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# SURVEY OF FUGITIVE DUST FROM COAL MINES

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# SURVEY OF FUGITIVE DUST FROM COAL MINES

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# FOREWARD

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# SUMMARY

There are several significant sources of particulate air pollution at surface coal mines. Emission factors were developed for individual mining operations at five different Western surface mines; the factors presented in this report apply only to Western coal mines.

The sampling method used to determine emission rates was upwind-downwind ambient sampling, with subsequent use of an atmospheric dispersion equation to relate ambient concentrations and emission rates. Sampling periods were only about one hour so that meteorological conditions and the mining operations would remain fairly constant, but were long enough to ensure that the activity was representative and that a measurable particulate loading was obtained. Samplers were placed downwind at two heights and three or four different distances from the source to provide an averaging effect in calculating emission rates.

By sampling simultaneously at several distances, it was hoped that a source depletion factor, or fallout function, could be developed from the data. However, the apparent emission rates did not consistently decrease with distance from the source. A published fallout function, in the form of a negative exponential relation with distance and the inverse of wind speed, was used in developing the emission factors.

Emission factors for the significant mining sources are summarized in Table 1. These values are the initial emission rates from the sources and must be used in conjunction

Table 1. EMISSION FACTORS FOR INDIVIDUAL COAL MINING OPERATIONS

| Operation | Units | Mine A N.W. Colo. | Mine B S.W. Wyom. | Mine C S.E. Mont. | Mine D Cent. N.D. | Mine E N.E. Wyom. |
|---|---|---|---|---|---|---|
| Dragline | $lb/yd^3$ | .0056 | .053 | .0030[b] | .021 | |
| Haul roads | lb/veh-mi[a] | | | | | |
| w/watering | | 6.8 | 13.6 | 3.3[b] | | 4.3 |
| no watering | | | 17.0 | | 11.2 | |
| Shovel/Truck loading | lb/ton | | | | | |
| coal | | .014 | .007 | .002[b] | | .0035 |
| overburden | | | | | | .037[b] |
| Blasting | lb/blast | | | | | |
| coal | | | | 25.1 | 78.1 | 72.4 |
| overburden | | 1690[b] | | 14.2 | | 85.3 |
| Truck dump | lb/ton | | | | | |
| bottom dump | | .014 | .020 | .005 | .027 | |
| end dump | | | | | | .007 |
| overburden | | | | | | .002[b] |
| Storage pile | lb/acre-hr | 1.6 u, where u is in m/sec | | | | |
| Drilling | lb/hole | | | | | |
| coal | | | | | | .22 |
| overburden | | | | 1.5 | | |
| Fly-ash dump | lb/hr | 3.9 | | | | |
| Train loading | lb/ton | | | .0002 | | |
| Topsoil removal | $lb/yd^3$ | | | | | |
| scraping | | | | | .35 | |
| dumping | | | | | .03 | |
| Front-end loader | lb/ton | | | | .12 | |

[a] Only veh-mi by haul trucks; travel by other vehicles on haul roads (pickup trucks, ANFO trucks) is incorporated into these values.

[b] These values were all noted to be somehow atypical and should not be used without first determining the limitations to their applicability described in this report.

with a fallout function in predicting ambient air quality impact from a mine. If the dispersion model to be used does not have provision for considering fallout, alternative regional-scale emission factors which already include a reduction for fallout are also presented in the report. The regional emission factors should not be used to predict concentrations within 5 km of mining operations.

According to the emission factors in Table 1, haul road traffic would almost always be the largest particulate source at a surface coal mine. Other major sources would be open storage piles and the dragline operation. Sampling for one source, exposed areas, produced data which could not be converted into an emission factor. It is estimated that exposed areas would also be a major source.

The mass median diameter for most samples was in the range of 10 to 35 microns, indicating a high percentage of material outside the respirable size range and subject to deposition. There was no significant difference in the size distribution of emissions from different operations at the mines.

The expected variation (in terms of standard deviation) in emission rates for an operation during different time periods at the same mine is about 60 percent of the mean value. This is much lower than the variation in an operation's emission rate for different mines, and it explains why separate emission factors were derived for the individual mines, to be applied to others on the basis of similar climate, geology, and operating characteristics. Individual emission factors are estimated to generally be accurate within a factor of two.

It should be emphasized that this is the first comprehensive sampling study at coal mines for the specific purpose of determining particulate emission rates. Additional work is needed to quantify emission rates from some sources that were not successfully sampled and to define the deposition rate of the emissions with distance from the sources. Design of these future studies should benefit from the critique of the sampling design of the present study included herein.

Availability of reliable emission factors for mining sources does not, by itself, ensure that accurate estimates of the air quality impacts from mines can be made. This also requires a model that correctly simulates dispersion of the emissions throughout the surrounding area. Current dispersion models may not be adequate because of some features usually associated with the mines: rugged terrain, sources in pits or at ground level, wind speed-related emission rates, wind channeling, and poorly defined source locations. Further development may be required in this area also.

# 1. INTRODUCTION

A large number of new surface coal mines will be opened in the Western states in future years to meet the nation's energy needs. Under various state and federal laws, the air quality impacts of proposed mines must be determined prior to approval. Three stages at which approval and an air quality analysis may be required are: 1) environmental impact statement, 2) review for prevention of significant air quality deterioration, and 3) construction or operating permit.

In order to perform these air quality analyses, reliable estimates of particulate air pollution emissions from Western coal mines are urgently needed. The purpose of the present study is to provide such emission estimates.

There are several different sources of particulate emissions at the mines. The operations which are significant air pollution sources have been identified, but no sampling had been done prior to the present study to measure the emission rates from these sources.[1] Many analyses of the air quality impacts from proposed or existing mines have already been performed; these analyses have used emission factors adapted from similar activities such as construction and quarrying or based on the best judgment of those performing the analyses.

Separate emission factors were developed for each of the major fugitive dust sources associated with surface coal mining. This will permit emission estimates by operation to be made from readily available information concerning operation of a mine, and the tailoring of estimates for the entire mine to the types of operations which are present.

Sampling data to develop the emission factors were obtained at five different mines so that atypical conditions at one mine would not bias the values. Sampling at several different mines also permits the determination of expected variability in emission rates between different mines. Two of the five mines were in Wyoming and one each was in Colorado, Montana, and North Dakota.

Table 1-1 briefly summarizes some of the climatological, geological, and topographical data for these mines. Information on mining operations at each mine can be found in Appendix A. The surrounding terrain varies greatly from mine to mine, but all have sparse to moderate vegetation and semiarid climate.

There is also considerable variation in mining methods at the different mines. One uses open pit mining rather than strip mining. Overburden is removed by truck and shovel instead of dragline, and the coal is removed in benches because of the seam thickness. At another mine, the coal seam is inclined at a 23 percent slope. The dragline moves up and down the side of the mountain forming an open strip with the same slope as the seam. These differences in mining techniques between mines are quite common and are the primary reason that emission factors have been developed by operation rather than solely on the basis of tons of coal mined.

Emission factors are presented in this report for 12 different surface coal mining operations:

- Dragline
- Haul road traffic
- Drilling
- Shovel/Truck loading

Table 1-1. CHARACTERISTICS OF SURFACE COAL MINES

| Mine | Location | Type of coal mined | Terrain | Vegetative cover | Surface soil type and erodibility index | Mean annual wind speed, mph | Mean annual precipitation, in. |
|---|---|---|---|---|---|---|---|
| A | N.W. Colorado | Sub-bituminous | Moderately steep | Moderate, sagebrush | Clayey, loamy (71) | 5.1 | 15 |
| B | S.W. Wyoming | Sub-bituminous | Semi-rugged | Sparse, sagebrush | Arid soil with clay and alkali or carbonate accumulation (86) | 13.4 | 14 |
| C | S.E. Montana | Sub-bituminous | Gently rolling to semi-rugged | Sparse-moderate, prarie grassland | Shallow clay loamy deposits on bedrock (47) | 10.7 | 11-16 |
| D | Central N. Dakota | Lignite | Gently rolling | Moderate, prarie grassland | Loamy, loamy to sandy (71) | 11.2 | 17 |
| E | N.E. Wyoming | Sub-bituminous | Flat to gently rolling | Sparse, sagebrush | Loamy, sandy, clayey, and clay loamy (102) | 13.4 | 14 |

- Blasting
- Truck dumping
- Open storage piles
- Train loading
- Topsoil removal
- Fly-ash dump
- Front-end loader
- Overburden dumping

Extensive sampling was done for one other source, exposed areas, but no emission factor could be developed.

A unique and significant feature of the emission factor data presented in this report is that it considers the fall-out of large particles. This is important for at least two reasons:

- Health effects research data clearly indicate that adverse effects are associated with respirable particles rather than the large particles which fall out within a short distance of the source.
- Diffusion models which do not include such a fallout function would tend to overpredict ambient concentrations with increasing distances from the source and, as a result, may predict the existence of an air quality problem where none in fact would exist.

The methods used to sample for emissions from the mining operations are discussed in detail in Chapter 2. The data analysis methods used to translate sampled ambient concentrations into emission rates are discussed in Chapter 3. Chapter 4 presents results of the data analysis. Chapters 5 and 6 present the emission factors calculated for each of the operations and evaluations of expected accuracy, variations between sampling periods and between mines, agreement with values previously used, and consistency with ambient air quality data measured in the vicinity of some Western mines.

## 2. SAMPLING METHODOLOGY

Emission rates from unconfined fugitive dust sources such as those at surface mines cannot be measured by the standard procedures used to determine emissions from stacks. Recent work to develop generally applicable measurement methods for fugitive emissions has produced three basic methods:

- Quasi-stack sampling
- Roof monitor sampling
- Upwind-downwind sampling[2]

As the name implies, quasi-stack sampling involves the temporary confinement or enclosure of emissions from the source and passage through a regular cross-section duct for measurement. Roof monitor sampling requires that the fugitive emissions initially be discharged into an interior space. Neither of these methods is applicable for sampling at surface coal mines because of the large areas over which the dust is emitted.

The sampling method employed was upwind-downwind sampling for particulate matter in the ambient air. Emission rates were determined by use of atmospheric dispersion equations which relate emissions and ambient concentrations. These equations assume Gaussian distribution of the particulate matter about the plume centerline in both the horizontal and vertical planes as it moves downwind.

Mining sources do not actually have constant emission rates nor do they have well-established plumes. However, the irregular puffs of dust can be represented by an equivalent symmetric distribution if a sufficiently long averaging period is used.

Gaussian dispersion equations require data on average wind speed, wind direction, distance from the source to the sampler, and atmospheric stability class. The specific form of the equations and the assumptions made in back-calculating emission rates based on net downwind concentrations are discussed in Chapter 3.

This chapter describes the procedures used to sample mining operations, discusses the advantages and disadvantages of the specific methods used, and briefly describes some of the problems encountered while implementing the field sampling program.

## DESCRIPTION OF THE METHODOLOGY USED

### Mining Operations Sampled

Fifteen different mining operations were identified as significant fugitive dust sources at Western coal mines. It was intended that these operations would be sampled at each of the five mines where they were present. The number of sampling periods for each operation was determined based on its expected importance to total mine emissions, with the major sources being delegated most of the samples.

As shown in Table 2-1, seven of the operations were sampled several times at each of the mines: haul road traffic, draglines, shovel/truck loading, truck dumping, blasting, open storage piles, and exposed areas. However, fewer than the desired number of samples were obtained for some of the other operations. For example, topsoil removal was not being conducted at four of the mines during the time that sampling crews were present. In some cases, the operation was unique to a single mine. Front-end loaders for

Table 2-1. OPERATIONS SAMPLED AT EACH MINE

| Operation | No. of sampling periods Mine A | B | C | D | E | Total |
|---|---|---|---|---|---|---|
| Dragline | 8 | 10 | 6 | 6 | | 30 |
| Haul road traffic | 10 | 10 | 10 | 9 | 8 | 47 |
| Shovel/Truck loading | 6 | 6 | 4 | 0 | 10 | 26 |
| Blasting | | | | | | |
| overburden | 1 | | 2 | | 2 | |
| coal | | 2 | 2 | 2 | 2 | 13 |
| Truck dump | 6 | 2 | 4 | 6 | 4 | 22 |
| Storage piles | 6 | 8 | 4 | 4 | | 22 |
| Exposed areas | 4 | 6 | 4 | 3 | 4 | 21 |
| Drilling | 1 | 0 | 2 | 0 | 2 | 5 |
| Fly-ash dump | 3 | 0 | | | | 3 |
| Train loading | | | 4 | | 5 | 9 |
| Topsoil removal | 0 | 0 | 0 | 10 | 0 | 10 |
| Front-end loaders | | | | 1 | | 1 |
| Graders | 0 | | | 0 | | 0 |
| Bucket wheel | | | | | 0 | 0 |
| Overburden dump | | | | | 4 | 4 |
| Total | 45 | 44 | 42 | 41 | 41 | 213 |

truck loading and bucket wheels are examples. In other cases, no appropriate sampling locations could be found. Therefore, more confidence can be placed in resulting emission factors for the major operations than in those for operations which occur at only one mine or which were not sampled repeatedly.

Sampling Equipment

Standard high volume sampling units, General Metal Works Model GMW T-2200, were used. The units were set on tripods instead of in shelters so that they would be more portable. The tripod stands have standard roofs to prevent deposition and to control intake velocity. Filter holders were utilized to facilitate sample changing. Short-term samples of approximately one hour were taken; the actual running times for each period were manually controlled and recorded on data sheets.

A Bendix Aerovane recording wind instrument was located at a central location at each mine. The anemometer was placed at a height of 2.4 m. A hand-held wind speed indicator was also used for all sampling periods, in case local topography rendered the recorded data unrepresentative of actual conditions in the plume. The Bendix instrument ran continuously and produced a single strip chart for each sampling period at each mine. Time on the charts was synchronized daily with the watch used to record start and stop times for each sampling period.

Records of other weather conditions necessary to estimate atmospheric stability (e.g., cloud cover and solar intensity) were routinely recorded on the data sheets described elsewhere in this chapter.

Three Onan gasoline-powered generators (one 5 kw and two 3 kw) provided power for all the sampling equipment operated during the field study. One generator was available to run each of the two sets of samplers downwind of operations; the third was used with the upwind samplers. Generators were located so that their engine exhaust did not interfere with the sampling.

A nucleopore filter holder and pump were used to collect samples on 47 mm diameter millipore filters for determination of particle size distribution. A total of 67 millipore samples were taken, or about six percent of the number of hi vol samples. The exposed millipore filters were returned to the laboratory for microscopic determination of particle size distribution. It was assumed that all particles had the same density in order to calculate mass distribution by particle size.

<u>Sampler Heights</u>

Hi vol samples were taken simultaneously at two different heights (1.2 and 2.4 m) during almost half the 213 sampling periods to provide information on vertical distribution of particulate concentrations in the plume. Ideally, concentrations would have been obtained at four or more vertical points in the plume to completely define the gradient with height, such as was done with the vertical profile sampler used in some previous fugitive dust sampling studies.[3,4] However, it was thought to be more important in this study to sample at several downwind distances to evaluate fallout than to completely define the vertical profile of the plume at a single distance. If several samplers were used in both dimensions simultaneously, the complexity of the resulting array would have compromised the portability of the sampling configuration and resulted in far fewer total sampling periods. The sampling configuration described below was agreed upon as optimum (for an initial sampling of surface coal mines) for providing many samples of different mining operations and a reasonably large number of samplers in the plume during each sampling period.

Sampler Configuration

A total of 12 high volume samplers were available for deployment. Normally, two samplers were placed together at a remote upwind location, four were placed in a line downwind of a source at 1.2 m height, and the remaining six were placed at 1.2 and 2.4 m heights at three distances downwind of another source. In this manner, two sampling periods could be conducted either concurrently or sequentially. Because of the difficulty in setting up in two different parts of the mine and monitoring two mining operations at one time, the two groups of samplers were frequently run on the same operation at once. This was still considered to be two sampling periods in reporting the data.

The most commonly used downwind distances were 10, 20, 30, and 40 m. For some operations such as blasting or dragline, plume development and/or personnel safety required that greater distances be used. At mines C, D, and E, sampling distances were less standardized and at mine E the mining company placed additional downwind samplers in the array. The data from the company's samplers have also been included in the estimates of emission rates.

There were no differences in sampling configurations for line sources (such as haul roads) and area sources (such as truck dumping). For line sources, the samplers were placed in line with the wind direction at the beginning of the sampling period rather than perpendicular to the source. A typical sampling setup with samplers at both 1.2 and 2.4 m heights is shown in Figure 2-1. Photographs of the samplers in the mines are presented in Figure 2-2.

Two samplers were placed at an upwind or crosswind location at the mine, usually remote from the operation

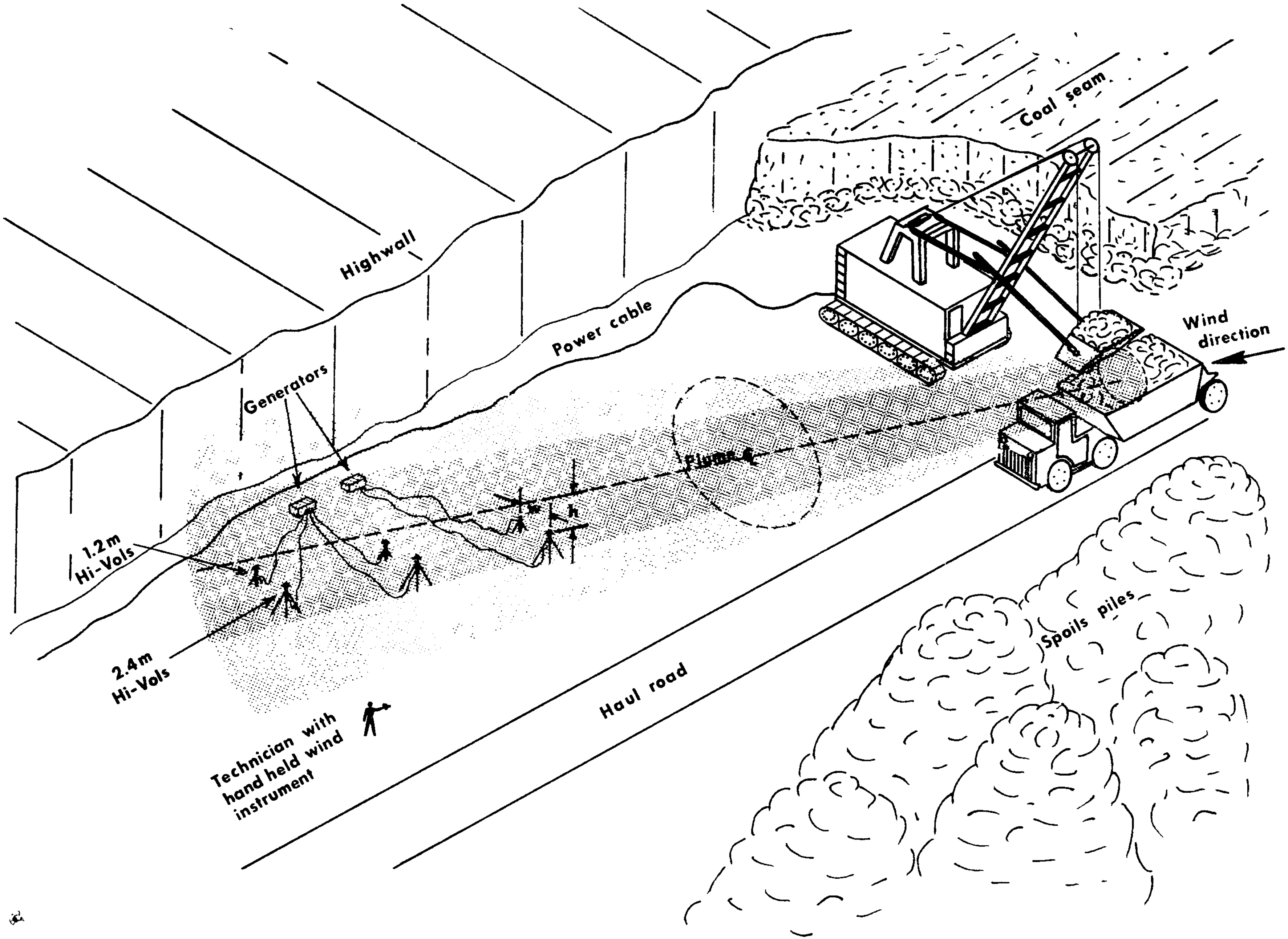
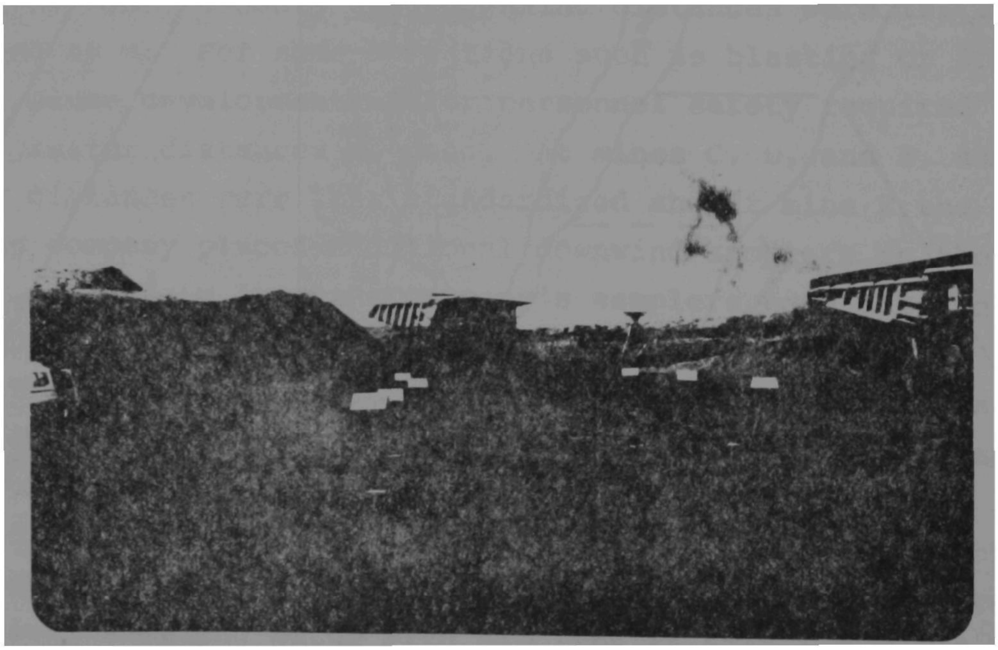



Figure 2-1. Typical sampler array.

Area source



Line source

Figure 2-2. Samplers downwind of area and line sources.

being sampled. The upwind or background concentrations were subtracted from measured downwind concentrations to obtain the net contribution from the source being studied. For obvious reasons, the upwind samplers were run for approximately the same time periods as the downwind samplers. Locations distant from the activity being sampled and from other dust-producing operations were selected so that brief reversals of wind direction during a sampling period did not produce a contribution from the source and thereby render the site useless as a measure of incoming particulate concentration. A disadvantage of not having an immediate upwind sampling location was that other sources at the mine might also contribute to the concentrations downwind of the source being investigated; the remote upwind site did not account for any such contribution.

In a few cases where source impact on the upwind samplers was suspected, lower background concentrations measured at other (downwind) samplers during the same time period or the preceding or following sampling period were substituted.

Selection of Sampler Locations

Sampling equipment was normally moved at least once per day to different locations to sample different operations. The sequence of sampling was determined by the PEDCo field engineer, with approval by the mine contact man. The general sampling locations were preselected during initial visits to the five mines.

One consideration in selection of the operations to be sampled for that day was wind direction, so that samplers could be placed in a convenient direction from the operation being sampled. The intent was to minimize interferences from other fugitive dust sources and prevent any possible safety hazards.

## Estimation of Initial Plume Dispersion

The value desired for use in the dispersion equations is the standard deviation of the initial plume dispersion, $\sigma_{zo}$ in the vertical plane and $\sigma_{yo}$ in the horizontal plane. A value of 1.5 m for $\sigma_{zo}$ has been found through experimental work to be representative for highway sources, so values of 3 to 5 m were used for haul road traffic.[5] For other sources, $\sigma_{zo}$ was estimated as the total initial plume height (if it was visible) divided by 2.15.[6] For horizontal plume dispersion, $\sigma_{yo}$ was estimated as the initial plume width (side of source perpendicular to wind direction) divided by 4.3, as recommended in the Workbook of Atmospheric Dispersion Estimates.[7]

## Data Records

For each one-hour sampling period, a separate data sheet was used to record information on the location of sampling, filter numbers, meteorological data, and mining activity observed. Examples of mining activity are the number of haul trucks and other vehicles using the mine road during the sampling period, the number of bucketsful of overburden lifted during the period, or the area blasted. Notation was made on the data sheet whether the fixed met station was representative of wind conditions at the sampling location or whether the hand-held instrument's data should be used.

Data sheets were also used to indicate any problems that occurred during a sampling period. Such information as wind shift, sampling equipment malfunction, and nonrepresentative activity during sampling times were recorded to explain inconsistencies in the data collected.

A sample of one of the data sheets produced during the sampling activity is shown in Figure 2-3.

MINE A DATE 7/7/77

OPERATION Coal loading LOCATION NO. 1

NOTES ON OPERATION 1 shovel 18 cu. yd. bucket

ACTIVITY PARAMETERS: COUNT (USE MARKS):

- ☒ PER HAUL TRUCK IIII
- ☐ PER OTHER VEHICLE
- ☐ PER BUCKETFUL
- ☐ PER HOUR
- ☐ PER TON OF COAL
- ☐ PER ACRE
- ☐ PER LOAD
- ☒ OTHER 2 units per truck (28 tons per unit) TOTAL: 4

SIZE OF SOURCE:

WIDTH PERPENDICULAR TO WIND, M 15 (from scoop to dump)

INITIAL VERTICAL PLUME DISPERSION, M 7

PARTICLE SIZE DATA TAKEN? ☒YES (A-2) ☐NO
(MARK SAMPLE NOS. BESIDE HI-VOL SAMPLER NOS.)

PHOTOS TAKEN ? ☐YES ☒NO
NO. ON FILM ROLL

PLACE SKETCH ON BACK

MET DATA: B.P. = 29.48 Temp. = 85°F

TIME SINCE RAIN 24 hours

SOLAR INTENSITY ☒ STRONG ☐ MODERATE ☐ SLIGHT

INITIAL WIND DIRECTION 240°
(DIRECTION FROM SAMPLER TO SOURCE)

CAN FIXED MET STATION BE USED FOR WINDS AT THIS SITE ☐YES ☒NO

TIME IN PLUME, MIN 60

HAND HELD INSTRUMENT:

| TIME | DIR | SPD m.p.h. |
|---|---|---|
| 1:35 | 240 | 6 |
| 1:40 | 240 | 8 |
| 1:45 | 235 | 6 |
| 1:50 | 235 | 9 |
| 1:55 | 240 | 7 |
| 2:00 | 245 | 7 |
| 2:05 | 240 | 8 |
| 2:10 | 240 | 6 |
| 2:15 | 235 | 7 |
| 2:20 | 240 | 6 |
| 2:25 | 235 | 8 |
| 2:30 | 240 | 7 |
| AV. | 238.8 | 7.1 |

Met. station – 325° – 5 m.p.h.

DOWNWIND SAMPLES: START TIME 1:31 OFF TIME 2:31 (VISIFLOAT #8)

| DIST/HT, M | HT REL TO PLUME ℄, M | SAMPLER NO. | FILTER NO. | FLOW RATE INIT | FLOW RATE FINAL | (LATER) MEAS CONC | NET CONC |
|---|---|---|---|---|---|---|---|
| 16/1.2 | -2.3 | 3 | 616 | 53 | 49 | 2027 | 1940 |
| 26/1.2 A-2 | -2.3 | 4 | 615 | 44 | 40 | 1561 | 1474 |
| 36/1.2 | -2.3 | 5 | 614 | 46 | 42 | 1649 | 1562 |
| 46/1.2 | -2.3 | 6 | 613 | 50 | 46 | 1355 | 1268 |

UPWIND SAMPLES: (VISIFLOAT #8)

START TIME 11:57 OFF TIME 1:51

LOCATION 2

| | | |
|---|---|---|
| SAMPLER NOS. | 1 | 2 |
| FILTER NOS. | 622 | 621 |
| FLOW - INIT | 40 | 38 |
| FLOW - FINAL | 37 | 35 |
| CONCENTRATIONS | 94.1 | 79.5 |

PROBLEMS DURING SAMPLING:

- ☐ WIND SHIFT (OUT OF PLUME)
- ☐ SAMPLING EQPT MALFUNCTION
- ☐ NON-REP. MINING ACTIVITY
- ☒ OTHER moving and piling coal
  ① between truck loading
  ② set up beside haul road

NOTES: one water truck on haul road (not spraying)

Figure 2-3. Sample field data sheet.

### Quality Control

The high volume samplers were calibrated immediately prior to the field work at each mine and again at the completion of the field work. One in every 25 filters was a blank that was sent out with the other filters and returned unused for reweighing. The quality assurance procedures outlined in the Quality Assurance Handbook for Air Pollution Measurement System were used for filter preparation, for sample collection and analysis, and in auditing the particulate data generated.[8]

## ADVANTAGES AND DISADVANTAGES

There were several advantages and disadvantages associated with the specific sampling method described above. In the following section, these factors are briefly discussed.

### Advantages

Advantages associated with the method used are:

- The samplers are near the mining operation, hence they are almost always being impacted by the plume from the operation.
- Several different portions of the plume are sampled simultaneously, providing an averaging effect in calculating emission rates.
- The portability of the sampling gear permitted all mining operations to be sampled.
- The use of an array of samplers set at different distances theoretically permitted the fallout rate to be calculated directly.
- The large number of samples allowed temporal and mine-to-mine variations in emission rates to be determined.

- The mining operation could be described in great detail because the sampling crew was close to the operation and the sampling period was relatively short.

- Setting the sampling array close to the mining operation minimized the relative impact and interference from other emission sources.

- The proximity also permitted a fairly precise estimate of the time-in-plume to be made.

- The high concentrations in the plume near the source ensured that filters would collect measurable loadings during the short sampling period.

Disadvantages

There were also some disadvantages associated with the methodology used. Varying in seriousness with the operation being sampled, these disadvantages are as follows:

- The source strength (emission rate) must be calculated based upon an assumption concerning plume dispersion. In this study, a Gaussian plume was assumed.

- Using only two sampler heights can result in an incomplete understanding of the plume's vertical profile.

- Sampling very close to a mining operation can result in the collection of some heavier particles which would otherwise settle near the source.

