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Source Assessment

Transport of Sand and Gravel

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SOURCE ASSESSMENT:
TRANSPORT OF SAND AND GRAVEL

by

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DISCLAIMER

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of air emissions from the transport of sand and gravel. This study was conducted to provide sufficient information for EPA to ascertain the need for developing control technology in this industry. Further information on this subject may be obtained from the Extraction Technology Branch, Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
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PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and solid waste legislation. If control technology is unavailable, inadequate, uneconomical, or socially unacceptable, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include process modification, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for developing control technology for a large number (>500) of operations in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL. This report contains the data necessary to make that decision for the air emissions from the transport of sand and gravel.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries which represent sources of pollution in accordance with EPA's responsibility as outlined above. Dr. Robert C. Binning serves as MRC Program Manager in this overall program entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer for this series. This study of the transport of sand and gravel was initiated by IERL-Research Triangle Park in August 1974; Mr. David K. Oestreich served as EPA Project Leader. The project was transferred to the Resource Extraction and Handling Division, IERL-Cincinnati, in October 1975; Mr. John Martin served as EPA Project Leader through completion of the study.

ABSTRACT

This report describes a study of air pollutants emitted by the transport of sand and gravel on unpaved roads. The potential environmental effect of the source was evaluated using a source severity (defined as the ratio of the maximum time-averaged ground level concentration to an ambient air quality standard or an adjusted threshold limit value).

Sand and gravel production is the largest nonfuel mineral industry in the U.S. Production of sand and gravel is associated with needs of the construction industry, which consumes over 90% of the output.

Trucks transport 92% of sand and gravel output. Air pollution is created by movement of these vehicles over unpaved roads and by wind erosion of the sand and gravel from truck beds. This report focuses on emissions caused by vehicular movement on unpaved roads because emissions due to wind erosion are shown to be insignificant.

Of the ambient air quality criteria pollutants, only particulate matter is emitted. The hazardous constituent of the emitted particulate is free silica. The average particulate emission factor for the transport of sand and gravel is 0.49 g/vehicle-m, with an average free silica content of 14% (by weight).

A representative sand and gravel plant processes 274 metric tons/hr, with vehicular traffic of 22 vehicles/hr (allows for round trips). The average length of the unpaved roads of the plants is 2.2 km, and each truck carries an average load of 21 metric tons. The uncontrolled particulate emission factor for the industry, due to vehicular movement, is 87 g/metric ton. The source severities for particulate and free silica particulates are 0.02 and 2.9, respectively.

Some plants have effectively used control measures such as applying oil, or chemical solutions onto the road surface. Spot measurements have shown that about 4% to 10% road moisture content reduces emissions by 99%. Future control techniques would consider the emission influencing factors of vehicle speed, vehicle size, number of wheels, tire width, particle size distribution, and road moisture content.

Truck transport of sand and gravel is still expected to be the dominant mode of transport in the future.

This report was submitted in partial fulfillment of Contract 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency. The study covers the period August 1974 through February 1976, and the work completed in September 1977.

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ABBREVIATIONS AND SYMBOLS

$a_1 \ldots a_2$ $b_1 \ldots b_2$	-- constants
a', b', c'	-- exponents expected to be in following range: $2.6 < a' < 3.0$ $2 < b' < 6$ $0.15 < c' < 0.35$
A	-- vehicle cross section
ACGIH	-- American Conference of Governmental Industrial Hygienists
B	-- surface area of the transported sand and gravel, m^2
CO	-- carbon monoxide
D	-- representative distance from source
d'	-- variable exponent which is a function of V and P.E.
E_c	-- emissions due to wind erosion of coal storage pile, kg/hr
E_s	-- emissions due to wind erosion, kg/m^2-yr
E_t	-- emissions due to wind erosion of sand and gravel during transport, kg/hr-vehicle
E_u	-- emissions, g/vehicle
exp	-- Napernian log base e = 2.72, a constant
F	-- hazard factor
Kc	-- constant of proportionality
K_s	-- function of soil or knoll erodibility, surface crust stability, and ridge roughness
K_t	-- constant for transport operations
K_u	-- constant of proportionality
L	-- length of unpaved road
L_t	-- distance of truck transport between finished stockpile and user
M	-- surface moisture or P.E. index
n	-- number of wheels per vehicle
NO_x	-- nitrogen oxide
P	-- percent of particles in road surface material (0 cm to 10 cm depth) <100 microns
P.E.	-- precipitation--evaporation index
Q	-- emission rate
r^2	-- correlation coefficient
s	-- surface area
S	-- source severity
SO_x	-- sulfur oxide
S_p	-- severity of particulate matter
S_s	-- severity of free silica particulate matter

t	-- student's t
T	-- vehicle weight
TLV	-- threshold limit value
U	-- wind speed
U_*	-- relative wind speed
V	-- vehicle speed
W	-- tire width
X	-- vehicular traffic
x_{S_p}	-- distance at which the source severity of particulate matter equals 0.1
x_{S_s}	-- distance at which the source severity of free silica particulate matter equals 0.1
y	-- production rate
$\overline{\chi}_{max}$	-- time-averaged maximum ground level concentration
π	-- a constant, 3.14
ρ	-- bulk density
σ	-- overall standard deviation

CONVERSION FACTORS AND METRIC PREFIXES[a]

CONVERSION FACTORS

To convert from	to	Multiply by
centimeter (cm)	inch	0.394
gram (g)	pound-mass (lb mass avoirdupois)	2.204×10^{-3}
kilogram (kg)	pound-mass (lb mass avoirdupois)	2.204
kilometer (km)	mile	0.622
kilometer^2 (km^2)	mile^2	3.860×10^{-1}
meter (m)	foot	3.281
meter (m)	inch	3.937×10^{1}
meter^2 (m^2)	foot^2	1.076×10^{1}
meter^2 (m^2)	inch^2	1.550×10^{3}
meter^3 (m^3)	foot^3	3.531×10^{3}
meter^3 (m^3)	inch^3	5.907×10^{4}
metric ton	ton (short, 2000 lb mass)	1.102

METRIC PREFIXES

Prefix	Symbol	Multiplication factor	Example
kilo	k	10^3	1 kg = 1×10^3 grams
milli	m	10^{-3}	1 mm = 1×10^{-3} meter
micro	μ	10^{-6}	1 μm = 1×10^{-6} gram
nono	n	10^{-9}	1 nm = 1×10^{-9} meter

[a]Metric Practice Guide. ASTM Designation E 380-74, American Society for Testing and Materials, Philadelphia, Pennsylvania, November 1974. 34 pp.

SECTION 1

INTRODUCTION

Transport of sand and gravel results in dust emissions due to vehicular movement on unpaved roads. A literature and sampling survey of these emissions was conducted to provide a better understanding of the distribution and character of emissions than has been previously available in the literature. When collecting data, emphasis was focused on accumulating sufficient information to permit EPA to decide on the need for control technology development.

The following information is compiled in this document:

- a method to estimate emissions from transport of sand and gravel
- composition of emissions
- hazard potential of emissions
- vehicular traffic around a sand and gravel plant
- trends in the transportation of sand and gravel and their effects
- types of control technology used and proposed

SECTION 2

SUMMARY

Sand and gravel production is the largest nonfuel mineral industry in the U.S. Since the construction industry consumes more than 90% of the sand and gravel output, sand and gravel production is associated chiefly with the needs of this industry. In 1972, there were 5,384 sand and gravel plants engaged in active production. A total of 1,008 million metric tons of sand and gravel were sold or used by producers in 1972. California, with 129 million metric tons/yr, ranked first in sand and gravel output, followed in order by Michigan, Ohio, Illinois, Minnesota, Wisconsin, and Texas as the top seven producing states.

Trucks transport 92% of the vast quantity of sand and gravel, resulting in a high degree of traffic activity within sand and gravel sites. Air pollution is created by vehicular movement over unpaved roads and by wind erosion of the sand and gravel from truck beds; however, wind erosion emissions are shown to be insignificant. This report focuses on the emissions caused by vehicular movement on unpaved roads.

Of the ambient air quality criteria pollutants, only particulate matter is emitted. The average particulate emission factor for transport of sand and gravel on unpaved roads is 0.49 g/vehicle-m.

The hazardous constituent of the emitted particulate is free silica. Prolonged exposure to free silica results in a pulmonary fibrosis known as silicosis. The threshold limit value for free silica is less than half the threshold limit value of inert dusts. Free silica particulates therefore present a greater health hazard than inert particulate matter. Particulate emissions from the transport of sand and gravel contain from 1.4% to 47% (by weight) free silica, with an average of 14% (by weight).

This study characterizes the health hazard potential of uncontrolled emissions from all transport of sand and gravel sources. This is accomplished by computing various evaluation criteria for a defined representative source with average operating parameters.

Production per sand and gravel plant can vary from <23,000 metric tons/yr to highly automated plants capable of supplying 3.6 million metric tons/yr. A representative sand and gravel plant processes 274 metric tons/hr, with vehicular traffic of 22 vehicles/

hr (allows for round trips). The average length of unpaved road is 2.2 km and each truck carries an average load of 21 metric tons. The uncontrolled particulate emission factor per metric ton due to vehicular movement is 87 g/metric ton. The free silica particulate emission factor is 12 g/metric ton.

To quantify the impact of this source on the environment, a source severity (S) was defined. Source severity is the ratio of the time-averaged ground level concentration ($\overline{\chi}$) at a representative downwind distance (D) to a criteria pollutant ambient air quality standard or an adjusted threshold limit value. When the ratio or severity is >1.0, the source is considered a definite candidate for control technology development, while $0.1 < S < 1.0$ indicates a possible need for additional control technology. The severities for particulate matter treated as total suspened for particulate and free silica containing particulate are 0.02 and 2.9, respectively.

Affected population is defined as the product of the land area beyond the plant boundry, where severity is >0.1 or >1.0 and the representative population density. No population is affected by particulate matter severity. Free silica particulates affect a population of 30,000 persons down to a severity of 0.1 and 1,650 persons to a severity of 1.0.

The state and national emission burdens are the ratio of mass emissions of a criteria pollutant from the transport of sand and gravel to the total mass emissions of that pollutant in each state and in the nation, respectively. Twenty-one states each have emission burdens for particulates >1.0%. The highest state emissions burden is in Alaska, 9.8%. The national emission burden for particulate is 0.49%.

The growth factor is defined as the ratio of mass emissions from the transport of sand and gravel in 1977 to the 1972 emissions level. The growth factor for particulates is 1.15.

Control of emissions from unpaved roads is not widely practiced within the sand and gravel industry; however, some plants have effectively used certain control measures. Both applying $CaCl_2$ solutions, oil and lignin sulfonates and mixing stabilization chemicals into the road surface have been practiced. Spot measurements have shown that about 4% to 10% road moisture content reduces emissions by 99%. This would produce a controlled particulate emission factor of 0.87 g/metric ton. Future control techniques would involve consideration of the factors affecting emissions. Emissions are primarily influenced by vehicle speed, vehicle cross-sectional area and weight, number of wheels, tire width, particle size distribution, and road moisture content.

Sand and gravel production is expected to grow at an average annual rate of 3.9% to 4.7%. By the year 2000, sand and gravel production is expected to be 2,860 to 3,619 million metric tons/

yr. Truck transport of sand and gravel is still expected to be the dominant mode of transport in the year 2000.

SECTION 3

SOURCE DESCRIPTION

PROCESS DESCRIPTION

The sand and gravel industry is the largest nonfuel mineral industry in the U.S. A total of 1,008,075,000 metric tons[a] of sand and gravel were sold or used by producers in 1972 (1). Government and contractor operations accounted for 14% of the sand and gravel output while commercial operations produced 86% (1). Government and contract operations are primarily involved with large-scale projects such as highways and reclamation works. Sand and gravel is primarily used in the construction industry, which consumes over 90% of the output (2).

Because of the widespread occurrence of producing sand and gravel near construction sites, 5,384 plants were engaged in commercial production in 1972 (2). No single firm dominates the industry; plant sizes vary from very small producers to highly automated permanent installations. A survey of the sand and gravel industry indicates that an average plant size is 6.4×10^5 metric tons/yr (Appendix A).

