |
| A-B | 317 | -0.035 | 242 | 113 | -0.0303 | 242 | 39.4 | -0.033 | 189 |
| C-D | 2.91 | -0.020 | 184 | 0.698 | -0.0205 | 109 | 0.420 | -0.019 | 91 |
| Site 4/ | | | | | | | | | |
| A-C | 43.8 | -0.027 | 237 | 19.8 | -0.0082 | 679 | | | |
| D-F | 3.43 | -0.015 | 202 | 2.09 | -0.0034 | 979 | | | |
| Site 5/ | | | | | | | | | |
| A-C | 59.1 | -0.034 | 196 | 245 | -0.026 | 315 | | | |
| D-F | 1.29 | -0.0089 | 320 | 16.8 | -0.017 | 318 | | | |
| Site 6/ | | | | | | | | | |
| A-C | 74.5 | -0.020 | 345 | 331 | -0.028 | 294 | | | |
| D-F | 1.71 | -0.014 | 218 | 142 | -0.038 | 201 | | | |
| Site 7/ | | | | | | | | | |
| A-C | 56.1 | -0.043 | 154 | 55.2 | -0.022 | 293 | | | |
| D-F | 18.0 | -0.090 | 609 | 66.9 | -0.019 | 362 | | | |
| Site 8/ | | | | | | | | | |
| A-C | 28.2 | -0.020 | 292 | 68.2 | -0.0088 | 774 | | | |
| D-F | 3.58 | -0.016 | 238 | 27.0 | -0.0070 | 846 | | | |

[a] Distance of mud/dirt carryout impact in meters from access point, see test for explanation.

$$\Delta E(x^*) = \int_0^{x^*} f\,[A\exp(-bx) + (sL)_0]dx - \int_0^{x^*} f[(sL)_0]dx \qquad (2)$$

where: $\Delta E(x^*)$ = increase in emissions (mass/vehicle pass);
$f(\;)$ = MRI predictive emission factor equation (mass/vehicle distance traveled);
$x$ = distance from site access point;
$x^*$ = distance at which construction site impact becomes negligible (length).

The MRI predictive emission factor equation is:

$$EF = k \; {\frac{sLx}{0.5}}^{\;P} \qquad (3)$$

where: EF = emission factor (g/vehicle · kilometer) and k and P are empirical correction parameters based on particle size (Table 3-3).

TABLE 3-3. PAVED ROAD EMISSION FACTOR EQUATION PARAMETERS (by particle size fraction)

| Particle size fraction (aerodynamic diameter) | k (g/VKT) | P |
|---|---|---|
| < ~ 30 μm | 5.87 | 0.9 |
| < 15 μm | 2.54 | 0.8 |
| < 10 μm | 2.28 | 0.8 |
| < 2.5 μm | 1.02 | 0.6 |

The distance at which the construction site impact becomes negligible ($x^*$), was defined as that point where the silt loading decayed to one standard deviation above the operational background (0.104 g/m$^2$ + 0.075 g/m$^2$ ≅ 0.180 g/m$^2$). The standard deviation refers to the six measurements that were averaged to produce the background silt loading. The $x^*$ value was determined for each sample set based upon the exponential fit of the observed silt loading measurements. It should be noted that the integration was performed separately in each direction from the access point because there were often large differences in loading depending upon construction and access road traffic patterns. The resultant estimates were then added to obtain total emissions increase.

The results of the analysis are presented for individual sample sets in Table 3-4, and are summarized by particle size fraction in Table 3-5. Assuming that the mean ($\bar{x}$) is representative of the entire construction sequence, then for a 1,000 ADT paved road adjacent to a site, and a 12 month project, the additional emissions of TSP would be approximately 18 tons/year. This result suggests that the increased emissions associated with construction related mud/dirt carryout are a temporary but potentially significant emissions source. This may be particularly true in developing suburban areas where there are usually very few traditional point emissions sources.

