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MODELING FUGITIVE DUST IMPACTS FROM SURFACE COAL MINING OPERATIONS - PHASE II

Model Evaluation Protocol

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PREFACE

This model evaluation protocol was prepared by Midwest Research Institute (MRI) and AlphaTRAC, Inc. (subcontractor) for the U.S. Environmental Protection Agency under EPA Contract No. 68-D2-0159, Work Assignment (WA) No. I-06. Mr. Jawad Touma is the EPA Work Assignment Manager (WAM) for the Technical Support Division, Office of Air Quality Planning and Standards. This protocol presents the methodology for evaluating the performance of atmospheric dispersion models in predicting the fugitive dust impacts from surface coal mines. During the process of developing this protocol, input regarding the objectives of the model evaluation and the methodologies incorporated were solicited and received from the Wyoming Mining Association and the State of Wyoming; comments received were incorporated into this final protocol.

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SECTION 1

INTRODUCTION

Section 234(a) of the amended Clean Air Act states the following: "Prior to any use of the Industrial Source Complex (ISC) Model using AP-42 Compilation of Air Pollutant Emission Factors to determine the effect on air quality of fugitive particulate emissions from surface coal mines, for purposes of new source review or for purposes of demonstrating compliance with national ambient air quality standards for particulate matter applicable to periods of 24 hours or less, under section 110 or parts C or D of title I of the Clean Air Act, the Administrator shall analyze the accuracy of such model and emission factors and make revisions as may be necessary to eliminate any significant over-prediction of air quality effect of fugitive particulate emissions from such sources. Such revisions shall be completed not later than 3 years after the date of enactment of the Clean Air Act Amendments of 1990. Until such time as the Administrator develops a revised model for surface mine fugitive emissions, the State may use alternative empirical based modeling approaches pursuant to guidelines issued by the Administrator."

In response to the Clean Air Act mandate, a two-phase program is being conducted to evaluate the performance of emission factors and dispersion models applicable to surface coal mining operations. In Phase I, a two-part field study was performed to compile a comprehensive data base that could be used as a base for the performance evaluation (Phase II).

The first part of the Phase I study consisted of a field testing program (Muleski, et al., 1994) performed in September-October 1992 at a large Western surface coal mine, under Work Assignments 37 and 55 of Contract No. 68-D2-0123. The study site was the Cordero mine within Wyoming's Powder River Basin. The majority of this research was directed toward the validation and improvement of particulate emission factors for various mining operations.

The second part of the Phase I study (EPA, 1994), to gather and assemble monitoring data for dispersion model evaluation, was performed during the May-July 1993 time period at the Cordero mine, under Work Assignment No. 8 of EPA Contract No. 68-D2-0159. The primary purpose of this effort was to compile concurrent ambient air quality data, meteorological data, and source activity data collected during thirty 24-h monitoring periods. This work included the following activities:

- Collection of 24-h air quality data for TSP (particulate matter captured by the standard high-volume air samples) and PM-10 (particulate matter nominally 10 microns and less in aerodynamic diameter) from a nine-station monitoring network distributed in and around the Cordero mine;

- Collection of continuous on-site meteorological data (including temperature, precipitation, wind speed, and wind direction) both above grade and inside an active pit within the mine;

- Collection of time-resolved information about mining operations (source activity) during three observation periods constituting each 24-hr monitoring period.[a]

- Estimation of hourly emission rates for all significant sources (i.e., traffic on haul roads and equipment operations associated with topsoil, overburden, and coal removal) operating during the monitoring periods; and

- Assembly of a comprehensive data base containing all of the above information in a suitable electronic format.

This protocol has been prepared to define the procedure that will be used (a) to identify the best-performing model(s) for predicting the impacts of particulate emissions from surface coal mines and (b) to identify "significant" overprediction, if it occurs. A "model" refers to the combination of an atmospheric dispersion model and the required input data on source emissions and meteorology. The models of greatest interest for predicting air pollutant concentration fields in the vicinity of open pit mines are the current version and a new version of the Industrial Source Complex Short

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[a]Because the fixed source activity observation periods corresponded closely to mine work shifts, the term "shift" is used in this report to characterize observation periods.

Term (ISCST) dispersion model. in conjunction with existing AP-42 emission factors and revised factors developed from the Phase I source testing at the Cordero mine.