- The initial plume dispersion--a critical factor in calculating the apparent emission rate--has to be estimated visually.

- The short sampling period increased the chance that emissions were non-representative during sampling.

## PROBLEMS ENCOUNTERED

Any sampling network, no matter how well designed in theory, will encounter unanticipated problems which result in data limitations or the need for design modifications. The methodology that has been described thus far is no exception. In the following few paragraphs, the major problems encountered are briefly discussed.

### Mining Operations Did Not Always Produce Stationary Points of Plume Origin

The equations used to back-calculate apparent emission rates assume that the point of origin of a plume is stationary. This was not always the case. A good example is the dragline operation. The bucket scoops up the overburden, the boom swings in an arc, the bucket is elevated and then lowered, and the material is dumped. The point of origin of the emissions, the bucket, moves great enough distances to cause the plume centerline to vary considerably. The result was that the sampler array was not always directly or completely in the plume. Topsoil removal was another operation with this type of problem.

### Hand-held Wind Instrument Did Not Always Produce Adequate Data

The hand-held instrument could not measure wind speeds of less than about five miles per hour. Also, it only made instantaneous rather than continuous measurements. The combined impact of these two facts was that wind data taken at the sampling site were not accurate during periods of low or variable wind speeds. Selection of most appropriate wind data (remote continuous or on-location intermittent) was made at the conclusion of the sampling period.

### Instances of Inconsistency Between Sampling Crews Occurred

Two different sampling crews participated in the study. Near the end of the project, it was noted that there was some variation in the ways the two crews handled their assignments. Differences were noted in the methods used to estimate distances from mining operations and between samplers, in the frequency with which the sampling array was moved to keep it within the plume, in judgment as to what constituted a suitable sampling site, in judgment as to where to sample for the impact of exposed areas, and in judgment as to where and how often particle size samples should be taken.

An attempt was made to account for these differences in the subsequent data analysis steps. However, sampling data for a few sampling periods were voided because of these inconsistencies.

### Not All Sampling Locations Could Meet Necessary Criteria

In order of priority, decisions as to where to place a sampling array were based upon the following criteria: the mining operation had to be active, the sampling site had to be physically safe for the sampling crew, the site had to be physically accessible, and the site had to be downwind of the mining operation. In some cases, there was only one feasible location and the wind never blew in the proper direction to use that location. In other cases, the operation simply was not active during the five to ten days the sampling crew was present at the mine. In still other cases, it was not possible to sample in a physically safe or accessible location.

### Difficult to Determine Time-in-Plume

Most mining operations emit dust in a discontinuous fashion, producing puffs of dust varying in intensity and frequency. As a result, there was frequently no visible plume with which the sampling crew could relate. Not being able to define the plume clearly, they were consequently unable to time the duration of the period during which the samplers were in the plume.

A related problem was the highly variable emission rates observed for sources caused primarily by wind erosion, such as storage piles and exposed areas. Emission rates were negligible with low or moderate wind speeds but were very high during periods with high winds. For these sources, many sampling periods only confirmed that emission rates were negligible.

No Empirical Determination of Fallout

Theoretical calculations indicate that much of the fallout of heavier particles occurs in the first 100 m from a source. It was hoped that this study would yield an empirically determined fallout rate which could be compared to the theoretical one. Unfortunately, the data were too scattered to provide this information.

- The reduction in apparent emission rates with distance from the source was not as consistent as was expected.
- Review of the particle size distribution data yielded no relationship between mass median particle size and downwind distance from the source.
- Analysis of the relationship between mass median particle size and type of operation proved inconclusive.

Low Wind Speeds

In the Gaussian dispersion equation, there is an inverse relationship between wind speed and ambient concentrations.

With low wind speeds (i.e., less than 1.0 m/sec), ambient concentrations are predicted to approach infinity if the emission rate remains constant. At the same time, heavier particles are predicted to fall out much more quickly with low wind speeds than would otherwise be the case. The interactive result of these two processes is that the ability to estimate emission rates decreases dramatically as wind speeds approach zero. A related problem is that at low wind speeds the wind direction tends to vary, thus causing the sampling array to be in the plume a lower percentage of the sampling time.

### High Filter Loadings Cause Quality Assurance Problems

Emissions from operations such as blasting, dragline, coal loading, and coal dumping produced downwind concentrations of such great magnitude that they caused filters to become overloaded with particulate matter. No matter how well handled, some of this material was lost. An attempt was made to alleviate this problem by sampling for shorter periods of time for those operations which emitted at very high rates.

## PROPOSED MODIFICATIONS

If the study were to be redone now in light of the results obtained, the following changes in the study design would be made:

1. The high volume samplers would be spaced further apart in order to better measure the rate of deposition. Typical spacings would be 50 m.

2. Some of the sampling would be done at controlled sampling locations by having the mining equipment operate at other than their normal locations. This would also permit use of a continuous wind speed and direction instrument at the sampling location.

3. Samples for particle size analysis would be taken simultaneously at different distances from the source.

4. Wind erosion sources (e.g., exposed areas, storage piles) would only be sampled during periods with moderate to high wind speeds.

5. Background concentrations would be measured immediately upwind of the sources as well as at remote locations. This would prevent interference from other sources in the mine. The remote upwind sites would still be needed in case the wind reversed during sampling.

6. The project manager would be at each mine during part or all of the sampling period to ensure consistency of sampling procedures.

# 3. DATA ANALYSIS METHODOLOGY

The steps involved in calculating emission factors for the coal mining operations are shown as a flow diagram in Figure 3-1. The most important step is the conversion of downwind ambient concentrations into corresponding emission rates with a dispersion equation. The forms of this equation and input data requirements are discussed below.

Other data analysis procedures which are discussed include tests to determine the degree of variation among the estimates of emission rates from individual samples; the method for incorporating consideration of fallout into the emission factors; and the criteria for eliminating certain data points from the emission factor development process.

## DISPERSION EQUATIONS

Emission rates for fugitive dust sources were estimated from short-term (approximately one-hour) high volume samples taken at known distances downwind of the sources. Two Gaussian dispersion equations were used--one for line sources and the other for area sources. In both cases, the *net* downwind (downwind minus upwind) concentrations at each of the samplers were substituted into the equation with other appropriate input data to calculate the apparent source strength. Therefore, four to six estimates of source strength were generated for each sampling period.

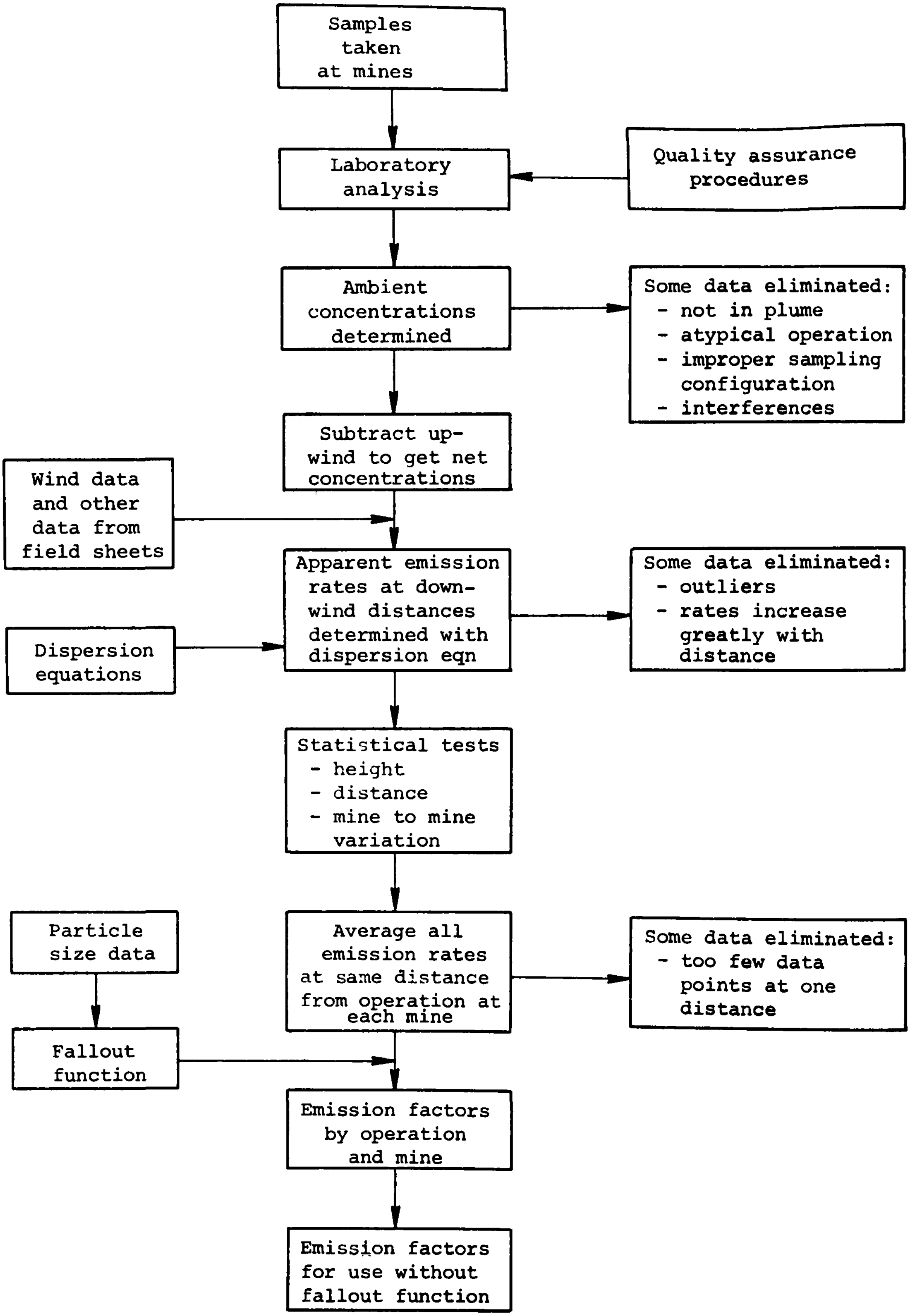



Figure 3-1. Flow diagram of data analysis procedures.

The line source dispersion equation is:

$$\chi = \frac{2q}{\sin \phi \sqrt{2\pi}\, \sigma_z\, u} \qquad \text{(eq.1)}$$

where $\chi$ = plume centerline concentration at a distance x downwind from the mining source, $g/m^3$

$q$ = line source strength, g/sec-m

$\phi$ = angle between wind direction and the line source

$\sigma_z$ = the vertical standard deviation of plume concentration distribution at the downwind distance x, for the prevailing atmospheric stability and including an initial $\sigma_z$, m

$u$ = mean wind speed, m/sec

The calculated values of q were converted to an emission rate per vehicle by dividing by the traffic volume during the sampling period.

The area source dispersion equation is:

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad \text{(eq.2)}$$

where $Q$ = area source strength, g/sec

$\sigma_y$ = the horizontal standard deviation of plume concentration distribution at the downwind distance x, for the prevailing atmospheric stability and including an initial $\sigma_y$, m

$\chi$, $\sigma_z$, $u$ = same as above

These equations assume that sampling is done along the plume centerline. For line sources, this is a reasonable assumption because the emissions occur at ground level and have an initial vertical dispersion ($\sigma_{zo}$) of 3 to 5 m. Therefore, the plume centerline is at 1.5 to 2.5 m height, the same as the sampler heights. Field personnel made an effort to position samplers so that this relationship was maintained even in rough terrain. Horizontal dispersion does not enter into the calculation for line sources. The sampling time must be corrected for any brief period of time when the wind reverses so that the samplers are upwind of the line source.

For area sources, it is not possible to sample continuously along the plume centerline because of varying wind directions and possibly because of varying emission heights (e.g., shovels and draglines). The problem of varying wind direction was accounted for by first determining the resultant wind direction relative to the line of samplers, trigonometrically calculating the horizontal distance from the sampler to the plume centerline (y), and then determining the reduction from centerline concentration with the following equation:

$$\text{reduction factor}_y = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

If the samplers were completely out of the plume for part of the sampling period but this was not reflected in the resultant wind direction, the percent of time that the samplers were within the plume was estimated and emission rates were corrected by dividing by this fraction.

Differences in the height of sampling and height of emission release were accounted for in the area source dispersion equation with an additional exponential expression if the average difference in height could be determined.

Field personnel noted heights of area source emission on data sheets for later use in dispersion calculations. If possible, sampling heights were adjusted to be the same as the emission heights. The exponential expression used to determine the reduction from centerline concentration is:

$$\text{reduction factor}_z = \exp -\left[\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

where H = average vertical distance from plume centerline to samplers, m

Values of $\sigma_y$ and $\sigma_z$ are a function of downwind distance (x) and stability class. For the relatively short distances of x involved in sampling the mining operations, a linear relation between x (in meters) and $\sigma_y$ and a simple exponential variation between x and $\sigma_z$ were determined to be sufficiently accurate:[5,9]

$$\sigma_y = c(x + x_o) \quad \text{(eq.3)}$$

$$\sigma_z = a(x + x_o)^b \quad \text{(eq.4)}$$

Values for a, b, and c in equations 3 and 4 above are summarized in the table below. They were calculated from data on atmospheric dispersion (within 0.1 km of sources) that were presented in the User's Guide for HIWAY.[9]

| Stability class | a | b | c |
|---|---|---|---|
| A | 0.183 | 0.945 | 0.280 |
| B | 0.147 | 0.932 | 0.197 |
| C | 0.112 | 0.915 | 0.132 |
| D | 0.0856 | 0.870 | 0.086 |
| E | 0.0762 | 0.837 | 0.065 |
| F | 0.0552 | 0.816 | 0.042 |

The $x_o$ term in equations 3 and 4 is a virtual distance used to simulate the effect of the initial plume dispersion; it is calculated by substituting the estimated $\sigma_{yo}$ or $\sigma_{zo}$ value into the appropriate equation along with an x value of zero. The $\sigma_{yo}$ and $\sigma_{zo}$ values were obtained from visual observations of the plume's initial horizontal and vertical dispersion during each sampling period.

These estimates of horizontal and vertical dispersion were empirically determined for ground-level sources.

Studies of pollutant concentrations downwind of ground-level sources (mainly highways) have shown that Gaussian distributions can describe actual concentrations reasonably well within 100 meters of the source, but that model-predicted concentrations at these distances are quite sensitive to certain input data which may not be accurately measured:

- Initial plume dispersion, due to mechanical mixing of the air or uniform emission over an area
- Wind speed, which varies with height above ground level
- Estimated atmospheric stability, which may be locally affected by mechanical mixing or by plume buoyancy

There are also some reasons why particulate concentrations would deviate from a Gaussian distribution--primarily deposition and lack of reflection off the ground. However, many of these inaccuracies cancel out because the calculated emission rates are subsequently used in a Gaussian model to estimate ambient concentrations.

All field measurements were made in metric units so that conversions would not be necessary in order to use the dispersion equations.

STATISTICAL TESTS

Evaluation of variations in the emission rates calculated from separate downwind samples was of greatest interest in the statistical tests.

The first test planned was to compare emission rates determined from samplers at 1.2 m height with those at 2.4 m height to evaluate how well the actual plume followed the predicted Gaussian dispersion in the vertical plane. If the dispersion function is correct, there should not be any difference in values calculated from samples taken simultaneously at the two heights. The test to determine whether the measured difference is significant is the t-test, in which the paired data points are used to determine a t-value which is compared to standard limiting t-values for specified levels of significance:

$$t = \frac{\bar{d}}{\sigma_d \left(\frac{1}{n_1} + \frac{1}{n_2}\right)^{0.5}} \qquad \text{(eq.5)}$$

where d = the difference between two paired data points

$n_1 = n_2$ = number of data pairs

If the calculated t-value exceeds the standard value, the assumption that the difference is zero is rejected.

The second test evaluated changes in concentration with distance from the source. According to the particle deposition theory described in the following section of this chapter, apparent emission rates should decrease with distance from the source. The t-test can also be used to determine whether the measured reduction in emission rates is significant. Also, emission rates can be plotted versus distance to see if they match the theoretical fallout function; and observed fallout rates can be compared with particle sizes of material at different distances from the source by regression analysis to determine the correlation between these two parameters.

Finally, the relative variation in emission rates for different samples at one mine compared to emission rates for an operation in separate mines was evaluated. This evaluation determined whether a single emission factor should be developed for each operation or whether distinct emission factors should be developed for regional areas from the data for each mine. The test was accomplished by calculating standard deviations, as the measure of variation, for all the samples of an operation at a mine and for the average values determined for each mine.

FALLOUT FUNCTION

The deposition of small airborne particles has been investigated extensively and shown to be a function of ground-level particulate concentration and settling velocity.[10] The rate of deposition is best described numerically in terms of a source depletion factor ($Q_x/Q_o$), the ratio between the apparent emission rate ($Q_x$) at a distance x downwind and the initial emission rate ($Q_o$). Theoretical depletion factors for different stability classes are presented graphically in Figure 3-2.

The curves in Figure 3-2 are specific for a wind speed of 5 m/sec and particles with a settling velocity of 5 cm/sec. For other wind speeds or settling velocities, the source depletion factor from Figure 3-2 should be adjusted as follows:

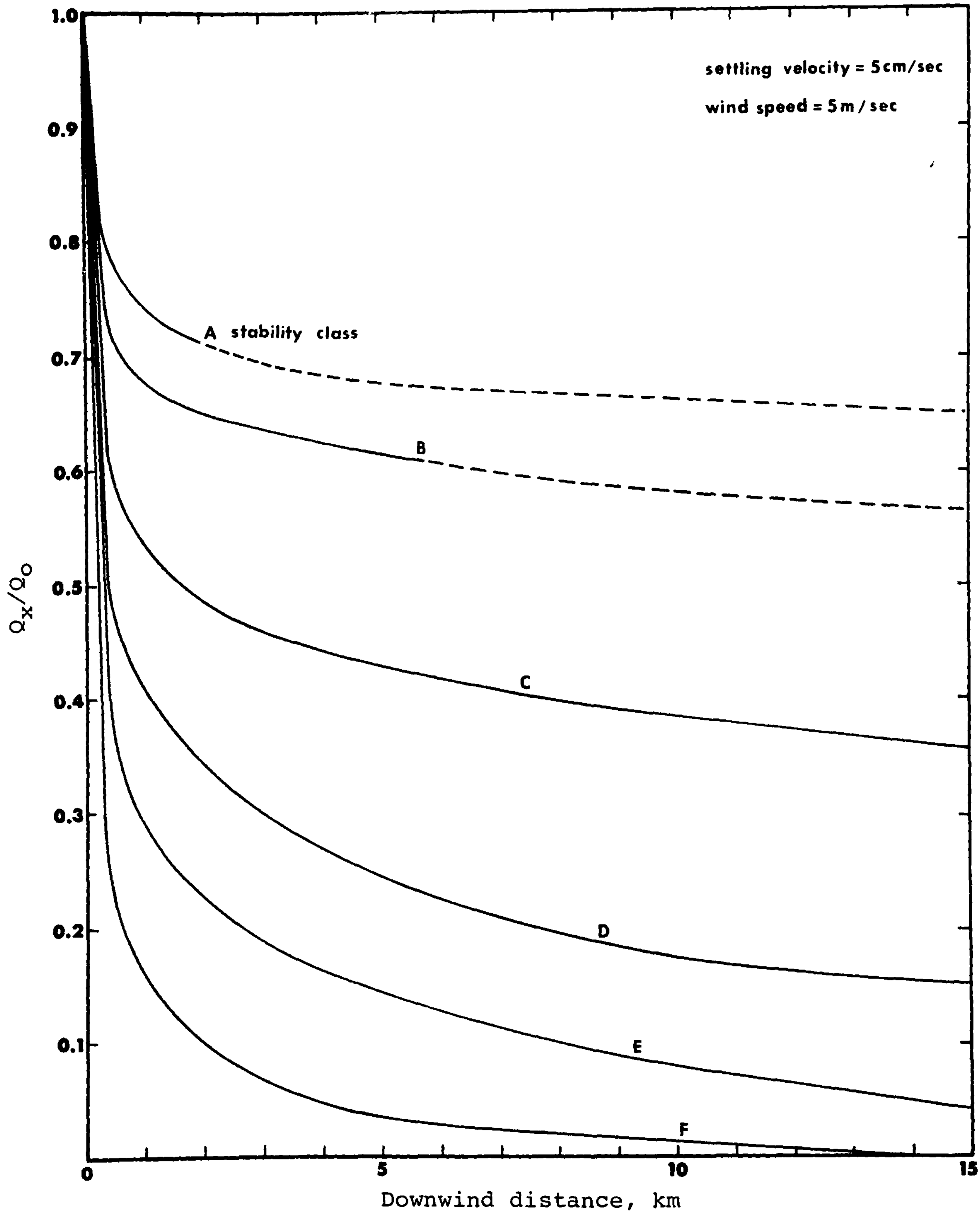



Figure 3-2. Source depletion factors by stability class for ground level sources.

Source: Meteorology and Atomic Energy. U.S. Atomic Energy Commission, Oak Ridge, Tennessee. Publication Number TID-24190. July 1968.

$$\left(\frac{Q_x}{Q_o}\right)_2 = \left(\frac{Q_x}{Q_o}\right)_1^{v_{d2}/u_2} \qquad \text{(eq.6)}$$

The deposition velocity ($v_d$) may be greater than the gravitational fall velocity ($v_g$) for the same size particles because it also includes such nongravitational removal mechanisms as surface impaction, electrostatic attraction, adsorption, and chemical interaction. The average $v_g$ for mining emissions, based on a mass median diameter of 22 u and an average density of 2.0 g/$cm^3$, would be about 3 cm/sec.[11] Therefore, a value of 5 cm/sec for $v_d$ appears to be appropriate for use unless specific test data produce an alternative value.

As can easily be seen from Figure 3-2, deposition may greatly reduce downwind air quality impact. For a neutral stability class (D) and an average wind speed of 5 cm/sec, only about 40 percent of initial emissions would remain in suspension 1.0 km downwind and only 17 percent at 10 km. Therefore, it is critical that fallout be considered in developing emission factors from downwind ambient particulate measurements.

The procedure used to determine fallout rates was to first plot calculated emission rates as a function of distance, then attempt to empirically define an average settling velocity ($v_d$) for the emissions. Next, initial emission rates ($Q_o$) were calculated from Figure 3-2 and equation 6 for apparent emission rates at all downwind distances. For each operation at a mine, the $Q_o$ values were averaged to arrive at an emission factor. In order to reduce the number of calculations, the $Q_x$ values at each distance were averaged before calculating $Q_o$ values. Averaging $Q_x$ values also smooths the plot of emission rate versus distance and permits the fallout rate to be determined more readily.

Emission factors developed on the basis of initial emission rates ($Q_o$) will absolutely require the use of some fallout function when they are subsequently applied in modeling air quality impact. This fallout function can easily be incorporated into computerized dispersion models. Its format is:

$$\frac{Q_x}{Q_o} = \exp\left[- \frac{a v_d \, x^b}{u}\right] \qquad \text{(eq.7)}$$

Where a, b = constants which are a function of stability class

$v_d$ = settling velocity, cm/sec (use 5.0 unless better data are available)

x = downwind distance, m

u = wind speed, m/sec

Constants for each stability class were obtained by curve fitting to approximate the curves shown in Figure 3-2. The resulting values are summarized below:

| Stability class | a | b |
|---|---|---|
| A | 0.120 | 0.14 |
| B | 0.135 | 0.15 |
| C | 0.183 | 0.18 |
| D | 0.115 | 0.30 |
| E | 0.160 | 0.30 |
| F | 0.114 | 0.40 |

For air quality analyses in which only regional scale modeling is required, the use of a fallout function may be avoided by using a reduced emission factor which already assumes a certain amount of fallout. Development of emission factors for use without a fallout function is discussed in Chapter 5.

It was previously mentioned that the equations used to estimate emissions assume perfect reflection of the plume after it strikes the ground. Probably, very little of a dust plume is actually reflected. However, by sampling at several different distances away from the source, this loss of source strength by impact with the ground is seen as part of the reduction in apparent emission rate with distance and is incorporated into the fallout function. This is one of the big advantages of sampling at several distances downwind rather than attempting to obtain a complete profile of the plume at only one downwind point.

## DATA VALIDATION

Data were eliminated at various times during the emission factor development process for several reasons, as indicated in Figure 3-1. In the field, a few samples were voided because of torn filters or excessive loadings. In addition, notes recorded on the field data sheets subsequently caused some samples to be eliminated because the samplers were not in the plume, the mining operation during the sampling period was atypical, the samplers were improperly placed relative to the source, or other sources severely interfered with sampling of the intended source.

After emission rates were calculated, some more data were eliminated as individual outliers or because apparent emission rates were shown to increase greatly with distance downwind of the source (indicative of unusual plume dispersion conditions or source interferences). Finally, some data were eliminated when initial emission rates were determined from downwind apparent emission rates because at some downwind distances there were only one or two data points; this would have overweighted these values and biased the resulting emission factor.

Negligible emission rates were included in determining average emission factors, unless they were eliminated for one of the above reasons.

The data which were dropped and reasons for their elimination are shown in the data summaries in the next chapter. A total of 20.5 percent of the original data was disqualified before being used to estimate emission factors. The bulk of this, 9.7 percent of the data, was samples from exposed areas where concentrations increased with downwind distance. Most of the remainder, 8.3 percent of the data, was eliminated due to problems with sampling noted on the field data sheets.

# 4. RESULTS

## CALCULATED EMISSION RATES

Emission rates were calculated from each of the downwind hi vol samples collected (approximately 1050), using the dispersion equations described in Chapter 3. The ambient concentrations for each sampling period are listed in Appendix B by operation and mine. Other data used in the dispersion equations, such as wind speed, stability class, initial plume dispersion, and background concentration, are presented by sampling period in Appendix C. These data were used to calculate the apparent emission rates summarized in Tables 4-1 through 4-7. The data are grouped by mining operation in these tables to facilitate comparisons.

Several background and downwind samples were also taken by the mining company at mine E. Either two or three samplers were placed in an arc at the same downwind distance during each sampling period. The emission rates calculated from these samples are not included in Tables 4-1 through 4-7, but they were used coequally with the data in these tables in developing emission factors. The mining company data are summarized below. Background samples taken by the company are incorporated in Appendix C.

| Operation | Sampling period | Downwind distance, m | Apparent emission rates | Units |
|---|---|---|---|---|
| Haul roads | 1 | 49 | 1.8, 2.4 | lb/veh-mi |
| | 3 | 49 | 2.7, 2.4 | |
| | 5 | 49 | 4.5, 4.8 | |
| | 7 | 49 | 1.7, 1.8 | |
| Overburden blasting | 1 | 177 | 18.0, 38.8 31.9 | lb/blast |
| Truck dump-coal | 1 | 44 | 1.6, 1.2, 0.7 | lb/truck |
| | 3 | 44 | 2.2, 2.2, 2.1 | |
| Overburden shovel | 1 | 142 | 8.5, 8.4 | lb/truck |
| | 3 | 142 | 4.4, 0.9, 0.7 | |
| | 5 | 142 | 8.7, 2.9 | |

Table 4-1. APPARENT EMISSION RATES FOR DRAGLINES

| Mine | Sampling period | Apparent emission rate, lb/bucketful | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | At 1.2 m ht | | | | At 2.4 m ht | | |
| | Dist | 30m | 40m | 50m | | 30m | 40m | 50m |
| A | 1 | .05 | .05 | .10 | | .07 | .08 | .08 |
| | 2 | .05 | .04 | .05 | | | | |
| | Dist | 40m | 50m | 60m | 70m | 50m | 60m | 70m |
| | 3 | | .01 | .02 | .02 | | | |
| | 4 | | .01 | .01 | .02 | .01 | .01 | .02 |
| | Dist | 40m | 50m | 60m | 70m | 40m | 50m | 60m |
| | 5 | .03 | | .03 | .04 | .02 | a | .02 |
| | 6 | .02 | | .01 | .03 | | | |
| | 7[b] | | | | | | | |
| | 8[b] | | | | | | | |
| | Dist | 50m | 65m | 80m | | 50m | 65m | 80m |
| B | 1 | 3.9 | 4.8 | 5.5 | | 4.1 | 1.0 | 7.2 |
| | 2 | 4.9 | 5.0 | 6.1 | | | | |
| | Dist | 70m | 80m | 90m | 100m | 70m | 80m | 90m |
| | 3 | 4.5 | 5.8 | 6.8 | | 1.3 | 4.7 | 6.5 |
| | 4 | 3.9 | 5.6 | 1.9 | | | | |
| | 5[c] | 1.9 | 5.8 | | 6.6 | | | |
| | 6[c] | 2.0 | 4.0 | | 7.1 | 1.8 | 4.0 | 5.3 |
| | 7 | 1.3 | 1.0 | 1.8 | | 1.5 | 1.3 | 1.1 |
| | 8 | 1.5 | 1.4 | 1.5 | 1.8 | | | |
| | 9 | 2.7 | .9 | 1.0 | 1.1 | | | |
| | 10 | .9 | .8 | .9 | | .6 | .9 | .8 |
| | Dist | 70m | 78.5m | 87m | 95.5m | 70m | 78.5m | 87m |
| C | 1 | .05 | .13 | .09 | | neg | .07 | .06 |
| | 2 | .02 | .05 | .09 | | | | |
| | 3 | .10 | .14 | .18 | | .03 | .01 | .10 |
| | 4 | .06 | .06 | .10 | .09 | | | |
| | 5 | .10 | .19 | .26 | | .22 | .11 | .18 |
| | 6 | .17 | .23 | .34 | .27 | | | |
| | Dist | 75m | 83.5m | 92m | 100m | 75m | 83.5m | 92m |
| D | 1 | .46 | .56 | .62 | .72 | | | |
| | 2 | .58 | .80 | .62 | | .97 | 1.02 | .92 |
| | 3 | .36 | .41 | .26 | .29 | | | |
| | 4 | .36 | .45 | .64 | | .41 | .47 | .93 |
| | 5 | .26 | .34 | .38 | .33 | | | |
| | 6 | .21 | .53 | .27 | .34 | | | |

[a] Filter lost.

[b] Samplers not in plume.

[c] Data not used to estimate emission factor because of large increases in apparent emission rates with distance.