Sand and gravel plants stockpile the finished products and variously sized aggregates of sand in storage areas. The finished products are transported to the consumer (primarily construction industries) by means of truck, rail, or barge systems. Truck haulage is the predominant form of transportation, accounting for 92% of the transported sand and gravel. Trucks used in hauling sand and gravel have an average capacity of 21 metric tons (Appendix A). The method of transporting sand and gravel in 23 states is presented in Table 1 (personal communication with W. Pajalich, U.S. Bureau of Mines, Division of Nonmetallic Minerals, Washington, D.C., November 7, 1974).

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[a] 1 metric ton = 10^6 grams = 1.1 short tons; conversion factors and metric prefixes are presented in the prefatory pages.

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(1) Minerals Yearbook 1973, Volume I. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1975. p. 1105.

(2) Pajalich, W. Sand and Gravel. In: Minerals Yearbook 1973, Volume I. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1975. pp. 1097-1115.

TABLE 1. SAND AND GRAVEL METHOD OF TRANSPORTATION IN 1973[a]
(10^3 metric tons)

State	Truck	Railway	Waterway	Other
California	114,161	2,857		
Connecticut	7,806			
Florida	18,394	1,773		
Georgia	3,515	1,461		
Idaho	8,327	66		
Illinois	41,632	1,907		
Iowa	18,104			1,608
Kansas	12,846	414		
Louisiana	12,915	833		
Missouri	9,540	810	380	149
Montana	11,646	47		
Nebraska	13,512	2,088		306
New Jersey	16,085	2,586		
New York	29,213	196		
North Carolina	13,997			
Rhode Island	2,429			
South Carolina	5,664	2,514		
South Dakota	13,616			
Tennessee	10,363	777	870	
Texas	30,564	5,462	2,521	
Virginia	9,190	1,428		
Wisconsin	38,956	1,294		
Wyoming	6,118	84		

Note.—Blanks indicate no reported data.
[a]Partial list of states which transport.

SOURCE COMPOSITION

Sand and gravel are the natural products from the weathering of rocks. The term "sand" is used to represent material within a size range of 20 µm to 2,000 µm. Material in the size range between 20 µm and 200 µm is termed as fine sand, and that between 200 µm and 2,000 µm is termed as coarse sand. The term "gravel" is used to represent material larger than 2,000 µm. Silt is material within a size range of 2 µ to 20 µm, and clay is defined as 0.1 µm to 2 µm particles (3).

(3) Stern, A. C. Air Pollution, Volume I-Air Pollution and Its Effects. Academic Press, New York, New York, 1968. 50 pp.

Sand and gravel consist primarily of silica. Other constituents may be limestone or combined silica in the form of feldspar, mica, and other mineral silicates and aluminosilicates (4).

EMISSION SOURCES

Dust emissions occur during truck transportation of sand and gravel. Emission sources are divided into two categories: 1) vehicular movement on unpaved roads and 2) wind erosion from the truck bed. However, based upon calculation, windblow emissions are insignificant compared to unpaved road emissions (Appendix B).

Emissions due to vehicular movement on unpaved roads are influenced by vehicle speed, vehicle dimensions, number and width of the wheels, particle size distribution and moisture content of the unpaved road surface, and distance of the unpaved road from the finished stockpile to the nearest paved highway. These factors are discussed in detail in Appendix C.

Vehicular traffic at a sand and gravel site varies with the production rate of the facility. Figure 1, based on survey results of the industry, illustrates this relationship. For a derivation of this relationship, see Appendix A.

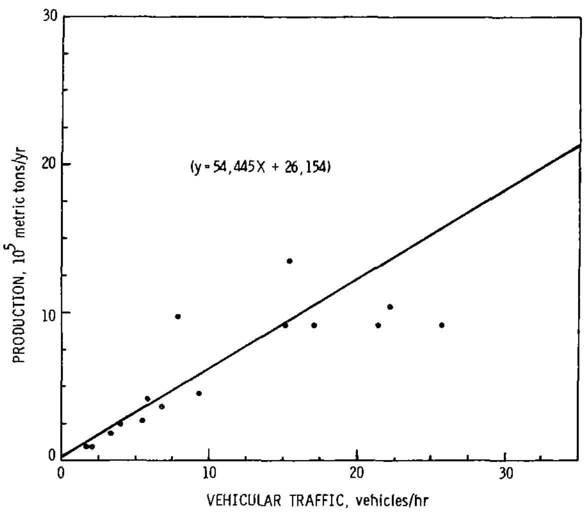

Figure 1. Relationship of vehicular traffic to production rate at a sand and gravel plant.

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(4) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Volume 12. John Wiley & Sons, Inc., New York, New York, 1967. 905 pp.

AREAS OF CONCENTRATION AND POPULATION DISTRIBUTION

Geographically, the sand and gravel industry is concentrated in large, rapidly expanding urban areas and on a transitory basis, in areas where highways, dams, and other large-scale public and private works are under construction. The distribution of sand and gravel sold or used by producers in the U.S. is provided in Table 2 (1). California ranks first in sand and gravel output with 129 million metric tons in 1972, producing nearly twice as much as second-ranked Michigan. The seven leading states in descending order of production are California, Michigan, Ohio, Illinois, Minnesota, Wisconsin and Texas. Combined production from these seven states accounts for 40% of the U.S. sand and gravel output.

TABLE 2. SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1972 BY STATE AND CLASS OF OPERATION (1)

(thousand metric ton and thousand dollars)

State	1970 Population density, persons/km²	Commercial		Government and contractor		Total[a]	
		Quantity	Value	Quantity	Value	Quantity	Value
Alabama	26	7,003	8,530	—[b]	—[b]	7,003	8,530
Alaska	<1	4,688	4,183	10,955	11,031	15,642	15,214
Arizona	6	24,938	29,131	2,451	3,290	27,389	32,420
Arkansas	14	11,030	15,045	1,732	1,514	12,761	16,558
California	49	115,126	154,544	14,189	8,075	129,314	162,619
Colorado	8	24,488	30,285	6,732	4,346	31,222	34,631
Connecticut	241	6,531	9,560	925	1,710	7,456	11,270
Delaware	107	2,488	2,660	—[b]	—[b]	2,488	2,660
Florida	48	24,606	16,963	50	45	24,656	17,009
Georgia	31	4,207	4,729	—[b]	—[b]	4,207	4,729
Hawaii	46	644	1,890	28	3	671	1,893
Idaho	3	4,217	5,896	4,268	4,398	8,485	10,294
Illinois	77	43,587	61,328	438	368	44,023	61,696
Indiana	56	29,385	32,348	1,462	943	30,847	33,290
Iowa	20	17,389	19,064	1,472	1,076	18,861	20,140
Kansas	11	10,215	9,588	2,565	1,333	12,779	10,920
Kentucky	31	9,174	11,919	180	48	9,355	11,967
Louisiana	31	20,439	26,255	422	740	20,860	26,996
Maine	12	4,549	4,394	8,481	3,140	13,030	7,535
Maryland	153	13,700	26,517	184	40	13,885	26,557
Massachusetts	281	18,267	23,782	2,552	1,873	2,819	25,655
Michigan	60	60,290	63,646	5,275	1,799	65,565	65,445
Minnesota	19	33,573	29,972	6,991	3,482	40,565	33,454
Mississippi	18	14,658	15,867	137	266	14,795	16,133
Missouri	26	11,100	14,779	15	27	11,116	14,806
Montana	2	2,357	3,022	8,795	14,126	11,153	17,149
Nebraska	7	13,580	13,376	1,547	1,688	15,127	15,063
Nevada	2	8,514	10,691	2,601	1,945	11,115	12,636
New Hampshire	32	5,309	5,951	1,327	305	6,637	6,256
New Jersey	368	19,477	38,010	14	11	19,492	38,020
New Mexico	3	6,184	6,894	2,195	1,659	8,379	8,553
New York	147	27,116	36,321	2,346	631	29,462	36,952
North Carolina	40	10,375	12,400	3,763	1,413	14,138	13,812
North Dakota	3	5,191	4,678	2,176	1,078	7,366	5,757
Ohio	100	47,713	59,702	252	230	47,967	59,932
Oklahoma	14	8,055	10,181	656	957	8,711	11,138
Oregon	8	22,862	30,462	4,138	4,519	27,000	34,981
Pennsylvania	101	20,680	36,804	—[b]	—[b]	20,680	36,804
Rhode Island	350	2,214	3,265	78	71	2,292	3,336
South Carolina	33	8,728	12,121	—[b]	—[b]	8,728	12,121
South Dakota	3	6,364	6,423	7,691	8,369	14,055	14,793
Tennessee	37	11,512	15,157	439	172	11,950	15,328
Texas	16	36,423	54,658	2,332	1,670	38,755	56,328
Utah	5	12,847	13,989	3,271	3,082	16,118	17,071
Vermont	18	2,731	3,014	910	199	3,641	3,214
Virginia	45	15,409	21,648	120	48	15,529	21,696
Washington	20	20,137	23,440	5,293	2,629	25,430	26,069
West Virginia	28	6,356	15,030	—[c]	1	6,356	15,031
Wisconsin	31	26,922	24,880	13,244	6,443	40,165	31,324
Wyoming	1	4,055	4,142	5,975	10,774	10,031	14,916
TOTAL	22	867,406	1,089,132	140,669	111,569	1,008,075	1,200,701

[a]Data may not add to totals shown because of independent rounding.

[b]None produced.

[c]Less than 1/2 unit.

Table 2 also lists the population density of each state. Using the densities of the seven leading producing states, the average population density of a sand and gravel producing area is defined as 50 persons/km^2.

SECTION 4

EMISSIONS

SELECTED POLLUTANTS

Of the ambient air quality criteria pollutants, only particulate matter is emitted. The main hazardous constituent of the particulate emitted due to sand and gravel transportation is free silica. Prolonged inhalation of dusts containing free silica may result in a disabling pulmonary fibrosis known as silicosis. The action of silica on the lungs results in the production of a diffuse, nodular progressive fibrosis which may continue to increase for several years after exposure is terminated. The first and most common symptom of uncomplicated silicosis is dry cough and shortness of breath upon exertion. As the disease advances, the shortness of breath becomes worse and the cough becomes more troublesome. Further progress of the disease results in marked fatigue, loss of appetite, pleuritic pain, and total incapacity to work. Extreme cases may eventually cause death due to destruction of the lung tissues (5).

The American Conference of Governmental Industrial Hygienists (ACGIH) has suggested a threshold limit value (TLV®) of 10/(% Quartz + 2) mg/m^3 for respirable dusts containing quartz or free silica. Furthermore, particulate is one of the criteria pollutants. Dusts with <1% silica are termed "inert," and a TLV of 10 mg/m^3 is suggested for these (6).

POLLUTANT CHARACTERISTICS

Mass Emissions

The average particulate emission factor for the transport of sand and gravel is 0.49 g/vehicle-m (Appendix C). Given the average production rate for a representative source (described below) of

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(5) Sax, N. I. Dangerous Properties of Industrial Materials, Fourth Edition. Van Nostrand Reinhold Company, New York, New York, 1975. 1258 pp.

(6) TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1975. American Conference of Government Industrial Hygienists, Cincinnati, Ohio, 1975. 97 pp.

274 metric tons/hr and the emission rate from Appendix D of 6.6 g/s, the emission factor per metric ton of sand and gravel transported is 87 g/metric ton and per year is 56 metric ton/yr.

Composition of Emissions

The free silica content of the particulate matter ranges from 1.4% to 47% (by weight). The average free silica content is 14.1% ± 4.6% at the 95% confidence level (Appendix E). The free silica particulate emission factor is 12 g/metric ton.

Definition of the Representative Source

A representative sand and gravel plant is defined in order to characterize emissions from the transport of these aggregates on unpaved roads. The representative source is defined as one that has the average emission parameters. These parameters were obtained from a survey of the sand and gravel industry (Appendix A) and are listed in Table 3.