While Section 234 of the CAA is directly concerned with model overprediction, it should be noted that model underprediction is also of concern to EPA. On balance, a model that is unbiased is preferable to one that significantly over- or underpredicts ambient levels. Clearly, use of an unbiased model minimizes the chance of making errors in either direction--i.e., inadequate protection against adverse environmental effects vs. unnecessary and costly control efforts.

During the process of developing this protocol, inputs were solicited and received from the Wyoming Mining Association and the State of Wyoming regarding the objectives of the model evaluation and the methodologies that are incorporated into this protocol.

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SECTION 2

OVERALL APPROACH TO MODEL PERFORMANCE EVALUATION

This section introduces the components of the candidate modeling systems and summarizes the methodology for model performance evaluation.

2.1 CANDIDATE MODELING SYSTEM COMPONENTS

Each candidate modeling system will consist of an atmospheric dispersion model, an emission inventory, and a geometric representation scheme for each source category. Two dispersion models will be evaluated: ISCST2 and ISCSTM. The latter is a variation of ISCST2 and contains a new deposition algorithm (DEPST), an upgraded area source algorithm (AREA-ST), and an added pit retention algorithm.

The emission inventory identifies and locates the emission sources of interest and assigns an estimated emission rate to each source element. A calculation of the estimated emission rate for a given source requires data on source activity, uncontrolled emission factor, and control efficiency. The mathematical expression for this calculation is as follows:

$$R = Me\,(1 - c) \qquad (1)$$

where: R = estimated mass emission rate in the specified particle size range (mass/time)

M = source activity (activity/time)

e = uncontrolled emission factor in the specified particle size range, i.e., mass of uncontrolled emissions per unit of source activity (mass/activity)

c = fractional efficiency of control (dimensionless)

Section 3 provides detailed information about (a) the sources to be included in the emission inventory, (b) three sets of emission factors to be used for these sources, (c) source activity representation, (d) control efficiency determination, and (e) appropriate geometric source representation schemes that are compatible with ISCST2 and ISCSTM.

Section 4 specifies the modeling systems that will be evaluated against the observational air quality data base for PM-10 and TSP. These modeling systems range from "base case" that best represents current practice for assessing surface coal mine impacts, to systems that incorporate more refinements to the base case dispersion model, emission factors, source representation, and source activity resolution.

Section 5 describes the observational data bases generated during the thirty 24-h monitoring periods at the Cordero mine. These include the source activity, meteorology, and air quality (PM-10 and TSP) data bases that will be used in the model evaluation. As noted above, the source activity data are incorporated into the emission inventory, providing the temporal resolution.

2.2 EVALUATION METHODOLOGY

The statistical methodology for model performance evaluation will be applied separately for PM-10 and TSP. It will consist of two steps, determining the best-performing model(s) and assessing model overprediction. The procedures for determination of model performance are presented in detail in Section 6. The procedures for evaluation of model overprediction are discussed in detail in Section 7.

The first step will be to identify one model (or a group of models) as the best performing model. This evaluation will be based on pair-wise comparisons of observed and predicted robust highest concentrations for each monitoring site, i.e., the concentrations will be paired in space but not in time. Models will be compared using a composite measure of performance across the nine monitoring stations, with the stations with the greatest source impact receiving greater weighting in the composite measure. Relative model performance will be evaluated statistically via a bootstrap resampling procedure.

The second stage of the model evaluation process will be to determine which model or models do not significantly overpredict. The evaluation of model overprediction will consist of three elements: (1) a statistical evaluation of model overprediction; (2) an historical data review of particulate concentrations observed in the Powder River Basin; and (3) a model sensitivity analysis to assess whether the best performing model is functioning in a reasonable manner for use in regulatory model applications.

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SECTION 3

SOURCE REPRESENTATION

Source representation denotes the manner in which (a) the sources identified in the emissions inventory are spatially and temporally distributed and (b) geometric forms are used to depict the various sources. Spatial variations in emissions occur because source locations move as the active mining area migrates; for example, such would be the case for in-pit operations. On the other hand, temporal variations in emissions may occur even though the source location is fixed, because of variations in (a) source activity, (b) emission factor correction parameters, or (c) efficiency of add-on control measures. For example, permanent haul road emission rates may vary in time because of variations in traffic volume of haul trucks or in the moisture content of the road surface material as caused by rainfall or watering for dust control.