## 3.4 OBJECTIVE 3 - DEVELOPMENT OF A STATISTICAL MODEL FOR EMISSIONS ASSOCIATED WITH CONSTRUCTION-RELATED MUD/DIRT CARRYOUT

As implied earlier, incomplete characterization of source activities prevented the development of formal statistical models to "explain" the increase in mud/carryout associated emissions. However, the data are sufficient to allow at least semiquantitative examination of the relative importance of several factors influencing the emissions increase ($\Delta E$) associated with active construction sites. These factors include:

1. Influence of site-associated traffic volume;
2. Influence of adjacent roadway traffic volume;
3. Influence of type of construction (i.e., commercial or residential); and
4. Influence of phase of construction.

Much of the following analysis relies on comparisons of means ($\bar{x}$) for various subcategories of the data set. The results must be interpreted cautiously due in part to the small sample sizes involved. The computed t-statistics may be viewed as indicators of potentially important relationships; however, the indicated significance is likely to be "inflated" because no adjustment is made for multiple comparisons on the same observations.

TABLE 3-4. MUD CARRYOUT EMISSIONS INCREASE (g/vehicle pass)

| Site No./ sample set | < ~ 30 μm[a] TSP | < 15 μm[a] IP | < 10 μm[a] PM-10 | < 2.5 μm[a] FP |
|---|---|---|---|---|
| Site 1 | | | | |
| Set 1 | 80 | 22 | 20 | 7.8 |
| Set 2 | 100 | 27 | 24 | 9.5 |
| Set 3 | 3.2 | 1.3 | 0.84 | 0.44 |
| Site 2 | | | | |
| Set 1 | 72 | 21 | 19 | 7.3 |
| Set 2 | 44 | 13 | 12 | 4.6 |
| Set 3 | 14 | 5.1 | 4.6 | 1.8 |
| Site 3 | | | | |
| Set 1 | 64 | 16 | 15 | 5.8 |
| Set 2 | 28 | 8 | 7.2 | 2.8 |
| Set 3 | 10 | 3.2 | 2.8 | 1.1 |
| Site 4 | | | | |
| Set 1 | 15 | 4.9 | 4.4 | 1.7 |
| Set 2 | 28 | 9.4 | 8.5 | 3.3 |
| Site 5 | | | | |
| Set 1 | 15 | 4.8 | 4.3 | 1.7 |
| Set 2 | 76 | 20 | 18 | 7.1 |
| Site 6 | | | | |
| Set 1 | 30 | 9 | 8.1 | 3.2 |
| Set 2 | 110 | 28 | 25 | 9.7 |
| Site 7 | | | | |
| Set 1 | 28 | 9 | 8.1 | 3.2 |
| Set 2 | 48 | 14 | 13 | 5 |
| Site 8 | | | | |
| Set 1 | 14 | 4.6 | 4.2 | 1.6 |
| Set 2 | 95 | 29 | 26 | 10 |

[a] Aerodynamic diameter.

TABLE 3-5. SUMMARY OF CALCULATED EMISSIONS INCREASE BY PARTICLE SIZE FRACTION (g/vehicle pass)

| Particulate size fraction[a] | Mean ($\bar{x}$) | Standard deviation ($\sigma$) | Range |
|---|---|---|---|
| < ~ 30 μm | 46 | 34 | 3.2-110 |
| < 15 μm | 13 | 8.9 | 1.3-28 |
| < 10 μm | 12 | 8.0 | 0.84-25 |
| < 2.5 μm | 4.6 | 3.1 | 0.44-9.7 |

[a] Aerodynamic diameter.