TABLE 3. REPRESENTATIVE SOURCE PARAMETERS

Parameter	Average	Standard Deviation
Production rate, metric tons/hr	274[a]	±265
Unpaved road distance, km	2.2	±2.7
Truck capacity, metric tons	21	±2.5
Vehicular traffic, vehicles/hr	22[b]	±21

[a]Based on 9 hr/day, 260 days/yr.

[b]Based on 2 trips/load.

The Criteria for Air Emissions

The hazard potential of emissions from the representative source are quantified through the following evaluation criteria: source severity, affected population, emission burden, and growth factor. These criteria are defined and presented in the following sections.

Source Severity--

Source severity, S, is defined as

$$S \equiv \frac{\bar{\chi}}{F} \qquad (1)$$

where $\bar{\chi}$ is the time-averaged ground level concentration of each pollutant and F is defined as the primary amibent air quality standard for criteria pollutants (particulates, SO_x, NO_x, CO and hydrocarbons). For noncriteria pollutants,

$$F \equiv TLV \cdot 8/24 \cdot 0.01 \quad (2)$$

The factor 8/24 adjusts the TLV® (threshold limit value) to a continuous rather than workday exposure, and the factor 0.01 accounts for the fact that the general population is a higher risk group than healthy workers. Thus, $\overline{\chi}/F$ represents the ratio of the time-averaged ground level concentration to the concentration constituting an incipient hazard potential.

Through a derivation presented in Reference 7, the source severity for particulate matter, S_p, is expressed as

$$S_p = \frac{4,020\ Q}{D^{1.814}} \quad (3)$$

where Q = emission rate, g/s
D = representative downwind distance, m

Distance, D, is the average length of unpaved road (2.2 km) which is assumed to be equal to the downwind distance from the plant boundary.

The source severity for particulates is computed as 0.02 (Appendix D).

The source severity of free silica, S_s, is given by (7)

$$S_s = \frac{316\ Q}{D^{1.814} \cdot TLV} \quad (4)$$

where TLV = threshold limit value

This source severity is computed to be 2.9 (Appendix D).

Affected Population--

Affected population is defined as the product of the land area outside the plant boundary where severity is > 0.1 or > 1.0 and the representative population density.

(7) Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. 84 pp.

This quantity is useful in characterizing emissions because although a given source may exceed some criteria, it may have only a small effect on human health if it is located in a sparsely populated area. In addition, a source may have a large value of S due to a small emission height. Again, its impact on human health may be small because the low emission height results in pollutants being dispersed over a very small area in the immediate vicinity of the source.

Since the severity for particulates at the plant boundary of a representative sand and gravel plant is < 0.1, the affected population for $S > 0.1$ and 1.0 is zero. Free silica particulates, however, affect a population of 30,000 persons for $S \geq 0.1$ and 1,650 persons for $S \geq 1.0$ (Appendix D). These numbers are based upon the assumption that the population density around a representative plant is 50 persons/km^2, the average population density of the seven leading producing states.

State and National Emission Burden--
Emission burdens are ratios of mass emission of criteria pollutants from a given source category (such as the transport of sand and gravel) to total emissions of those pollutants in a state or nationwide. Using the emission factor of 87 g/metric ton and 1972 production data from Table 2, mass emission levels from the transport of sand and gravel are computed and presented in Table 4. These levels are compared with the 1972 National Emissions Data Systems (NEDS) data base of mass emissions per state, and the emission burdens are calculated.

Growth Factor--
The growth factor is determined from the ratio of known to projected emissions from a source type. For this report,

$$\text{Growth Factor} = \frac{\text{Projected Emissions in 1977}}{\text{Emissions in 1972}} \qquad (5)$$

Other 5-yr periods (e.g., 1975 and 1980) could also be used depending on available data. The main purpose of this criterion is to eliminate from consideration those sources whose emissions are expected to decrease greatly in the near future due, for example, to the implementation of new emission controls or to a process being phased out of production.

Because the implementation of new controls is not expected to be widespread, projected emissions for 1977 will be totally dependent on production values. Production figures from Section 6 for 1972 and 1977 are 937 million metric tons and 1,080 million metric tons, respectively. These numbers were determined from a 20-yr production trend. Using the uncontrolled particulate emission factor of 87 g/metric ton, the emissions are

TABLE 4. STATE AND NATIONWIDE PARTICULATE EMISSIONS BURDEN DUE TO TRANSPORT OF SAND AND GRAVEL

State	1972 Overall particulate emissions, metric tons/yr	Overall particulate emissions,[a] metric tons/yr	Contribution to overall state emissions, %
Alabama	610	1,178,643	0.05
Alaska	1,360	13,913	9.78
Arizona	2,380	72,685	3.27
Arkansas	1,110	137,817	0.81
California	11,250	1,006,452	1.12
Colorado	2,720	201,166	1.35
Connecticut	650	40,074	1.62
Delaware	220	36,808	0.60
Florida	2,150	226,460	0.95
Georgia	370	404,574	0.09
Hawaii	60	61,621	0.10
Idaho	740	55,499	1.33
Illinois	3,830	1,143,027	0.34
Indiana	2,680	748,405	0.36
Iowa	1,640	216,493	0.76
Kansas	1,110	348,351	0.32
Kentucky	610	546,214	0.15
Louisiana	1,810	380,551	0.48
Maine	1,130	49,155	2.30
Maryland	1,210	494,921	0.24
Massachusetts	1,810	96,160	1.88
Michigan	5,700	705,921	0.81
Minnesota	3,530	266,230	1.33
Mississippi	1,290	168,355	0.77
Missouri	970	202,435	0.48
Montana	970	272,688	0.36
Nebraska	1,320	95,338	1.38
Nevada	970	94,040	1.03
New Hampshire	580	14,920	3.89
New Jersey	1,700	151,768	1.12
New Mexico	730	102,785	0.71
New York	2,560	160,044	1.60
North Carolina	1,230	481,017	0.26
North Dakota	640	78,978	0.81
Ohio	4,170	1,766,056	0.24
Oklahoma	760	93,595	0.81
Oregon	2,350	169,449	1.39
Pennsylvania	1,800	1,810,598	0.10
Rhode Island	200	13,073	1.53
South Carolina	760	198,767	0.38
South Dakota	1,220	52,336	2.33
Tennessee	1,040	409,704	0.25
Texas	3,370	549,399	0.61
Utah	1,400	71,692	1.95
Vermont	320	14,587	2.19
Virginia	1,350	477,494	0.28
Washington	2,210	161,934	1.36
West Virginia	550	213,715	0.26
Wisconsin	3,490	411,558	0.85
Wyoming	870	75,427	1.15
U.S. TOTALS	87,700	17,872,000[b]	0.49

[a]1972 National Emission Data System (NEDS) data base.

[b]Total does not equal sum of states due to sources which are considered to be uniformly distributed across the U.S.; i.e., forest fires.

1972: $87 \text{ g/metric ton} \times 937 \times 10^6 \text{ metric ton/yr} = 8.15 \times 10^{10} \text{ g/yr}$ (6)

1977: $87 \text{ g/metric ton} \times 1{,}080 \times 10^6 \text{ metric ton/yr} = 9.40 \times 10^{10} \text{ g/yr}$ (7)

The growth factor is

$$\frac{9.40 \times 10^{10} \text{ g/yr}}{8.15 \times 10^{10} \text{ g/yr}} = 1.15 \quad (8)$$

SECTION 5

CONTROL TECHNOLOGY

STATE OF THE ART

Current air pollution control technology or methodology is not widely practiced at sand and gravel transportation sources. Dust generated from vehicular movement on unpaved roads and around stockpiles is dependent upon the dryness of the area; hence, any method used to add moisture to unpaved roads is helpful in controlling dust levels. Natural phenomena such as rain or snow inhibit dust emissions because the dust adhering to water is less prone to emissions.

The prime source of dusts due to sand and gravel transportation is travel over soil- or gravel-surfaced unpaved roads. Some sand and gravel plants have employed several effective dust control methods mainly involving the incorporation of an additive(s) to a limited depth within the soil/gravel road surface.

FUTURE CONSIDERATIONS

Emissions due to the transport of sand and gravel on unpaved roads are influenced by a number of factors, such as vehicle speed, vehicle cross-sectional area and weight, number of wheels, tire width, particle size distribution, and moisture content of the unpaved road surface material.

Based on observations made during aggregate plant sampling, moisture content and vehicle speed affect the emissions more than any other of the above-listed factors. Moisture in the soil helps in binding the particles together and prevents them from becoming airborne. Though detailed measurements were not taken to study the influence of moisture content on emissions, spot measurements show that about 4% to 10% of moisture content reduces emissions by 99%.

The average vehicle speed of a haul truck on an unpaved road ranges from 24 to 32 km/hr with a maximum of 48 km/hr. On a thoroughly wet or oiled unpaved road, vehicle speed (<48 km/hr) does not seem to have an effect on emissions. However, on a dry unpaved road, higher vehicle speeds produce increased emissions.

Additives such as calcium chloride can be used to reduce the surface tension of water so that the dust can be wetted with less water. Calcium chloride can be applied at a cost of ∿$0.15/m^2-yr (8). The principal problems here are corrosion of vehicle bodies and leaching by rain water or melting snow. More frequent applications may be necessary during summer months.

Another effective dust control method is to mix stabilization chemicals into the road surface to a depth of from 2 cm to 5 cm (9). A cement company uses a special emulsion agent called Coheren, supplied by Golden Bears Division of Witco Chemicals Company. The treatment involves spraying a solution of 4 parts of water and 1 part of Coheren at the rate of 5×10^{-3} m^3/m^2 of the road surface. Certain pretreatment measures, such as working the road surface into a stiff mud, are necessary to prevent the Coheren binder from sticking to the vehicles. Periodic maintenance such as a 1:7 Coheren/water solution spray keeps the Coheren binder active. The dust control program as described is found to give 3 yr of service at a total cost of $0.12/m^2.

Some counties in Iowa have tried mixing cut-back asphalt into the road surface to a depth of from 5 cm to 8 cm (10). This type of surface treatment reduces dust emissions but requires periodic maintenance, such as patching potholes.

Treating the road surface with oil once a month is another efficient method of controlling unpaved road dust emissions. The estimated cost of such applications is $0.10/m^2-treated yr (11). However, it has been shown that 70% to 75% of oil applied moves from the surface of the road by dust transport and runoff. This may result in ecological harm caused by the oil or its heavy

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(8) Vandegrift, A. E., L. J. Shannon, E. W. Lawless, P. G. Gorman, E. E. Sallee, and M. Reichel. Particulate Pollutant System Study, Volume III--Handbook of Emission Properties. EPA-22-69-104, U.S. Environmental Protection Agency, Durham, North Carolina, May 1971. 629 pp.

(9) Significant Operating Benefits Reported from Cement Quarry Dust Control Programs. Pit and Quarry, 63(7):116, 1971.

(10) Hoover, J. M. Surface Improvement and Dust Palliation of Unpaved Secondary Roads and Streets. Project 856-S, Engineering Research Institute, Iowa City, Iowa, July 1973. 97 pp.

(11) Mineral Industry Surveys--1, 2. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1972. 12 pp.

metal constituents (12). Furthermore, surface oiling requires regular maintenance because roads treated in this way develop potholes.

Lignin sulfonates, byproducts from paper manufacture, are also used to control dust emissions. One of the commercially available lignin sulfonates, Orzan A, a product of Crown Zellerbach Corporation, was tested on a farm access road in Arizona State University (13). The method proved quite successful over 5 yr of service, effectively suppressing dust at a cost of $0.47/m^2 ($0.10/yr).

Paving the road surface is the best method to control dusts, but it is impractical due to its high cost and the temporary nature of sand and gravel plants.

Emissions due to wind erosion of sand and gravel can be easily controlled by water application. However, sand and gravel plants do not employ specific control methods since emissions from wind erosion of sand and gravel in the truck are minor and do not pose a health problem. All states have some sort of tarpaulin law, the implementation of which reduces emissions by wind erosion from the truck bed.