This section describes the emission source components of the candidate modeling systems that will be used as inputs for the dispersion models to be evaluated. These are (a) emission sources to be included in the inventory, (b) emission factors, (c) measure of source activity, (d) control efficiency, (e) geometric representation, (f) release height and initial vertical dispersion, and (g) particle size distribution.

3.1 EMISSION SOURCES

The following emission sources will be included in the Cordero mine emission inventory input to the dispersion models for evaluation:

- Haul trucks traveling on unpaved haul roads
- Water trucks traveling on unpaved haul roads (to control dust emissions)
- Light-duty vehicles traveling on unpaved haul roads
- Grader travel on unpaved haul roads (for road maintenance)
- Dragline (bucket dumping—overburden)

- Haul truck loading (with power shovel)
  - coal
  - overburden
- Haul truck dumping
  - coal
  - overburden
- Bulldozing (in truck loading area)
  - coal
  - overburden
- Scraper travel on unpaved surfaces (for topsoil removal and scoria mining)
- Wind erosion of active surface areas
  - haul roads
  - truck loading areas for coal and overburden
  - truck unloading areas for overburden

The above sources were selected based on those categories identified in past emission inventories of surface coal mines (e.g., Cole et al., 1985). Any additional sources are considered to be sufficiently insignificant to be neglected in this study.

In addition to the sources within the Cordero mine property, haul trucks traveling on the main unpaved haul road at the Caballo Rojo mine to the north constitute a potentially significant source impacting on the air quality monitoring stations under north wind conditions.

3.2 EMISSION FACTORS

Most of the emission factors that will be used are found in EPA's *Compilation of Air Pollutant Emission Factors, AP-42* (EPA, 1985). However, for the most important source category (haul trucks and water trucks traveling on haul roads), a new emission factor equation developed from Cordero source testing data will also be used, as discussed later in this subsection. Furthermore, for heavy-duty vehicles (haul trucks and water trucks) and light-duty vehicles traveling on haul roads, a third set of emission factors will also be used, as derived from adjustment of directly measured emission rates.

Table 1 summarizes the rationale for use of the three sets of emission factors. Note that for sources other than heavy-duty and light-duty vehicles traveling on haul roads, the Set 2 and Set 3 emission factors are identical.

Table 2 compares the set of PM-10 and TSP emission factors from AP-42 Section 8.24 (Western Surface Coal Mining), with the partially revised set of emission factors, for the sources to be included in the inventory. The set of emission factors found in Section 8.24 of AP-42 (Set 1) represents current practice in assessing the impact of surface coal mines. The Set 2 emission factors consist of: a new factor for the largest source (heavy vehicles traveling on unpaved haul roads); factors currently

TABLE 1. EMISSION FACTORS

Terminology	Description	Rationale
Set 1	Equations found in AP-42 Section 8 24 for all specified sources, with default values for all correction parameters	Represents the commonly used predictive equations for estimating dust emissions from surface coal mines
Set 2	• New equation for haul trucks • Section 11.2 equations for haul truck loading and dumping, dragline, light-duty vehicles, and wind erosion • Section 8.24 equations for scrapers, graders and bulldozers • Default values for all correction parameters except for haul road surface silt and moisture content[a]	Incorporates: • Recommended improvements to the predictive equations in Section 8.24 (except for scrapers, graders and bulldozers), and • Site-specific values of haul road surface silt and moisture content in lieu of default values
Set 3 (differs from Set 2 only for heavy-duty vehicles [haul trucks and water trucks] and light-duty vehicles traveling on haul roads)	• Hourly emission factor values (i.e., emission rate per unit of source activity) for each road segment • Derived from representative on-site (Cordero) emission measurements (uncontrolled) with adjustments for mitigation due to hourly rainfall and shift-resolved watering activity	Constitutes the most accurate short-term estimation of dust emissions from haul roads (the predominant source category) at Cordero

[a]Representative values of road surface silt and moisture content for coal and overburden haul roads, coal haul ramps and access roads will be derived from approximately 100 samples collected during the 30 days of ambient monitoring.