## Table 4-2. APPARENT EMISSION RATES FOR HAUL ROADS

| Mine | Sampling period | Apparent emission rate, lb/VMT | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | At 1.2 m ht | | | | At 2.4 m ht | | |
| | Dist | 10m | 20m | 30m | 40m | 10m | 20m | 30m |
| A | 1 | 7.4 | 7.7 | 7.1 | | 3.9 | 6.0 | 6.8 |
| | 2 | 6.6 | 7.9 | 9.8 | | | | |
| | 3 | 2.8 | 3.8 | 4.5 | | | | |
| | 4 | 3.2 | 5.2 | 4.7 | | 1.9 | 2.8 | 2.9 |
| | 5 | 1.8 | 2.1 | 2.9 | | 2.0 | 1.3 | 1.9 |
| | 6 | 3.4 | 1.7 | 2.7 | | | | |
| | 7 | 6.8 | 4.9 | 6.4 | | | | |
| | 8 | 5.9 | 3.5 | 1.4 | | 3.9 | 3.4 | 3.1 |
| | 9 | 2.4 | 1.9 | 2.2 | | | | |
| | 10 | 1.7 | 1.4 | 1.8 | | 1.2 | 1.1 | 1.0 |
| B | 1[a] | 11.5 | 12.7 | 14.0 | 18.0[b] | | | |
| | 2[a] | 10.6 | 14.2 | 12.6 | | 8.5 | 9.9 | 8.7 |
| | 3[a] | 21.0 | 18.8 | 16.7 | 18.8[b] | | | |
| | 4[a] | 21.1 | 20.4 | 16.5 | | 13.0 | 12.2 | 11.6 |
| | 5 | 19.0 | 17.8 | c | 21.0[b] | | | |
| | 6 | 22.1 | 22.7 | 11.5 | | 11.1 | 9.7 | 8.5 |
| | 7 | 16.0 | 10.6 | 9.0 | 13.0[b] | | | |
| | 8 | 15.0 | 11.6 | 15.9 | | 6.5 | 7.9 | 9.6 |
| | 9 | 12.6 | 5.0 | 8.1 | 5.2 | | | |
| | 10 | 12.9 | 7.4 | 12.1 | | 5.0 | 3.9 | 6.1 |
| C | 1 | .9 | 2.2 | :7 | .4 | | | |
| | 2 | .9 | 2.5 | 1.9 | | .9 | .81 | .1 |
| | 3 | .3 | 1.2 | 1.7 | .7 | | | |
| | 4 | .5 | 1.9 | 2.4 | | .3 | .6 | 1.1 |
| | 5 | 1.0 | 2.7 | 2.6 | 2.4 | | | |
| | 6 | .9 | 2.8 | 4.4 | | .7 | 1.5 | 2.1 |
| | 7 | 3.5 | 4.1 | 4.4 | 3.6 | | | |
| | 8 | 3.2 | 5.3 | 4.0 | | 5.2 | 5.0 | 3.2 |
| | 9 | 2.7 | 4.6 | 4.8 | 5.7 | | | |
| | 10 | 2.8 | 6.1 | 3.4 | | 2.9 | 4.0 | 2.5 |
| | Dist | 5m | 13.5m | 22m | 30.5m | 5m | 13.5m | 22m |
| D | 1[d] | | | | | | | |
| | 2[d] | | | | | | | |
| | 3 | 10.6 | 10.6 | 14.7 | | 10.8 | 6.4 | 5.2 |
| | 4 | 7.8 | 12.3 | 10.4 | 19.5[e] | | | |
| | 5 | 7.5 | 8.4 | 6.6 | | 4.4 | 5.4 | 3.0 |
| | 6 | 7.2 | 8.4 | 10.7 | 8.5 | | | |
| | Dist | 5m | 12m | 19m | 26m | 5m | 12m | 19m |
| | 7 | 6.9 | 6.7 | 11.5 | | 6.0 | 6.1 | 8.7 |
| | 8 | 8.0 | 15.1 | 13.6 | 12.4 | | | |
| | 9 | 13.8 | 15.4 | 16.7 | | 13.9 | 15.6 | 7.5 |
| | Dist | 8.5m | 17m | 25.5m | 34m | 8.5m | 17m | 25.5m |
| E | 1[a] | 2.3 | 3.7 | 4.4 | | 1.6 | 2.7 | 3.4 |
| | 2[a] | 1.7 | 4.1 | 3.7 | 3.7 | | | |
| | 3[a] | 1.9 | 2.8 | 4.7 | | 1.6 | 2.5 | 2.3 |
| | 4 | 1.4 | 2.8 | 3.2 | 4.2 | | | |
| | 5 | 4.5 | 7.0 | 7.9 | | 4.1 | 4.9 | 5.7 |
| | 6 | 3.9 | 6.0 | 7.3 | 9.0 | | | |
| | 7 | .8 | 1.1 | 2.4 | | .8 | 1.5 | 2.0 |
| | 8 | .7 | 1.4 | 2.0 | 3.1 | | | |

[a] No watering.
[b] Insufficient sample set.
[c] Filter torn.
[d] Samplers not in plume.
[e] Data outlier--more than 3 std. dev. from mean.

Table 4-3. APPARENT EMISSION RATES FOR SHOVEL/TRUCK LOADING

| Mine | Sampling period | Apparent emission rate, lb/truck | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | At 1.2 m ht | | | | At 2.4 m ht | | |
| | Dist | 15m | 30m | 45m | 60m | 30m | 45m | 60m |
| A | 1 | | .06 | .17 | .12 | .07 | .09 | .12 |
| | 2 | | .09 | .10 | .10 | | | |
| | 3 | .18 | .13 | .12 | | | | |
| | Dist | 15m | 30m | 45m | | 15m | 30m | 45m |
| | 4 | .12 | .21 | .23 | | .19 | .19 | .19 |
| | 5 | 1.08 | .95 | 1.11 | | | | |
| | 6 | .89 | 1.33 | 1.76 | | | | |
| | Dist | 30m | 40m | 50m | 60m | 30m | 40m | 50m |
| B | 1 | .58 | .57 | .46 | .46 | | | |
| | 2 | .54 | .61 | .44 | | .47 | .52 | .43 |
| | 3 | .08 | .19 | .18 | | .16 | .14 | .15 |
| | 4 | .20 | .16 | .17 | .20 | | | |
| | 5[a] | | | | | | | |
| | 6[a] | | | | | | | |
| | Dist | 50m | 58.5m | 67m | 75.5m | 50m | 58.5m | 67m |
| C | 1 | .23 | .24 | .27 | | .20 | .22 | .16 |
| | 2 | .13 | .20 | .26 | .32[b] | | | |
| | 3 | .14 | .14 | .21 | | .07 | .09 | .13 |
| | 4 | .09 | .09 | .04 | .16[b] | | | |
| | Dist | 20m | 28.5m | 37m | 45.5m | 20m | 28.5m | 37m |
| E | 1 | .31 | .37 | .43 | | .27 | .20 | .13 |
| | 2 | .17 | .41 | .41 | .27 | | | |
| | 3 | .21 | .31 | .42 | | .20 | .28 | .33 |
| | 4 | .21 | .18 | .45 | .34 | | | |

[a] Samplers not in plume.

[b] Insufficient sample set.

Table 4-4. APPARENT EMISSION RATES FOR BLASTING

| Mine | Sampling period | Apparent emission rate, lb/blast At 1.2 m ht | | | | At 2.4 m ht | | |
|---|---|---|---|---|---|---|---|---|
| Coal blast | | | | | | | | |
| | Dist | 100m | 108.5m | 117m | 125.5m | 100m | 108.5m | 117m |
| B | 1[a] | | | | | | | |
| | 2[a] | | | | | | | |
| C | 1 | 17.8 | 17.7 | 19.5 | | 6.6[b] | 21.5 | 16.0 |
| | 2 | 17.1 | 20.5 | 17.4 | 18.5 | | | |
| D | 1 | 69.1 | 72.1 | 90.6 | | 37.6 | 44.4 | c |
| | 2 | 58.5 | 50.9 | 42.5 | 34.0 | | | |
| | Dist | 200m | 208.5m | 217m | | 200m | 208.5m | 217m |
| E | 1 | 45.3 | 46.0 | 32.2 | | 36.6 | 40.7 | 35.0 |
| | Dist | 100m | 108.5m | 117m | 125.5m | | | |
| | 2 | 24.2 | 33.9 | 24.6 | 30.1 | | | |
| Overburden blast | | | | | | | | |
| | Dist | 100m | 110m | 120m | | | | |
| A | 1 | 1323 | 849 | 559 | | | | |
| | Dist | 30m | 38.5m | 47m | 55.5m | 30m | 38.5m | 47m |
| C | 1 | 10.2 | 13.1 | 11.0 | 13.6 | | | |
| | 2 | 11.2 | 9.4 | 11.3 | | 8.8 | 6.0 | 9.5 |
| | Dist | 67m | 73m | 80m | 86m | 67m | 73m | 80m |
| E | 1 | 52.9 | 79.3 | 79.2 | 46.8 | | | |
| | 2 | 64.2 | 56.1 | 64.0 | | 20.4 | 23.3 | 18.0 |

[a] Improper sampling configuration--samplers on highwall above blast area.

[b] Inconsistent data point; removed as an outlier.

[c] Sampler malfunction.

Table 4-5. APPARENT EMISSION RATES FOR TRUCK DUMP

| Mine | Sampling period / Dist | Apparent emission rate, lb/truck: At 1.2 m ht | | | | At 2.4 m ht | | |
|---|---|---|---|---|---|---|---|---|
| | Dist | 10m | 20m | 30m | 40m | 10m | 20m | 30m |
| A | 1 | .32 | .36 | .55 | | | | |
| | 2 | .55 | .83 | .65 | | | | |
| | 3 | 1.33 | 1.44 | .73 | | | | |
| | 4 | .41 | .22 | .51 | | | | |
| | 5 | .33 | .30 | .45 | | | | |
| | 6 | .03 | .03 | .11 | | | | |
| B | 1 | 2.7 | 2.0 | 2.1 | 2.1 | | | |
| | 2 | 2.5 | 1.8 | 2.2 | | 2.7 | .90 | 1.7 |
| | Dist | 30m | 38.5m | 47m | 55.5m | 30m | 38.5m | 47m |
| C | 1[a] | | | | | | | |
| | 2[a] | | | | | | | |
| | 3 | .26 | .42 | .71 | | .02[b] | .41 | .35 |
| | 4 | .42 | .44 | .76 | .80[c] | | | |
| | Dist | 20m | 26m | 32m | 38m | 20m | 26m | 38m |
| D | 1 | 2.2 | 4.4 | 6.3 | 5.7 | | | |
| | 2 | .9 | 1.2 | 1.8 | | 1.8 | 2.1 | 2.0 |
| | 3[d] | 5.8 | 9.5 | 14.0 | | 7.8 | 9.4 | 7.2 |
| | 4[d] | 7.1 | 11.6 | 15.3 | 12.7 | | | |
| | 5 | 3.6 | 6.3 | 8.0 | 7.4 | | | |
| | 6 | 2.7 | 3.4 | 3.2 | | 2.1 | 3.3 | 4.0 |
| | Dist | 8.5m | 17m | 25.5m | 34m | 8.5m | 17m | 25.5m |
| E | 1 | .19 | .49 | .60 | | .20 | .45 | .61 |
| | 2 | .27 | .86 | .81 | 1.3[c] | | | |
| | 3 | .19 | .43 | .34 | | .25 | .31 | 1.7 |
| | 4 | .70 | .88 | 2.0 | 2.5[c] | | | |

[a] Samplers not in plume.

[b] Data outlier--more than 3 std. dev. away from mean.

[c] Insufficient sample set.

[d] Atypical operation (only two trucks in 80 minutes); not used to estimate emission factor.

Table 4-6. APPARENT EMISSION RATES FOR STORAGE PILE

| Mine | Sampling period | Apparent emission rate, lb/hr: At 1.2 m ht | | | | At 2.4 m ht | | |
|---|---|---|---|---|---|---|---|---|
| | Dist | 175m | 190m | 205m | | 175m | 190m | 205m |
| A | 1 | 17.7 | 33.1 | 25.4 | | 20.9 | 30.4 | 30.1 |
| | Dist | 30m | 40m | 50m | | 30m | 40m | 50m |
| | 2 | 9.3 | 5.4 | 10.8 | | 8.1 | 8.2 | 7.8 |
| | 3 | .2 | .7 | 1.2 | | 1.0 | .1 | 0 |
| | 4 | .9 | .9 | 1.4 | | 1.7 | .4 | 1.5 |
| | 5 | 21.3 | 14.5 | 20.3 | | 13.7 | 17.4 | 15.8 |
| | 6 | .4 | 2.1 | 0 | | .5 | 1.0 | 1.1 |
| | Dist | 25m | 40m | 55m | 70m | 25m | 40m | 55m |
| B | 1 | 64.5 | 105.7 | 133.0 | 161.4 | | | |
| | 2 | 88.5 | 100.7 | 95.0 | | 58.4 | 72.5 | 115.1 |
| | 3 | 63.6 | 58.5 | 69.3 | 97.2 | | | |
| | 4 | 41.7 | 57.9 | 75.9 | | 16.2 | 47.4 | 55.5 |
| | Dist | 35m | 45m | 55m | 65m | 35m | 45m | 55m |
| | 5 | 9.6 | 13.4 | 14.6 | 12.5 | | | |
| | 6 | 12.9 | 10.4 | 9.3 | | 6.0 | 10.7 | 7.8 |
| | Dist | 30m | 40m | 50m | 60m | 30m | 40m | 50m |
| | 7[a] | 50.3 | 79.9 | 97.6 | 113.0 | | | |
| | 8[a] | 43.0 | 41.7 | 91.5 | | 28.4 | 35.4 | 51.3 |
| | Dist | 60m | 70m | 80m | 90m | 60m | 70m | 80m |
| C | 1[a] | 50.6 | 52.8 | 106.3 | | 38.3 | 41.0 | 56.3 |
| | 2[a] | 250.9 | 322.2 | 444.4 | 554.1 | | | |
| | 3[a] | 147.3 | 169.9 | 173.4 | | 45.6 | 139.0 | 204.3 |
| | 4[a] | 62.7 | 25.2 | 160.0 | 130.7 | | | |
| | Dist | 25m | 33.5m | 42m | 50.5m | 25m | 33.5m | 42m |
| D | 1 | 2.8 | 1.5 | 5.0 | | 0 | 1.3 | 1.5 |
| | 2 | .8 | 2.1 | 1.9 | .2 | | | |
| | 3 | 3.1 | 3.5 | 6.9 | | 2.2 | 4.1 | 2.6 |
| | 4 | 4.3 | 5.8 | 6.4 | 0 | | | |

[a] Severe interference from other sources; not used in estimating emission factor.

## Table 4-7. APPARENT EMISSION RATES FOR MISCELLANEOUS OPERATIONS

| Mine | Sampling period | At 1.2 m ht | | | | At 2.4 m ht | | |
|---|---|---|---|---|---|---|---|---|
| **Coal drilling, lb/hole** | | | | | | | | |
| | Dist | 5m | 13.5m | 22m | 30.5m | 5m | 13.5m | 22m |
| E | 1 | .20 | .30 | .28 | .32[a] | | | |
| | 2 | .16 | .17 | .07 | | .55 | .04 | 0 |
| **Overburden drilling, lb/hole** | | | | | | | | |
| | Dist | 5.6m | 15m | 24.4m | 33.9m | 5.6m | 15m | 24.4m |
| A | 1[b] | | | | | | | |
| C | 1 | .004 | .41 | 1.4 | | 1.5 | .90 | 2.0 |
| | 2 | .13 | .86 | 3.6 | 7.2[a] | | | |
| **Overburden shovel, lb/truck** | | | | | | | | |
| | Dist | 20m | 25m | 30m | 35m | 20m | 25m | 30m |
| E | 1 | 2.6 | 1.5 | 2.2 | | 2.8 | 3.4 | 3.4 |
| | 2 | 2.5 | 4.2 | 5.0 | 7.0 | | | |
| | 3 | 1.0 | .94 | 1.0 | | .57 | .70 | 1.0 |
| | 4 | 1.0 | .82 | 1.8 | 1.6 | | | |
| | 5 | 1.9 | 1.6 | 1.5 | | 1.5 | 1.9 | 2.4 |
| | 6 | 2.1 | 2.6 | 5.7 | 5.3 | | | |
| **Fly-ash dump, lb/hr** | | | | | | | | |
| | Dist | 10m | 20m | 30m | | 10m | 20m | 30m |
| A | 1[c] | | | | | | | |
| | 2 | 3.7 | 4.7 | 4.7 | | | | |
| | 3 | 2.4 | 1.7 | 3.9 | | 2.1 | 1.8 | 3.6 |
| **Overburden dump, lb/truck** | | | | | | | | |
| | Dist | 15m | 20m | 25m | 30m | 15m | 20m | 25m |
| E | 1 | .29 | .22 | .27 | | .25 | .16 | .14 |
| | 2 | .23 | .17 | .26 | .45[a] | | | |
| | 3[b] | | | | | | | |
| | 4[b] | | | | | | | |
| **Train loading, lb/car** | | | | | | | | |
| | Dist | 12m | 20.5m | 29m | 37.5m | 12m | 20.5m | 29m |
| C | 1 | .025 | .004 | .027 | | .008 | .004 | .001 |
| | 2 | .006 | .016 | .014 | .004 | | | |
| | 3 | .024 | .014 | .045 | | .011 | .010 | .027 |
| | 4 | .010 | .014 | .012 | .016 | | | |
| E | 1[d] | | | | | | | |
| | 2[d] | | | | | | | |
| | 3[d] | | | | | | | |
| | 4[d] | | | | | | | |
| | 5[d] | | | | | | | |
| **Topsoil removal-scraper, lb/VMT** | | | | | | | | |
| | Dist | 30m | 34m | 38m | 42m | 30m | 34m | 38m |
| D | 1 | 75.3 | 110.4 | 81.3 | | 20.6 | 97.3 | 71.4 |
| | 2 | 368.9 | 176.2 | 438.7 | 554.7 | | | |
| | 3 | 731.2 | 767.8 | 1154.7 | | 357.8 | 480.5 | 536.7 |
| | 4 | 172.5 | 260.3 | 228.8 | 321.2 | | | |
| | 5 | 217.3 | 289.0 | 138.9 | 256.3 | | | |
| **Topsoil dumping-scraper, lb/VMT** | | | | | | | | |
| | Dist | 5m | 10m | 15m | 20m | 5m | 10m | 15m |
| D | 1 | 28.1 | 30.0 | 20.7 | 26.4 | | | |
| | 2 | 21.4 | 15.3 | 21.7 | | 5.5 | 23.3 | 17.9 |
| | 3 | 33.5 | 29.8 | 20.3 | 27.0 | | | |
| | 4 | 13.1 | 10.4 | 7.4 | | 22.1 | 15.6 | 11.9 |
| | 5 | 38.6 | 32.2 | 26.2 | 31.0 | | | |
| **Front-end loader, lb/bucket** | | | | | | | | |
| | Dist | 80m | 88m | 97m | 105m | | | |
| D | 1 | .4 | .6 | .8 | .7 | | | |

[a] Insufficient sample set. [b] Samplers out of plume.

[c] Severe interference from other sources.

[d] Data voided because of inadequate wind measurements, air turbulence near source and samplers, and excessive reentrained material.

Emission rates were not determined for one of the sources sampled--exposed areas. During most of the sampling periods, particulate concentrations increased with distance downwind from the edge of the source, as shown in Table 4-8. These values would have produced highly erratic emission rates at different distances. The increases in concentration with distance downwind are so consistent that they appear to be related to the way in which the plume is formed rather than to a sampling problem. Also, there is no obvious relationship between wind speed and measured downwind concentrations. In analyzing these data, no alternative method of estimating emissions from this source could be found.

Some variations in the indicated emission rates for each of the other operations would be expected. Specifically, it is anticipated that apparent emission rates would decrease with distance from the source as a result of fallout, because fallout is not considered in the basic dispersion equations. Also, emission rates would be expected to vary from mine to mine due to differences in soil type, equipment, climate, controls, etc. However, if concentrations are in fact in a Gaussian distribution about the plume centerline, there should not be any difference between emission rates calculated from the samplers at 1.2 m height and those at 2.4 m height.

These hypotheses were tested statistically. For 242 data sets where there were samples taken simultaneously at 1.2 and 2.4 m height, a higher emission rate was calculated at the 1.2 m sampler height on 173 occasions. The samplers at 1.2 m had emission rates that averaged 14 percent higher than the emission rates for the samplers at 2.4 m. Using a t-test, the difference in emission rates associated with the two groups of samplers was determined to be statistically significant at the 95 percent confidence level for three of the mining operations but not significant for three others.

Table 4-8. MEASURED CONCENTRATIONS DOWNWIND OF EXPOSED AREAS

| Mine | Sampling period | Downwind concentrations, ug/$m^3$ | | | | | | | Background concentration | Wind speed, m/sec |
|---|---|---|---|---|---|---|---|---|---|---|
| | | At 1.2 m ht | | | | At 2.4 m ht | | | | |
| | Dist | 10m | 20m | 30m | 40m | 10m | 20m | 30m | | |
| A | 1 | 103 | 253 | 171 | | | | | 64 | .8 |
| | 2 | 377 | 603 | 313 | | | | | 64 | 1.0 |
| | 3 | 423 | 322 | 347 | 349 | | | | 88 | .4 |
| | 4 | 490 | 240 | 338 | 297 | | | | 88 | .4 |
| B | 1 | 1376 | 1865 | 1979 | 2431 | | | | 84 | 7.2 |
| | 2 | 1480 | 1944 | 2139 | | 689 | 742 | 1111 | 84 | 7.2 |
| | 3 | 3846 | 4716 | 9309 | | 815 | 1325 | 1640 | 84 | 8.2 |
| | 4 | 4842 | 6199 | 6433 | 6407 | | | | 84 | 8.2 |
| | 5 | 1398 | 2310 | 2565 | | 398 | 850 | 991 | 84 | 7.5 |
| | 6 | 1602 | 2203 | 2446 | 2771 | | | | 84 | 7.5 |
| | Dist | Samplers within exposed area | | | | | | | | |
| C | 1 | 82 | 77 | 109 | | 120 | 32 | 74 | 32 | 2.2 |
| | 2 | 86 | 111 | 171 | 81 | | | | 32 | 2.2 |
| | 3 | 99 | 168 | 117 | 134 | | | | 32 | 2.2 |
| | 4 | 106 | 117 | 165 | | 64 | 42 | 117 | 32 | 2.2 |
| | Dist | 0m | 10m | 20m | 30m | 0m | 10m | 20m | | |
| D | 1 | 213 | 100 | 172 | 109 | | | | 87 | 5.7 |
| | 2 | 457 | 317 | 474 | | 429 | 409 | 1705 | 105 | 9.7 |
| | 3 | 598 | 567 | 270 | 559 | | | | 105 | 8.8 |
| E | 1 | | 298 | 143 | 228 | 91 | 74 | 110 | a | 4.8 |
| | 2 | 119 | 134 | 153 | 153 | | | | a | 4.8 |
| | 3 | 144 | 66 | 104 | | 98 | 105 | 66 | a | 6.2 |
| | 4 | 65 | 95 | 94 | 117 | | | | a | 6.2 |

[a] Wind reversal at start of sampling period; no upwind samplers.

The t-test values are shown in Table 4-9. These tests indicated some problems with the assumption of Gaussian distribution. Possible reasons for non-Gaussian plume dispersion near ground level might be variation in wind speed with height above ground or imperfect plume reflection off the ground.

FALLOUT RATES

A similar comparison of emission rates determined at two different distances from the source was made. For the 559 data sets in which emission rates were available for samples taken simultaneously at two consecutive distances and at the same height, the apparent emission rate decreased with distance on only 200. Contrary to expectations, emission rates increased an average of 19 percent when they were from a sampler that was 10 m further from the source. The t-tests indicated that these increases were significant (95 percent confidence level) for two of the six major mining operations, as shown in Table 4-9. These data do not support the fallout theory described in Chapter 3, which should have shown one to seven percent reductions in emission rates per 10 m interval and total reductions of about 10 percent between 10 and 40 m.

Curves of average emission rate versus distance are shown for the major operations in Figure 4-1. Only about half of these curves have negative slopes. Data for storage piles could not be included in this figure because emission rates varied so much with wind speed that average values were not meaningful.

Although the occurrence of fallout is not obvious from the sampling data, the large particle sizes of the material in the plumes would indicate that it is taking place. Mass median diameters for 67 samples taken on millipore filters and analyzed microscopically are shown in Table 4-10. The

Table 4-9. t-TEST VALUES FOR PAIRS OF EMISSION RATES

| Operation | No. of data pairs | Av difference in emission rate, 1.2 to 2.4 m | Av difference in emission rate, x to x+10 m | t-test value | t value at which diff is significant[a] |
|---|---|---|---|---|---|
| With height | | | | | |
| Dragline | 35 | -0.173 | | 0.77 | 2.03 |
| Haul roads | 67 | -2.518 | | 4.83 | 2.00 |
| Shovel/T ldg | 24 | -0.051 | | 2.36 | 2.06 |
| Blasting | 15 | -14.56 | | 2.35 | 2.13 |
| Truck dump | 21 | -0.159 | | 0.31 | 2.08 |
| Storage pile | 42 | -8.50 | | 1.89 | 2.02 |
| With distance | | | | | |
| Dragline | 86 | | 0.186 | 0.95 | 1.99 |
| Haul roads | 146 | | 0.215 | 0.79 | 1.98 |
| Shovel/T ldg | 58 | | 0.033 | 1.59 | 2.00 |
| Blasting | 38 | | -20.418 | 0.99 | 2.02 |
| Truck dump | 60 | | 0.480 | 2.02 | 2.00 |
| Storage pile | 73 | | 12.775 | 2.53 | 2.00 |

[a] 5 percent risk level.

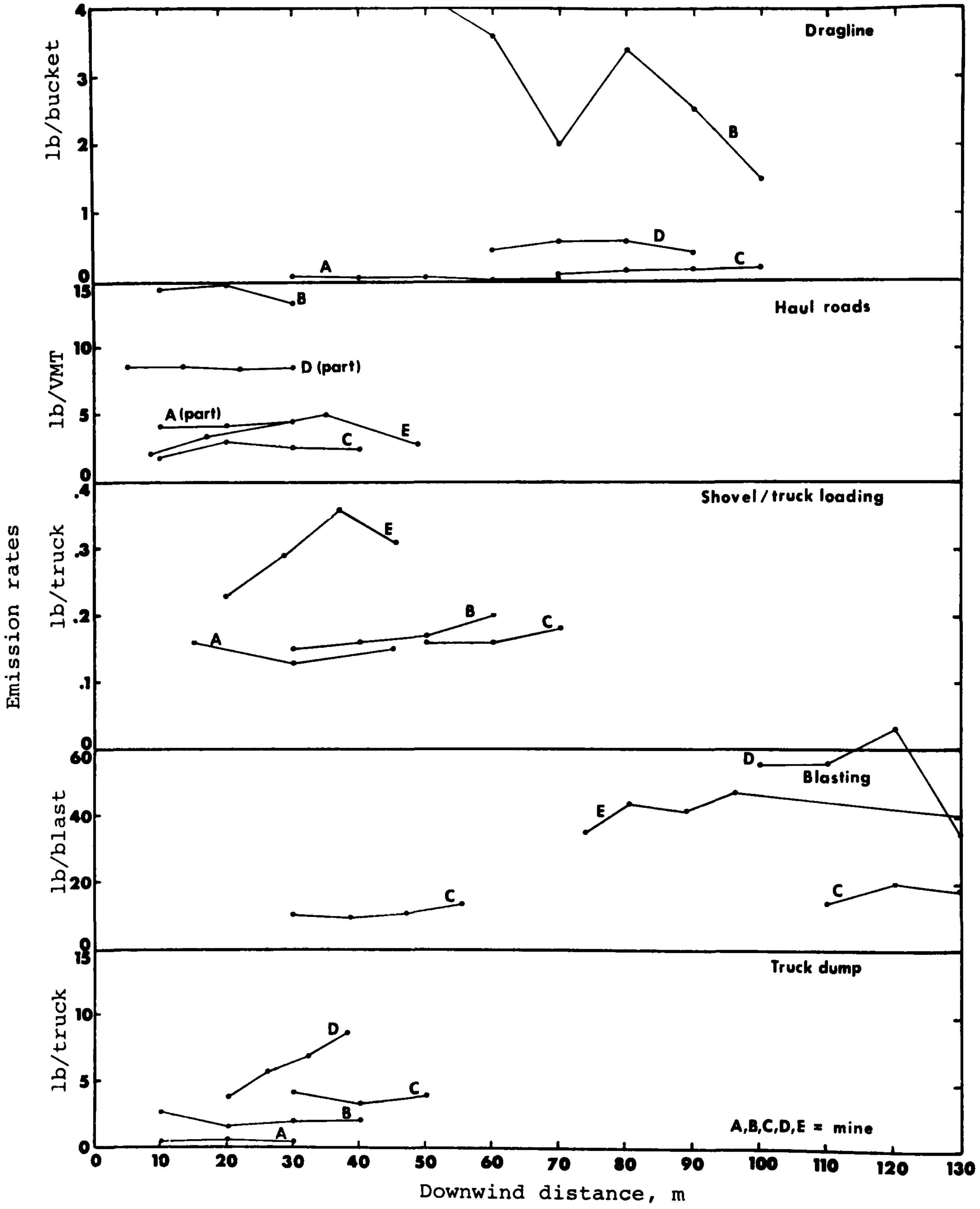



Figure 4-1. Average emission rates versus distance.