The literature surveyed revealed that dust emissions due to sand and gravel transportation can be reasonably controlled by methods currently available. These methods require an appreciable managerial dedication and expertise and the necessary monetary investment to purchase, install, and maintain such systems.

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(12) Freestone, F. J. Runoff of Oils from Rural Roads Treated to Suppress Dust. EPA-R2-72-054, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1972. 29 pp.

(13) Bub, R. E. Air Pollution Alleviation by Suppression of Road Dust. M.S.E. Thesis, Arizona State University, Flagstaff, Arizona, 1968. 45 pp.

SECTION 6

GROWTH AND NATURE OF THE INDUSTRY

PRESENT TECHNOLOGY

Present technological improvements include larger operating units, more efficient portable and semiportable plants, new prospecting methods utilizing aerial and geophysical surveying, and greater awareness of pollution control and land reclamation. Automatic controls which were installed in many of the larger and newer operations resulted in recovery of salable fractions even from low-quality deposits. As urban deposits of sand and gravel become depleted, the present trend is towards investigating local bodies of water for new deposits.

PRODUCTION TRENDS

Sand and gravel production is very closely tied to activity in the consuming industries. Sand and gravel production is associated chiefly with the needs of the construction industry since it consumes more than 90% of the sand and gravel output. Figure 2

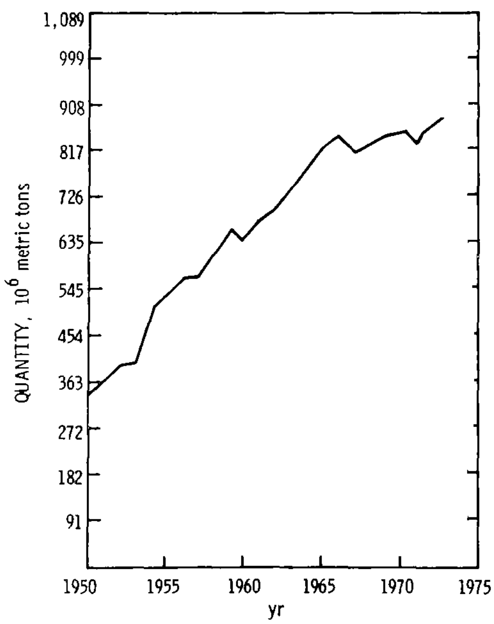

Figure 2. Production of sand and gravel in the United States (14).

shows the yearly production of sand and gravel from 1950 to 1972 (14). The average annual growth rate for domestic production between 1950 and 1965 was about 5.5%. This high rate was mainly due to the large-scale highway construction program. Production has leveled off since 1965 mainly due to a decreased activity in the highway construction program.

Contingency forecasts by end use of sand and gravel demands in the year 2000 are given in Table 5 and Figure 3 (15). The forecast range was determined by assuming both positive and negative effects from various contingencies, such as technological shifts affecting the end use pattern, restrictions caused by land use conflicts and environmental controls, availability of public funds for construction, and competition from alternate materials such as crushed stone used in asphalt paving. The final demand range forecast for the year 2000 is 2,860 to 3,619 million metric tons, corresponding to an average annual growth rate of 3.9% to 4.7%.

TABLE 5. CONTINGENCY FORECASTS OF DEMAND FOR SAND AND GRAVEL BY END USE, YEAR 2000 (15) (10^6 metric tons)

End use	U.S. Demand in yr 2000 Low	High
Highway and street construction	1,524	2,032
Other heavy construction, general building contractors	774	1,092
Excavation and foundation work	241	454
Concrete construction materials	66	93
Molding and foundry sands	16	33
Glass	22	50
Other uses	27	56
TOTAL	2,670	3,810
Adjusted range	2,860	3,619
	(Mean 3,239)	

(14) Minerals Yearbook 1973, Volume I. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1975. p. 1099.

(15) Minerals, Facts and Problems. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1970. p. 1193.

The 20-yr and 5-yr straight-line trend projections, also shown in Figure 3, are much lower than the demand estimates based on contingency forecasting methods, primarily due to the use of exponentially controlled growth factors.

Transportation costs constitute a major part of the delivered cost of sand and gravel; in many cases, these costs may exceed the sales value of the material at the processing plant. Hence, sand and gravel plants are located near the point of use. However, local zoning and environmental regulations and also depletion of urban deposits may necessitate locating future sand and gravel plants away from the point of use, thereby increasing the share of rail and barge systems in sand and gravel transportation in order to hold down transportation costs. Truck haulage will still remain important, especially for local delivery of sand and gravel, even if rail and water transportation are used for long hauls to central distribution points. Ultimately, truck transporation will finally increase the delivered price of sand and gravel and thus may result in using cheaper substitute materials, such as crushed stone and other manufactured aggregates.

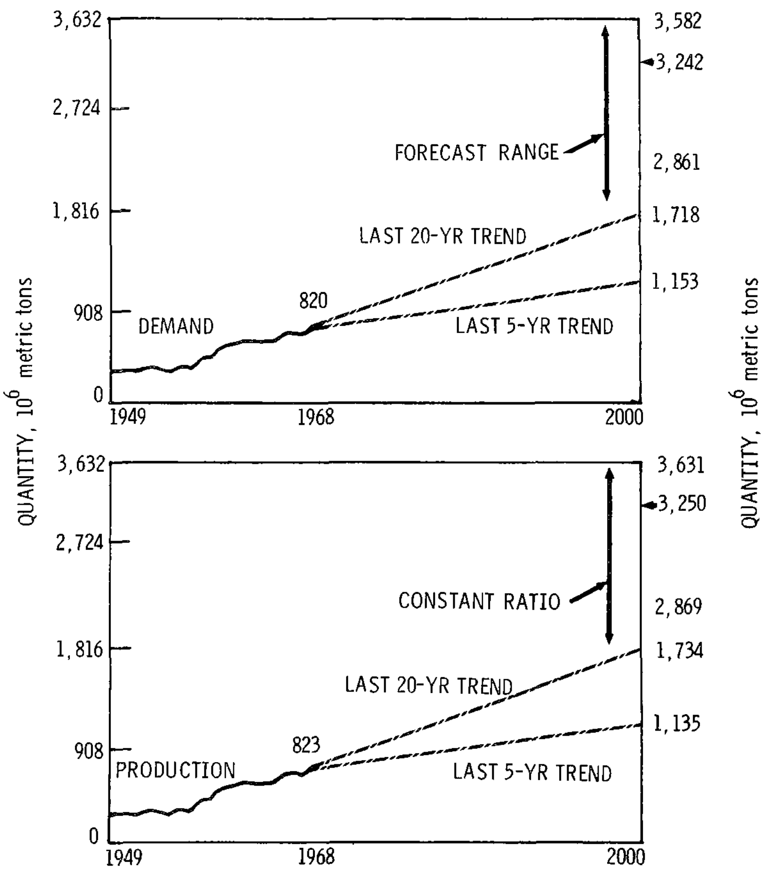

Figure 3. Comparison of trend projections and forecasts for sand and gravel (15).

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APPENDIX A

QUESTIONNAIRE RESULTS

The results of completed questionnaires (shown in Figure A-1) received from 19 sand and gravel plants are shown in Table A-1.[a]

Name and Address of Company ______________________

Person Preparing this Questionnaire ______________________

Phone Number ______________________

Number[1]	Plant Location County and State	Production Rate Short Tons/Year[2]	Percent Transported By Truck	Frequency of Truck Transport[3]	Number and Hauling Capacity of Trucks	Type of Unpaved Roads[4]			Approximate Distance of Unpaved Road[4]	Average Distance of Truck Haulage[5]
						Gravel	Soil	Other (Specify)		
1										
2										
3										

[1]Please furnish the required information for plants with (1)minimum, (2)average and (3)maximum capacities.
[2]This data will be treated as confidential.
[3]Hours per day the transport operation lasts.
[4]Unpaved road from finished stockpiles to the nearest paved highway.
[5]Average distance of truck haulage from finished stockpile to the user.

Figure A-1. Survey Questionnaire.

The average size of sand and gravel plants is 6.4×10^5 metric tons/yr. Plants operate for ∿9 hr/day, 260 days/yr throughout the year. The trucks in use have an average capacity of 21 metric tons.

Unpaved road length has no relationship to production rate and vehicular traffic. Various correlations, such as nonlinear and multiple linear regressions, were instigated but these did not provide any significant results. The mean distance of unpaved road is 2.2 kilometers.

[a]Nonmetric units shown in this appendix correspond to those used on the questionnaire.

TABLE A-1. QUESTIONNAIRE RESULTS

Response number	Production rate: 10^5 metric tons	Production rate: tons/yr	Distance of unpaved roads: kilometers	Distance of unpaved roads: miles	Average truck capacity: metric tons	Average truck capacity: tons	Vehicular traffic, vehicles/hr
1	9.10	10.00	0.80	0.50	20.4	22.5	15.0
2	0.90	1.00	0.40	0.25	15.9	17.5	2.0
3	1.80	2.00	1.61	1.00	22.7	25.0	3.4
4	0.90	1.00	1.61	1.00	22.7	25.0	1.7
5	9.10	10.00	1.61	1.00	22.7	25.0	17.0
6	4.10	4.50	1.61	1.00	22.7	25.0	5.8
7	3.60	4.00	3.22	2.00	22.7	25.0	6.8
8	3.60	4.00	8.05	5.00	22.7	25.0	6.8
9	13.60	15.00	8.05	5.00	22.7	25.0	15.3
10	0.90	1.00	1.61	1.00	22.7	25.0	1.7
11	0.90	1.00	8.05	5.00	22.7	25.0	1.7
12	9.10	10.00	0.80	0.50	18.1	20.0	21.4
13	9.10	10.00	0.53	0.33	15.2	16.7	25.6
14	2.30	2.50	1.21	0.75	22.7	25.0	3.9
15	4.50	5.00	0.80	0.50	19.1	21.0	9.3
16	9.10	10.00	0.40	0.25	22.7	25.0	7.8
17	2.60	2.86	0.40	0.25	22.7	25.0	5.5
18	10.40	11.50	0.16	0.10	22.7	25.0	22.2
19	26.10	28.80	0.19	0.12	22.7	25.0	41.5
AVERAGE	6.40	7.00	2.20	1.30	21.4	23.6	11.3

With the paired values of vehicular traffic and annual production rate (x, y), an investigation was made into what mathematical formula best describes the relationship between the variables. An effort was made to fit the data to three curve types: linear, logarithmic, and exponential. The results are as follows:

Linear

$$y = a_1x + a_0 \qquad \text{(A-1)}$$
$$a_1 = 54{,}445$$
$$a_0 = 26{,}154$$
$$r^2 = 0.86$$

Logarithmic

$$y = a_2 + b_1 \ln x$$
$$a_2 = -394{,}395$$
$$b_1 = 519{,}494 \qquad \text{(A-2)}$$
$$r^2 = 0.70$$

Exponential

$$y = a_3 e^{b_2 x}$$
$$a_3 = 158{,}643$$
$$b_2 = 0.08 \qquad \text{(A-3)}$$
$$r^2 = 0.72$$

The quantities a_0, a_1, a_2, a_3, b_1 and b_2 are constants. A third value was also found for each type, the coefficient of determination, r^2. The value of r^2 lies between 0 and 1 and indicates how closely the equation fits the experimental data. The closer r^2 is to 1, the better the fit; therefore, a linear relationship is the best fit. The resultant equation may be expressed as follows:

$$y = 54{,}445x + 26{,}154 \qquad \text{(A-4)}$$

APPENDIX B

EMISSION FACTOR ESTIMATION

EMISSIONS FROM VEHICULAR MOVEMENT ON UNPAVED ROADS

Studies conducted by the Puget Sound Air Pollution Control Agency and Midwest Research Institute were used to determine an emission factor per vehicle for particulate matter (Appendix C). The average speed of a haul truck on an unpaved road is 32 km/hr. By adjusting values reported at other speeds through a linear correction factor, a range of emission factors for particle sizes <30 µm is obtained. For example, a value reported by Midwest Research Institute of 0.95 g/vehicle-m at 48 km/hr and 2 µm to 30 µm is adjusted to 32 km/hr by the factor (32/48), yielding 0.63 g/vehicle-m. The following table results.