Factor 1 - Site-Associated Traffic Volume

A comparison of ΔE for two levels of site-associated traffic volume was conducted based on only the first set of samples from each site. These samples were used because they had the most reliable information on site-associated traffic volumes. This comparison is summarized in Table 3-6. As expected, the sites with higher traffic volumes show substantially greater increases in emissions than did those with relatively low traffic volumes. Taken over all particle size fractions, the emission increase is approximately 2.5 times greater for sites with > 25 vehicles/day than for those with < 25 vehicles/day. A t-statistic calculated for the TSP data set could not be considered significant at the 90% level. This result is indicative of the fact that there is substantial variability in ΔE within traffic volume categories, particularly for the sites with > 25 vehicles/day.

Factor 2 - Adjacent Paved Road Traffic Volume

The second analysis was based on emissions increases averaged for the two or three site visits, and ADT counts obtained by MRI during the program (and/or supplied by the MPCA). If more than one ADT count was available for a road adjacent to the site, an average value was computed and used in the analysis.

TABLE 3-6. EMISSIONS INCREASE (ΔE) BY SITE TRAFFIC VOLUME[a]

| Particle size fraction[b] | Sites with > 25 veh./day | | | Sites with < 25 veh./day | | |
|---|---|---|---|---|---|---|
| | Mean ($\bar{x}$) | Standard deviation ($\sigma$) | Range | Mean ($\bar{x}$) | Standard deviation ($\sigma$) | Range |
| < ~ 30 µm | 52 | 28 | 15-80 | 19 | 7.8 | 14-28 |
| < 15 µm | 15 | 7.5 | 4.9-22 | 6.1 | 2.5 | 4.6-9 |
| < 10 µm | 13 | 6.7 | 4.4-20 | 5.5 | 2.3 | 4.2-8.1 |
| < 2.5 µm | 5.1 | 2.6 | 1.7-7.8 | 2.2 | 0.88 | 1.6-3.2 |

[a] ΔE expressed in g/vehicle pass.

[b] Aerodynamic diameter.

The relationship between emissions increase and ADT was determined by calculating Spearman's rank correlation.[5] The analysis indicated a positive relationship significant at approximately the 90% level. The most logical explanation for the positive relationship is that higher traffic volumes carry the mud/dirt from the site to greater distances and spread the material more uniformly over the road surface. This in turn leads to a greater emissions increase per vehicle pass.

Factor 3 - Type of Construction

The third comparison was based on sample sets from the commercial and residential construction sites. This comparison is summarized in Table 3-7. As indicated, commercial sites apparently produce higher emissions increases than residential sites. Taken over all particle size fractions, the ΔE is approximately 1.6 times greater for commercial sites than for residential sites. The calculated t-statistic indicates that this difference is significant beyond the 90% level.

TABLE 3-7. EMISSIONS INCREASED ($\Delta E$) BY CONSTRUCTION TYPE[a]

| Particle size fraction[b] | Commercial | | | Residential | | |
|---|---|---|---|---|---|---|
| | Mean ($\bar{x}$) | Standard deviation ($\sigma$) | Range | Mean ($\bar{x}$) | Standard deviation ($\sigma$) | Range |
| < ~ 30 μm | 65 | 39 | 14-110 | 39 | 22 | 10-72 |
| < 15 μm | 18 | 10 | 4.6-28 | 11 | 6 | 3.2-21 |
| < 10 μm | 16 | 9.3 | 4.2-25 | 10 | 5.4 | 2.8-19 |
| < 2.5 μm | 6.3 | 3.6 | 1.6-9.7 | 3.9 | 2.1 | 1.1-7.3 |

[a] $\Delta E$ expressed in g/vehicle pass.

[b] Aerodynamic diameter.

Part of this difference may be attributed to the different natures of commercial and residential construction. Commercial construction usually occurs at sites considerably smaller than a subdivision and is generally completed in a shorter time than residential construction. Housing contractors often complete only a few homes before initiating work on other houses in the same tract. As a result, commercial construction presents a much more concentrated activity offering a greater potential for mud/dirt carry-out.