Table 4-10. MASS MEDIAN DIAMETERS OF DOWNWIND SAMPLES

| Operation | Sample | Distance, m | Median mass diameter, u | % by weight < 3u | Wind speed, mph |
|---|---|---|---|---|---|
| Dragline | B1[a] | 65 | 12.8 | .00 | 8 |
| | B2 | 80 | 11 | .00 | 13 |
| | B3 | 85 | 7.9 | 2.56 | 12 |
| | B8 | 80 | 9.2 | 1.08 | 13 |
| | B14 | 90 | 36 | .00 | 7 |
| | B15 | 90 | 35 | .07 | 8 |
| | C8 | 80 | 37 | .05 | 10 |
| | C9 | 80 | 18 | .00 | 8 |
| | D7 | 85 | 28.7 | .02 | 16 |
| | A5 | 105 | 25 | .00 | 1 |
| | A6 | 35 | 16.2 | .00 | 4 |
| | A17 | 60 | 26.5 | .00 | <1 |
| | A18 | 40 | 12 | .17 | <1 |
| | A19 | 50 | 15 | .22 | <1 |
| | A7 | 35 | 36 | .02 | 4 |
| | Average | | 22 | | |
| Haul roads | E6 | 20 | 16 | .03 | 8 |
| | E7 | 20 | 20 | .00 | 6 |
| | B4 | 30 | 26.5 | .15 | 8 |
| | B5 | 30 | 11 | .00 | 10 |
| | B6 | 30 | 47 | .00 | 14 |
| | B7 | 30 | 26 | .11 | 2 |
| | C1 | 30 | 35.5 | .00 | 6 |
| | C2 | 30 | 22 | .02 | 7 |
| | C3 | 20 | 36 | .00 | 8 |
| | C4 | 20 | 25 | .00 | 7 |
| | C5 | 20 | 33 | .00 | 6 |
| | D3 | 15 | 22 | .00 | 10 |
| | D4 | 15 | 17.4 | .24 | 9 |
| | A8 | 10 | 22 | .00 | <1 |
| | A9 | 10 | 13.5 | .34 | <1 |
| | A10 | 20 | 24.5 | .00 | <1 |
| | A11 | 30 | 12.4 | .00 | 1 |
| | A12 | 20 | 16.5 | .06 | 2 |
| | A13 | 20 | 27.5 | .11 | 4 |
| | Average | | 24 | | |
| Shovel/Truck loading | E1 | 20 | 44 | .12 | 6 |
| | E3 | 30 | 50 | .25 | 6 |
| | B9 | 50 | 9.4 | 1.57 | <1 |
| | B10 | 55 | 16.2 | .07 | 1 |
| | C12 | 60 | 24.6 | .10 | 6 |
| | A16 | 45 | 8.4 | 1.05 | 1 |
| | Average | | 25 | | |

[a] These sample numbers do not correspond with sampling periods.

Table 4-10 (continued). MASS MEDIAN DIAMETERS OF DOWNWIND SAMPLES

| Operation | Sample | Distance, m | Median mass diameter, u | % by weight < 3u | Wind speed, mph |
|---|---|---|---|---|---|
| Coal blast | C11 | 110 | 22.5 | .09 | 10 |
| Overburden shovel | E5 | 20 | 29 | .01 | 7 |
| Exposed areas | B12 | 40 | 13 | .05 | 18 |
| | B13 | 30 | 21.5 | .44 | 17 |
| | C13 | ? | 16 | .47 | 4 |
| | Average | | 17 | | |
| Truck dump | E2 | 10 | 11.7 | .90 | 7 |
| | E4 | 20 | 58 | .20 | 7 |
| | B11 | 30 | 17 | .27 | 8 |
| | C14 | 40 | 11.3 | .00 | 6 |
| | D1 | 30 | 32.5 | .00 | 8 |
| | D2 | 30 | 26 | .00 | 8 |
| | A1 | 20 | 13 | .03 | 1 |
| | A2 | 20 | 16 | .15 | 6 |
| | A3 | 20 | 20.8 | .07 | 2 |
| | A4 | 20 | 14 | .03 | 3 |
| | Average | | 22 | | |
| Overburden dump | E8 | 10 | 24.6 | .00 | 14 |
| Storage pile | B16 | 30 | 18.5 | .07 | 7 |
| | C6 | 60 | 14.5 | .45 | 12 |
| | D10 | 10 | 35.5 | .00 | 2 |
| | Average | | 23 | | |
| Fly-ash dump | A14 | 10 | 10.8 | .45 | 3 |
| | A15 | 60 | 12.4 | 1.14 | 9 |
| | Average | | 11 | | |
| Train loading | C10 | 25 | 28 | .02 | 10 |
| Topsoil removal | D5 | 30 | 28 | .04 | 14 |
| | D6 | ? | 29 | .11 | 20 |
| | Average | | 28 | | |

full size distributions for the 67 samples are shown in Appendix D; the laboratory analysis procedures are described in Appendix E. Differences in particle sizes for separate samples of the same operation were found to be greater than differences in particle sizes between operations. The uniformity of particle sizes for emissions from different sources is shown in the composite size distribution curves presented in Figure 4-2. Also, no reduction in average particle size with distance from the sources was noted with these data. Therefore, the particle size data do not provide any assistance in quantifying fallout rates.

A recent field study using the same sampling methods on better defined particulate line sources (highways) produced data which definitely demonstrated a reduction in apparent emission rate with distance.[6] The mass median diameter of the reentrained dust from streets was determined to be 15 u and the settling velocity ($v_d$) which best fit the sampling data was 5 cm/sec. Five cm/sec is a conservative estimate of the settling velocity of fugitive dust from coal mines, based on median particle size compared to that for reentrained dust from streets.

The subsequent data analyses in this report continue to assume that deposition of the larger particles is occurring, but that this fallout has been masked by the non-ideal sampling conditions (primarily reentrainment and source interferences) at the mines.

## EMISSION RATES AT DIFFERENT MINES

Variations in emission rates between mines were reviewed next. These variations were measured in terms of the standard deviations, expressed as a percent of the mean values, of the data sets. Standard deviations were determined at two levels: for all of the calculated emission rates for an operation at one mine, and for the average emission rates

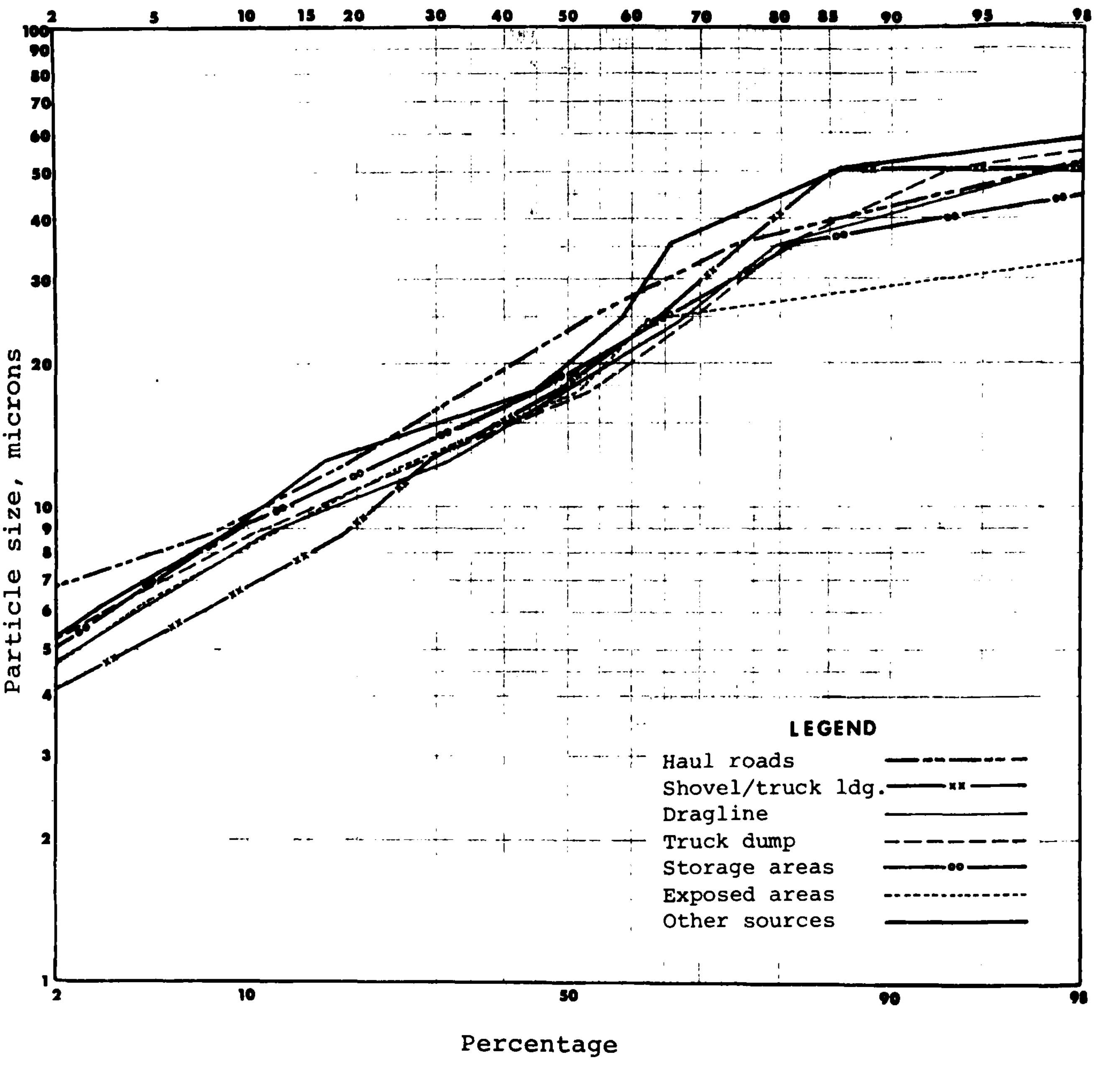



Figure 4-2. Composite size distribution curves for major mine emission sources

for an operation from all the mines. The resulting values are shown in Table 4-11. For all mining operations except shovel/truck loading, the emissions varied less between different sampling periods at one mine than they did between mines. In most cases, the standard deviation of the values for all mines was greater than the average emission rate, indicating substantial differences in the mine-to-mine emission rates. This finding adds support to the intent expressed earlier of reporting the emission factors separately for each mine rather than developing an average emission factor for each operation to be used at all Western mines.

The average emission rates at various downwind distances (most were previously shown in Figure 4-1) were combined with the fallout function described in Chapter 3 to calculate an average initial emission rate for each operation at each mine. These values are shown in Table 4-12.

Although the very wide variations in storage pile emission rates are not readily apparent from the data in Table 4-11, they were obvious early in the data analysis and were observed to be closely related to wind speed during the sampling period. Therefore, the calculated emission rates for individual sampling periods at a mine were not averaged to determine the emission factor for storage piles. Instead, an initial emission rate ($Q_o$) was calculated for each sampling period. The resulting values from all the mines were plotted against wind speed, as shown in Figure 4-3.

Although more than half the sampling periods had low wind speeds and emission rates, a linear relationship between these two parameters can be hypothesized. The 16 data points in Figure 4-3 have a linear regression correlation of 0.90. The slope of the line of best fit through the origin in 15.83:

Table 4-11. VARIATIONS IN CALCULATED EMISSION RATES

| | Standard deviation, as % of mean | | | | | |
|---|---|---|---|---|---|---|
| | All emission rates det'd from one mine | | | | | Av emission rates from |
| Operation | A | B | C | D | E | different mines |
| Dragline | 73 | 69 | 45 | 45 | | 154 |
| Haul road traffic | 60 | 39 | 66 | 40 | 60 | 71 |
| Shovel/Truck loading | 122 | 55 | 48 | | 33 | 32 |
| Blasting | 42 | | 32 | 34 | 43 | 171 |
| Truck dump | 76 | 26 | 39 | 68 | 73 | 121 |
| Storage pile | 113 | 68 | 89 | 74 | | 126 |
| Drilling | | | 91 | | 78 | 100 |

Table 4-12. INITIAL EMISSION RATES BY OPERATION AND MINE

| Operation | Mine | Av initial emission rate | Units | Conversion factor | Resulting units for emission factor |
|---|---|---|---|---|---|
| Dragline | A | 0.10 | lb/bucket | 18 $yd^3$/bkt | lb/$yd^3$ |
| | B | 4.0 | | 75 | |
| | C | 0.18 | | 60 | |
| | D | 0.66 | | 32 | |
| Haul roads | A | 6.8 | lb/veh-mi | - | lb/veh-mi |
| | B[a] | 17.0 | | | |
| | B | 13.6 | | | |
| | C | 3.3 | | | |
| | D | 11.2 | | | |
| | E | 4.3 | | | |
| Shovel/ Truck loading | A | 0.81 | lb/truck | 56 tn/trk | lb/ton |
| | B | 0.85 | | 120 | |
| | C | 0.24 | | 120 | |
| | E | 0.42 | | 120 | |
| Blasting | A[b] | 1694 | lb/blast | - | lb/blast |
| | C | 25.1 | | | |
| | C[b] | 14.2 | | | |
| | D | 78.1 | | | |
| | E | 72.4 | | | |
| | E[b] | 85.3 | | | |
| Truck dump | A | 0.8 | lb/truck | 56 tn/trk | lb/ton |
| | B | 2.5 | | 120 | |
| | C | 0.6 | | 120 | |
| | D | 4.9 | | 180 | |
| | E | 0.8 | | 120 | |
| | E[c] | 0.25 | | 120 | |
| Drilling | C | 1.5 | lb/hole | - | lb/hole |
| | E | 0.22 | | | |
| Fly-ash dump | A | 3.9 | lb/hr | - | lb/hr |
| Train loading | C | 0.016 | lb/car | 100 tn/car | lb/ton |
| Topsoil removal | D[d] | 385 | lb/veh-mi | 21 $yd^3$/ .02 mi | lb/$yd^3$ |
| | D | 30 | | | |
| Front-end loader | D | 1.18 | lb/scoop | 9.5 ton/scoop | lb/ton |

[a] No watering of roads during these sampling periods; watering during others.

[b] Blasting of overburden; other sampling periods are for coal blasting.

[c] Overburden dumping.

[d] Scraping mode; other emission rate is for dumping mode.

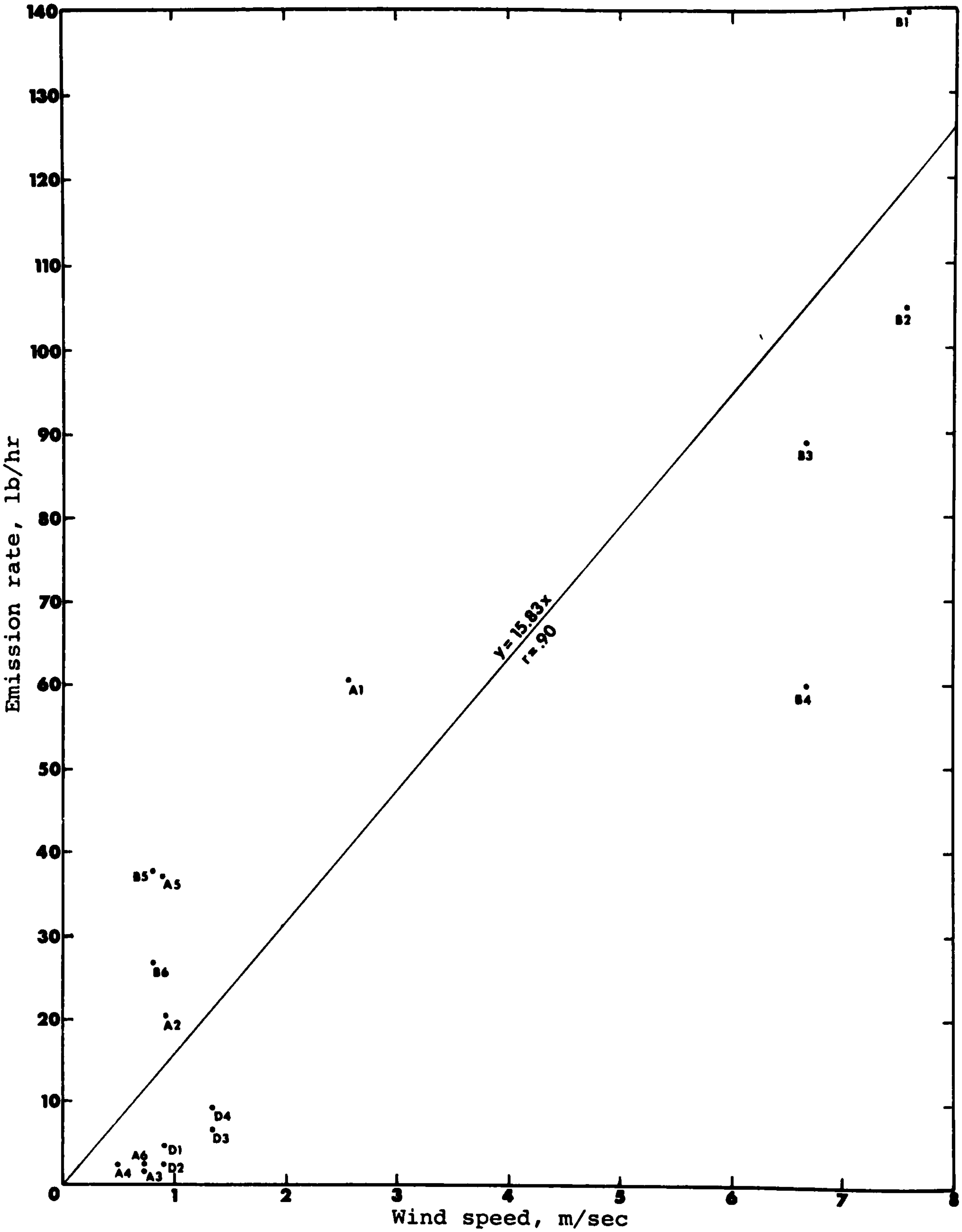



Figure 4-3. Emission rates from storage piles.

$$\text{emission rate, lb/hr} = 15.83\ u \qquad \text{(eq.8)}$$

where $u$ = average wind speed, m/sec

This emission rate includes emissions from equipment working the pile as well as from wind erosion. All three of the mines with data used in this analysis had storage piles with surface areas of about 10 acres. It is assumed that emissions would vary with the surface area of storage piles (for estimating emissions from piles of different sizes). Therefore, the emission factor for storage piles is expressed in lb/acre-hr:

$$\text{emission factor, lb/acre-hr} = 1.6\ u \qquad \text{(eq. 9)}$$

Because data from three of the mines were used to generate the general relationship, separate emission factors by geographic area cannot be developed.

# 5. EMISSION FACTORS FOR MINING OPERATIONS

Emission factors were determined from the initial emission rates presented in Table 4-12 by converting those values into equivalent ones in more applicable units. The resulting emission factors by operation and mine are shown in Table 5-1. *They are to be used only in conjunction with the fallout function described in Figure 3-2 and equation 7.*

For applications where fallout cannot be efficiently incorporated and where important air quality impacts all occur at greater than 5 km distance from the mining operations, other emission factors can be adapted for direct use. The following assumptions have been made for these regional scale emission factors:

- Minimum distance of impact = 5 km
- Average wind speed = 5.0 m/sec
- Average stability class = D

The resulting values are obtained by multiplying the factors in Table 5-1 by 0.24. Although the fraction of initial emissions remaining in suspension at distances greater than 5 km would be less than 0.24, additional deposition beyond that point is minimal (see Figure 3-2); this assumption represents a conservative estimate of a mine's ambient impact at long distances. For areas where the average annual wind speed is significantly different than 5.0 m/sec, the multiplier can be calculated as $0.24^{5/u}$. Emission factors for use without separate consideration of fallout are summarized in Table 5-2.

Table 5-1. EMISSION FACTORS FOR COAL MINING OPERATIONS (TO BE USED IN CONJUNCTION WITH A FALLOUT FUNCTION)

| Operation | Units | Mine A | Mine B | Mine C | Mine D | Mine E |
|---|---|---|---|---|---|---|
| Dragline | $lb/yd^3$ | .0056 | .053 | .0030 | .021 | |
| Haul roads | lb/veh-mi[a] | | | | | |
| w/watering | | 6.8 | 13.6 | 3.3[b] | | 4.3 |
| no watering | | | 17.0 | | 11.2 | |
| Shovel/Truck loading | lb/ton | | | | | |
| coal | | .014 | .007 | .002 | | .0035 |
| overburden | | | | | | .037 |
| Blasting | lb/blast | | | | | |
| coal | | | c | 25.1 | 78.1 | 72.4 |
| overburden | | 1690[d] | | 14.2 | | 85.3 |
| Exposed areas | | c | c | c | c | c |
| Truck dump | lb/ton | | | | | |
| bottom dump | | .014 | .020 | .005 | .027 | |
| end dump | | | | | | .007 |
| overburden | | | | | | .002[e] |
| Storage pile | lb/acre-hr | 1.6 u, where u is in m/sec | | | | |
| Drilling | lb/hole | | | | | |
| coal | | | | | | .22 |
| overburden | | c | | 1.5 | | |
| Fly-ash dump | lb/hr | 3.9 | | | | |
| Train loading | lb/ton | | | .0002 | | c |
| Topsoil removal | $lb/yd^3$ | | | | | |
| scraping | | | | | .35 | |
| dumping | | | | | .03 | |
| Front-end loader | lb/ton | | | | .12 | |

[a] Only veh-mi by haul trucks; travel by other vehicles on haul roads (pickup trucks, ANFO trucks) is incorporated into these values.

[b] Atypical watering conditions, probably minimum rather than average.

[c] Sampling was done for this operation, but no emission factor could be developed.

[d] Atypical blast, probably maximum rather than average.

[e] Not all emissions from overburden dumping.

Table 5-2. REGIONAL SCALE EMISSION FACTORS FOR COAL MINING OPERATIONS (NO FALLOUT FUNCTION REQUIRED)

| Operation | Units | Mine | | | | |
|---|---|---|---|---|---|---|
| | | A | B | C | D | E |
| Dragline | lb/yd$^3$ | .0013 | .013 | .0007 | .005 | |
| Haul roads | lb/veh-mi[a] | | | | | |
| w/watering | | 1.6 | 3.3 | .8[b] | | 1.0 |
| no watering | | | 4.1 | | 2.7 | |
| Shovel/Truck loading | lb/ton | | | | | |
| coal | | .003 | .002 | .0005 | | .0008 |
| overburden | | | | | | .009 |
| Blasting | lb/blast | | | | | |
| coal | | 406[c] | | 6.0 | 18.7 | 17.4 |
| overburden | | | | 3.4 | | 20.5 |
| Exposed areas | | | | | | |
| Truck dump | lb/ton | | | | | |
| bottom dump | | .003 | .005 | .001 | .006 | |
| end dump | | | | | | .002 |
| overburden | | | | | | .0005[d] |
| Storage pile | lb/acre-hr | 0.4 u, where u is in m/sec | | | | |
| Drilling | lb/hole | | | | | |
| coal | | | | | | .05 |
| overburden | | | | .4 | | |
| Fly-ash dump | lb/hr | .9 | | | | |
| Train loading | lb/ton | | | neg | | |
| Topsoil removal | lb/yd$^3$ | | | | | |
| scraping | | | | | .08 | |
| dumping | | | | | .01 | |
| Front-end loader | lb/ton | | | | .03 | |

[a] Only veh-mi by haul trucks; travel by other vehicles on haul roads (pickup trucks, ANFO trucks) is incorporated into these values.

[b] Atypical watering conditions, probably minimum rather than average.

[c] Maximum rather than average.

[d] Not all emissions from overburden dumping.

Using the above emission factors, total emissions from each operation at the five mines were calculated. The relative importance of the sources was approximately the same at each of the mines, with the haul road being the largest source and generally responsible for twice as many emissions as the next largest source. The general ranking of sources in descending order is:

Haul roads
Open storage pile
Dragline
Fly-ash dump (if present at mine)
Front end loader (if used for truck loading)
Topsoil removal
Blasting
Truck dump
Drilling
Shovel/Truck loading (unless also used for overburden; then second largest source)
Train loading

If emissions from exposed areas were included as a source, it would rank about fourth.

The emission factors were obtained from sampling during the summer, usually the driest time of year. However, emissions for many of the major operations are caused by mechanical breakdown of newly exposed material and are not highly dependent on surface moisture content or temperature. Also, operations such as topsoil removal are limited primarily to the summer months. Therefore, it is recommended that the factors for most operations be applied directly with annual activity data to calculate annual emissions, rather than attempting to adjust for seasonal differences in emission rates.

The exceptions to this recommendation are the two sources which are primarily caused by wind erosion and for which emission factors are in units of lb/hr--storage piles and fly ash dumps. For these two sources, annual emissions should be determined by multiplying the hourly rate by 24 and then by the number of days per year with no precipitation (>0.01 inch) or snow cover.

The source for which no emission factor could be developed, exposed areas, is a large enough source that some emission estimate should be included in coal mine analyses. A procedure for estimating emissions from this source, based on USDA's wind erosion equation, is presented in Appendix A to the EPA publication Development of Emission Factors for Fugitive Dust Sources.[3] For the soil and climatic conditions at the five mines sampled, this calculation procedure would indicate emission rates ranging from 0.4 to 1.0 ton/acre-yr.

For calculating maximum short-term concentrations near mines, the emission factors presented in Tables 5-1 or 5-2 would be used with peak activity rates. One point concerning prediction of maximum concentrations should be noted. With steady-state Gaussian models, maximum concentrations are predicted to occur at very low wind speeds. However, the fallout function also contains the wind speed parameter, so when fallout is incorporated into the model maximum concentrations no longer occur with very low winds (because particles settle out too quickly). As shown in Figure 5-1, maximum concentrations are predicted at wind speeds of about 2 m/sec with B stability, 3.5 m/sec with C stability, and 6 m/sec with D stability under the combined effects of dispersion and deposition.

The emission factors in Tables 5-1 or 5-2 can be used directly for mines with the same climatic conditions, soil types, and operating characteristics as any of the mines surveyed. The geographic locations of the five mines are:

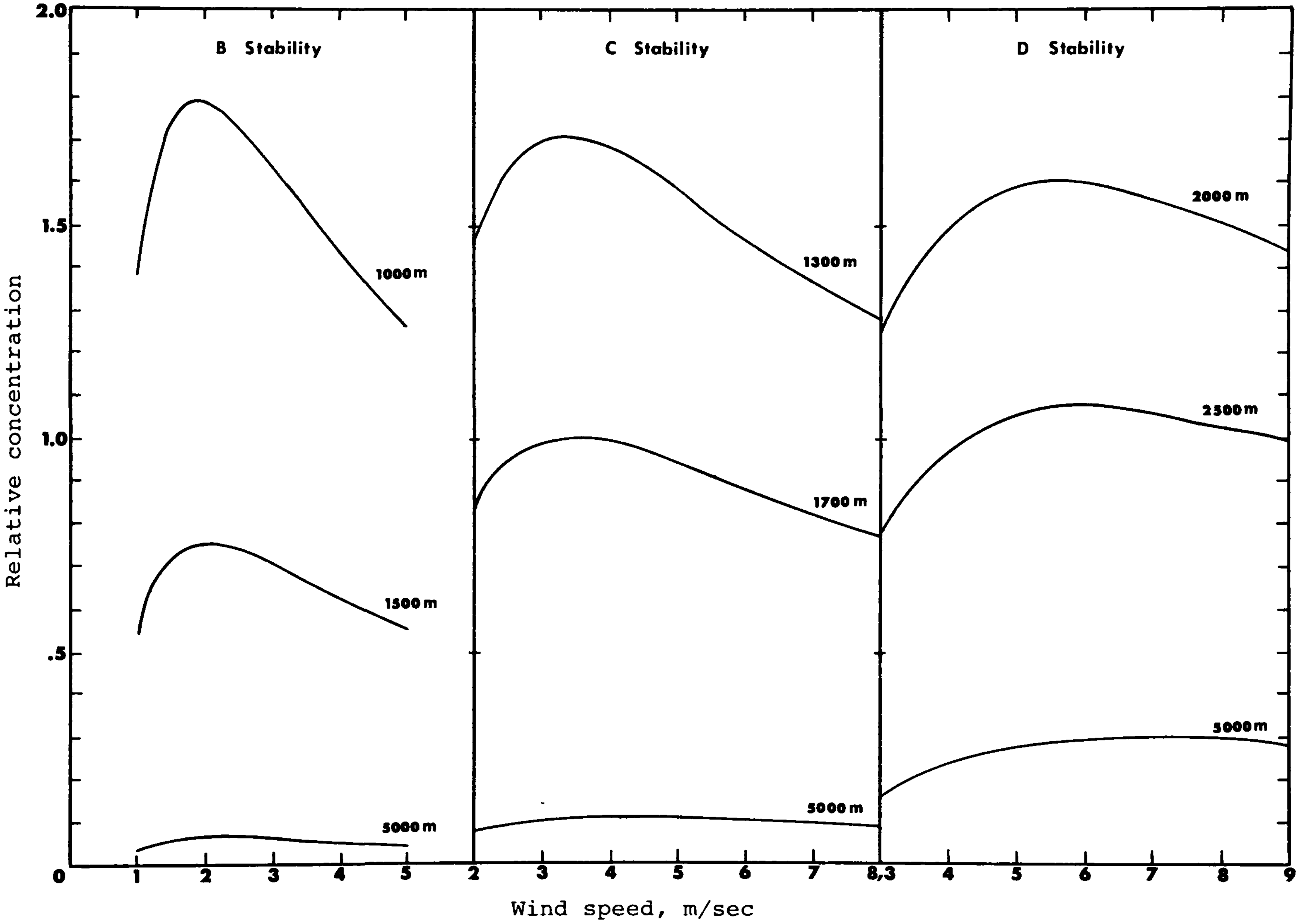



Figure 5-1. Predicted downwind concentrations as a function of wind speed.

| Mine | Area |
|---|---|
| A | Northwest Colorado |
| B | Southwest Wyoming |
| C | Southeast Montana |
| D | Central North Dakota |
| E | Northern Wyoming |

If no emission factor was developed for a particular mining operation in one of these five areas, a factor for the most similar other area or an average of the factors for the other areas should be used.

Sample calculations of annual emissions for a mine in Northwest Colorado are presented in Table 5-3.

For Western mining areas other than those which were sampled, the climate, geology, and operating characteristics should be compared with those of the five mines tested (see Tables 1-1 and A-1) to find the area most representative. Some arbitrary judgments may be involved, so the rationale for selection of appropriate emission factors should be documented. These factors are not meant to be used for Eastern or Midwestern surface coal mines.