TABLE B-1. EMISSION FACTORS CORRECTED TO AVERAGE SPEED

Reported value, g/vehicle-m	Speed, km/hr	Particle size, µm	Corrected value g/vehicle-m
Puget Sound Agency			
0.03	16	<2	0.06
0.12	16	<10	0.24
0.08	32	<2	0.08
0.65	32	<10	0.65
0.68	32	<10	0.68
0.12	48	<2	0.08
1.47	48	<10	0.98
Midwest Research Institute			
0.77	48	<2	0.51
0.95	48	2 to 30	0.63
0.882	48	<2	0.59
1.05	48	2 to 30	0.70
1.025	64	<2	0.51
1.22	64	2 to 30	0.61

From the corrected values, an average of 0.49 ± 0.28 g/vehicle-m is calculated as the emission factor from vehicular movement on unpaved roads due to the transport of sand and gravel.

EMISSIONS FROM THE WINDBLOWN TRUCK BED

For emissions from the windblown truck bed, the emission factor for coal storage is used (7).

270 g/metric ton-yr at 16 km/hr and density of 0.8×10^6 g/m^3

Correcting for 48 km/hr, the maximum speed of the trucks, and 1.6×10^6 g/m^3, the density of sand and gravel, the factor becomes

$$270 \text{ g/metric ton-yr} \cdot \left(\frac{48}{16}\right)^3 \cdot \left(\frac{1.6 \times 10^6}{0.8 \times 10^6}\right)^2$$

$$= 29{,}160 \text{ g/metric ton-yr} \qquad \text{(B-1)}$$

(The quantities in Equation B-1 are cubed and squared due to proportionalities developed in the coal storage program.) This factor is based upon 0.45 m^2 of surface per ton of coal stored. The emission factor will therefore have to be corrected for the geometry of the truck. For a 21-metric ton truck,

$$21 \text{ metric ton} \cdot \frac{10^6 \text{ g}}{\text{metric ton}} \cdot \frac{\text{m}^3}{1.6 \times 10^6 \text{ g}} \cdot \frac{1}{1.5 \text{ m deep}}$$

$$= 8.8 \text{ m}^2 \qquad \text{(B-2)}$$

the area is 8.8 m^2. The emissions for a single truck will thus be

$$29{,}160 \text{ g/metric ton-yr} \cdot \frac{\text{metric ton}}{0.45 \text{ m}^2} \cdot \frac{8.8 \text{ m}^2}{\text{vehicle}}$$

$$= 5.7 \times 10^5 \text{ g/yr-vehicle} \qquad \text{(B-3)}$$

Adjusting for plant operating hours,

$$5.7 \times 10^5 \text{ g/yr-vehicle} \left(\frac{260 \text{ day/yr}}{365 \text{ day/yr}}\right)\left(\frac{9 \text{ hr/day}}{24 \text{ hr/day}}\right)$$

$$= 1.5 \times 10^5 \text{ g/yr-vehicle or } 17 \text{ g/hr-vehicle} \qquad \text{(B-4)}$$

On the basis of 1 hr, a representative plant is using 22 vehicles. Therefore,

$$22 \text{ vehicles} \cdot 17 \text{ g/hr-vehicle} = 374 \text{ g/hr or } 0.10 \text{ g/s} \qquad \text{(B-5)}$$

This is only 2% of the 6.6 g/s caused by vehicular movement (Appendix D). The windblown emissions are therefore insignificant compared to unpaved road emissions.

APPENDIX C

LITERATURE SURVEY

EMISSIONS DUE TO VEHICULAR MOVEMENT ON UNPAVED ROADS

Emissions from vehicular movement are due to vehicle-generated air turbulence and mechanical forces of tires on the road surface. Emissions, E_u (g/vehicle), are affected by several factors which can be used to relate dependent and independent variables in equation form:

- vehicle speed, V, km/hr
- number wheels/vehicle, N
- particle size distribution, P, %
- surface moisture, M, or P.E. index
- vehicle weight, T, metric tons
- vehicle cross section, A, m^2
- tire width, W, m
- length of unpaved road, L, m

The literature search yielded only scattered quantitative information on emissions from unpaved roads. Most of the reported studies were directed toward quantifying the influence of vehicle speed on unpaved road emissions.

Vehicle Speed

Table C-1 lists results of various tests conducted on emissions from unpaved roads.

The study conducted by the Puget Sound Air Pollution Control Agency can be used to predict a mathematical relationship for the emission of respirable particles from unpaved roads. Their results show that emissions of particles <2 μm in diameter are proportional to the vehicle speed, and those <10 μm in diameter are proportional to the square of the vehicle speed. Based on this study, one can expect emissions of respirable particles (<10 μm) to be proportional to $(aV^2 + bV)$ where a and b are constants. Then

$$E_u = (aV^2 + bV) \qquad (C\text{-}1)$$

TABLE C-1. TESTS OF UNPAVED ROAD EMISSIONS

Investigator	Sampling site	Type of road	Vehicle speed, km/hr	Emission factor, g/veh-m	Particle size distribution, μm
Anderson, C. (16)	Bernalillo County, NM	Dirt	48	0.14 to 0.20	-[a]
School of Engineering, University of New Mexico (16)	University of NM	Dirt	40	0.26	<6
				0.01	<3
Pedco-Environmental Specialists, Inc. (17)	Sante Fe, NM	Dirt	24	0.19	-[a]
			40	0.28	-[a]
			56	0.56	-[a]
			64	0.99	-[a]
Engineering Research Institute, Iowa State University	Powshiek County, IA	Dirt	-[a]	1.55	-[a]
Puget Sound Air Pollution Control Agency (18)	Duwamich Valley, WA	Gravel	16	0.62	-[a]
				0.12	<10
				0.03	<2
			32	2.40	-[a]
				2.48	-[a]
				0.65	<10
				0.68	<10
				0.08	<2
			48	3.92	-[a]
				1.47	<10
				0.12	<2
Midwest Research Institute (19)	Franklin County, KS	Gravel	48	1.135	>30
				0.950	2 to 30
				0.770	<2
		Gravel	48	1.0	>30
				1.05	2 to 30
				0.882	<2
		Gravel	64	1.705	>30
				1.22	2 to 30
				1.025	<2
	Morton County, KS	Dirt	48	2.33	>30
				1.25	2 to 30
				1.05	<2
		Dirt	64	0.597	>30
				0.597	2 to 30
				0.512	<2
	Wallace County, KS	Dirt	48	6.82	>30
				5.35	2 to 30
				3.72	<2

[a]No designated size distribution.

(16) Anderson, C. Air Pollution from Dusty Roads. In: Proceedings of the 1971 Highway Engineering Conference, (Bulletin No. 44-NMSU-EES-44-71, Las Cruces, New Mexico, 1971. 12 pp.

(17) Investigation of Fugitive Dust Sources, Emissions, and Control. Contract 68-02-0044, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1973. 152 pp.

(18) Roberts, J. W., A. T. Rossano, P. T. Bosserman, G. C. Hofer, and H. A. Watters. The Measurement, Cost and Control of Traffic, Dust and Gravel Roads in Seattle's Duwamish Valley. In: Proceedings of the Annual Meeting of the Pacific Northwest International Section of the Air Pollution Control Association, Paper No. AP-72-5, Eugene, Oregon, 1972. 10 pp.

(19) Cowherd, J., Jr., K. Axetell, Jr., C. Guenther, F. Bennett, and G. Jutze. Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 172 pp.

where E_u = emissions in g/vehicle
V = vehicle speed
a, b = constants

Number of Wheels

A vehicle moving on an unpaved road generates dust in proportion to the number of wheels:

$$E_u \propto N \tag{C-2}$$

where N = number of wheels per vehicle

Particle Size Distribution of the Road Surface Material

Particles >100 µm are moved by saltation and surface creep[a] and are deposited in or near the affected area. Particles <100 µm are moved by wind mostly by suspension and are carried over long distances from their sources. Thus, smaller particles from unpaved road emissions have a significant impact on ambient air particulate levels. Wind tunnel studies and open field measurements show that the proportion of movement by suspension is approximately equal to the proportion of particles <100 µm found in the soil (20).

$$E_u \propto P \tag{C-3}$$

where P = percent of particles in the road surface material (0 cm to 10 cm depth) <100 µm

Surface Moisture

As particle moisture increases, the cohesive force between particles increases and the rate of soil entrainment therefore decreases. The rate of soil movement varies inversely as the

[a] Saltation refers to movement of particles (100 µm to 500 µm) in a series of short bounces, and surface creep refers to the rolling and sliding of particles (>500 µm) along the surface of the ground. Soil movement in saltation occurs below a height of 0.6 m to 1.0 m above ground level; over 90% of the soil transported by saltation is below a height of 0.3 m from ground level (20).

(20) Chepil, W. S. Dynamics of Wind Erosion: I. Nature of the Movement of Soil by Wind. Soil Science, 60(4):305-320, 1945.

square of its moisture content (21). However, soil surface moisture data are not available for different regions; hence, surface moisture is assumed to be proportional to the Thornthwaite P.E. Index. The P.E. Index, determined from total annual rainfall and mean annual temperature (22), is shown in Figure C-1.

$$E_u \propto \frac{1}{(PE)^2} \qquad \text{(C-4)}$$

Vehicle Weight, Vehicle Cross Section, and Tire Width

No quantitative data are available in the published literature on how these factors influence unpaved road emissions.

Distance of Unpaved Road, L

A vehicle generates dust in proportion to the length of unpaved road, L.

$$E_u \propto L \qquad \text{(C-5)}$$

where L = the length of unpaved road.

Conclusions

Based on available data in the published literature, emissions from unpaved roads can be expressed as

$$E_u = \frac{K_u(aV^2 + bV)\ P\ N}{(PE)^2} f(T,A,W)L \qquad \text{(C-6)}$$

where E_u = emissions in g/vehicle
K_u = constant of proportionality

(21) Chepil, W. S., W. H. Siddoway, and D. V. Armburst. Climatic Factor for Estimating Wind Erodability of Farm Fields. Journal of Soil and Water Conservation, 17:162-165, 1962.

(22) Thornthwaite, T. W. Climates of North America According to a New Classification. Georgraphic Review, 21:633-635. 1931.

EMISSIONS DUE TO WIND EROSION OF SAND AND GRAVEL DURING TRANSPORT

No quantitative data are available in published literature on emissions due to wind erosion of sand and gravel during transport. However, data from investigations of similar problems have been reported (23-25).

Emissions due to wind erosion of sand and gravel are comparable to those due to wind erosion of land surfaces. The wind erosion equation as developed by Woodruff and Chepil (23, 24) can be expressed in the following form:

$$E_s = K_s \frac{U^3}{PE^2} D^{d'} \qquad \text{(C-7)}$$

where E_s = emissions due to wind erosion in kg/m^2-yr

K_s = function of soil or knoll erodibility, surface crust stability, and ridge roughness.

U = wind speed.

D = unsheltered distance along the prevailing wind erosion direction.

d' = variable exponent, a function of K_s and U^3/PE^2.

Furthermore, a comparison can be made with emissions from coal storage piles due to wind erosion. The following equation was derived based on an analysis of results of wind tunnel experimentation conducted by Pittsburgh Mining and Safety Center, Pittsburgh, Pennsylvania (25).

$$E_c = \frac{K_c U^{a'} \rho^{b'} s^{c'}}{PE^2} \qquad \text{(C-8)}$$

(23) Woodruff, N. P., and F. H. Siddoway. A Wind Erosion Equation. Soil Science Society of American Proceedings, 29(5):602-608, 1965.

(24) Chepil, W. S. The Transport Capacity of the Wind. Soil Science, 60(4):475-480, 1945.