Factor 4 - Influence of Phase of Construction

Table 3-8 presents comparisons that emphasize the temporal variability in increases in TSP emissions. For Sites 1 to 3, the first two sample sets were collected during periods when on-site activities included grading, installation of underground utilities, and actual building construction. Based on the survey information it appears that the projects were 50 to 75% completed when sample sets 1 and 2 were taken. In other words, the samples were collected approximately midway through the construction process. The third set of samples were taken after most of the site activity was completed.

TABLE 3-8. COMPARISON OF TEMPORAL VARIATIONS IN TSP EMISSIONS INCREASES (ΔE)[a]

| Site/sample sets | Mean ($\bar{x}$) | Standard deviation ($\sigma$) | Range | Phase of construction |
|---|---|---|---|---|
| Sites 1-3 (sets 1-2): | 65 | 26 | 28-100 | Middle |
| Sites 1-3 (set 3): | 9.1 | 5.5 | 3.2-14 | Near completion |
| Sites 4-8 (set 1): | 21 | 7.9 | 14-30 | Initial |
| Sites 4-8 (set 2): | 71 | 33 | 28-110 | Post-initial |

[a] ΔE expressed in g/vehicle pass.

For example, at Sites 1 and 3, roads and curbs were already installed prior to the sample collection. As indicated, the emissions increase for the earlier period is approximately seven times greater than that of the last sample period.

For Sites 4 to 8, samples collected near the beginning of construction projects (~ 5 to 10% of the work completed) were compared with those collected about 3 weeks later in the process. The data suggest that the emissions increase due to carryout, changes considerably over this relatively short time period with the emissions increases (for set 2) being approximately 3.5 higher than those collected during the beginning phases of construction.

## 4.0 CONCLUSIONS

Based on an analysis of the field sampling data as discussed in Section 3, a number of conclusions can be drawn concerning the increase in emissions ($\Delta E$) associated with mud/dirt carryout from active construction sites. These include:

- Silt loadings collected near the access point of active construction sites are much heavier than those found on typical urban paved roads.
- Enhanced surface loadings associated with active construction are discernable out to distances of approximately 300 m in either direction from the site access point.
- Calculated increases in emissions ($\Delta E$) associated with mud/dirt carryout from active sites indicate that this is a temporary but significant source of particulate emissions.
- There appears to be a positive relationship between site-associated traffic volumes and the magnitude of the emissions increase as calculated in this study.
- The results of this study indicate that the increase in emissions on adjacent paved roads due to mud/dirt carryout is greater for roads with higher traffic volumes (ADT).
- Commercial construction projects produce a greater increase in emissions (65 g/vehicle pass-TSP) than do residential sites (39 g/vehicle pass-TSP). However, residential sites may have an influence on the ambient air quality for a longer period of time.
- The overall increase in emissions varys according to the phase of construction with relatively low values in the early stages of construction, increasing values of $\Delta E$ with higher site activity levels, and finally reduced $\Delta E$ values in the later stages of active construction.
- Further research would be necessary to determine more quantitative relationships between all of the above factors relative to different types of construction projects.

## 5.0 REFERENCES


1. National Assessment of the Urban Particulate Problem. Volume I: Summary of National Assessment. U.S. EPA, Research Triangle Park, NC. EPA-450/3-76-024.

2. Cowherd, Chatten, Jr., and Phillip J. Englehart, "Paved Road Particulate Emissions," EPA Contract No. 68-02-3158, Technical Directive No. 19, Midwest Research Institute, Kansas City, MO, December 29, 1982.

3. PEDCo Environmental, "Control of Reentrained Dust From Paved Streets," EPA-907/9-77-007, U.S. Environmental Protection Agency, Region III, Kansas City, MO, August 1977.

4. Sartor, James D. and Gail B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," EPA-R2-72-081, U.S. Environmental Protection Agency, Washington, D.C., November 1972.