TABLE 2. EMISSION FACTOR SETS[a]

Sources	Set 1 PM-10	Set 1 TSP	Set 2 PM-10	Set 2 TSP	Units
Bulldozing—coal	$14\ s^{1\ 5}/M^{1\ 4}$	$78\ 4\ s^{1\ 2}/M^{1\ 3}$	$14\ s^{1\ 5}/M^{1\ 4}$	$78\ 4\ s^{1\ 2}/M^{1\ 3}$	lb/h
—overburden	$0\ 75\ s^{1\ 5}/M^{1\ 4}$	$5\ 7\ s^{1\ 2}/M^{1\ 3}$	$0\ 75\ s^{1\ 5}/M^{1\ 4}$	$5\ 7\ s^{1\ 2}/M^{1.3}$	lb/h
Dragline[b]	$0.0016\ d^{0\ 7}/M^{0\ 3}$	$0\ 0021\ d^{1\ 1}/M^{0\ 3}$	$k(0\ 0032)(U/5)^{1\ 3}/(M/2)^{1\ 4}$		lb/yd^3 (Set 1) lb/ton (Set 2)
Graders	$0\ 0306\ S^{2\ 0}$	$0\ 040\ S^{2\ 5}$	$0\ 0306\ S^{2\ 0}$	$0.040\ S^{2\ 5}$	lb/VMT
Haul trucks traveling on unpaved roads[c]	$0.0031w^{3.5}$	$0\ 0067\ w^{3\ 4}L^{0\ 2}$	$k\ (s/3)^{0\ 8}(M/2)^{-0\ 2}$		lb/VMT
Haul truck loading—coal[b]	$0.089/M^{0\ 9}$	$1\ 16/M^{1\ 2}$	$k(0\ 0032)(U/5)^{1\ 3}/(M/2)^{1.4}$		lb/ton
—overburden[b]	None[d]	0 037	$k(0\ 0032)(U/5)^{1\ 3}/(M/2)^{1\ 4}$		lb/ton
Haul truck unloading—coal[b]	None[d]	0 027	$k(0\ 0032)(U/5)^{1.3}/(M/2)^{1.4}$		lb/ton
—overburden[b]	None[d]	0 002	$k(0.0032)(U/5)^{1\ 3}/(M/2)^{1\ 4}$		lb/ton
Light-duty vehicles traveling on unpaved roads[e]	$2\ 2/M^{4\ 3}$	$5.79/M^{4\ 0}$	$k(5.9)(s/12)(S/30)(W/3)^{0\ 7}(w/4)^{0\ 5}$		lb/VMT
Scrapers on unpaved surface travel	$3\ 7\times10^{-6}s^{1.4}W^{2\ 5}$	$2.7\times10^{-5}s^{1\ 3}W^{2\ 4}$	$3\ 7\times10^{-6}s^{1\ 4}W^{2\ 5}$	$2\ 7\times10^{-5}s^{1.3}W^{2.4}$	lb/VMT
Water trucks traveling on unpaved roads[c]	Not specifically stated, but can use equations for haul trucks traveling on unpaved roads		$k\ (s/3)^{0\ 8}(M/2)^{-0\ 2}$		lb/ton
Wind erosion					
—coal loading areas and haul roads[f]	None[d]	None, but can use factor for wind erosion from overburden loading areas	$k \sum_{i=1}^{n} P_i$		lb/acre/h (Set 1) g/m^2-yd (Set 2)
—overburden loading areas and unloading areas[f]	None[d]	0 087	$k \sum_{i=1}^{n} P_i$		lb/acre/h (Set 1) g/m^2-yd (Set 2)

[a]Symbols used·

d = drop height (m)
k = correction parameter, as noted in the following footnotes
L = surface silt loading (g/m^2)
M = moisture content (%)
N = number of disturbances per year (yr^{-1})
P_i = erosion potential corresponding to the observed fastest mile of wind from the ith period between disturbances (g/m^2)

$$P_i = 58\ (u^* - u_t^*)^2 + 25\ (u^* - u_t^*)$$

where: u^* = friction velocity (m/s)
u_t^* = threshold friction velocity (m/s)

S = mean vehicle speed (mph)
s = silt content (%)
U = mean wind speed (mph)
W = mean vehicle weight (ton)
w = mean number of wheels