There may be some situations in which very little information on the mining operations at a proposed mine is available, but a preliminary estimate of particulate emissions is needed for planning purposes. Also, it would be desirable to have an estimate of the degree of variation in total emissions between different mines. Therefore, total emissions per ton of coal mined were calculated for each of the five mines tested, using the mine-specific factors in Table 5-1 and corresponding operational data. The values obtained from that exercise are:

## Table 5-3. EXAMPLE CALCULATIONS OF ANNUAL EMISSIONS FROM A SURFACE COAL MINE

| Source | Activity rate | Emission factor | Emissions, lb/yr |
|---|---|---|---|
| Topsoil removal | 0.5 yd depth x 190,000 $yd^2$ surface area = 95,000 $yd^3$ | .35 $lb/yd^3$ + .03 $lb/yd^3$ | 36,100 |
| Overburden removal | 40 yd av depth x 190,000 $yd^2$ = 7,600,000 $yd^3$ | .0056 $lb/yd^3$ | 42,560 |
| Interburden removal (shovel/trk) | 15 yd av depth x 190,000 $yd^2$ x 2.2 $ton/yd^3$ = 6,270,000 ton | .037 (loading)+ .002 (dumping) | 244,530 |
| Coal loading (frt-end ldr) | 1,000,000 ton/yr | .12 lb/ton | 120,000 |
| Drilling | 512 holes/day x 260 days/yr = 133,120 holes/yr | .22 lb/hole for half, 1.5 lb/ hole for half | 114,480 |
| Blasting | 2/day x 260 days/yr | 58.5 lb/blast-obdn; 49.8 lb/ blast-coal | 28,160 |
| Haul roads (coal) | 10.0 mi/round trip x 40,000 trips/yr ($10^6$ ton ÷ 50 ton/truck) = 400,000 VMT/yr | 6.8 lb/VMT | 2,720,000 |
| Haul roads (inter-burden) | 2.2 mi/round trip x 125,400 trips/yr = 275,880 VMT/yr | 6.8 lb/VMT | 1,876,000 |
| Truck dump | 1,100,000 ton/yr | .014 lb/ton | 14,000 |
| Storage pile | enclosed storage (silos) | negligible | |
| Train ldg | 1,100,000 ton/yr | .0002 lb/ton | 200 |
| Fly ash dump | 275 day/yr w/no ppt x 24 hr/day | 3.9 lb/hr | 25,740 |
| <u>Other sources for which emission factors were not developed</u> | | | |
| Exposed areas | 142 acres | 1200 lb/acre-yr | 170,400 |
| Access road traffic | 41 veh/day x 6.0 mi/round trip x 314 days/yr = 76,752 VMT/yr | 4.4 lb/VMT | 337,700 |
| TOTAL | | | 5,729,870 (2865 ton/yr) |

| Mine | Particulate emissions, lb/ton of coal |
|---|---|
| A | 1.5 |
| B | 1.9 |
| C | 1.0 |
| D | 1.2 |
| E | 1.0 |

These estimates of emissions from the entire mines do not include point sources, such as crushers, or exposed areas. The range in emissions from lowest to highest (1.0 to 1.9) is a factor of slightly less than two. This amount of difference does not appear to preclude the use of an overall emission factor for providing a preliminary estimate. The median value of 1.2 lb/ton can be used for this purpose.

The sampling was all done with the mining operations being conducted in their routine manner. Therefore, there was little opportunity to compare the same operations being controlled and not being controlled. At mine B, watering of haul roads was done during some sampling periods but not during others; as indicated in Table 5-1, watering resulted in a 20 percent reduction in emission rates. The average emission rates from haul roads from all mines with consistent watering was 7.0 lb/veh-mi. For the two mines where no watering was done for extended periods, the average emission rate was 14.1 lb/veh-mi. By this method, watering is estimated to reduce emissions by 50 percent. The latter value compares well with other measurements of the effectiveness of watering reported in the literature.[11,12]

# 6. EVALUATION OF EMISSION FACTORS

## COMPARISON OF FACTORS FOR DIFFERENT MINES

One method of evaluating the emission factors presented in Table 5-1 is to compare factors derived for an operation at different mines and determine whether they have the same ranking (from highest to lowest emission rate) as they do on the basis of appearance. This method would not identify any procedural or systematic problems, but might point out non-representative values that resulted from sampling during a period with low wind speed, shortly after a rain, etc.

For the dragline operation, emissions from mine C may be too low. They appeared to be of the same magnitude as those from mines B and D and much greater than those from mine A, which has very rocky overburden.

Emissions from haul roads seem to be appropriate relative to one another. It was observed that watering may have been done more frequently than normal during the sampling periods at mine C.

The emission factor for shovel/truck loading at mine C also appears to be low in comparison with the factors at other mines. The single factor for shovel/truck loading of overburden obtained at mine E seems to be high in relation to the factors for loading of coal. Although overburden is normally dustier than coal, it probably does not produce 10 times as much dust using the same equipment, as would be indicated by the emission factors at mine E.

As noted in Table 5-1, the emission rate for blasting at mine A is not typical; it should be considered as a maximum rate rather than an average. The relative factors for blasting at the other mines all appear reasonable in relation to one another. Truck dumping and drilling, the remaining two mining operations for which emission factors were developed at more than one mine, both had apparently consistent factors at different mines.

## COMPARISON WITH PREVIOUS EMISSION FACTORS

In April 1976, a literature review was performed to identify emission estimates for mining operations.[1] In terms of total emissions from a coal mine, the values presented in that report are comparable to those in Table 5-1. However, the previous values were not intended to be used with a fallout function, so they would yield much higher ambient concentrations. Comparing the emission factors for individual mining operations, the previous estimates for dragline and coal loading were much higher than the new emission factors, truck dumping values were about the same, and the previous haul road estimates were much lower than the new factors:

| Operation | Previous emission estimate | New emission factor |
|---|---|---|
| Dragline | 0.0875 | .003-.053 $lb/yd^3$ |
| Haul roads | 0.8-2.2 | 3.3-17.0 lb/veh-mi |
| Shovel/Truck loading | 0.05 | .002-.014 lb/ton |
| Truck dump | 0.02 | .005-.027 lb/ton |

Subsequent to the above literature review, a study was performed to determine emission factors for lignite mining in North Dakota.[13] For two mines that were sampled for one month each, suspended particulate emission rates of 4.91 and 13.69 $g/sec/mi^2$ were determined. Using the emission factors in Table 5-1 for comparison, total initial mine emissions of

9.08 and 17.92 g/sec/$mi^2$ were calculated. The latter values do not include contributions from exposed areas or crushers. The factors in the present report produce slightly higher total mine emission rates than factors from the recent North Dakota report.

The recent North Dakota study also measured settleable particulate by means of dustfall jars. The calculated emission rates for settleable particulate indicated that suspended particulate at sampling distances of 1.5 to 6 km from the source was only 11 percent of total initial emissions. According to Figure 3-2, material remaining in suspension at these distances would be 25 to 50 percent of initial emissions (under the meteorological conditions at the time of the sampling).

COMPARISION WITH AMBIENT DATA

The most important evaluation of the emission factors is whether they result in the prediction of reasonable ambient particulate concentrations. Four mines were found for which there were operational data and extensive perimeter sampling at 1 to 6 km from the sources. The simple area source dispersion equation presented as equation 2 was used with the emission estimates to predict concentrations. This model was not expected to give extremely good estimates because it assumes that all the emissions are from a single area source and that the sampler is in the plume for the percent of time indicated by a wind rose.

The measured and predicted concentrations are shown in Table 6-1. The emission factors combined with the fallout function gave reasonably close predictions for about half of the sampling locations but predicted low for the other half. The underpredictions are apparently not related to the fallout function because all of the low values would still be

Table 6-1. COMPARISON OF MEASURED AND PREDICTED ANNUAL AVERAGE CONCENTRATIONS

| Mine location | Sampling site | Dist, mi | Stab class | u, m/sec | $\sigma_y$, m | $\sigma_z$, m | Q, g/sec | Time in plume | $\frac{Q_x}{Q_o}$ | Predicted conc, ug/$m^3$ | Measured arith mean, ug/$m^3$ | Measured conc minus backgrd, ug/$m^3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| North Dakota | 1 | 1.4 | D | 6.17 | 198 | 72 | 45.4 | .25 | .41 | 17 | 34 | 8.5 |
| | 2 | Within active mining area | | | | | | | | | | |
| | 3 | 1.7 | D | 7.38 | 235 | 84 | | .30 | .45 | 14 | 50 | 15 |
| | 4 | 3.7 | D | 6.57 | 512 | 165 | | .16 | .32 | 1.3 | 39 | 6.4 |
| North Dakota | 1 | Within active mining area | | | | | | | | | | |
| | 2 | 1.6 | D | 7.24 | 221 | 79 | 22.4 | .28 | .46 | 7.3 | 78 | 22 |
| | 3 | 3.0 | D | 7.60 | 415 | 137 | | .20 | .40 | 1.3 | 53 | 10 |
| | 4 | 1.9 | D | 6.66 | 263 | 92 | | .19 | .40 | 3.4 | 112 | 22 |
| Northern Wyoming | 1 | 2.2 | D | 5.36 | 314 | 108 | 26.5 | .33 | .30 | 4.6 | 26 | 6 |
| | 2 | 1.4 | D | 5.36 | 194 | 71 | | .41 | .36 | 17 | 96 | 76 |
| | 3 | 0.7 | D | 5.36 | 108 | 42 | | .46 | .41 | 65 | 117 | 87 |
| | 4 | 1.3 | D | 5.36 | 185 | 68 | | .37 | .36 | 17 | 41 | 21 |
| North-west Colorado | 1 | 1.1 | D | 4.0 | 156 | 59 | 11.2 | .14 | .28 | 3.8 | 47 | 31 |
| | 2 | Haul road adjacent to site | | | | | | | | | | |
| | 3 | 2.0 | D | 4.0 | 281 | 98 | | .13 | .22 | 1.0 | 32 | 16 |
| | 4 | 0.6 | D | 4.0 | 87 | 35 | | .67 | .32 | 63 | 63 | 47 |

n.a. = data not available

low even if the deposition factor ($Q_x/Q_o$) were removed. They could be due to sources for which emission estimates were not included, such as exposed areas, but more likely are caused by mining operations nearer than the centroid of the single area source that have a larger than predicted impact on measured concentrations.

ACCURACY OF EMISSION FACTORS

A technical manual describing the upwind-downwind sampling method concluded that emission rates could be determined within ±10 to ±50 percent of the actual rates with this method if a carefully designed sampling program including replicate samples, a range of operating conditions, and appropriate instrumentation were employed.[2] A brief sampling program without sample replication was estimated to provide data within a factor of two to five of actual emissions.

The average difference in emission rates of 14 percent for data from the two sampler heights was attributed to non-Gaussian plume dispersion. The resulting deviation from actual emission rates was probably less than this amount and was probably an overestimate because of the greater number of samples at the 1.2 m height.

Another indication of non-Gaussian dispersion was the increase in apparent emission rates with distance from the source. If this was caused by the vertical wind speed gradient hindering the plume from dispersing upward or by reentrainment, then all the predicted values would be too high. The magnitude of the overprediction would be at least the difference between the average rates at the nearest samplers and the average rates at all samplers, or about 20 percent.

The extrapolation of emission rates determined during the sampling periods to annual emissions probably did not bias the resulting values, as discussed in Chapter 5. If it did, it would have caused an overestimate of the annual emission rates.

The elimination of some data points during the data analysis steps tended to reduce the final emission factors because most of the data removed were higher than average values. Likewise, the incorporation of a fallout function even though the data did not demonstrate its occurrence resulted in lowering the regional scale emission factors and ambient concentrations predicted with the initial emission rates.

The comparisons with previous emission factors for surface coal mining operations and with ambient concentrations near mines indicated that the factors from the present study are either the right order of magnitude or too low.

Some of the above analyses indicated the emission factors might be higher than actual emission rates and some indicated they might be lower. Considering all of these evaluations, it is concluded that the factors are probably accurate within a factor of two except for those operations identified at the beginning of this chapter:

Dragline at mine C
Shovel/Truck loading at mine C
Shovel/Truck loading of overburden at mine E
Blasting at mine A

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# APPENDIX A

# MINING OPERATIONS AT THE MINES SAMPLED

Table A-1. CHARACTERISTICS OF THE COAL MINES SAMPLED

| Parameter | Required information | Units | Mine A | Mine B | Mine C | Mine D | Mine E[a] |
|---|---|---|---|---|---|---|---|
| Production rate | Coal mined | $10^6$ ton/yr | 1.13 | 5.0 | 9.5 | 3.8 | 12.0[b] |
| Coal transport | Av. unit train frequency | per day | n.a. | n.a. | 2 | n.a. | 2 |
| Stratigraphic data | Overburden thickness | ft | 21 | 80 | 90 | 65 | 35 |
| | Overburden density | lb/cuyd | 4000 | 3705 | 3000 | - | - |
| | Coal seam thickness | ft | 9,35 | 15,9 | 27 | 2,4,8 | 70 |
| | Parting thickness | ft | 50 | 15 | n.a. | 32,16 | n.a. |
| | Spoils bulking factor | % | 22 | 24 | 25 | 20 | - |
| | Active pit depth | ft | 52 | 100 | 114 | 80 | 105 |
| Coal analysis data | Moisture | % | 10 | 18 | 24 | 38 | 30 |
| | Ash | %, wet | 8 | 10 | 8 | 7 | 6 |
| | Sulfur | %, wet | .46 | .59 | .75 | .65 | .48 |
| | Heat content | Btu/lb | 11000 | 9632 | 8628 | 8500 | 8020 |
| Surface disposition | Total disturbed land | ac | 168 | 1030 | 2112 | 1975 | 217 |
| | Active pit | ac | 34 | 202 | 87 | - | 71 |
| | Spoils | ac | 57 | 326 | 144 | - | 100 |
| | Reclaimed | ac | 100 | 221 | 950 | - | 100 |
| | Barren land | ac | - | 30 | 455 | - | - |
| | Associated disturbances | ac | 12 | 186 | 476 | - | 46 |
| Storage | Capacity | ton | n.a. | n.a. | - | n.a. | 48000 |
| Blasting | Frequency, coal | per wk | 4 | 4 | 3 | 7 | 7[b] |
| | Frequency, overburden | per wk | 3 | .5 | 3 | n.a. | 7[b] |
| | Area blasted, coal | sq ft | 16000 | 40000 | - | 30000 | - |
| | Area blasted, overburden | sq ft | 20000 | - | - | n.a. | - |

[a] Based on 1974 data.

[b] Estimate.

Table A-2. MINING EQUIPMENT AT THE MINES SAMPLED

| Mine | No. | Major operating equipment |
|---|---|---|
| A | 1 | 770 Bucyrus-Erie dragline |
| | 1 | 650 Bucyrus-Erie dragline |
| | 2 | Cat 627 scrapers |
| | 2 | 7400 loaders |
| | 6 | Haul trucks 56 ton |
| | 6 | Tractors |
| | 2 | Overburden drills 40 yd |
| | 1 | D-4 coal drill |
| | 11 | Pick-ups |
| | 2 | Moter graders |
| | 1 | 988 front-end loader |
| | 2 | Water trucks 6000 gal |
| B | 10 | WABCO coal haulers 120 ton |
| | 4 | WABCO ash haulers 75 ton |
| | 3 | Cat 657 scrapers 44 cu yd |
| | 1 | Cat 633 scraper 34 cu yd |
| | 1 | Cat 641 water wgn 11000 gl |
| | 1 | WABCO 65C water wagon 11000 gal |
| | 1 | DAMCO 6000 rotary drill 150 ft/hr |
| | 1 | Auger drill 200 ft/hr |
| | 1 | Chicago Pneumatic T650W rotary drill |
| | 4 | Cat D9G dozers |
| | 2 | Cat D9H dozers |
| | 1 | Cat992 front-end loader 10 cu yd |
| | 1 | Michigan 380 dozer |
| | 1 | Cat 834 dozer |
| | 1 | Michigan 275 B cable reel |
| | 1 | Cat 16G patrol |
| | 1 | Cat 16H patrol |
| | 1 | Marion 8200 drgln 75 cu yd |
| | 1 | Page 732 dragline 20 cu yd |
| | 1 | B-E 60-R rotary drill 120 ft/hr |
| | 2 | B-E 195B pwr shvls 18 cuyd |
| C | 2 | Marion 8050 drgln 60 cu yd |
| | 1 | Marion 360 dragline |
| | 2 | B-E 550&280B coal shovels |
| | 1 | B-E 1050 stripping shovel |
| C | 6 | Cat D8/u dozers |
| | 2 | Cat D9/u dozers |
| | 2 | Cat D9/c dozers |
| | 3 | Cat 631-C tractor-scrapers |
| | 2 | Cat 980 front-end loaders |
| | 2 | Cat 992 front-end loaders |
| | 10 | Euclid CH120 coal haulers |
| | 3 | Cat 660 coal haulers |
| | 3 | Cat water tankers 8000 gal |
| | 1 | Cat water tanker 6000 gal |
| | 3 | Service trucks |
| | 2 | 14-6 Motor graders |
| | 2 | B-E 45R overburden drills |
| | 1 | Failing RB-2 coal drill |
| | 1 | B-E 60P blast hole drill |
| | 1 | Cat D-9 cushion pusher |
| | 1 | Ford 5000 farm tractor |
| D[a] | 1 | B-E 1250B dragline 32 cuyd |
| | 1 | Marion 181M shovel 17 cuyd |
| | 1 | B-E 85B shovel 5.5 cu yd |
| | 5 | Haul trucks 180 ton |
| | 4 | Euclid 24 TDT haul trk 60t |
| | 10 | Cat DW20 haul trucks 45 t |
| | 1 | Unit rig 196 ton |
| | 1 | HD-41 tractor dozer |
| | 2 | D-9 tractor dozers |
| | 2 | D-8 tractor dozers |
| | 1 | Paris 2-1/4" coal drill |
| | 1 | Cat 988 front-end loader 6.5 cu yd |
| | 1 | Water truck, 7,000 gal |
| E[a] | 2 | B-E 295B shovels 24 cu yd |
| | 2 | B-E 295B shovels 20 cu yd |
| | 5 | Dart diesel dump 75 ton |
| | 17 | End dump trucks 120 ton |
| | 8 | Lectrahaul trucks 120 ton |
| | 1 | Terex end dump trk 170 ton |
| | 3 | Michigan dozers |
| | 1 | Motor grader model 12 |
| | 1 | Coal drill |
| | 1 | Cat 988 front-end loader |
| | 2 | Water trucks 10,000 gal |

[a] Based on 1974 data.

# APPENDIX B

# DOWNWIND AMBIENT PARTICULATE CONCENTRATIONS

Table B-1. DOWNWIND PARTICULATE CONCENTRATIONS
MINE A

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Dragline | | | | |
| 1 | 30 | 5.0 | 5.5 | 1476 |
| | 40 | 5.0 | 8.9 | 825 |
| | 50 | 5.0 | 12.3 | 1376 |
| | 30 | 6.3 | 4.5 | 1324 |
| | 40 | 6.3 | 7.9 | 1247 |
| | 50 | 6.3 | 11.3 | 1020 |
| 2 | 30 | 5.0 | 3.5 | 1658 |
| | 40 | 5.0 | 6.9 | 1145 |
| | 50 | 5.0 | 10.3 | 1234 |
| 3 | 50 | 5.0 | 11.3 | 500 |
| | 60 | 5.0 | 16.7 | 303 |
| | 70 | 5.0 | 23.6 | 322 |
| 4 | 50 | 5.0 | 9.3 | 408 |
| | 60 | 5.0 | 14.7 | 337 |
| | 70 | 5.0 | 21.6 | 416 |
| | 50 | 6.3 | 10.3 | 466 |
| | 60 | 6.3 | 15.7 | 337 |
| | 70 | 6.3 | 22.6 | 305 |
| 5 | 40 | -3.0 | 3.0 | 954 |
| | 55 | -3.0 | 3.0 | 828 |
| | 70 | -3.0 | 3.0 | 1155 |
| | 40 | -1.8 | 2.0 | 795 |
| | 55 | -1.8 | 2.0 | 351 |
| 6 | 40 | -3.0 | 1.0 | 990 |
| | 55 | -3.0 | 1.0 | 569 |
| | 70 | -3.0 | 1.0 | 944 |
| 7 | 75 | 11.0 | 46.0 | 414 |
| | 90 | 11.0 | 55.0 | 272 |
| | 105 | 11.0 | 64.0 | 258 |
| | 75 | 12.2 | 45.0 | 174 |
| | 90 | 12.2 | 54.0 | 290 |
| | 105 | 12.2 | 63.0 | 334 |
| 8 | 75 | 11.0 | 46.0 | 38 |
| | 90 | 11.0 | 55.0 | 52 |
| | 105 | 11.0 | 64.0 | 83 |
| | 75 | 12.2 | 45.0 | 47 |
| | 90 | 12.2 | 54.0 | 0 |
| | 105 | 12.2 | 63.0 | 51 |

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Haul roads | | | | |
| 1 | 10 | -1.3 | | 1299 |
| | 20 | -1.3 | | 1130 |
| | 30 | -1.3 | | 855 |
| | 10 | -.1 | | 762 |
| | 20 | -.1 | | 872 |
| | 30 | -.1 | | 816 |
| 2 | 10 | -1.3 | | 1156 |
| | 20 | -1.6 | | 1036 |
| | 30 | -1.9 | | 1057 |
| 3 | 10 | -1.3 | | 596 |
| | 20 | -1.6 | | 601 |
| | 30 | -1.9 | | 588 |
| 4 | 10 | -1.3 | | 679 |
| | 20 | -1.6 | | 825 |
| | 30 | -1.9 | | 618 |
| | 10 | -.1 | | 454 |
| | 20 | -.4 | | 499 |
| | 30 | -.7 | | 425 |
| 5 | 10 | -2.5 | | 517 |
| | 20 | -2.5 | | 502 |
| | 30 | -2.5 | | 545 |
| | 10 | -1.3 | | 668 |
| | 20 | -1.3 | | 362 |
| | 30 | -1.3 | | 401 |
| 6 | 10 | -2.5 | | 992 |
| | 20 | -2.5 | | 420 |
| | 30 | -2.5 | | 506 |
| 7 | 10 | -2.5 | | 1330 |
| | 20 | -2.5 | | 812 |
| | 30 | -2.5 | | 870 |
| 8 | 10 | -2.5 | | 1170 |
| | 20 | -2.5 | | 579 |
| | 30 | -2.5 | | 196 |
| | 10 | -1.3 | | 896 |
| | 20 | -1.3 | | 638 |
| | 30 | -1.3 | | 468 |
| 9 | 14 | -2.5 | | 1024 |
| | 29 | -2.5 | | 661 |
| | 43 | -2.5 | | 607 |

Table B-1 (continued). DOWNWIND PARTICULATE CONCENTRATIONS MINE A

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Haul roads | | | | |
| 10 | 14 | -2.5 | | 734 |
| | 29 | -2.5 | | 497 |
| | 43 | -2.5 | | 488 |
| | 14 | -1.3 | | 589 |
| | 29 | -1.3 | | 416 |
| | 43 | -1.3 | | 296 |
| Drilling | | | | |
| 1 | 16 | .2 | a | 146 |
| | 26 | .2 | a | 292 |
| | 36 | .2 | a | 247 |
| | 16 | 1.4 | a | 29 |
| | 26 | 1.4 | a | 39 |
| | 36 | 1.4 | a | - |
| Shovel/Truck loading | | | | |
| 1 | 30 | -2.3 | -3.0 | 660 |
| | 45 | -2.3 | -3.0 | 1273 |
| | 60 | -2.3 | -3.0 | 583 |
| | 30 | -1.1 | -2.0 | 786 |
| | 45 | -1.1 | -2.0 | 643 |
| | 60 | -1.1 | -2.0 | 618 |
| 2 | 30 | -2.3 | -1.0 | 980 |
| | 45 | -2.3 | -1.0 | 705 |
| | 60 | -2.3 | -1.0 | 528 |
| 3 | 15 | -2.3 | -1.0 | 3104 |
| | 30 | -2.3 | -1.0 | 1217 |
| | 45 | -2.3 | -1.0 | 790 |
| 4 | 15 | -2.3 | -3.0 | 1786 |
| | 30 | -2.3 | -3.0 | 1965 |
| | 45 | -2.3 | -3.0 | 1477 |
| | 15 | -1.1 | -2.0 | 3528 |
| | 30 | -1.1 | -2.0 | 1916 |
| | 45 | -1.1 | -2.0 | 1227 |
| 5 | 16 | -2.3 | 0 | 4135 |
| | 26 | -2.3 | 0 | 2449 |
| | 36 | -2.3 | 0 | 1699 |
| | 46 | -2.3 | 0 | 1399 |
| 6 | 16 | -2.3 | 0 | 1940 |
| | 26 | -2.3 | 0 | 1474 |
| | 36 | -2.3 | 0 | 1562 |
| | 46 | -2.3 | 0 | 1268 |

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Overburden blast | | | | |
| 1 | 100 | -47.6 | 0 | 5340 |
| | 110 | -47.6 | 0 | 3222 |
| | 120 | -47.6 | 0 | 2002 |
| Exposed areas | | | | |
| 1 | 10 | 0 | | 40 |
| | 20 | 0 | | 190 |
| | 30 | 0 | | 108 |
| 2 | 10 | 0 | | 114 |
| | 20 | 0 | | 115 |
| | 30 | 0 | | 225 |
| 3 | 10 | 0 | | 335 |
| | 20 | 0 | | 234 |
| | 30 | 0 | | 259 |
| | 40 | 0 | | 261 |
| 4 | 10 | 0 | | 402 |
| | 20 | 0 | | 152 |
| | 30 | 0 | | 250 |
| | 40 | 0 | | 209 |
| Fly-ash dump | | | | |
| 1 | 50 | -.3 | 8.3 | 19013 |
| | 60 | -.3 | 8.3 | 25941 |
| | 70 | -.3 | 8.3 | 15745 |
| 2 | 10 | -.3 | 0 | 2936 |
| | 20 | -.3 | 0 | 2236 |
| | 30 | -.3 | 0 | 1522 |
| 3 | 10 | -.3 | 0 | 1872 |
| | 20 | -.3 | 0 | 832 |
| | 30 | -.3 | 0 | 1254 |
| | 10 | .9 | 0 | 1521 |
| | 20 | .9 | 0 | 843 |
| | 30 | .9 | 0 | 1184 |
| Truck dump | | | | |
| 1 | 10 | 0 | 4.0 | 7921 |
| | 20 | 0 | 4.0 | 5541 |
| | 30 | 0 | 4.0 | 5425 |
| 2 | 11 | 0 | 4.0 | 838 |
| | 22 | 0 | 4.0 | 654 |
| | 33 | 0 | 4.0 | 282 |
| 3 | 10 | 0 | 4.0 | 4203 |
| | 20 | 0 | 4.0 | 3333 |
| | 30 | 0 | 4.0 | 1188 |

[a] Samplers not in plume.

Table B-1 (continued). DOWNWIND PARTICULATE CONCENTRATIONS MINE A

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Truck dump | | | | |
| 4 | 10 | 0 | 4.0 | 6010 |
| | 20 | 0 | 4.0 | 2007 |
| | 30 | 0 | 4.0 | 2993 |
| 5 | 10 | 0 | 4.0 | 4365 |
| | 20 | 0 | 4.0 | 2462 |
| | 30 | 0 | 4.0 | 2353 |
| 6 | 10 | 0 | 4.0 | 581 |
| | 20 | 0 | 4.0 | 364 |
| | 30 | 0 | 4.0 | 795 |
| Storage pile | | | | |
| 1 | 175 | -11.3 | 0 | 186 |
| | 190 | -11.3 | 0 | 320 |
| | 205 | -11.3 | 0 | 227 |
| | 175 | -10.1 | 0 | 219 |
| | 190 | -10.1 | 0 | 294 |
| | 205 | -10.1 | 0 | 269 |
| 2 | 30 | -11.3 | 25.0 | 429 |
| | 40 | -11.3 | 25.0 | 250 |
| | 50 | -11.3 | 25.0 | 506 |
| | 30 | -10.1 | 25.0 | 426 |
| | 40 | -10.1 | 25.0 | 380 |
| | 50 | -10.1 | 25.0 | 363 |
| 3 | 30 | -11.3 | 25.0 | 13 |
| | 40 | -11.3 | 25.0 | 47 |
| | 50 | -11.3 | 25.0 | 83 |
| | 30 | -10.1 | 25.0 | 73 |
| | 40 | -10.1 | 25.0 | 9 |
| | 50 | -10.1 | 25.0 | - |
| 4 | 33 | -11.3 | 25.0 | 81 |
| | 44 | -11.3 | 25.0 | 81 |
| | 56 | -11.3 | 25.0 | 118 |
| | 33 | -10.1 | 25.0 | 170 |
| | 44 | -10.1 | 25.0 | 39 |
| | 56 | -10.1 | 25.0 | 135 |
| 5 | 50 | -11.3 | 25.0 | 584 |
| | 67 | -11.3 | 25.0 | 373 |
| | 83 | -11.3 | 25.0 | 445 |
| | 50 | -10.1 | 25.0 | 431 |
| | 67 | -10.1 | 25.0 | 448 |
| | 83 | -10.1 | 25.0 | 389 |
| Storage pile | | | | |
| 6 | 30 | -11.3 | 25.0 | 19 |
| | 40 | -11.3 | 25.0 | 105 |
| | 50 | -11.3 | 25.0 | - |
| | 30 | -10.1 | 25.0 | 29 |
| | 40 | -10.1 | 25.0 | 53 |
| | 50 | -10.1 | 25.0 | 55 |