5. Hollander, Myles and Douglas A. Wolfe, Nonparametric Statistical Methods, Wiley and Sons, New York, 1973.

APPENDIX

FIELD DATA FORMS AND SILT ANALYSIS PROCEDURE

TABLE A-1. FIELD DATA FORM FOR PHASE I.

MIDWEST RESEARCH INSTITUTE
Mud Carryout Sample

Sample No. ____________________ Date ____________________
MRI Project No. ____________________ Recorded By ____________________

Type of Material Sampled: ____________________ Traffic Count ____________ Vehicles/ ______
Site of Sampling: ______________________________ No. of Traffic Lanes ______
Type of Pavement: Asphalt/Concrete Surface Condition ____________________

## SAMPLING METHOD

1. Sampling device: Portable vacuum cleaner (broom sweep first if loading is heavy)
2. Sampling depth: Loose surface material
3. Sample container: Metal or plastic bucket with sealed poly liner
4. Gross sample specifications:
   (a) 1 sample within 100 m of the air sampling site
   (b) composite of up to 3 increments: lateral strips of 1 m minimum width extending from curb to curb
   (c) total sample weight of at least 4.5 Kg

Indicate deviations from above method: ______________________________

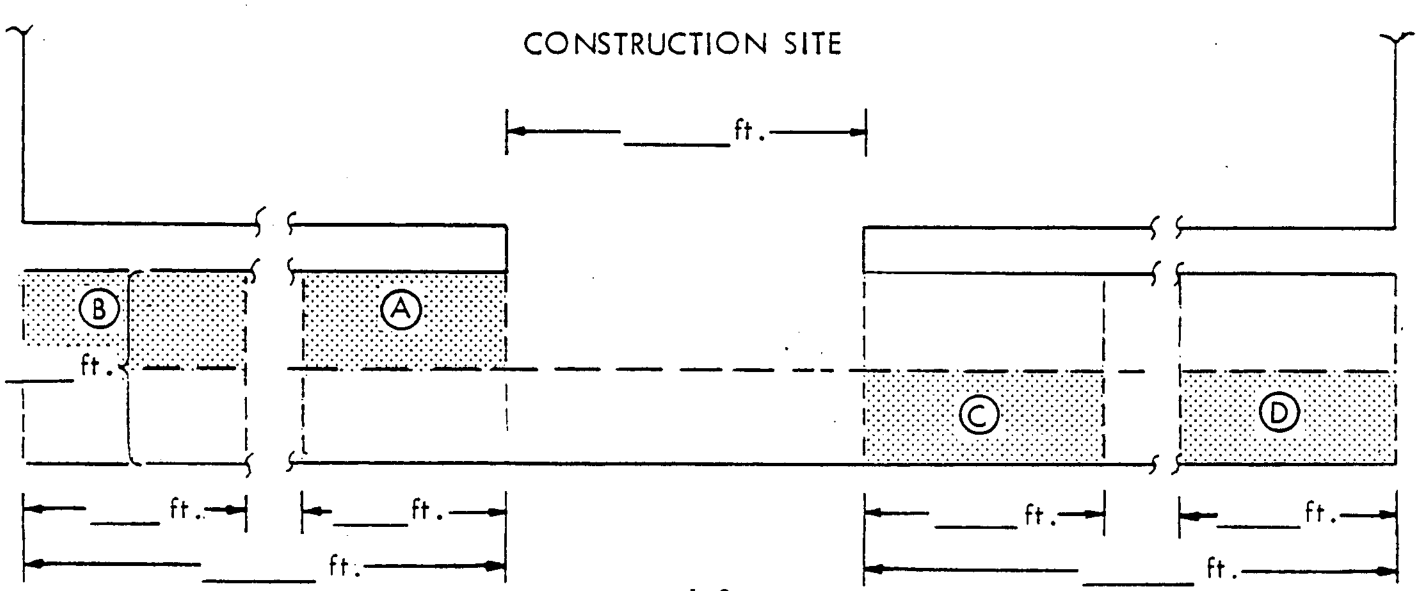
______________________________

## SAMPLING DATA

| Sample No. | Vac Bag | Time | Surface Area | Quantity of Sample |
|---|---|---|---|---|
| A-1 | | | | |
| A-2 | | | | |
| A-3 | | | | |
| B-1 | | | | |
| B-2 | | | | |
| B-3 | | | | |