(25) Singer, J. M., E. B. Cook, and J. Grumer. Dispersal of Coal and Rock Dust Deposits. Report of Investigations No. 7642, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1972. 32 pp.

where E_c = emissions due to wind erosion of coal storage pile in kg/hr

ρ = bulk density

s = surface area

a',b',c' = exponents expected to be in the range

$2.6 < a' < 3.0$

$2 < b' < 6$

$0.15 < c' < 0.35$

K_c = constant of proportionality

Based on the relationship expressed in Equations C-7 and C-8, emissions due to wind erosion of sand and gravel can be expressed as

$$E_t = K_t \frac{U_*^3}{PE^2} \cdot f(B) \cdot f(\rho) \qquad \text{(C-9)}$$

where E_t = emissions due to wind erosion of sand and gravel during transport expressed in kg/hr-vehicle

U_* = relative wind speed expressed as (U-V cosΘ), where U is wind speed, V is vehicle speed, and Θ is the angle between the direction of the prevailing wind and that of the vehicle in km/hr

B = surface area of the transported sand and gravel in m^2

ρ = bulk density in kg/m^3

K_t = constant for transport operations

So that the units of E_u and E_t are comparable, Equation C-9 can be modified as

$$E_t = K_t \frac{U^3}{PE^2} \cdot f(P) \cdot f(\rho) \cdot \frac{L_t}{V} \qquad \text{(C-10)}$$

where L_t = distance of truck transport between the finished stockpile and the user.

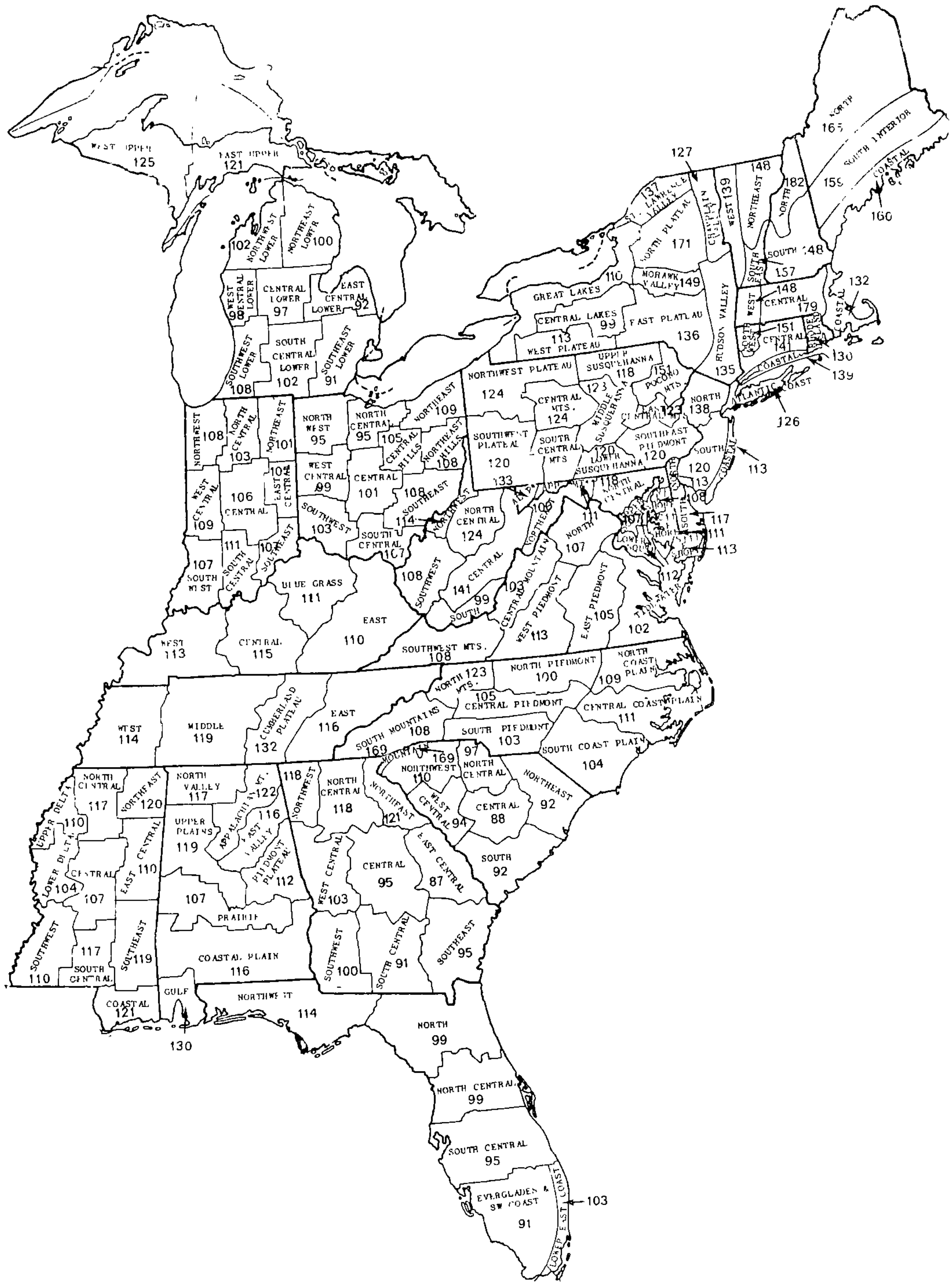

Figure C-1. Map of P.E. values for state climatic divisions.

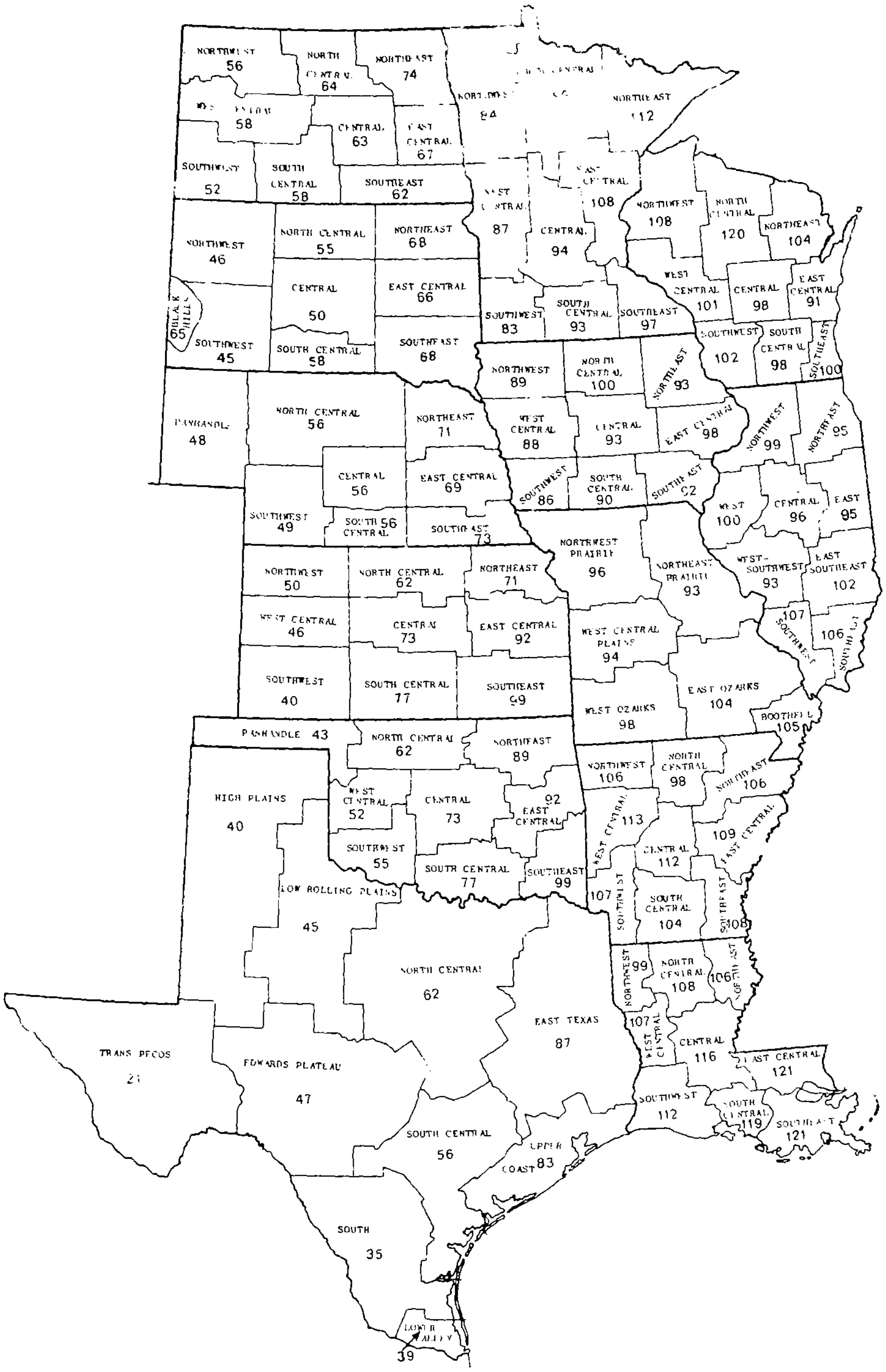

Figure C-1 (continued).

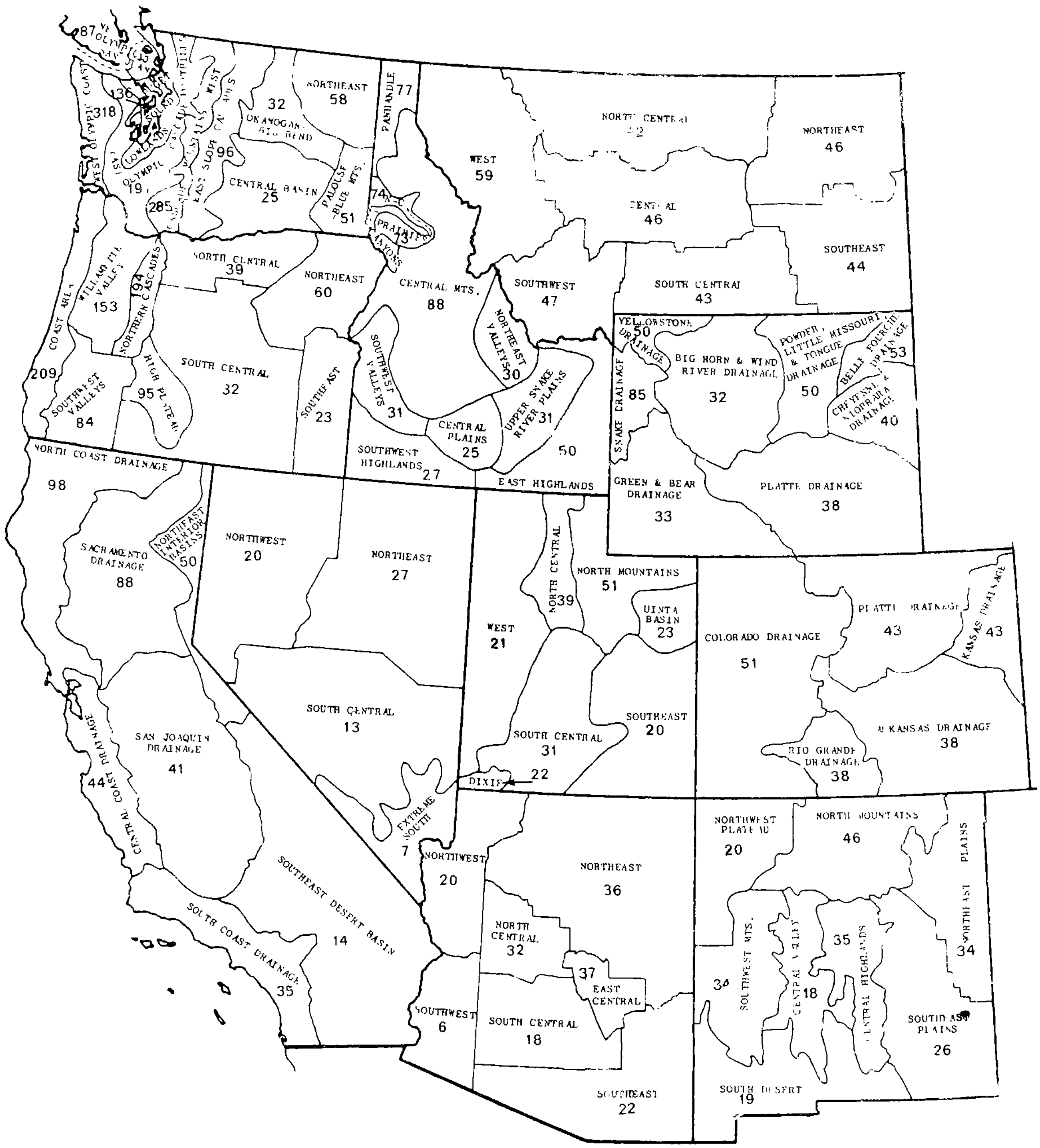

Figure C-1 (continued).