Table B-2.DOWNWIND PARTICULATE CONCENTRATIONS
MINE B

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Dragline | | | | |
| 1 | 50 | -1.3 | 0 | 20154 |
| | 65 | -1.3 | 0 | 18010 |
| | 80 | -1.3 | 0 | 15633 |
| | 50 | -.1 | 0 | 21087 |
| | 65 | -.1 | 0 | 3935 |
| | 80 | -.1 | 0 | 20542 |
| 2 | 50 | -1.3 | 0 | 24846 |
| | 65 | -1.3 | 0 | 19034 |
| | 80 | -1.3 | 0 | 17520 |
| 3 | 70 | -1.3 | 0 | 23216 |
| | 80 | -1.3 | 0 | 27025 |
| | 90 | -1.3 | 0 | 26753 |
| | 70 | -.1 | 0 | 7429 |
| | 80 | -.1 | 0 | 22000 |
| | 90 | -.1 | 0 | 25867 |
| 4 | 70 | -1.3 | 0 | 21860 |
| | 80 | -1.3 | 0 | 26017 |
| | 90 | -1.3 | 0 | 7476 |
| 5 | 70 | -1.3 | 0 | 7594 |
| | 85 | -1.3 | 0 | 18664 |
| | 100 | -1.3 | 0 | 17497 |
| 6 | 70 | -1.3 | 0 | 7722 |
| | 85 | -1.3 | 0 | 12809 |
| | 100 | -1.3 | 0 | 18765 |
| | 70 | -.1 | 0 | 7197 |
| | 85 | -.1 | 0 | 12686 |
| | 100 | -.1 | 0 | 14131 |
| 7 | 70 | -3.8 | 0 | 5184 |
| | 80 | -3.8 | 0 | 3304 |
| | 90 | -3.8 | 0 | 5222 |
| | 70 | -2.6 | 0 | 6564 |
| | 80 | -2.6 | 0 | 4899 |
| | 90 | -2.6 | 0 | 3681 |
| 8 | 70 | -3.8 | 0 | 5848 |
| | 80 | -3.8 | 0 | 4574 |
| | 90 | -3.8 | 0 | 4449 |
| | 100 | -3.8 | 0 | 4769 |
| 9 | 70 | -3.8 | 0 | 12853 |
| | 80 | -3.8 | 0 | 3499 |
| | 90 | -3.8 | 0 | 3509 |
| | 100 | -3.8 | 0 | 3619 |
| Dragline | | | | |
| 10 | 70 | -3.8 | 0 | 4393 |
| | 80 | -3.8 | 0 | 3266 |
| | 90 | -3.8 | 0 | 3396 |
| | 70 | -2.6 | 0 | 3090 |
| | 80 | -2.6 | 0 | 3982 |
| | 90 | -2.6 | 0 | 3180 |
| Haul roads | | | | |
| 1 | 10 | -1.5 | | 1920 |
| | 20 | -1.5 | | 1829 |
| | 30 | -1.5 | | 1670 |
| | 40 | -1.5 | | 1798 |
| 2 | 10 | -1.5 | | 1767 |
| | 20 | -1.5 | | 2034 |
| | 30 | -1.5 | | 1504 |
| | 10 | -.3 | | 1773 |
| | 20 | -.3 | | 1584 |
| | 30 | -.3 | | 1156 |
| 3 | 10 | -1.5 | | 3022 |
| | 20 | -1.5 | | 2321 |
| | 30 | -1.5 | | 1720 |
| | 40 | -1.5 | | 1617 |
| 4 | 10 | -1.5 | | 3034 |
| | 20 | -1.5 | | 2516 |
| | 30 | -1.5 | | 1689 |
| | 10 | -.3 | | 2336 |
| | 20 | -.3 | | 1681 |
| | 30 | -.3 | | 1318 |
| 5 | 10 | -1.5 | | 1938 |
| | 20 | -1.5 | | 1679 |
| | 30 | -1.5 | | void |
| | 40 | -1.5 | | 1542 |
| 6 | 10 | -1.5 | | 2254 |
| | 20 | -1.5 | | 2140 |
| | 30 | -1.5 | | 947 |
| | 10 | -.3 | | 1414 |
| | 20 | -.3 | | 1019 |
| | 30 | -.3 | | 786 |
| 7 | 10 | -.8 | | 1518 |
| | 20 | -.8 | | 738 |
| | 30 | -.8 | | 491 |
| | 40 | -.8 | | 597 |

Table B-2 (continued). DOWNWIND PARTICULATE CONCENTRATIONS MINE B

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Haul roads | | | | |
| 8 | 10 | -.8 | | 1427 |
| | 20 | -.8 | | 808 |
| | 30 | -.8 | | 871 |
| | 10 | .4 | | 617 |
| | 20 | .4 | | 548 |
| | 30 | .4 | | 524 |
| 9 | 14 | -.8 | | 858 |
| | 29 | -.8 | | 238 |
| | 43 | -.8 | | 298 |
| | 57 | -.8 | | 156 |
| 10 | 14 | -.8 | | 879 |
| | 29 | -.8 | | 356 |
| | 43 | -.8 | | 443 |
| | 14 | .4 | | 345 |
| | 29 | .4 | | 185 |
| | 43 | .4 | | 224 |
| Shovel/Truck loading | | | | |
| 1 | 35 | -2.8 | 3.5 | 5276 |
| | 45 | -2.8 | 3.5 | 3706 |
| | 55 | -2.8 | 3.5 | 2766 |
| | 65 | -2.8 | 3.5 | 2149 |
| 2 | 35 | -2.8 | 3.5 | 4924 |
| | 45 | -2.8 | 3.5 | 3910 |
| | 55 | -2.8 | 3.5 | 2662 |
| | 35 | -1.6 | 3.5 | 4763 |
| | 45 | -1.6 | 3.5 | 3712 |
| | 55 | -1.6 | 3.5 | 2576 |
| 3 | 30 | -2.8 | 3.5 | 1449 |
| | 40 | -2.8 | 3.5 | 2607 |
| | 50 | -2.8 | 3.5 | 2185 |
| | 30 | -1.6 | 3.5 | 3337 |
| | 40 | -1.6 | 3.5 | 2194 |
| | 50 | -1.6 | 3.5 | 1806 |
| 4 | 30 | -2.8 | 3.5 | 3907 |
| | 40 | -2.8 | 3.5 | 2223 |
| | 50 | -2.8 | 3.5 | 2096 |
| | 60 | -2.8 | 3.5 | 1859 |
| 5 | 40 | 1.7 | a | 1569 |
| | 50 | 1.7 | a | 2351 |
| | 60 | 1.7 | a | 1743 |
| | 40 | 2.9 | a | 1470 |
| | 50 | 2.9 | a | 554 |
| | 60 | 2.9 | a | 1466 |

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Shovel/Truck loading | | | | |
| 6 | 40 | 1.7 | a | 1739 |
| | 50 | 1.7 | a | 1410 |
| | 60 | 1.7 | a | 2450 |
| | 70 | 1.7 | a | 1516 |
| Coal blast | | | | |
| 1 | 11 | 0 | 0 | - |
| | 22 | 0 | 0 | 66611 |
| | 33 | 0 | 0 | 76174 |
| | 11 | 0 | 0 | 5448 |
| | 22 | 0 | 0 | 50274 |
| | 33 | 0 | 0 | 67913 |
| 2 | 11 | 0 | 0 | 59125 |
| | 22 | 0 | 0 | 67093 |
| | 33 | 0 | 0 | 74570 |
| Exposed areas | | | | |
| 1 | 10 | 0 | | 1292 |
| | 20 | 0 | | 1781 |
| | 30 | 0 | | 1895 |
| | 40 | 0 | | 2347 |
| 2 | 10 | 0 | | 1396 |
| | 20 | 0 | | 1860 |
| | 30 | 0 | | 2055 |
| | 10 | 0 | | 605 |
| | 20 | 0 | | 658 |
| | 30 | 0 | | 1027 |
| 3 | 10 | 0 | | 3762 |
| | 20 | 0 | | 4632 |
| | 30 | 0 | | 9225 |
| | 10 | 0 | | 731 |
| | 20 | 0 | | 1241 |
| | 30 | 0 | | 1556 |
| 4 | 10 | 0 | | 4758 |
| | 20 | 0 | | 6115 |
| | 30 | 0 | | 6349 |
| | 40 | 0 | | 6323 |
| 5 | 10 | 0 | | 1314 |
| | 20 | 0 | | 2226 |
| | 30 | 0 | | 2481 |
| | 10 | 0 | | 314 |
| | 20 | 0 | | 766 |
| | 30 | 0 | | 907 |

[a] Samplers not in plume.

Table B-2 (continued). DOWNWIND PARTICULATE CONCENTRATIONS MINE B

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Exposed areas | | | | |
| 6 | 10 | 0 | | 1518 |
| | 20 | 0 | | 2119 |
| | 30 | 0 | | 2362 |
| | 40 | 0 | | 2687 |
| Truck dump | | | | |
| 1 | 10 | -.3 | -2.0 | 30821 |
| | 20 | -.3 | -2.0 | 14902 |
| | 30 | -.3 | -2.0 | 10901 |
| | 40 | -.3 | -2.0 | 7622 |
| 2 | 10 | -.3 | -2.0 | 28886 |
| | 20 | -.3 | -2.0 | 13489 |
| | 30 | -.3 | -2.0 | 11360 |
| | 10 | .9 | -2.0 | 28440 |
| | 20 | .9 | -2.0 | 6601 |
| | 30 | .9 | -2.0 | 8730 |
| Storage pile | | | | |
| 1 | 25 | -.3 | 0 | 11484 |
| | 40 | -.3 | 0 | 13722 |
| | 55 | -.3 | 0 | 12859 |
| | 70 | -.3 | 0 | 12367 |
| 2 | 25 | -.3 | 0 | 15777 |
| | 40 | -.3 | 0 | 13074 |
| | 55 | -.3 | 0 | 9183 |
| | 25 | .9 | 0 | 9363 |
| | 40 | .9 | 0 | 8466 |
| | 55 | .9 | 0 | 10019 |
| 3 | 25 | -.3 | 0 | 12848 |
| | 40 | -.3 | 0 | 8620 |
| | 55 | -.3 | 0 | 7592 |
| | 60 | -.3 | 0 | 9786 |
| 4 | 25 | -.3 | 0 | 8399 |
| | 40 | -.3 | 0 | 8537 |
| | 55 | -.3 | 0 | 8309 |
| | 25 | .9 | 0 | 2941 |
| | 40 | .9 | 0 | 6266 |
| | 55 | .9 | 0 | 5480 |
| 5 | 39 | -.3 | 0 | 4200 |
| | 51 | -.3 | 0 | 4174 |
| | 64 | -.3 | 0 | 3376 |
| | 76 | -.3 | 0 | 2252 |
| Storage pile | | | | |
| 6 | 39 | -.3 | 0 | 5659 |
| | 51 | -.3 | 0 | 3250 |
| | 64 | -.3 | 0 | 2157 |
| | 39 | .9 | 0 | 2636 |
| | 51 | .9 | 0 | 3314 |
| | 64 | .9 | 0 | 1811 |
| 7 | 53 | -.3 | 0 | 5084 |
| | 87 | -.3 | 0 | 4462 |
| | 120 | -.3 | 0 | 3461 |
| | 153 | -.3 | 0 | 2794 |
| 8 | 53 | -.3 | 0 | 4350 |
| | 87 | -.3 | 0 | 2327 |
| | 120 | -.3 | 0 | 3245 |
| | 53 | .9 | 0 | 2876 |
| | 87 | .9 | 0 | 1978 |
| | 120 | .9 | 0 | 1820 |

## Table B-3. DOWNWIND PARTICULATE CONCENTRATIONS MINE C

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Dragline | | | | |
| 1 | 70 | -6.5 | 0 | 96 |
| | 70 | -5.0 | 0 | 0 |
| | 79 | -6.5 | 0 | 210 |
| | 79 | -5.0 | 0 | 125 |
| | 87 | -6.5 | 0 | 133 |
| | 87 | -5.0 | 0 | 89 |
| 2 | 70 | -6.5 | 0 | 37 |
| | 79 | -6.5 | 0 | 78 |
| | 87 | -6.5 | 0 | 127 |
| | 96 | void | | |
| 3 | 70 | -6.5 | 0 | 208 |
| | 79 | -6.5 | 0 | 262 |
| | 87 | -6.5 | 0 | 287 |
| | 70 | -5.0 | 0 | 72 |
| | 79 | -5.0 | 0 | 12 |
| | 87 | -5.0 | 0 | 170 |
| 4 | 70 | -6.5 | 0 | 113 |
| | 79 | -6.5 | 0 | 100 |
| | 87 | -6.5 | 0 | 161 |
| | 96 | -6.5 | 0 | 128 |
| 5 | 70 | -6.5 | 0 | 139 |
| | 79 | -6.5 | 0 | 236 |
| | 87 | -6.5 | 0 | 297 |
| | 70 | -5.0 | 0 | 323 |
| | 79 | -5.0 | 0 | 144 |
| | 87 | -5.0 | 0 | 217 |
| 6 | 70 | -6.5 | 0 | 241 |
| | 79 | -6.5 | 0 | 287 |
| | 87 | -6.5 | 0 | 394 |
| | 96 | -6.5 | 0 | 289 |
| Haul roads | | | | |
| 1 | 10 | 0 | | 172 |
| | 20 | 0 | | 287 |
| | 30 | 0 | | 73 |
| | 40 | 0 | | 31 |
| 2 | 10 | 0 | | 170 |
| | 20 | 0 | | 320 |
| | 30 | 0 | | 184 |
| | 10 | 1.2 | | 151 |
| | 20 | 1.2 | | 97 |
| | 30 | 1.2 | | 8 |
| Haul roads | | | | |
| 3 | 11 | 0 | | 49 |
| | 22 | 0 | | 148 |
| | 33 | 0 | | 154 |
| | 44 | 0 | | 56 |
| 4 | 11 | 0 | | 94 |
| | 22 | 0 | | 239 |
| | 33 | 0 | | 236 |
| | 11 | 1.2 | | 51 |
| | 22 | 1.2 | | 70 |
| | 33 | 1.2 | | 105 |
| 5 | 10 | 0 | | 167 |
| | 20 | 0 | | 319 |
| | 30 | 0 | | 232 |
| | 40 | 0 | | 174 |
| 6 | 10 | 0 | | 152 |
| | 20 | 0 | | 325 |
| | 30 | 0 | | 387 |
| | 10 | 1.2 | | 112 |
| | 20 | 1.2 | | 173 |
| | 30 | 1.2 | | 183 |
| 7 | 11 | -.3 | | 657 |
| | 22 | -.3 | | 519 |
| | 33 | -.3 | | 427 |
| | 44 | -.3 | | 287 |
| 8 | 11 | -.3 | | 596 |
| | 22 | -.3 | | 671 |
| | 33 | -.3 | | 388 |
| | 11 | .9 | | 885 |
| | 22 | .9 | | 629 |
| | 33 | .9 | | 318 |
| 9 | 10 | -.3 | | 787 |
| | 20 | -.3 | | 947 |
| | 30 | -.3 | | 763 |
| | 40 | -.3 | | 727 |
| 10 | 10 | -.3 | | 844 |
| | 20 | -.3 | | 1253 |
| | 30 | -.3 | | 537 |
| | 10 | .9 | | 772 |
| | 20 | .9 | | 820 |
| | 30 | .9 | | 389 |

Table B-3 (continued). DOWNWIND PARTICULATE CONCENTRATIONS MINE C

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m³ |
|---|---|---|---|---|
| Drilling | | | | |
| 1 | 6 | 1.0 | .3 | 461 |
| | 6 | 2.2 | 1.3 | 244 |
| | 15 | 1.0 | 4.2 | 403 |
| | 15 | 2.2 | 5.2 | 222 |
| | 24 | 1.0 | 8.2 | 274 |
| | 24 | 2.2 | 9.2 | 129 |
| 2 | 6 | 1.0 | 2.3 | 269 |
| | 15 | 1.0 | 6.2 | 171 |
| | 24 | 1.0 | 10.2 | 175 |
| | 34 | 1.0 | 14.2 | 214 |
| Shovel/Truck loading | | | | |
| 1 | 50 | -3.8 | 1.0 | 341 |
| | 50 | -2.6 | 0 | 320 |
| | 59 | -3.8 | 1.0 | 293 |
| | 59 | -2.6 | 0 | 296 |
| | 67 | -3.8 | 1.0 | 287 |
| | 67 | -2.6 | 0 | 183 |
| 2 | 50 | -3.8 | 1.0 | 184 |
| | 59 | -3.8 | 1.0 | 244 |
| | 67 | -3.8 | 1.0 | 269 |
| | 76 | -3.8 | 1.0 | 290 |
| 3 | 50 | -3.8 | 1.0 | 226 |
| | 50 | -2.6 | 0 | 130 |
| | 59 | -3.8 | 1.0 | 192 |
| | 59 | -2.6 | 0 | 134 |
| | 67 | -3.8 | 1.0 | 238 |
| | 67 | -2.6 | 0 | 164 |
| 4 | 50 | -3.8 | 1.0 | 141 |
| | 59 | -3.8 | 1.0 | 120 |
| | 67 | -3.8 | 1.0 | 44 |
| | 76 | -3.8 | 1.0 | 154 |
| Train loading | | | | |
| 1 | 12 | -3.4 | 1.0 | 457 |
| | 12 | -2.2 | 2.0 | 167 |
| | 21 | -3.4 | 1.0 | 50 |
| | 21 | -2.2 | 2.0 | 48 |
| | 29 | -3.4 | 1.0 | 221 |
| | 29 | -2.2 | 2.0 | 11 |
| 2 | 12 | -3.4 | 3.0 | 77 |
| | 21 | -3.4 | 3.0 | 172 |
| | 29 | -3.4 | 3.0 | 103 |
| | 38 | -3.4 | 3.0 | 25 |
| Train loading | | | | |
| 3 | 12 | -3.4 | 1.0 | 404 |
| | 12 | -2.2 | 2.0 | 186 |
| | 21 | -3.4 | 1.0 | 158 |
| | 21 | -2.2 | 2.0 | 119 |
| | 29 | -3.4 | 1.0 | 328 |
| | 29 | -2.2 | 2.0 | 220 |
| 4 | 12 | -3.4 | 3.0 | 115 |
| | 21 | -3.4 | 3.0 | 132 |
| | 29 | -3.4 | 3.0 | 76 |
| | 38 | -3.4 | 3.0 | 84 |
| Coal blast | | | | |
| 1 | 111 | -3.8 | -.5 | 3079 |
| | 111 | -2.6 | .5 | 1137 |
| | 121 | -3.8 | -.5 | 2721 |
| | 121 | -2.6 | .5 | 3307 |
| | 130 | -3.8 | -.5 | 2669 |
| | 130 | -2.6 | .5 | 2189 |
| 2 | 111 | -3.8 | 1.5 | 2967 |
| | 121 | -3.8 | 1.5 | 3156 |
| | 130 | -3.8 | 1.5 | 2381 |
| | 139 | -3.8 | 1.5 | 2254 |
| Overburden blast | | | | |
| 1 | 30 | -3.8 | 0 | 9085 |
| | 39 | -3.8 | 0 | 8799 |
| | 47 | -3.8 | 0 | 5782 |
| | 56 | -3.8 | 0 | 5751 |
| 2 | 30 | -3.8 | 0 | 9930 |
| | 30 | -2.6 | 0 | 7810 |
| | 39 | -3.8 | 0 | 6297 |
| | 39 | -2.6 | 0 | 4503 |
| | 47 | -3.8 | 0 | 5924 |
| | 47 | -2.6 | 0 | 5531 |
| Truck dump | | | | |
| 1 | 32 | -10.0 | a | 398 |
| | 32 | -8.8 | a | 334 |
| | 41 | -10.0 | a | 209 |
| | 41 | -8.8 | a | 335 |
| | 50 | -10.0 | a | 480 |
| | 50 | -8.8 | a | 454 |
| 2 | 32 | -10.0 | a | 248 |
| | 41 | -10.0 | a | 188 |
| | 50 | -10.0 | a | 411 |
| | 59 | -10.0 | a | 318 |

[a] Samplers not in plume.

Table B-3 (continued). DOWNWIND PARTICULATE CONCENTRATIONS MINE C

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ | Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|---|---|---|---|---|
| Truck dump | | | | | | | | | |
| 3 | 32 | -10.0 | 5.7 | 238 | | | | | |
| | 32 | -8.8 | 6.7 | 18 | | | | | |
| | 41 | -10.0 | 7.7 | 309 | | | | | |
| | 41 | -8.8 | 8.7 | 313 | | | | | |
| | 50 | -10.0 | 9.6 | 419 | | | | | |
| | 50 | -8.8 | 10.6 | 241 | | | | | |
| 4 | 32 | -10.0 | 7.7 | 281 | | | | | |
| | 41 | -10.0 | 9.7 | 280 | | | | | |
| | 50 | -10.0 | 11.6 | 374 | | | | | |
| | 59 | -10.0 | 12.5 | 416 | | | | | |
| Storage pile | | | | | | | | | |
| 1 | 60 | -6.3 | 0 | 1560 | | | | | |
| | 70 | -6.3 | 0 | 1595 | | | | | |
| | 80 | -6.3 | 0 | 2807 | | | | | |
| | 60 | -5.1 | 0 | 1326 | | | | | |
| | 70 | -5.1 | 0 | 1240 | | | | | |
| | 80 | -5.1 | 0 | 1488 | | | | | |
| 2 | 60 | -6.3 | 0 | 5470 | | | | | |
| | 70 | -6.3 | 0 | 6895 | | | | | |
| | 80 | -6.3 | 0 | 8306 | | | | | |
| | 90 | -6.3 | 0 | 9076 | | | | | |
| 3 | 60 | -6.3 | 0 | 4265 | | | | | |
| | 70 | -6.3 | 0 | 4830 | | | | | |
| | 80 | -6.3 | 0 | 4307 | | | | | |
| | 60 | -5.1 | 0 | 1485 | | | | | |
| | 70 | -5.1 | 0 | 3952 | | | | | |
| | 80 | -5.1 | 0 | 5072 | | | | | |
| 4 | 60 | -6.3 | 0 | 1815 | | | | | |
| | 70 | -6.3 | 0 | 716 | | | | | |
| | 80 | -6.3 | 0 | 3973 | | | | | |
| | 90 | -6.3 | 0 | 2844 | | | | | |

## Table B-4. DOWNWIND PARTICULATE CONCENTRATIONS MINE D

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Dragline | | | | |
| 1 | 75 | -3.8 | 0 | 1475 |
| | 84 | -3.8 | 0 | 1585 |
| | 92 | -3.8 | 0 | 1577 |
| | 100 | -3.8 | 0 | 1631 |
| 2 | 75 | -3.8 | 0 | 898 |
| | 75 | -2.6 | 0 | 1498 |
| | 84 | -3.8 | 0 | 1095 |
| | 84 | -2.6 | 0 | 1389 |
| | 92 | -3.8 | 0 | 763 |
| | 92 | -2.6 | 0 | 1258 |
| 3 | 75 | -3.8 | 0 | 1047 |
| | 84 | -3.8 | 0 | 1062 |
| | 92 | -3.8 | 0 | 608 |
| | 100 | -3.8 | 0 | 610 |
| 4 | 75 | -3.8 | 0 | 808 |
| | 75 | -2.6 | 0 | 911 |
| | 84 | -3.8 | 0 | 892 |
| | 84 | -2.6 | 0 | 914 |
| | 92 | -3.8 | 0 | 1128 |
| | 92 | -2.6 | 0 | 1821 |
| 5 | 75 | -3.8 | 0 | 925 |
| | 84 | -3.8 | 0 | 1078 |
| | 92 | -3.8 | 0 | 1082 |
| | 100 | -3.8 | 0 | 838 |
| 6 | 75 | -3.8 | 0 | 672 |
| | 84 | -3.8 | 0 | 1475 |
| | 92 | -3.8 | 0 | 668 |
| | 100 | -3.8 | 0 | 756 |
| Haul roads | | | | |
| 1 | 5 | -.3 | | 3783 |
| | 5 | .9 | | 3305 |
| | 15 | -.3 | | 2766 |
| | 15 | .9 | | 2857 |
| | 25 | -.3 | | 2915 |
| | 25 | .9 | | 2490 |
| 2 | 5 | -.3 | | 6711 |
| | 15 | -.3 | | 6992 |
| | 25 | -.3 | | 4515 |
| | 35 | -.3 | | 3728 |
| Haul roads | | | | |
| 3 | 5 | -.3 | | 391 |
| | 5 | .9 | | 320 |
| | 14 | -.3 | | 312 |
| | 14 | .9 | | 170 |
| | 22 | -.3 | | 361 |
| | 22 | .9 | | 116 |
| 4 | 5 | -.3 | | 288 |
| | 14 | -.3 | | 362 |
| | 22 | -.3 | | 255 |
| | 31 | -.3 | | 411 |
| 5 | 5 | -.3 | | 1123 |
| | 5 | .9 | | 585 |
| | 14 | -.3 | | 908 |
| | 14 | .9 | | 525 |
| | 22 | -.3 | | 531 |
| | 22 | .9 | | 238 |
| 6 | 5 | -.3 | | 1079 |
| | 14 | -.3 | | 913 |
| | 22 | -.3 | | 860 |
| | 31 | -.3 | | 558 |
| 7 | 5 | -.3 | | 653 |
| | 5 | .9 | | 454 |
| | 12 | -.3 | | 434 |
| | 12 | .9 | | 356 |
| | 19 | -.3 | | 588 |
| | 19 | .9 | | 400 |
| 8 | 5 | -.3 | | 750 |
| | 12 | -.3 | | 975 |
| | 19 | -.3 | | 695 |
| | 26 | -.3 | | 508 |
| 9 | 5 | -.3 | | 1002 |
| | 5 | .9 | | 809 |
| | 12 | -.3 | | 766 |
| | 12 | .9 | | 699 |
| | 19 | -.3 | | 657 |
| | 19 | .9 | | 267 |

Table B-4 (continued). DOWNWIND PARTICULATE CONCENTRATIONS MINE D

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, $ug/m^3$ |
|---|---|---|---|---|
| Coal blast | | | | |
| 1 | 100 | -13.8 | 0 | 1186 |
| | 100 | -12.6 | 0 | 668 |
| | 109 | -13.8 | 0 | 1149 |
| | 109 | -12.6 | 0 | 733 |
| | 117 | -13.8 | 0 | 1340 |
| 2 | 100 | -13.8 | 0 | 1004 |
| | 109 | -13.8 | 0 | 810 |
| | 117 | -13.8 | 0 | 628 |
| | 126 | -13.8 | 0 | 469 |
| Truck dump | | | | |
| 1 | 20 | -8.8 | 0 | 1285 |
| | 26 | -8.8 | 0 | 2171 |
| | 32 | -8.8 | 0 | 3064 |
| | 38 | -8.8 | 0 | 2412 |
| 2 | 20 | -8.8 | 0 | 625 |
| | 26 | -8.8 | 0 | 751 |
| | 32 | -8.8 | 0 | 1001 |
| | 20 | -7.6 | 0 | 1250 |
| | 26 | -7.6 | 0 | 1489 |
| | 32 | -7.6 | 0 | 1269 |
| 3 | 20 | -8.8 | 0 | 762 |
| | 26 | -8.8 | 0 | 1100 |
| | 32 | -8.8 | 0 | 1438 |
| | 20 | -7.6 | 0 | 1023 |
| | 26 | -7.6 | 0 | 1239 |
| | 32 | -7.6 | 0 | 843 |
| 4 | 20 | -8.8 | 0 | 933 |
| | 26 | -8.8 | 0 | 1343 |
| | 32 | -8.8 | 0 | 1568 |
| | 38 | -8.8 | 0 | 1185 |
| 5 | 20 | -8.8 | 0 | 2320 |
| | 26 | -8.8 | 0 | 3663 |
| | 32 | -8.8 | 0 | 4085 |
| | 38 | -8.8 | 0 | 3432 |
| 6 | 20 | -8.8 | 0 | 1741 |
| | 26 | -8.8 | 0 | 1991 |
| | 32 | -8.8 | 0 | 1634 |
| | 20 | -7.6 | 0 | 1394 |
| | 26 | -7.6 | 0 | 2165 |
| | 32 | -7.6 | 0 | 2349 |

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, $ug/m^3$ |
|---|---|---|---|---|
| Topsoil dump (scraper) | | | | |
| 1 | 5 | -.3 | | 7201 |
| | 10 | -.3 | | 6152 |
| | 15 | -.3 | | 3421 |
| | 20 | -.3 | | 3763 |
| 2 | 5 | -.3 | | 6154 |
| | 10 | -.3 | | 3589 |
| | 15 | -.3 | | 4326 |
| | 5 | .9 | | 1588 |
| | 10 | .9 | | 5475 |
| | 15 | .9 | | 3554 |
| 3 | 5 | -.3 | | 6858 |
| | 10 | -.3 | | 5004 |
| | 15 | -.3 | | 2879 |
| | 20 | -.3 | | 3323 |
| 4 | 5 | -.3 | | 3185 |
| | 10 | -.3 | | 2060 |
| | 15 | -.3 | | 1238 |
| | 5 | .9 | | 5354 |
| | 10 | .9 | | 3102 |
| | 15 | .9 | | 2001 |
| 5 | 5 | -.3 | | 6280 |
| | 10 | -.3 | | 4286 |
| | 15 | -.3 | | 2948 |
| | 20 | -.3 | | 3020 |
| Topsoil removal (scraper) | | | | |
| 1 | 30 | -.3 | | 1704 |
| | 34 | -.3 | | 2310 |
| | 38 | -.3 | | 1583 |
| | 30 | .9 | | 466 |
| | 34 | .9 | | 2035 |
| | 38 | .9 | | 1390 |
| 2 | 30 | -.3 | | 6914 |
| | 34 | -.3 | | 3055 |
| | 38 | -.3 | | 7075 |
| | 42 | -.3 | | 8363 |
| 3 | 30 | -.3 | | 12149 |
| | 34 | -.3 | | 11800 |
| | 38 | -.3 | | 16507 |
| | 30 | .9 | | 5944 |
| | 34 | .9 | | 7385 |
| | 38 | .9 | | 7672 |

Table B-4 (continued). DOWNWIND PARTICULATE CONCENTRATIONS MINE D

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ | Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|---|---|---|---|---|
| Topsoil removal (scraper) | | | | | | | | | |
| 4 | 30 | -.3 | | 5415 | | | | | |
| | 34 | -.3 | | 7556 | | | | | |
| | 38 | -.3 | | 6178 | | | | | |
| | 42 | -.3 | | 8107 | | | | | |
| 5 | 30 | -.3 | | 4797 | | | | | |
| | 37 | -.3 | | 5925 | | | | | |
| | 41 | -.3 | | 5658 | | | | | |
| | 45 | -.3 | | 4597 | | | | | |
| Storage pile | | | | | | | | | |
| 1 | 25 | -8.8 | 0 | 182 | | | | | |
| | 34 | -8.8 | 0 | 86 | | | | | |
| | 42 | -8.8 | 0 | 244 | | | | | |
| | 34 | -7.6 | 0 | 71 | | | | | |
| | 42 | -7.6 | 0 | 73 | | | | | |
| | 25 | -7.6 | 0 | 0 | | | | | |
| 2 | 25 | -8.8 | 0 | 53 | | | | | |
| | 34 | -8.8 | 0 | 115 | | | | | |
| | 42 | -8.8 | 0 | 94 | | | | | |
| | 50 | -8.8 | 0 | 8 | | | | | |
| 3 | 25 | -8.8 | 0 | 109 | | | | | |
| | 34 | -8.8 | 0 | 107 | | | | | |
| | 42 | -8.8 | 0 | 183 | | | | | |
| | 25 | -7.6 | 0 | 76 | | | | | |
| | 34 | -7.6 | 0 | 122 | | | | | |
| | 42 | -7.6 | 0 | 69 | | | | | |
| 4 | 25 | -8.8 | 0 | 150 | | | | | |
| | 34 | -8.8 | 0 | 173 | | | | | |
| | 42 | -8.8 | 0 | 170 | | | | | |
| | 50 | -8.8 | 0 | 0 | | | | | |
| Front-end loader | | | | | | | | | |
| 1 | 80 | -1.3 | 0 | 1812 | | | | | |
| | 88 | -1.3 | 0 | 2149 | | | | | |
| | 97 | -1.3 | 0 | 2539 | | | | | |
| | 106 | -1.3 | 0 | 1972 | | | | | |

Table B-5. DOWNWIND PARTICULATE CONCENTRATIONS
MINE E

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, $ug/m^3$ |
|---|---|---|---|---|
| Haul roads | | | | |
| 1 | 8 | -.3 | | 693 |
| | 17 | -.3 | | 794 |
| | 26 | -.3 | | 748 |
| | 8 | .9 | | 427 |
| | 17 | .9 | | 575 |
| | 26 | .9 | | 571 |
| | 49[a] | -.3 | | 188 |
| 2 | 8 | -.3 | | 500 |
| | 17 | -.3 | | 877 |
| | 26 | -.3 | | 619 |
| | 34 | -.3 | | 509 |
| | 49[a] | -.3 | | 256 |
| 3 | 8 | -.3 | | 727 |
| | 17 | -.3 | | 788 |
| | 26 | -.3 | | 1051 |
| | 8 | .9 | | 548 |
| | 17 | .9 | | 711 |
| | 26 | .9 | | 510 |
| | 49[a] | -.3 | | 376 |
| 4 | 8 | -.3 | | 550 |
| | 17 | -.3 | | 791 |
| | 26 | -.3 | | 704 |
| | 34 | -.3 | | 764 |
| | 49[a] | -.3 | | 341 |
| 5 | 8 | -.3 | | 1350 |
| | 17 | -.3 | | 1502 |
| | 26 | -.3 | | 1341 |
| | 8 | .9 | | 1106 |
| | 17 | .9 | | 1053 |
| | 26 | .9 | | 964 |
| | 49[a] | -.3 | | 487 |
| 6 | 8 | -.3 | | 1160 |
| | 17 | -.3 | | 1287 |
| | 26 | -.3 | | 1237 |
| | 34 | -.3 | | 1258 |
| | 49[a] | -.3 | | 517 |
| 7 | 8 | -.3 | | 308 |
| | 17 | -.3 | | 321 |
| | 26 | -.3 | | 553 |
| | 8 | .9 | | 271 |
| | 17 | .9 | | 425 |
| | 26 | .9 | | 458 |
| | 49[a] | -.3 | | 238 |
| Haul roads | | | | |
| 8 | 8 | -.3 | | 281 |
| | 17 | -.3 | | 393 |
| | 26 | -.3 | | 464 |
| | 34 | -.3 | | 585 |
| | 49[a] | -.3 | | 252 |
| Drilling | | | | |
| 1 | 5 | .7 | 1.0 | 2723 |
| | 14 | .7 | 1.0 | 1862 |
| | 22 | .7 | 1.0 | 1127 |
| | 30 | .7 | 1.0 | 717 |
| 2 | 5 | .7 | 1.0 | 2116 |
| | 14 | .7 | 1.0 | 1049 |
| | 22 | .7 | 1.0 | 255 |
| | 5 | 1.9 | 0 | 1307 |
| | 14 | 1.9 | 0 | 132 |
| | 22 | 1.9 | 0 | 0 |
| Shovel/Truck loading-coal | | | | |
| 1 | 20 | 6.3 | 1.0 | 1191 |
| | 20 | 5.1 | 0 | 1031 |
| | 28 | 6.3 | 1.0 | 1059 |
| | 28 | 5.1 | 0 | 655 |
| | 37 | 6.3 | 1.0 | 954 |
| | 37 | 5.1 | 0 | 311 |
| 2 | 20 | 6.3 | 1.0 | 652 |
| | 28 | 6.3 | 1.0 | 1163 |
| | 37 | 6.3 | 1.0 | 911 |
| | 46 | 6.3 | 1.0 | 537 |
| 3 | 20 | 6.3 | 1.0 | 855 |
| | 20 | 5.1 | 0 | 822 |
| | 28 | 6.3 | 1.0 | 806 |
| | 28 | 5.1 | 0 | 817 |
| | 37 | 6.3 | 1.0 | 859 |
| | 37 | 5.1 | 0 | 762 |
| 4 | 20 | 6.3 | 1.0 | 880 |
| | 28 | 6.3 | 1.0 | 558 |
| | 37 | 6.3 | 1.0 | 1061 |
| | 46 | 6.3 | 1.0 | 735 |
| Shovel/Truck loading-overburden | | | | |
| 1 | 20 | -1.3 | 2.7 | 2569 |
| | 20 | -.1 | 3.7 | 2510 |
| | 25 | -1.3 | 4.1 | 1232 |
| | 25 | -.1 | 5.1 | 2426 |
| | 30 | -1.3 | 5.6 | 1361 |
| | 30 | -.1 | 6.6 | 1825 |
| | 142[a] | -1.3 | 16.0 | 679 |
| | 142[a] | -1.3 | 41.0 | 317 |

[a] Sampled by the mining company.