| Sample No. | Vac Bag | Time | Surface Area | Quantity of Sample |
|---|---|---|---|---|
| C-1 | | | | |
| C-2 | | | | |
| C-3 | | | | |
| D-1 | | | | |
| D-2 | | | | |
| D-3 | | | | |

## DIAGRAM




6/82

MIDWEST RES. RCH INSTITUTE
Mud Carryout Sample

Sample No. ____________________ Date ____________________
MRI Project No. ____________________ Recorded By ____________________

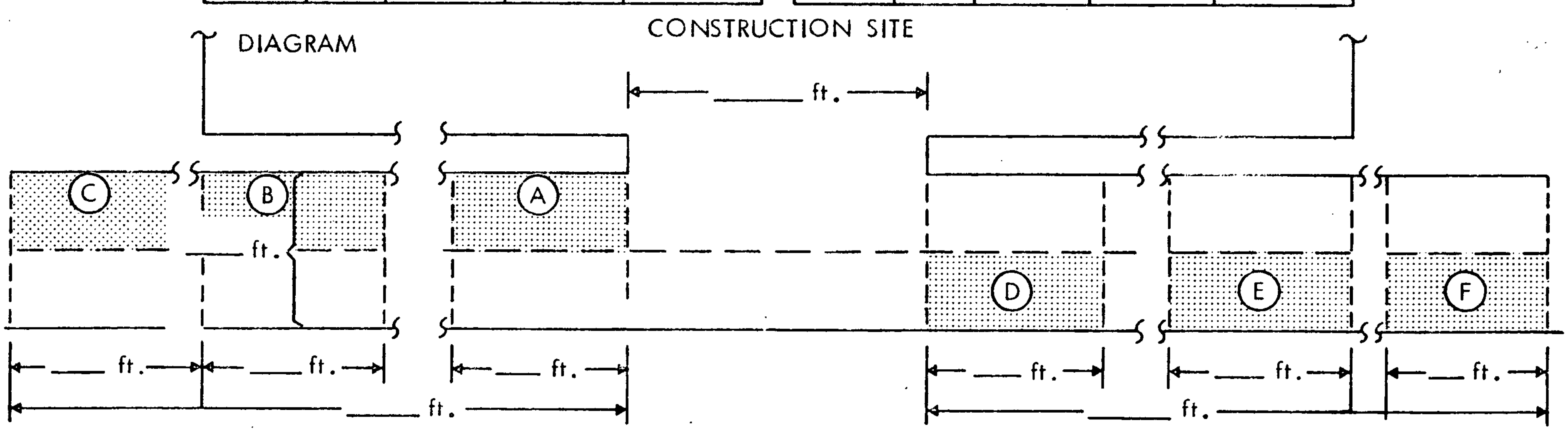
Type of Material Sampled: ____________________ Traffic Count ____________ Vehicles/ ________
Site of Sampling: ______________________________ No. of Traffic Lanes ________
Type of Pavement: Asphalt/Concrete ____________ Surface Condition ____________________

SAMPLING DATA

| Sample No. | Vac Bag | Time | Surface Area | Quantity of Sample |
|---|---|---|---|---|
| A-1 | | | | |
| A-2 | | | | |
| A-3 | | | | |
| B-1 | | | | |
| B-2 | | | | |
| B-3 | | | | |
| C-1 | | | | |
| C-2 | | | | |
| C-3 | | | | |

| Sample No. | Vac Bag | Time | Surface Area | Quantity of Sample |
|---|---|---|---|---|
| D-1 | | | | |
| D-2 | | | | |
| D-3 | | | | |
| E-1 | | | | |
| E-2 | | | | |
| E-3 | | | | |
| F-1 | | | | |
| F-2 | | | | |
| F-3 | | | | |

DIAGRAM




COMMENTS:

TABLE A-2. FIELD DATA FORM FOR PHASE II.