APPENDIX D

SOURCE SEVERITY CALCULATIONS

PARTICULATES

Source Severity

The source severity, for particulates, S_p, is given as

$$S_p = \frac{4,020\ Q}{D^{1.814}} \qquad \text{(D-1)}$$

where Q = emission rate, g/s

D = representative downwind distance, m

This equation involves the derivation of downwind ground level concentrations from an open source when Q and D are known. The derivation is presented in Reference 7.

The average size of a sand and gravel plant is 6.40×10^5 metric tons/yr. At 9 hr/day and 260 days/yr, the average production rate is equal to 274 metric tons/hr. Since the average size of a haul truck is 21 metric tons, the vehicular traffic around the plant is 11 vehicles/hr. One truck makes two trips on the unpaved road per load; therefore, traffic doubles to 22 vehicles/hr. The average distance of unpaved road is 2.2 km, and the average emission factor for particulates is 0.49 g/vehicle-m for a vehicle traveling at 32 km/hr. Consequently, the emission rate, Q, is obtained from

$$Q = \left(\frac{0.49\ \text{g}}{\text{vehicle-m}}\right)\left(\frac{22\ \text{vehicles}}{\text{hr}}\right)\left(2.2\ \text{km}\right)\left(\frac{\text{hr}}{3,600\ \text{s}}\right)\left(\frac{1,000\ \text{m}}{\text{km}}\right)$$

$$= 6.6\ \text{g/s} \qquad \text{(D-2)}$$

The representative distance, D, for use in Equation D-1 is taken as the distance of the unpaved road from the finished stockpile to the nearest highway. Hence, the maximum source severity, S_p, is

$$S_p = \frac{(4,020)(6.6)}{(2,200)^{1.814}} = 0.02 \qquad \text{(D-3)}$$

Affected Population

The distance from the source to that point where the source severity is 0.1, X_{S_p}, is calculated from

$$X_{S_p} = \left(\frac{4,020\ Q}{S_p}\right)^{1/1.814} \qquad \text{(D-4)}$$

where $S_p = 0.1$

Hence,

$$X_{S_p} = \left[\frac{(4,020)(6.6)}{0.1}\right]^{1/1.814} = 980\ \text{m} \qquad \text{(D-5)}$$

Since the above value is less than the representative distance (2,200 m), the population affected by sand and gravel plants is zero.

FREE SILICA

Source Severity

The source severity for free silica emissions, S_s, is given as

$$S_s = \frac{316\ Q}{D^{1.814} \cdot \text{TLV}} \qquad \text{(D-6)}$$

Average free silica content is 14%. Hence, the TLV is 10/(14 + 2) = 0.625 mg/m^3. Therefore,

$$S_s = \frac{(316)(6.6)}{(2,200)^{1.814}(0.625 \times 10^{-3})} = 2.9 \qquad \text{(D-7)}$$

Affected Population

The distance from the source to that point where the source severity is 0.1, X_{S_s}, is calculated from

$$X_{S_s} = \left(\frac{316\ Q}{\text{TLV} \cdot S_s}\right)^{1/1.814} \qquad \text{(D-8)}$$

For $S_s = 0.1$,

$$X_{S_s} = \left[\frac{(316)(6.6)}{(0.625 \times 10^{-3})(0.1)}\right]^{1/1.814}$$

$$= 14.0 \text{ km} \qquad \text{(D-9)}$$

For $S_s = 1.0$,

$$X_{S_s} = \left[\frac{(316)(6.6)}{(0.625 \times 10^{-3})(1.0)}\right]^{1/1.814}$$

$$= 3.9 \text{ km} \qquad \text{(D-10)}$$

Since the representative distance is 2.2 km, the affected area is

$$\pi\ (14.0^2 - 2.2^2) = 600 \text{ km}^2 \qquad \text{(D-11)}$$

For a representative population density of 50 persons/km^2, the affected population is 30,000 persons for $S_s \geq 0.1$. Since

$$\pi\ (3.9^2 - 2.2^2) = 33 \text{ km}^2 \qquad \text{(D-12)}$$

The affected population is 1,650 persons for $S_s \geq 1.0$.

APPENDIX E

FREE SILICA DISTRIBUTION

Emissions of dusts occur due to vehicular movement on unpaved road surface while transporting sand and gravel. Information is available on the magnitude of unpaved road emissions but not on the free silica composition of emissions. Hence, 30 sand and gravel plants were randomly selected, and samples of unpaved road surface were collected from 28 of these for free silica analysis. Procedures for sample collection, size separation of respirable particles, and free silica analysis are described in the following sections.

PROCEDURE FOR SAMPLE COLLECTION

A scoop, sampling jar, and recommended procedure for grab sampling were sent to each of the 28 sand and gravel plants. Procedures that were sent to industry for selecting grab sampling locations and taking samples are shown below:

<u>Procedure for Choosing Grab Sampling Spots</u>

- Note the approximate distance of the unpaved road from the finished stockpile to the nearest paved highway.

- Divide the unpaved road into four equal sections.

- Take two grab samples from each section as shown in Figure E-1 (one from the center of the lower half and one from the center of the upper half).

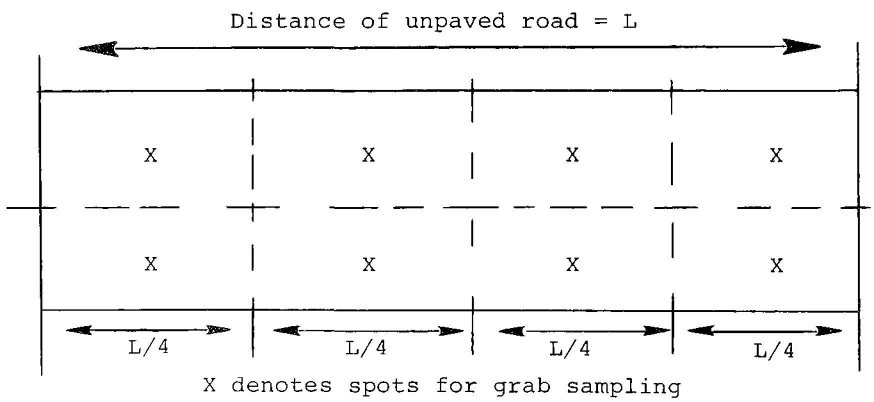

Figure E-1. Schematic for selecting grab-sampling spots.

Procedure for Taking a Grab Sample

- Use a hand shovel to scoop samples from the top 1-in. layer of unpaved road surface. Collect about 1/4 lb sample from one spot.

- Samples from different spots can be collected in one jar (total weight of samples about two pounds); samples should be labelled and shipped to: Monsanto Research Corporation, 1515 Nicholas Road, Dayton, Ohio 45407, Attn: P. K. Chalekode.

SEPARATION OF RESPIRABLE DUST FROM SAMPLES

Samples obtained from sand and gravel plants were dried at 105°C for about 12 hr to drive off any moisture present. The respirable fraction of the dried sample was then separated using an experimental setup as shown in Figure E-2.

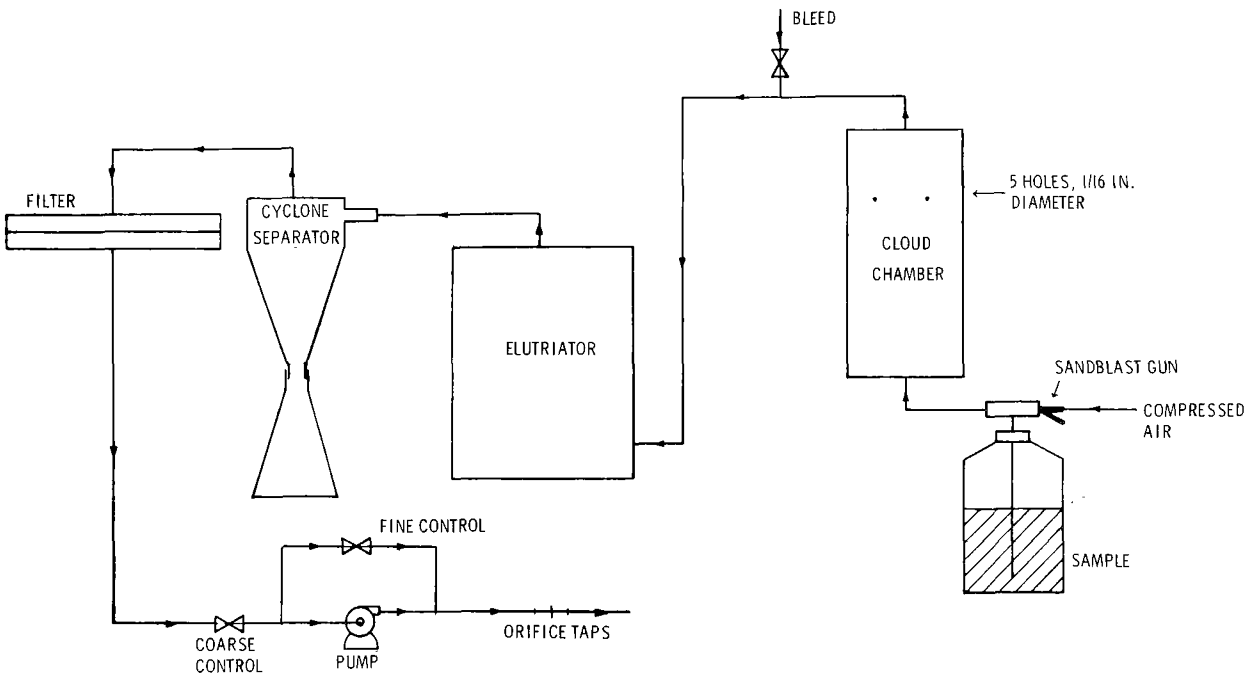

Figure E-2. Experimental setup for separating respirable fraction from sample.

The dried sample was sieved through a 60-mesh screen to separate the particles which were <250 μm. A mini-sandblast gun was used to spray the sample into a cloud chamber to create a "dusty atmosphere." A vacuum pump was used to pull the "dirty air" through an elutriator and a cyclone separator prior to final collection on a Nucleopore® filter. A flow of 1 cfm was maintained through the cyclone and elutriator. The elutriator was sized so that at 1 cfm, the throughput velocity was 1 cm/s, which is the terminal velocity for a particle 15 μm in diameter.

Thus, particles >15 μm settle in the elutriator. The cyclone separator described in EPA Method 5 for stack sampling was used to separate respirable particles <7 μm. This cyclone separator removes about 99% of the particulate having a spherical equivalent diameter above 7 μm. Nucleopore filters were used to collect respirable particles, which were then analyzed for free silica.

The sandblast gun, cloud chamber, elutriator, cyclone separator, filter holder, and all connecting lines were cleaned well before starting a new sample analysis Two runs were made for each sample. The first run lasted about 15 min and was used to determine the sampling time required for the second run in order to collect a weight of respirable dust on the filter equal to the filter tare weight. Samples collected in the second run were analyzed for free silica.