Table B-5 (continued). DOWNWIND PARTICULATE CONCENTRATIONS MINE E

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Shovel/Truck loading-overburden | | | | |
| 2 | 20 | -1.3 | 4.7 | 2255 |
| | 25 | -1.3 | 6.1 | 2633 |
| | 30 | -1.3 | 7.6 | 2676 |
| | 35 | -1.3 | 9.0 | 2668 |
| | 142[a] | -1.3 | 66.0 | 646 |
| 3 | 20 | -1.3 | 1.2 | 4572 |
| | 20 | -.1 | 2.2 | 2298 |
| | 25 | -1.3 | 2.2 | 3406 |
| | 25 | -.1 | 3.2 | 2263 |
| | 30 | -1.3 | 3.4 | 2841 |
| | 30 | -.1 | 4.4 | 2802 |
| | 142[a] | -1.3 | 5.0 | 262 |
| | 142[a] | -1.3 | 30.0 | 205 |
| 4 | 20 | -1.3 | 3.2 | 4117 |
| | 25 | -1.3 | 4.2 | 2369 |
| | 30 | -1.3 | 5.4 | 4427 |
| | 35 | -1.3 | 6.4 | 3231 |
| | 142[a] | -1.3 | 55.0 | 308 |
| 5 | 22 | -1.3 | 6.3 | 2739 |
| | 22 | -.1 | 7.3 | 2106 |
| | 28 | -1.3 | 8.6 | 1548 |
| | 28 | -.1 | 9.6 | 1839 |
| | 33 | -1.3 | 11.0 | 1172 |
| | 33 | -.1 | 12.0 | 1558 |
| | 158[a] | -1.3 | 41.0 | 267 |
| | 158[a] | -1.3 | 66.0 | 240 |
| 6 | 22 | -1.3 | 8.3 | 2531 |
| | 28 | -1.3 | 10.6 | 2053 |
| | 33 | -1.3 | 13.0 | 2730 |
| | 39 | -1.3 | 15.3 | 2178 |
| | 158[a] | -1.3 | 91.0 | 403 |
| Coal blast | | | | |
| 1 | 200 | -3.8 | 43.0 | 2289 |
| | 208 | -2.6 | 44.0 | 2194 |
| | 217 | -3.8 | 46.0 | 1456 |
| | 200 | -2.6 | 42.0 | 1851 |
| | 208 | -3.8 | 43.0 | 1939 |
| | 217 | -2.6 | 45.0 | 1587 |
| 2 | 100 | -13.8 | 21.0 | 2627 |
| | 108 | -13.8 | 23.0 | 3347 |
| | 117 | -13.8 | 25.0 | 2203 |
| | 126 | -13.8 | 27.0 | 2485 |

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m$^3$ |
|---|---|---|---|---|
| Overburden blast | | | | |
| 1 | 74 | -16.3 | 29.0 | 1094 |
| | 81 | -16.3 | 31.0 | 1502 |
| | 89 | -16.3 | 34.0 | 1359 |
| | 96 | -16.3 | 36.0 | 740 |
| | 197[a] | -16.3 | 78.0 | 394 |
| 2 | 74 | -16.3 | 24.0 | 1327 |
| | 81 | -16.3 | 26.0 | 1064 |
| | 89 | -16.3 | 29.0 | 1097 |
| | 74 | -15.1 | 19.0 | 1265 |
| | 81 | -15.1 | 21.0 | 1323 |
| | 89 | -15.1 | 24.0 | 616 |
| | 197[a] | -16.3 | 64.0 | 479 |
| | 197[a] | -16.3 | 53.0 | 445 |
| Exposed areas | | | | |
| 1 | 10 | 1.2 | | n.d. |
| | 10 | 2.4 | | n.d. |
| | 20 | 1.2 | | n.d. |
| | 20 | 2.4 | | n.d. |
| | 30 | 1.2 | | n.d. |
| | 30 | 2.4 | | n.d. |
| 2 | 0 | 1.2 | | n.d. |
| | 10 | 1.2 | | n.d. |
| | 20 | 1.2 | | n.d. |
| | 30 | 1.2 | | n.d. |
| 3 | 0 | 1.2 | | n.d. |
| | 0 | 2.4 | | n.d. |
| | 10 | 1.2 | | n.d. |
| | 10 | 2.4 | | n.d. |
| | 20 | 1.2 | | n.d. |
| | 20 | 2.4 | | n.d. |
| 4 | 0 | 1.2 | | n.d. |
| | 10 | 1.2 | | n.d. |
| | 20 | 1.2 | | n.d. |
| | 30 | 1.2 | | n.d. |
| Truck dump-coal | | | | |
| 1 | 9 | -1.8 | 3.0 | 2487 |
| | 19 | -1.8 | 6.9 | 2177 |
| | 28 | -1.8 | 10.9 | 1485 |
| | 9 | -.6 | 4.0 | 2187 |
| | 19 | -.6 | 7.9 | 1765 |
| | 28 | -.6 | 11.9 | 1130 |
| | 49[a] | -1.8 | 19.5 | 656 |
| | 49[a] | -1.8 | 20.5 | 709 |

[a] Sampled by the mining company.

n.d. = no data: no upwind samples.

Table B-5 (continued). DOWNWIND PARTICULATE CONCENTRATIONS MINE E

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m3 |
|---|---|---|---|---|
| Truck dump-coal | | | | |
| 2 | 9 | -1.8 | 5.0 | 2169 |
| | 19 | -1.8 | 8.9 | 2301 |
| | 28 | -1.8 | 12.9 | 1505 |
| | 38 | -1.8 | 16.8 | 1125 |
| | 49[a] | -1.8 | 21.5 | 941 |
| 3 | 8 | -1.8 | 3.9 | 2103 |
| | 17 | -1.8 | 8.8 | 1313 |
| | 26 | -1.8 | 13.7 | 689 |
| | 8 | -.6 | 4.9 | 2536 |
| | 17 | -.6 | 9.8 | 711 |
| | 26 | -.6 | 14.7 | 1221 |
| | 49[a] | -1.8 | 24.4 | 666 |
| | 49[a] | -1.8 | 25.4 | 675 |
| 4 | 8 | -1.8 | 5.9 | 3785 |
| | 17 | -1.8 | 10.8 | 1803 |
| | 26 | -1.8 | 15.7 | 1349 |
| | 34 | -1.8 | 20.6 | 1294 |
| | 49[a] | -1.8 | 26.4 | 642 |
| Truck dump-overburden | | | | |
| 1 | 15 | -.3 | 1.0 | 788 |
| | 20 | -.3 | 1.0 | 460 |
| | 25 | -.3 | 1.0 | 460 |
| | 15 | .9 | 0 | 611 |
| | 20 | .9 | 0 | 309 |
| | 25 | .9 | 0 | 210 |
| 2 | 15 | -.3 | 1.0 | 623 |
| | 20 | -.3 | 1.0 | 360 |
| | 25 | -.3 | 1.0 | 437 |
| | 30 | -.3 | 1.0 | 609 |
| 3 | 15 | -.3 | b | 201 |
| | 20 | -.3 | b | - |
| | 25 | -.3 | b | 219 |
| | 15 | .9 | b | 97 |
| | 20 | .9 | b | 263 |
| | 25 | .9 | b | 128 |
| 4 | 15 | -.3 | b | 157 |
| | 20 | -.3 | b | 175 |
| | 25 | -.3 | b | 220 |
| | 30 | -.3 | b | 175 |

| Operation/ sample | Down-wind dist, m | Vert dist from ℄, m | Hor dist from ℄, m | Net conc, ug/m3 |
|---|---|---|---|---|
| Train loading | | | | |
| 1 | 10 | -1.3 | n.d. | 3136 |
| | 20 | -1.3 | n.d. | 1474 |
| | 30 | -1.3 | n.d. | 943 |
| | 40 | -1.3 | n.d. | 1919 |
| 2 | 10 | -1.3 | n.d. | 1416 |
| | 20 | -1.3 | n.d. | 2050 |
| | 30 | -1.3 | n.d. | 383 |
| | 40 | -1.3 | n.d. | 1041 |
| 3 | 10 | -1.3 | n.d. | 2047 |
| | 10 | -.1 | n.d. | 2022 |
| | 20 | -1.3 | n.d. | 1340 |
| | 20 | -.1 | n.d. | 1155 |
| | 30 | -1.3 | n.d. | 1041 |
| | 30 | -.1 | n.d. | 1223 |
| 4 | 10 | -1.3 | n.d. | 281 |
| | 10 | -.1 | n.d. | 372 |
| | 20 | -1.3 | n.d. | 127 |
| | 20 | -.1 | n.d. | 105 |
| | 30 | -1.3 | n.d. | 123 |
| | 30 | -.1 | n.d. | 117 |
| 5 | 10 | -1.3 | n.d. | 329 |
| | 20 | -1.3 | n.d. | 254 |
| | 30 | -1.3 | n.d. | 263 |
| | 40 | -1.3 | n.d. | 150 |

[a] Sampled by the mining company.

[b] Samplers not in plume.

n.d. = not determined

# APPENDIX C

## DATA USED IN DISPERSION CALCULATIONS FOR EACH SAMPLING PERIOD

Table C-1. SAMPLING PERIODS AT MINE A

| Operation | Sample no. | Wind speed, m/sec | Stab class | Init plume ht, m | Init plume width, m | Sample time, min | Time in plume, % | Activity rate | Background conc, ug/m$^3$ |
|---|---|---|---|---|---|---|---|---|---|
| Dragline | 1 | .4 | B | 5 | 25 | 60 | 100 | 28 | 88 |
| | 2 | .4 | B | 5 | 25 | 60 | 100 | 28 | 88 |
| | 3 | .4 | B | 5 | 25 | 65 | 100 | 62 | 88 |
| | 4 | .4 | B | 5 | 25 | 65 | 100 | 62 | 88 |
| | 5 | 1.8 | B | 5 | 10 | 60 | 100 | 65 | 64 |
| | 6 | 1.8 | B | 5 | 10 | 60 | 100 | 65 | 64 |
| | 7 | .4 | B | 8 | 5 | 60 | 40 | 62 | 64 |
| | 8 | .4 | B | 8 | 5 | 60 | 25 | 71 | 64 |
| Haul roads | 1 | 1.6 | B | 5 | n.a. | 50 | 100 | 14 | 88 |
| | 2 | 1.6 | B | 5 | n.a. | 50 | 100 | 14 | 88 |
| | 3 | .9 | B | 5 | n.a. | 60 | 100 | 12 | 88 |
| | 4 | .9 | B | 5 | n.a. | 60 | 100 | 12 | 88 |
| | 5 | .4 | A | 5 | n.a. | 60 | 100 | 10 | 88 |
| | 6 | .4 | A | 5 | n.a. | 60 | 100 | 10 | 88 |
| | 7 | .9 | B | 5 | n.a. | 50 | 100 | 10 | 88 |
| | 8 | .9 | B | 5 | n.a. | 50 | 100 | 10 | 88 |
| | 9 | .4 | B | 5 | n.a. | 52 | 100 | 8 | 88 |
| | 10 | .4 | B | 5 | n.a. | 52 | 100 | 8 | 88 |
| Drilling | 1 | .9 | B | 2 | 5 | 60 | 0 | 2 | 88 |
| Shovel/ Truck loading | 1 | .5 | B | 7 | 20 | 60 | 90 | 11 | 88 |
| | 2 | .5 | B | 7 | 20 | 60 | 90 | 11 | 88 |
| | 3 | .4 | B | 7 | 20 | 60 | 100 | 7 | 88 |
| | 4 | .4 | B | 7 | 20 | 60 | 100 | 7 | 88 |
| | 5 | 1.3 | A | 7 | 15 | 60 | 100 | 7 | 87 |
| | 6 | 1.3 | A | 7 | 15 | 60 | 100 | 4 | 87 |
| Overburden blast | 1 | 2.4 | B | 100 | 100 | 73 | 100 | 1 | 88 |
| Exposed areas | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| Fly-ash dump | 1 | 4.2 | B | 3 | 50 | 45 | 100 | 1 | 113 |
| | 2 | 1.5 | B | 3 | 50 | 60 | 100 | 1 | 113 |
| | 3 | 1.5 | B | 3 | 50 | 60 | 100 | 1 | 113 |
| Truck dump | 1 | .7 | B | 3 | 8 | 60 | 100 | 7 | 60 |
| | 2 | 1.2 | A | 3 | 8 | 60 | 100 | 1 | 60 |
| | 3 | 2.7 | C | 3 | 8 | 60 | 100 | 3 | 42 |
| | 4 | .9 | B | 3 | 8 | 60 | 90 | 6 | 60 |
| | 5 | 1.5 | B | 3 | 8 | 60 | 100 | 8 | 42 |
| | 6 | .4 | B | 3 | 8 | 60 | 60 | 5 | 42 |
| Storage pile | 1 | 2.6 | C | 25 | 100 | 52 | 80 | n.a. | 42 |
| | 2 | .9 | B | 25 | 100 | 70 | 90 | n.a. | 42 |
| | 3 | .7 | B | 25 | 100 | 60 | 100 | n.a. | 60 |
| | 4 | .5 | B | 25 | 100 | 55 | 100 | n.a. | 60 |
| | 5 | .9 | A | 25 | 100 | 66 | 60 | n.a. | 60 |
| | 6 | .7 | B | 25 | 100 | 60 | 75 | n.a. | 42 |

n.a. = not applicable

Table C-2. SAMPLING PERIODS AT MINE B

| Operation | Sample no. | Wind speed, m/sec | Stab class | Init plume ht, m | Init plume width, m | Sample time, min | Time in plume, % | Activity rate | Background conc, ug/m$^3$ |
|---|---|---|---|---|---|---|---|---|---|
| Dragline | 1 | 3.6 | C | 5 | 25 | 44 | 100 | 25 | 131 |
| | 2 | 3.6 | C | 5 | 25 | 44 | 100 | 25 | 131 |
| | 3 | 5.8 | D | 5 | 5 | 56 | 100 | 29 | 131 |
| | 4 | 5.8 | D | 5 | 5 | 56 | 100 | 29 | 131 |
| | 5 | 5.4 | D | 5 | 25 | 45 | 100 | 25 | 131 |
| | 6 | 5.4 | D | 5 | 25 | 45 | 100 | 25 | 131 |
| | 7 | 3.1 | C | 10 | 40 | 36 | 100 | 35 | 125 |
| | 8 | 3.1 | C | 10 | 40 | 36 | 100 | 35 | 125 |
| | 9 | 3.6 | C | 10 | 40 | 41 | 100 | 56 | 125 |
| | 10 | 3.6 | C | 10 | 40 | 41 | 100 | 56 | 125 |
| Haul roads | 1 | 3.7 | C | 4 | n.a. | 60 | 100 | 32 | 152 |
| | 2 | 3.7 | C | 4 | n.a. | 60 | 100 | 32 | 152 |
| | 3 | 4.7 | C | 4 | n.a. | 60 | 100 | 35 | 152 |
| | 4 | 4.7 | C | 4 | n.a. | 60 | 100 | 35 | 152 |
| | 5 | 6.2 | D | 4 | n.a. | 60 | 100 | 29 | 152 |
| | 6 | 6.2 | D | 4 | n.a. | 60 | 100 | 29 | 152 |
| | 7 | 1.1 | B | 4 | n.a. | 60 | 100 | 5 | 125 |
| | 8 | 1.1 | B | 4 | n.a. | 60 | 100 | 5 | 125 |
| | 9 | .5 | B | 4 | n.a. | 45 | 100 | 1 | 125 |
| | 10 | .5 | B | 4 | n.a. | 45 | 100 | 1 | 125 |
| Shovel/ Truck loading | 1 | .6 | B | 8 | 9 | 44 | 100 | 8 | 153 |
| | 2 | .6 | B | 8 | 9 | 44 | 100 | 8 | 153 |
| | 3 | .4 | B | 8 | 9 | 46 | 100 | 10 | 153 |
| | 4 | .4 | B | 8 | 9 | 46 | 100 | 10 | 153 |
| Coal blast | 1 | 3.0 | B | 75 | 75 | 24 | 100 | 1 | 153 |
| | 2 | 3.0 | B | 75 | 75 | 24 | 100 | 1 | 153 |
| Exposed areas | 1 | 7.2 | D | 3 | n.a. | 60 | 100 | n.a. | 84 |
| | 2 | 7.2 | D | 3 | n.a. | 60 | 100 | n.a. | 84 |
| | 3 | 8.2 | D | 3 | n.a. | 50 | 100 | n.a. | 84 |
| | 4 | 8.2 | D | 3 | n.a. | 50 | 100 | n.a. | 84 |
| | 5 | 7.5 | D | 3 | n.a. | 48 | 100 | n.a. | 84 |
| | 6 | 7.5 | D | 3 | n.a. | 48 | 100 | n.a. | 84 |
| Truck dump | 1 | 3.7 | C | 3 | 17 | 26 | 100 | 6 | 153 |
| | 2 | 3.7 | C | 3 | 17 | 26 | 100 | 6 | 153 |
| Storage pile | 1 | 7.6 | D | 3 | 40 | 37 | 100 | n.a. | 123 |
| | 2 | 7.6 | D | 3 | 40 | 37 | 100 | n.a. | 123 |
| | 3 | 6.7 | D | 3 | 40 | 20 | 100 | n.a. | 123 |
| | 4 | 6.7 | D | 3 | 40 | 20 | 100 | n.a. | 123 |
| | 5 | .8 | B | 3 | 40 | 30 | 83 | n.a. | 108 |
| | 6 | .8 | B | 3 | 40 | 30 | 83 | n.a. | 108 |
| | 7 | 3.2 | C | 3 | 40 | 50 | 71 | n.a. | 108 |
| | 8 | 3.2 | C | 3 | 40 | 50 | 71 | n.a. | 108 |

n.a. = not applicable

Table C-3. SAMPLING PERIODS AT MINE C

| Operation | Sample no. | Wind speed, m/sec | Stab class | Init plume ht, m | Init plume width, m | Sample time, min | Time in plume, % | Activity rate | Background conc, ug/m$^3$ |
|---|---|---|---|---|---|---|---|---|---|
| Dragline | 1 | 3.6 | B | 15 | 50 | 60 | 100 | 65 | 89 |
| | 2 | 3.6 | B | 15 | 50 | 60 | 100 | 65 | 89 |
| | 3 | 4.0 | B | 15 | 50 | 43 | 100 | 56 | 89 |
| | 4 | 4.0 | B | 15 | 50 | 43 | 100 | 56 | 89 |
| | 5 | 5.4 | C | 15 | 50 | 60 | 100 | 53 | 89 |
| | 6 | 5.4 | C | 15 | 50 | 60 | 100 | 53 | 89 |
| Haul roads | 1 | 2.7 | B | 3 | n.a. | 60 | 100 | 20 | 89 |
| | 2 | 2.7 | B | 3 | n.a. | 60 | 100 | 20 | 89 |
| | 3 | 3.1 | B | 3 | n.a. | 60 | 100 | 22 | 89 |
| | 4 | 3.1 | B | 3 | n.a. | 60 | 100 | 22 | 89 |
| | 5 | 3.6 | B | 3 | n.a. | 60 | 100 | 24 | 89 |
| | 6 | 3.6 | B | 3 | n.a. | 60 | 100 | 24 | 89 |
| | 7 | 3.1 | B | 3 | n.a. | 55 | 100 | 20 | 89 |
| | 8 | 3.1 | B | 3 | n.a. | 55 | 100 | 20 | 89 |
| | 9 | 2.7 | B | 3 | n.a. | 60 | 100 | 32 | 89 |
| | 10 | 2.7 | B | 3 | n.a. | 60 | 100 | 32 | 89 |
| Drilling | 1 | 3.6 | C | 1 | 2 | 30 | 100 | 1 | 89 |
| | 2 | 3.6 | C | 1 | 2 | 30 | 100 | 1 | 89 |
| Shovel/ Truck loading | 1 | 3.6 | C | 10 | 15 | 45 | 100 | 9 | 59 |
| | 2 | 3.6 | C | 10 | 15 | 45 | 100 | 9 | 59 |
| | 3 | 3.6 | C | 10 | 15 | 60 | 100 | 13 | 59 |
| | 4 | 3.6 | C | 10 | 15 | 60 | 100 | 13 | 59 |
| Train loading | 1 | 4.9 | B | 5 | 5 | 44 | 100 | 35 | 89 |
| | 2 | 4.9 | B | 5 | 5 | 44 | 100 | 35 | 89 |
| | 3 | 4.5 | B | 5 | 5 | 40 | 100 | 26 | 89 |
| | 4 | 4.5 | B | 5 | 5 | 40 | 100 | 26 | 89 |
| Coal blast | 1 | 5.4 | C | 10 | 6 | 13 | 100 | 1 | 89 |
| | 2 | 5.4 | C | 10 | 6 | 13 | 100 | 1 | 89 |
| Overburden blast | 1 | 3.6 | B | 10 | 12 | 10 | 100 | 1 | 61 |
| | 2 | 3.6 | B | 10 | 12 | 10 | 100 | 1 | 61 |
| Truck dump | 1 | 3.6 | C | 10 | 15 | 60 | 100 | 21 | 89 |
| | 2 | 3.6 | C | 10 | 15 | 60 | 100 | 21 | 89 |
| | 3 | 3.6 | C | 10 | 15 | 55 | 70 | 20 | 89 |
| | 4 | 3.6 | C | 10 | 15 | 55 | 70 | 20 | 89 |
| Storage pile | 1 | 6.3 | C | 15 | 30 | 17 | 100 | 1 | 146 |
| | 2 | 8.9 | C | 15 | 30 | 19 | 100 | 1 | 146 |
| | 3 | 6.7 | C | 15 | 30 | 27 | 100 | 1 | 146 |
| | 4 | 6.7 | C | 15 | 30 | 35 | 100 | 1 | 146 |

n.a. = not applicable

Table C-4. SAMPLING PERIODS AT MINE D

| Operation | Sample no. | Wind speed, m/sec | Stab class | Init plume ht, m | Init plume width, m | Sample time, min | Time in plume, % | Activity rate | Background conc, ug/m$^3$ |
|---|---|---|---|---|---|---|---|---|---|
| Dragline | 1 | 6.3 | D | 10 | 12 | 31 | 100 | 20 | 94 |
| | 2 | 7.2 | D | 10 | 12 | 42 | 100 | 15 | 94 |
| | 3 | 7.2 | D | 10 | 12 | 35 | 100 | 24 | 94 |
| | 4 | 7.2 | D | 10 | 12 | 35 | 100 | 18 | 101 |
| | 5 | 6.3 | D | 10 | 12 | 33 | 100 | 24 | 101 |
| | 6 | 5.8 | D | 10 | 12 | 34 | 100 | 20 | 101 |
| Haul roads | 1 | 5.4 | C | 3 | n.a. | 47 | 100 | 5 | 119 |
| | 2 | 5.4 | C | 3 | n.a. | 47 | 100 | 5 | 119 |
| | 3 | 5.4 | D | 3 | n.a. | 59 | 100 | 5 | 70 |
| | 4 | 5.4 | D | 3 | n.a. | 59 | 100 | 5 | 70 |
| | 5 | 5.8 | C | 3 | n.a. | 60 | 100 | 20 | 103 |
| | 6 | 5.8 | C | 3 | n.a. | 60 | 100 | 20 | 103 |
| | 7 | 4.0 | C | 3 | n.a. | 69 | 100 | 9 | 62 |
| | 8 | 4.0 | C | 3 | n.a. | 69 | 100 | 9 | 62 |
| | 9 | 4.5 | C | 3 | n.a. | 62 | 100 | 7 | 62 |
| Coal blast | 1 | 4.0 | B | 30 | 40 | 43 | 100 | 1 | 115 |
| | 2 | 4.0 | B | 30 | 40 | 43 | 100 | 1 | 115 |
| Truck dump | 1 | 4.5 | C | 20 | 15 | 20 | 100 | 2 | 126 |
| | 2 | 6.2 | D | 20 | 15 | 30 | 100 | 4 | 125 |
| | 3 | 6.2 | D | 20 | 15 | 80 | 100 | 2 | 125 |
| | 4 | 6.2 | D | 20 | 15 | 80 | 100 | 2 | 125 |
| | 5 | 6.2 | D | 20 | 15 | 32 | 100 | 4 | 128 |
| | 6 | 6.7 | D | 20 | 15 | 37 | 100 | 5 | 128 |
| Topsoil dump (scraper) | 1 | 2.2 | B | 3 | n.a. | 20 | 100 | 6 | 85 |
| | 2 | 3.2 | C | 3 | n.a. | 25 | 100 | 11 | 81 |
| | 3 | 3.4 | C | 3 | n.a. | 27 | 100 | 9 | 81 |
| | 4 | 3.1 | C | 3 | n.a. | 25 | 100 | 9 | 81 |
| | 5 | 3.6 | C | 3 | n.a. | 25 | 100 | 7 | 81 |
| Topsoil removal (scraper) | 1 | 5.8 | C | 3 | n.a. | 31 | 100 | 4 | 158 |
| | 2 | 6.2 | C | 3 | n.a. | 35 | 100 | 4 | 158 |
| | 3 | 7.2 | C | 3 | n.a. | 34 | 100 | 4 | 158 |
| | 4 | 7.2 | C | 3 | n.a. | 18 | 100 | 4 | 158 |
| | 5 | 7.6 | C | 3 | n.a. | 23 | 100 | 4 | 158 |
| Storage pile | 1 | .9 | A | 20 | 158 | 91 | 100 | n.a. | 102 |
| | 2 | .9 | A | 20 | 158 | 91 | 100 | n.a. | 102 |
| | 3 | 1.3 | A | 20 | 158 | 64 | 78 | n.a. | 103 |
| | 4 | 1.3 | A | 20 | 158 | 64 | 78 | n.a. | 103 |
| Front-end loader | 1 | 2.7 | B | 5 | 10 | 21 | 100 | 19 | 122 |