Figure A-1

QUESTIONNAIRE FOR CONSTRUCTION SITE PERSONNEL

1. Type of construction activity (check one)

   a. Residential _____
   b. Commercial _____
   c. Industrial _____

   Additional description (i.e., multi unit, residential or suburban commercial, etc.)

2. How long have you worked at this location? ____________

   Note: In the case of a multi-year project, we are only interested in the current season.

3. How long is the job projected to last? ________________

4. What percentage of the work is completed? _____ %

5. What construction activities are you currently performing?

6. What construction activities have you been performing over the past week to ten days?

7. What is the construction activity's source extent which is currently being performed (e.g., tons of earth moved/day or yards of concrete poured/day)?

8. Estimate the number of daily vehicle passes through the site entrance (check 1).

   a. <25 vehicles _____
   b. 25-50 vehicles _____
   c. 51-100 vehicles _____
   d. >100 vehicles _____

   If more than 100, approximately how many? _______ vehicles/day

9. What types of vehicle enter the site daily and what percentage of the traffic is of each type?

| | Vehicle Type | Percent |
|---|---|---|
| a. | Cars | ______ % |
| b. | Pickups/Vans | ______ % |
| c. | Med. Duty Trucks | ______ % |
| d. | Other | ______ % |

10. Do you employ control measures to keep dust down? If yes, what type?

11. What is the usual frequency and intensity of application? When was the most recent application?

TABLE A-3. SILT ANALYSIS PROCEDURES

1. Select the appropriate 8-in. diameter, 2-in. deep sieve sizes. Recommended U.S. Standard Series sizes are: 3/8 in., Nos. 4, 20, 40, 100, 140, 200, and a pan. Comparable Tyler Series sizes can also be utilized. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available or if buildup on one particular sieve during sieving indicates that an intermediate sieve should be inserted.

2. Obtain a mechanical sieving device such as a vibratory shaker or a Roto-Tap (without the tapping function).

3. Clean the sieves with dry compressed air and/or a soft brush. Material lodged in the sieve openings or adhering to the sides of the sieve should be removed (if possible) without handling the screen roughly.

4. Obtain a balance (capacity of at least 2,600 g (3.5 lb)) and record make, capacity, smallest division, date of last calibration, and accuracy.

5. Tare sieves and pan. Check the zero before every weighing. Record weights.

6. After nesting the sieves in order from the largest to the smallest openings with pan at the bottom, transfer the dried sample (immediately after drying) into the top sieve. Should the sample require splitting, the subsample should weigh between 300 and 1,000 grams. Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.

7. Place nested sieves into the mechanical shaking device and sieve for 5 min. Remove pan containing minus No. 200 and weigh. Replace pan beneath the sieves and sieve for another 5 min. Remove pan and weigh. When the difference between two successive pan sample weightings spaced 5 min apart (where the tare of the pan has been subtracted) is less than 3.0%, the sieving is complete. (However, as a check on the efficiency of this method, one sample per site per visit (generally sample A) was sieved and weighed at 10 min intervals for a maximum of 40 min or until a 3.0% variation was obtained.)

8. In the 40 min sieve analysis, weigh each sieve and its contents and record the weight. In the 20 min sieve analysis, weigh and record only the bottom pan weight. Check the zero of the scale before all weighing operations.

9. Collect the laboratory sample and place the sample in a separate container if further analysis is expected.

10. Calculate the percent of mass less than the 200 mesh screen (74 μm). This is the silt content.