FREE SILICA ANALYSIS

The infrared spectrophotometric approach is the method chosen for this study. Although several procedures can be adapted to these types of speciments, we propose to use the method developed by Cares, et al (26) for determining quartz in airborne respirable granite dust. The method involves ashing of the filter and sample at 550°C and mixing and pressing the sample ash with KBr to form a solid pellet which is placed in an infrared spectrophotometer for spectral analysis. The detailed analytical procedure is as follows.

1. The sample is taken on a low ash polyvinyl chloride membrane filter, which has excellent moisture stability (Mine Safety Appliances Co. Membrane Filter, Part No. 62513 or equivalent) (Note: The infrared spectrum of the ash from the MSA filter does not interfere with the quartz determination.)

2. Place the filters in porcelain evaporating dishes (Coors 4/0) and transfer them to a muffle furnace.

3. Heat to 550°C and maintain until the carbon is destroyed (about 1-1/2 hr to 2 hr).

4. Remove the dishes carefully, cover, and cool.

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(26) Cares, J. W., A. S. Goldin, J. J. Lynch, and W. A. Burgess. The Determination of Quartz in Airborne Respirable Granite Dust by Infrared Spectrophotometry. American Industrial Hygiene Association Journal, 34(7):298-305, July 1973.

5. Add 40 mg ± 5 mg of infrared-quality KBr (Harshaw Chemical Co., Cleveland, Ohio) previously ground to -200 mesh and kept in an oven at 110°C. (If sample weight is excessive, a larger amount of accurately weighed KBr should be added and aliquots taken for final sample.)

6. Mull the sample ash and KBr with a small alundum pestle until they are thoroughly mixed. Take care not to grind or apply pressure as this may alter the spectrum.

7. With a spatula, transfer the mixture as completely as possible to a pellet press equipped with a 6.4 cm (1/4 in.) diameter punch and die.

8. Tap lightly to distribute the powder evenly, center the punch carefully, and press. Release the pressure, turn the die about 180°, and repeat the pressing. With good technique, a clear pellet without cracks or opaque spots will be obtained.

9. Transfer the pellet to a pellet holder and place the mounted pellet in the sample beam of an infrared spectrophotometer (Perkin-Elmer Model 421 Grating Spectrophotometer or equivalent).

10. At a wavelength of about 11.8 μm and wide slit, adjust the base line to a maximum transmission (or minimum absorbance) and scan to 13 μm. For identification purposes, observing the 14 μm quartz band may be necessary. Reverse the sample for a repeat scan.

11. To obtain the weight of quartz in the sample, subtract the absorbance of the base line at 12 μm from that at 12.5 μm and compare the net absorbance with a calibration curve obtained from a series of quartz-KBr standards. Absorbances should be below 0.5 for satisfactory linearity. Samples of greater absorbance are brought into this range by breaking up the pellet, diluting it with KBr, and aliquoting it if necessary. Assuming 100% sample recovery and a minimum possible measurement of absorbance of 0.02, the detection limit is ∿5 μg of quartz in a sample.

Preparation of calibration standards is done as follows:

1. Prepare quartz standards from 5 μm grade Minusil R, a high-purity crystalline silica obtainable in several size ranges from the Pennsylvania Glass Sand Corp., Pittsburgh. Ninety-eight percent of the particles of this grade are <5 μm in diameter.

2. Place the standards in a muffle furnace and heat them to the same temperature as the samples before use.

3. Prepare stock standards by blending carefully weighed amounts of Minusil and R-grade KBr either by mulling 5-μm grade Minusil R and infrared-quality KBr with an alundum mortar and pestle or by using a commercial type of mixer, such as the "Wig-L-Bug."

4. Dilute the stock mixture in the same manner to obtain concentrations which will yield 40 mg of pellets containing from 5 μg to 150 μg of quartz.

5. Press pellets and record spectra in the same manner as with the samples.

6. Plot calibration curve of net absorbance versus weight of quartz.

RESULTS OF FREE SILICA ANALYSIS

Results of the free silica analysis are shown in Table E-1 and in Figure E-3. The free silica values quoted at each site are accurate within ±20%. The highest value of free silica is 47% (near Cleveland, Ohio) and the lowest value is 1.4% (near Toledo, Ohio). The mean value is 14.1% with a standard deviation of ±12.0% and a 95% confidence level of 4.6%.

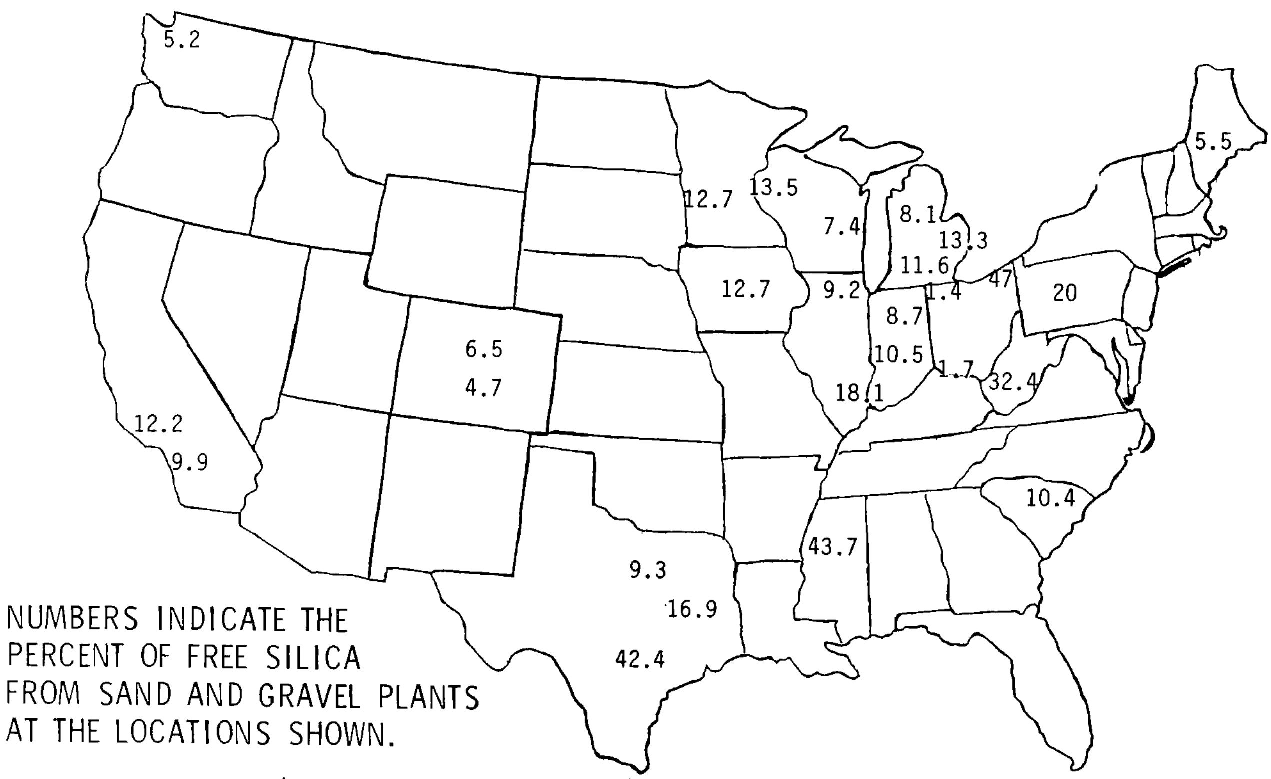

Figure E-3. Free silica distribution.

TABLE E-1. RESULTS OF FREE SILICA ANALYSIS

Sample number	City and state	Free silica, %
1	Parkersburg, WV	32.4
2	Dayton, OH	1.7
3	Garwood, TX	42.4
4	Milwaukee, WI	7.4
5a	Kosse, TX	8.3
5b	Kosse, TX	10.2
6a	Jay, ME	5.6
6b	Jay, ME	5.5
7	Elgin, IL	9.2
8	Greenville, MS	43.7
9	Blenheim, SC	10.4
10	Fergus Falls, MN	12.7
11	Indio, CA	9.9
12	Orange County, CA	12.2
13	Des Moines, IA	12.7
14	College Station, TX	16.9
15	Pittsburgh, PA	20.0
16	Grand Rapids, MI	8.1
17	Grey Cloud Township, MN	13.5
18	Kalamazoo, MI	11.6
19	Oxford, MI	13.3
20	Fort Wayne, IN	8.7
21	Indianapolis, IN	10.5
22	Thompson, OH	47.0
23	Clay Center, OH	1.4
24	Littleton, CO	6.5
25	Redmond, WA	5.2
26	Denver, CO	4.7
27	Mt. Carmel, IL	18.1
Mean value		14.1
Standard deviation		±12.0
95% Confidence level[a]		±4.6

[a] 95% confidence level = $t \cdot \sigma / \sqrt{n-1}$

where t = student's t, 2.048
σ = overall standard deviation
n = number of samples

GLOSSARY

affected population: Product of the land area where severity is greater than 0.1 or 1.0 and the representative population density.

confidence interval: Range over which the true mean of a population is expected to lie at a specific level of confidence.

criteria pollutant: Pollutant for which ambient air quality standards have been established.

emission burden: Ratio of the total annual emissions of a pollutant from a specific source to the total annual state or national emissions of that pollutant.

fibrosis: Abnormal increase in the amount of fibrous connective tissue in an organ or tissue.

free silica: Crystalline silica defined as silicon dioxide (SiO_2) arranged in a fixed pattern (as opposed to an amorphous arrangement).

growth factor: Ratio of known to projected emissions from a source type.

hazard factor: Measure of the toxicity of prolonged exposure to a pollutant.

lignin sulfonates: Organic substances forming the essential part of woody fibers introduced into the sulfonic group by treatment with sulfuric acid.

precipitation-evaporation index: Reference used to compare the precipitation and temperature levels of various P.E. regions of the U.S.

representative source: Source that has the mean emission parameters.

severity: Hazard potential of a representative source defined as the ratio of time-averaged maximum concentration to the hazard factor.

silicosis: Chronic disease of the lungs caused by the continued inhalation of silica dust.

silt-sized: Fine particle sized, as soil or sand.

threshold limit value: concentration of an airborne contaminant to which workers may be exposed repeatedly, day after day, without adverse affect.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-78-004y	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE SOURCE ASSESSMENT: TRANSPORT OF SAND AND GRAVEL		5. REPORT DATE October 1978 issuing date
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J. C. Ochsner, P. K. Chalekode, and T. R. Blackwood		8. PERFORMING ORGANIZATION REPORT NO. MRC-DA-721
9. PERFORMING ORGANIZATION NAME AND ADDRESS Monsanto Research Corporation, 1515 Nicholas Road, Dayton, OH 45407		10. PROGRAM ELEMENT NO. 1BB610
		11. CONTRACT/GRANT NO. 68-02-1874
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Lab. - Cinn,OH; Office of Research and Development; U.S. Environmental Protection Agency; Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Task Final, 8/74 - 9/77
		14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES
IERL-Ci project leader for this report is John Martin, 513-684-4417

16. ABSTRACT
This report describes a study of atmospheric emissions from the transport of sand and gravel on unpaved roads. The potential environmental effect of this emission source was evaluated using source severity, defined as the ratio of the time-averaged maximum ground level concentration of a pollutant at a representative plant boundary to a hazard factor. The hazard factor is the ambient air quality standard for criteria pollutants and an adjusted threshold limit value for noncriteria pollutants. A representative sand and gravel plant processes 274 metric tons/hr, with vehicular traffic of 22 vehicles/hr. The average unpaved road length of sand and gravel plants is 2.2 kilometers, and each truck carries an average of 21 metric tons. The uncontrolled particulate emission factor for the industry due to vehicular movement is 87 g/metric ton. The source severities for particulates and free silica-containing particulates are 0.02 and 2.9, respectively.

Some plants have effectively used certain control measures, such as application of oil and chemical solutions into the road surface. Future control techniques would consider the emission-influencing factors of vehicle speed, vehicle size, number of wheels, tire width, particle size distribution, and road moisture content.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air pollution Dust Silicon dioxide Sands Gravel	Air pollution control Stationary sources Source severity Particulate	68A

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