n.a. = not applicable

Table C-5. SAMPLING PERIODS AT MINE E

| Operation | Sample no. | Wind speed, m/sec | Stab class | Init plume ht, m | Init plume width, m | Sample time, min | Time in plume, % | Activity rate | Background conc, $ug/m^3$ |
|---|---|---|---|---|---|---|---|---|---|
| Haul roads | 1 | 3.7 | B | 3 | n.a. | 53 | 100 | 37 | 105 |
| | 2 | 3.7 | B | 3 | n.a. | 53 | 100 | 37 | 105 |
| | 3 | 3.1 | B | 3 | n.a. | 60 | 100 | 46 | 145 |
| | 4 | 3.1 | B | 3 | n.a. | 60 | 100 | 46 | 145 |
| | 5 | 3.4 | B | 3 | n.a. | 45 | 100 | 29 | 120 |
| | 6 | 3.4 | B | 3 | n.a. | 45 | 100 | 29 | 120 |
| | 7 | 2.5 | B | 3 | n.a. | 44 | 100 | 28 | 166 |
| | 8 | 2.5 | B | 3 | n.a. | 44 | 100 | 28 | 166 |
| Drilling | 1 | 4.1 | C | 1 | 3 | 39 | 100 | 2 | 676 |
| | 2 | 4.1 | C | 1 | 3 | 39 | 100 | 2 | 676 |
| Shovel/ Truck loading-coal | 1 | 2.5 | B | 15 | 15 | 48 | 100 | 16 | 64 |
| | 2 | 2.5 | B | 15 | 15 | 48 | 100 | 16 | 64 |
| | 3 | 2.3 | B | 15 | 15 | 61 | 100 | 20 | 64 |
| | 4 | 2.3 | B | 15 | 15 | 61 | 100 | 20 | 64 |
| Shovel/ Truck loading-overburden | 1 | 3.6 | B | 15 | 10 | 43 | 100 | 4 | 112 |
| | 2 | 3.6 | B | 15 | 10 | 43 | 100 | 4 | 112 |
| | 3 | 3.1 | B | 15 | 10 | 28 | 100 | 9 | 112 |
| | 4 | 3.1 | B | 15 | 10 | 28 | 100 | 9 | 112 |
| | 5 | 2.7 | B | 15 | 10 | 30 | 100 | 5 | 112 |
| | 6 | 2.7 | B | 15 | 10 | 30 | 100 | 5 | 112 |
| Coal blast | 1 | 2.6 | B | 30 | 40 | 8 | 100 | 1 | 128 |
| | 2 | 2.6 | B | 30 | 40 | 8 | 100 | 1 | 128 |
| Overburden blast | 1 | 3.7 | C | 35 | 10 | 8 | 100 | 1 | 77 |
| | 2 | 3.7 | C | 35 | 10 | 8 | 100 | 1 | 77 |
| Exposed areas | 1 | 4.9 | B | 0 | n.a. | 78 | 100 | n.a. | n.d. |
| | 2 | 4.9 | B | 0 | n.a. | 78 | 100 | n.a. | n.d. |
| | 3 | 6.3 | C | 0 | n.a. | 72 | 100 | n.a. | n.d. |
| | 4 | 6.3 | C | 0 | n.a. | 72 | 100 | n.a. | n.d. |
| Truck dump-coal | 1 | 3.1 | B | 6 | 10 | 30 | 100 | 11 | 55 |
| | 2 | 3.1 | B | 6 | 10 | 30 | 100 | 11 | 55 |
| | 3 | 2.7 | B | 6 | 10 | 30 | 100 | 10 | 55 |
| | 4 | 2.7 | B | 6 | 10 | 30 | 100 | 10 | 55 |
| Truck dump-overburden | 1 | 6.2 | C | 3 | 12 | 60 | 100 | 21 | 480 |
| | 2 | 6.2 | C | 3 | 12 | 60 | 100 | 21 | 480 |
| | 3 | 5.4 | C | 3 | 12 | 60 | 100 | 21 | 157 |
| | 4 | 5.4 | C | 3 | 12 | 60 | 100 | 21 | 157 |
| Train loading | 1 | n.d. | n.d. | 5 | 6 | 35 | 100 | 44 | 28 |
| | 2 | n.d. | n.d. | 5 | 6 | 46 | 100 | 50 | 28 |
| | 3 | n.d. | n.d. | 5 | 6 | 83 | 100 | 100 | 28 |
| | 4 | n.d. | n.d. | 6 | 5 | 87 | 100 | 100 | 43 |
| | 5 | n.d. | n.d. | 6 | 5 | 87 | 100 | 100 | 43 |

n.a. = not applicable
n.d. = not determined

# APPENDIX D

## PARTICLE SIZE DISTRIBUTIONS FOR SELECTED MINING SOURCE SAMPLES

Table D-1. PARTICLE SIZE DISTRIBUTIONS FOR SELECTED MINING SOURCE SAMPLES

| Size range, | Sample A1 Truck dump @20m | Sample A2 Truck dump @20m | Sample A3 Truck dump @20m | Sample A4 Truck dump @20m | Sample A5 Dragline @105m |
|---|---|---|---|---|---|
| <3.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.08 | 0.03 | 0.15 | 0.07 | 0.03 | 0.01 |
| 4.36 | 0.26 | 1.65 | 0.41 | 0.62 | 0.19 |
| 6.17 | 2.92 | 4.80 | 0.64 | 2.51 | 0.32 |
| 8.72 | 11.00 | 9.90 | 1.81 | 5.67 | 1.49 |
| 12.33 | 25.27 | 14.93 | 6.52 | 24.06 | 3.36 |
| 17.44 | 60.51 | 23.77 | 19.76 | 51.06 | 7.14 |
| 24.66 | 0.00 | 44.80 | 40.97 | 16.04 | 33.64 |
| 34.88 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 49.33 | 0.00 | 0.00 | 29.81 | 0.00 | 53.86 |
| >49.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| Size range, | Sample A6 Dragline @35m | Sample A7 Dragline @35m | Sample A8 Haul road @10m | Sample A9 Haul road @10m | Sample A10 Haul road @20m |
|---|---|---|---|---|---|
| <3.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.08 | 0.00 | 0.02 | 0.00 | 0.34 | 0.00 |
| 4.36 | 0.26 | 0.13 | 0.44 | 1.24 | 0.00 |
| 6.17 | 3.63 | 0.25 | 0.75 | 3.12 | 0.55 |
| 8.72 | 10.24 | 2.42 | 1.41 | 16.51 | 0.77 |
| 12.33 | 23.16 | 6.85 | 13.93 | 18.67 | 13.12 |
| 17.44 | 16.39 | 5.54 | 22.52 | 35.22 | 18.56 |
| 24.66 | 46.33 | 0.00 | 15.92 | 24.90 | 17.49 |
| 34.88 | 0.00 | 22.15 | 45.04 | 0.00 | 49.50 |
| 49.33 | 0.00 | 62.65 | 0.00 | 0.00 | 0.00 |
| >49.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| Size range, | Sample A11 Haul road @30m | Sample A12 Haul road @20m | Sample A13 Haul road @20m | Sample A14 Fly ash dump @10m | Sample A15 Fly ash dump @60m |
|---|---|---|---|---|---|
| <3.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.08 | 0.00 | 0.06 | 0.11 | 0.45 | 1.14 |
| 4.36 | 0.00 | 0.16 | 0.28 | 1.68 | 2.65 |
| 6.17 | 1.19 | 2.23 | 0.94 | 3.58 | 7.19 |
| 8.72 | 16.76 | 6.30 | 1.51 | 13.47 | 13.84 |
| 12.33 | 28.43 | 10.68 | 6.42 | 0.00 | 23.48 |
| 17.44 | 53.63 | 0.00 | 15.14 | 80.82 | 51.69 |
| 24.66 | 0.00 | 0.00 | 17.12 | 0.00 | 0.00 |
| 34.88 | 0.00 | 80.58 | 24.22 | 0.00 | 0.00 |
| 49.33 | 0.00 | 0.00 | 34.26 | 0.00 | 0.00 |
| >49.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Table D-1 (continued). PARTICLE SIZE DISTRIBUTIONS FOR SELECTED MINING SOURCE SAMPLES

| Size range, | Sample A16 Coal loading @45m | Sample A17 Dragline @60m | Sample A18 Dragline @40m | Sample A19 Dragline @50m | Sample B1 Dragline @65m |
|---|---|---|---|---|---|
| <3.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.08 | 1.05 | 0.00 | 0.17 | 0.22 | 0.00 |
| 4.36 | 4.47 | 0.00 | 0.72 | 0.63 | 0.00 |
| 6.17 | 16.91 | 0.00 | 3.40 | 1.80 | 1.84 |
| 8.72 | 29.83 | 0.58 | 11.53 | 3.38 | 8.64 |
| 12.33 | 0.00 | 3.26 | 38.04 | 28.68 | 34.21 |
| 17.44 | 47.73 | 9.23 | 46.13 | 27.05 | 55.31 |
| 24.66 | 0.00 | 13.05 | 0.00 | 38.24 | 0.00 |
| 34.88 | 0.00 | 73.87 | 0.00 | 0.00 | 0.00 |
| 49.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| >49.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| Size range, | Sample B2 Dragline @80m | Sample B3 Dragline @85m | Sample B4 Haul road @30m | Sample B5 Haul road @30m | Sample B6 Haul road @30m |
|---|---|---|---|---|---|
| <3.08 | 0.00 | 0.43 | 0.00 | 0.00 | 0.00 |
| 3.08 | 0.00 | 2.13 | 0.00 | 0.15 | 0.00 |
| 4.36 | 3.81 | 8.47 | 0.00 | 0.83 | 0.00 |
| 6.17 | 8.09 | 18.86 | 0.71 | 1.17 | 0.00 |
| 8.72 | 3.81 | 29.05 | 2.34 | 18.22 | 0.00 |
| 12.33 | 53.83 | 41.06 | 4.73 | 42.16 | 0.72 |
| 17.44 | 30.46 | 0.00 | 24.09 | 0.00 | 4.08 |
| 24.66 | 0.00 | 0.00 | 7.57 | 37.47 | 2.88 |
| 34.88 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 49.33 | 0.00 | 0.00 | 60.57 | 0.00 | 46.16 |
| >49.33 | 0.00 | 0.00 | 0.00 | 0.00 | 46.16 |

| Size range, | Sample B7 Haul road @30m | Sample B8 Dragline @80m | Sample B9 Coal loading @50m | Sample B10 Coal loading @55m | Sample B11 Truck dump @30m |
|---|---|---|---|---|---|
| <3.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.08 | 0.11 | 1.08 | 1.57 | 0.01 | 0.27 |
| 4.36 | 0.29 | 4.05 | 6.04 | 0.23 | 1.10 |
| 6.17 | 0.81 | 10.28 | 11.00 | 2.36 | 2.03 |
| 8.72 | 2.28 | 25.68 | 20.71 | 7.27 | 5.03 |
| 12.33 | 10.14 | 41.04 | 42.28 | 10.27 | 12.61 |
| 17.44 | 5.22 | 17.87 | 18.41 | 38.76 | 31.12 |
| 24.66 | 22.12 | 0.00 | 0.00 | 41.09 | 25.87 |
| 34.88 | 0.00 | 0.00 | 0.00 | 0.00 | 21.97 |
| 49.33 | 59.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| >49.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Table D-1 (continued). PARTICLE SIZE DISTRIBUTIONS FOR SELECTED MINING SOURCE SAMPLES

| Size range, | Sample B12 Exposed area @40m | Sample B13 Exposed area @30m | Sample B14 Dragline @90m | Sample B15 Dragline @90m | Sample B16 Storage pile @30m |
|---|---|---|---|---|---|
| <3.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.08 | 0.05 | 0.44 | 0.00 | 0.07 | 0.07 |
| 4.36 | 1.09 | 1.04 | 0.05 | 0.19 | 0.63 |
| 6.17 | 2.32 | 2.23 | 0.03 | 0.53 | 2.33 |
| 8.72 | 7.64 | 3.73 | 0.29 | 0.00 | 5.26 |
| 12.33 | 27.77 | 9.72 | 0.55 | 2.53 | 14.88 |
| 17.44 | 61.13 | 13.75 | 3.88 | 16.73 | 18.04 |
| 24.66 | 0.00 | 32.41 | 17.57 | 6.76 | 46.75 |
| 34.88 | 0.00 | 36.68 | 24.86 | 19.12 | 12.03 |
| 49.33 | 0.00 | 0.00 | 17.58 | 54.08 | 0.00 |
| >49.33 | 0.00 | 0.00 | 35.17 | 0.00 | 0.00 |

| Size range | Sample C1 Haul road @30m | Sample C2 Haul road @30m | Sample C3 Haul road @20m | Sample C4 Haul road @20m | Sample C5 Haul road @20m |
|---|---|---|---|---|---|
| <3.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.08 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 |
| 4.36 | 0.04 | 0.10 | 0.02 | 0.21 | 0.00 |
| 6.17 | 0.11 | 0.57 | 0.24 | 1.22 | 0.09 |
| 8.72 | 1.24 | 2.83 | 0.86 | 0.00 | 0.73 |
| 12.33 | 3.51 | 10.29 | 2.44 | 4.85 | 3.44 |
| 17.44 | 4.97 | 12.95 | 4.14 | 0.00 | 3.90 |
| 24.66 | 14.04 | 0.00 | 7.80 | 38.81 | 16.53 |
| 34.88 | 19.87 | 0.00 | 22.07 | 54.91 | 31.19 |
| 49.33 | 56.21 | 73.24 | 62.43 | 0.00 | 44.12 |
| >49.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| Size Range, | Sample C6 Storage pile @60m | Sample C8 Dragline @80m | Sample C9 Dragline @80m | Sample C10 Train loading @25m | Sample C11 Coal blast @110m |
|---|---|---|---|---|---|
| <3.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.08 | 0.45 | 0.05 | 0.00 | 0.02 | 0.09 |
| 4.36 | 1.89 | 0.18 | 0.10 | 0.05 | 0.62 |
| 6.17 | 3.15 | 0.23 | 0.29 | 0.51 | 0.53 |
| 8.72 | 6.21 | 0.78 | 3.27 | 2.18 | 1.98 |
| 12.33 | 22.12 | 1.10 | 9.25 | 4.10 | 5.61 |
| 17.44 | 36.70 | 2.07 | 13.09 | 2.90 | 23.82 |
| 24.66 | 12.21 | 8.78 | 74.00 | 24.60 | 22.44 |
| 34.88 | 17.27 | 16.56 | 0.00 | 0.00 | 0.00 |
| 49.33 | 0.00 | 46.84 | 0.00 | 0.00 | 0.00 |
| >49.33 | 0.00 | 23.42 | 0.00 | 65.65 | 44.91 |

Table D-1 (continued). PARTICLE SIZE DISTRIBUTIONS FOR SELECTED MINING SOURCE SAMPLES

| Size range, | Sample C12 Coal loading @60m | Sample C13 Exposed area ? | Sample C14 Truck dump @40m | Sample D1 Truck dump @30m | Sample D2 Truck dump @30m |
|---|---|---|---|---|---|
| <3.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.08 | 0.10 | 0.47 | 0.00 | 0.00 | 0.00 |
| 4.36 | 0.68 | 1.79 | 0.42 | 0.06 | 0.32 |
| 6.17 | 0.83 | 3.81 | 2.78 | 0.43 | 1.91 |
| 8.72 | 2.34 | 10.75 | 13.44 | 0.84 | 4.75 |
| 12.33 | 4.42 | 6.75 | 47.51 | 3.75 | 10.75 |
| 17.44 | 6.25 | 0.00 | 35.85 | 6.75 | 17.74 |
| 24.66 | 35.35 | 0.00 | 0.00 | 13.64 | 7.17 |
| 34.88 | 50.02 | 76.43 | 0.00 | 30.87 | 0.00 |
| 49.33 | 0.00 | 0.00 | 0.00 | 43.66 | 57.36 |
| >49.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| Size range, | Sample D3 Haul road @15m | Sample D4 Haul road @15m | Sample D5 Topsoil removal @30m | Sample D6 Topsoil removal ? | Sample D7 Dragline @85m |
|---|---|---|---|---|---|
| <3.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.08 | 0.00 | 0.24 | 0.04 | 0.11 | 0.02 |
| 4.36 | 0.15 | 0.54 | 0.44 | 0.23 | 0.19 |
| 6.17 | 0.33 | 1.65 | 1.03 | 1.46 | 1.04 |
| 8.72 | 0.00 | 3.23 | 1.29 | 5.27 | 2.77 |
| 12.33 | 5.24 | 14.18 | 5.02 | 8.42 | 6.36 |
| 17.44 | 19.78 | 31.54 | 6.45 | 12.83 | 5.54 |
| 24.66 | 34.94 | 48.63 | 25.54 | 15.54 | 19.56 |
| 34.88 | 39.55 | 0.00 | 30.98 | 14.66 | 33.21 |
| 49.33 | 0.00 | 0.00 | 29.21 | 41.48 | 31.32 |
| >49.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| Size range, | Sample D8 Topsoil dump @20m | Sample D9 Topsoil dump @20m | Sample D10 Storage pile @10m | Sample E1 Coal loading @20m | Sample E2 Truck dump @10m |
|---|---|---|---|---|---|
| <3.08 | 0.00 | 0.00 | 0.00 | 0.03 | 0.48 |
| 3.08 | 0.05 | 0.00 | 0.00 | 0.09 | 0.42 |
| 4.36 | 0.22 | 0.09 | 0.52 | 0.30 | 3.42 |
| 6.17 | 0.63 | 0.52 | 1.36 | 0.64 | 6.53 |
| 8.72 | 1.19 | 2.21 | 3.20 | 1.40 | 14.62 |
| 12.33 | 1.69 | 4.16 | 6.33 | 2.34 | 28.76 |
| 17.44 | 9.55 | 2.94 | 10.23 | 3.31 | 5.09 |
| 24.66 | 13.50 | 0.00 | 0.00 | 7.02 | 0.00 |
| 34.88 | 19.11 | 23.53 | 20.47 | 9.93 | 40.69 |
| 49.33 | 54.05 | 66.56 | 57.90 | 37.47 | 0.00 |
| >49.33 | 0.00 | 0.00 | 0.00 | 37.47 | 0.00 |

Table D-1 (continued). PARTICLE SIZE DISTRIBUTIONS FOR SELECTED MINING SOURCE SAMPLES

| Size range, | Sample E3 Coal loading @30m | Sample E4 Truck dump @20m | Sample E5 Overburden shovel @20m | Sample E6 Haul road @20m | Sample E7 Haul road @20m |
|---|---|---|---|---|---|
| <3.08 | 0.05 | 0.02 | 0.00 | 0.00 | 0.00 |
| 3.08 | 0.20 | 0.18 | 0.01 | 0.03 | 0.00 |
| 4.36 | 0.56 | 0.07 | 0.34 | 0.70 | 0.32 |
| 6.17 | 0.44 | 0.62 | 0.81 | 1.70 | 0.68 |
| 8.72 | 2.33 | 2.27 | 3.19 | 4.04 | 1.91 |
| 12.33 | 2.71 | 0.49 | 5.80 | 10.00 | 21.59 |
| 17.44 | 4.38 | 6.97 | 23.70 | 44.48 | 20.37 |
| 24.66 | 6.19 | 3.94 | 10.31 | 22.86 | 14.40 |
| 34.88 | 8.76 | 22.32 | 14.58 | 16.18 | 40.74 |
| 49.33 | 24.79 | 0.00 | 41.26 | 0.00 | 0.00 |
| >49.33 | 49.58 | 63.13 | 0.00 | 0.00 | 0.00 |

| Size range, | Sample E8 Overburden dump @10m |
|---|---|
| <3.08 | 0.00 |
| 3.08 | 0.00 |
| 4.36 | 0.31 |
| 6.17 | 1.27 |
| 8.72 | 4.14 |
| 12.33 | 9.36 |
| 17.44 | 28.70 |
| 24.66 | 6.24 |
| 34.88 | 0.00 |
| 49.33 | 49.97 |
| >49.33 | 0.00 |

# APPENDIX E

# PROCEDURES FOR PARTICLE SIZE DETERMINATION

Samples for particle size analysis were collected at the same locations as some of the downwind hi vol samples. A nucleopore filter holder and pump were used to obtain the particulate samples on 47 mm millipore filters. Samples were taken for a shorter time period than the corresponding hi vols so that distinct particles could easily be observed as a result of the light loading on the filter media. No effort was made to determine the weight of material collected or to calculate concentrations from the millipore samples.

The 67 samples were labeled and transported to the laboratory in individual plastic containers.

A wedge was cut from each filter and a slide prepared by wetting the wedge with fluid of refractive index 1.55 and covering it with a cover slip. A Porton reticle of field area 0.0492 $mm^2$ was used to define the counting area. The particle size distributions in four of these fields were determined using a polarizing microscope.

The majority of particles on all slides were roughly square in cross section, so a cubic shape factor was assumed. The number of particles in the four fields in each of 11 size ranges was counted and recorded. Distribution of particles by weight was calculated by computer. A uniform density for all particles was assumed. Finally, mass median diameter for each sample was determined by plotting the percentages by weight in each size range cumulatively on log probability paper. In most cases, the resulting curves were nearly linear.

A Polaroid photograph at 100X magnification was taken of each slide. The photographs are not necessarily of one of the four fields which was counted. One photograph for each of the five mines is shown in Figures D-1 through D-5.

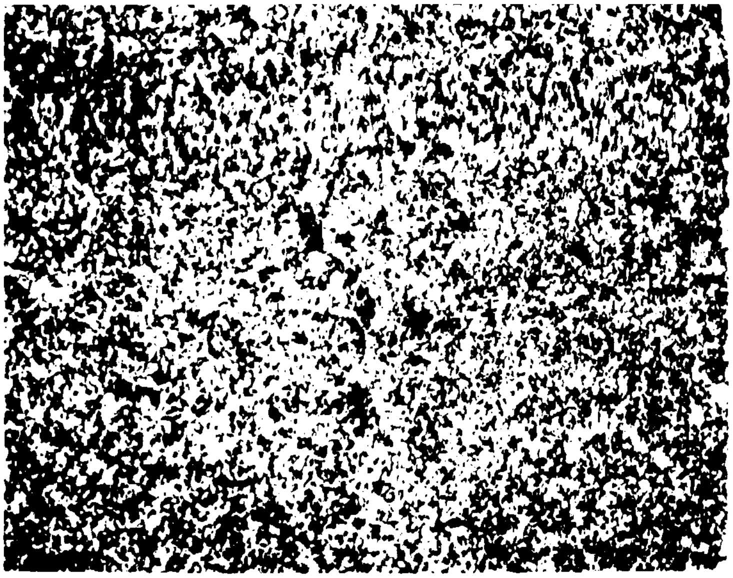

Figure D-1. Particles from haul roads at mine A at 20 m distance, 100X.

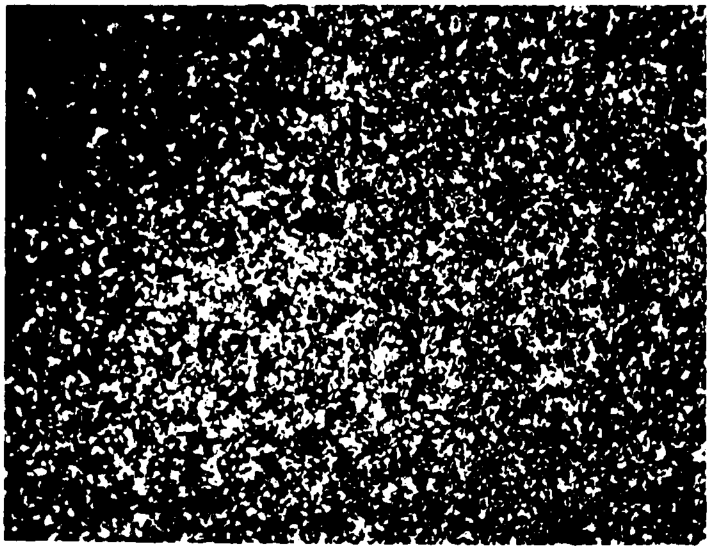

Figure D-2. Particles from storage piles at mine B at 30 m distance, 100X.

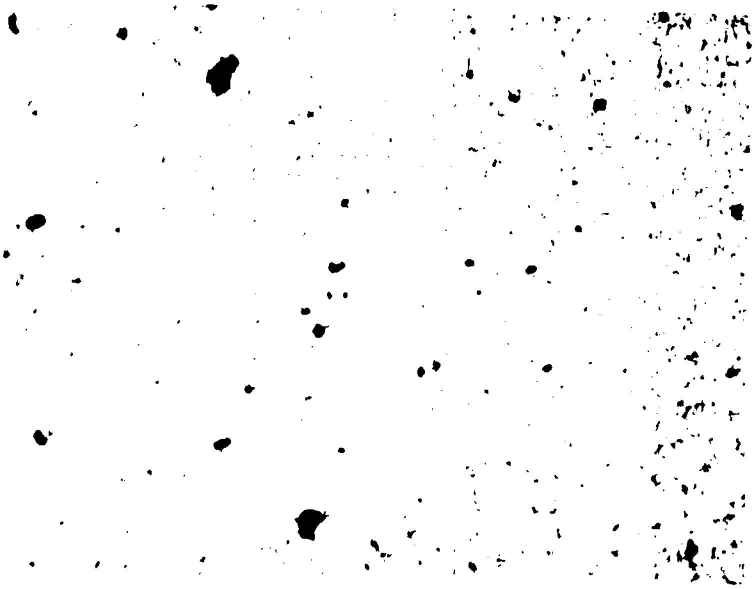

Figure D-3. Particles from coal blasting at mine C at 110 m distance, 100X.

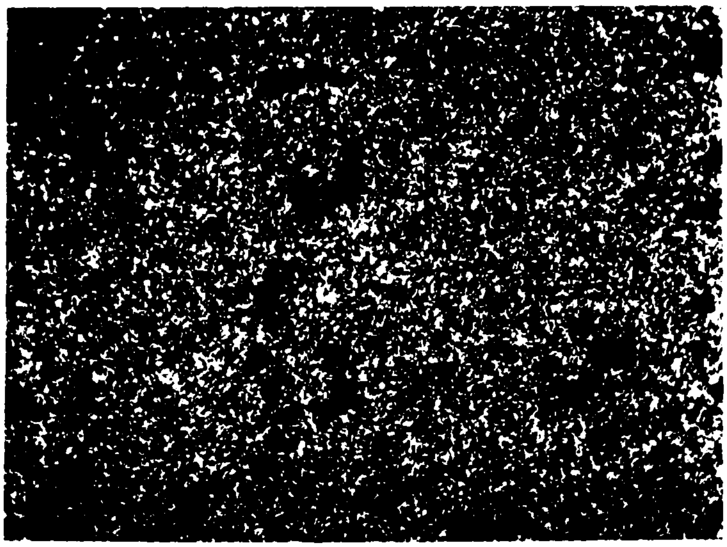

Figure D-4. Particles from dragline operation at mine D at 85 m distance, 100X.

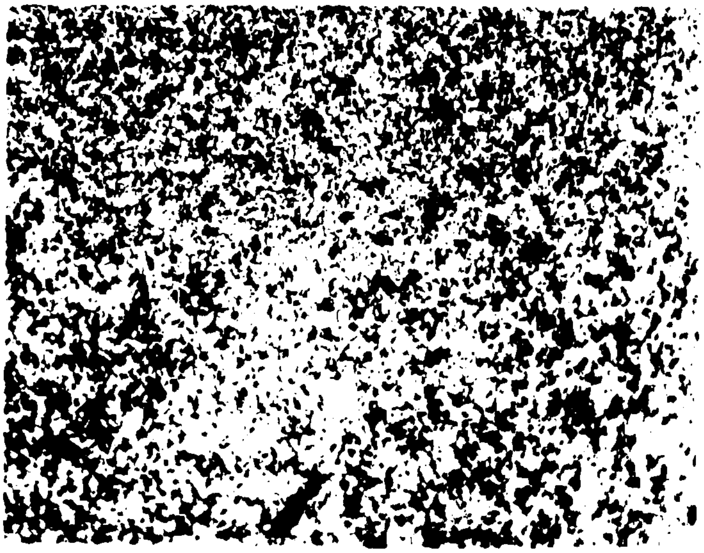

Figure D-5. Particles from truck dump at mine E at 10 m distance, 100X.

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

| 1. REPORT NO. | 2. | 3. RECIPIENT'S ACCESSION NO. |
|---|---|---|
| EPA-908/1-78-003 | | |

| 4. TITLE AND SUBTITLE | 5. REPORT DATE |
|---|---|
| Survey of Fugitive Dust from Coal Mines | February 1978 |
| | 6. PERFORMING ORGANIZATION CODE |

| 7. AUTHOR(S) | 8. PERFORMING ORGANIZATION REPORT NO. |
|---|---|
| Kenneth Axetell, Jr. | 3311 |

| 9. PERFORMING ORGANIZATION NAME AND ADDRESS | 10. PROGRAM ELEMENT NO. |
|---|---|
| PEDCo Environmental, Inc.<br>Chester Towers, 11499 Chester Road<br>Cincinnati, Ohio 45246 | 11. CONTRACT/GRANT NO.<br>68-01-4489 |

| 12. SPONSORING AGENCY NAME AND ADDRESS | 13. TYPE OF REPORT AND PERIOD COVERED |
|---|---|
| U.S. Environmental Protection Agency<br>Region VIII, Air Planning & Operations Section<br>Denver, Colorado 80295 | Final<br>14. SPONSORING AGENCY CODE |

15. SUPPLEMENTARY NOTES

U.S. EPA Project Officer - E. A. Rachal, Air Planning & Operations Section

16. ABSTRACT

Particulate sampling was performed at five Western surface coal mines for the purpose of developing emission factors for individual mining operations. The sampling method for these unconfined fugitive dust sources was upwind/downwind ambient sampling, with two upwind samplers and either four or six samplers in the plume for each sampling period. Emission rates were determined by use of atmospheric dispersion equations relating emissions and ambient concentrations. A total of 213 sampling periods were evenly distributed among the five mines.

Emission factors were produced for 12 mining operations: dragline, haul roads, shovel/truck loading, blasting, truck dump, storage pile, drilling, fly-ash dump, train loading, topsoil removal, front-end loader, and overburden dumping. One other source, exposed areas, was sampled extensively but yielded unexplainable data that could not be used to develop an emission factor.

The study was also designed to evaluate the fallout or deposition rate of particulate from the coal mining sources. However, the apparent emission rates calculated from concurrent samples taken at different distances from the source did not show a consistent decrease with distance to indicate that fallout was occurring.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Descriptors:<br>Coal Mines<br>Particulates<br>Emission Factors<br>Mining | Identifier:<br>Western United States<br>Fugitive Emissions<br>Particle Size Distribution | |

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