[b]For PM-10, k = 0 35, for TSP, k = 0 74
[c]For PM-10, k = 3 4, for TSP, k = 16
[d]Will be assumed to be half of the TSP factor; based on particle size data from AP-42 Section 11 2 3
[e]For PM-10, k = 0 36, for TSP, k = 0 80.
[f]For PM 10, k = 0 5, for TSP, k = 1 0

contained in AP-42 Section 11.2 (Fugitive Dust Sources) for aggregate materials handling (i.e., dragline operation and truck loading/dumping), light-duty traffic on unpaved roads, and wind erosion; and factors currently contained in Section 8.24 of AP-42 for bulldozing and for grader and scraper travel on unpaved surfaces.

The rationale for selecting the Set 2 emission factors for heavy vehicles (haul trucks and water trucks) on unpaved haul roads, light-duty traffic on unpaved roads, and scraper travel on unpaved surfaces comes from the results of the fall 1992 emission testing program at the Cordero Mine (Muleski, et al., 1994). Selection of emission factors from Section 11.2. rather than Section 8.24, for materials handling operations (dragline operation and truck loading/dumping) and wind erosion reflects the strengthening of the respective Section 11.2 equations through more recent AP-42 revisions that incorporate the results of additional PM-10 emission testing.

The new (Set 2) emission factor for heavy-duty trucks traveling on unpaved roads (haul trucks and water trucks), as developed from the 1992 emission testing program at Cordero (Muleski, et al., 1994), is given by:

$$e = k\left(\frac{s}{3}\right)^{0.8}\left(\frac{M}{2}\right)^{-0.2} \qquad (2)$$

where:
- e = emission factor in lb/VMT
- k = correction parameter (3.4 for PM-10, 16 for TSP)
- s = surface material silt content (percent)
- M = surface moisture content (percent)

Equation 2 was developed for haul trucks and water trucks together, because both were present on haul roads during testing. Although water trucks are not as heavy as loaded haul trucks, they are much heavier than any other vehicles traveling on haul roads. Also, because water is sprayed from the rear of a water truck, its emissions reflect the before-watering conditions of the road. It should be noted, moreover, that water trucks constituted only a small fraction of haul road traffic.

Table 3 lists the default values for correction parameters for Set 1 and Set 2 emission factors. Default values will be used for the correction parameters required for Set 1 and Set 2 emission factors, with one exception. The exception is the use of haul road moisture and silt content values based upon on-site measurements as correction parameters for the new emission factor equation for heavy duty haul trucks traveling on unpaved roads (Equation 2). In the case of the Set 1 emission factors, the default values used will be the mean values of correction parameters specified in Section 8.24 of AP-42. In the case of the Set 2 emission factors, default values will be selected for the emission factor equations in Chapter 11 of AP-42 based on the following priority: specified mean values; denominators of dimensionless correction parameter terms in the given emission factor equation; or geometric means of specified correction parameter ranges.

TABLE 3. DEFAULT VALUES FOR SETS 1 AND 2 EMISSION FACTOR EQUATIONS

Source	Default Values	
	Set 1	Set 2
Bulldozing-coal	s = 8.8%, M = 10.4%	Same as Set 1
-- overburden	s = 6.9% M = 7.9%	
Dragline	d = 28.1 ft, M = 3.2%	U = 5 mph, M = 2%
Graders	S = 7.1 mph	Same as Set 1
Haul trucks (coal, overburden, water) traveling on unpaved roads	w = 8.1 wheels, L = 40.8 g/m^2	
Coal haul ramps		M = 5.7%, s = 5.57%[a]
Main coal haul roads		M = 5.5%, s = 2.65%[a]
Overburden haul roads		M = 6.8%, s = 4.02%[a]
Access roads		M = 2.1%, s = 9.18%[a]
Haul truck loading (coal)	M = 17.8%	U = 5 mph, M = 2%
Haul truck loading (overburden)	NA	U = 5 mph, M = 2%
Haul truck unloading (coal, overburden)	NA	U = 5 mph, M = 2%
Light duty vehicles traveling on unpaved roads	M = 1.2%	s = 8.4%, S = 30 mph, W = 3 tons, w = 4 wheels
Scrapers on unpaved surface travel	s = 16.4%, W = 53.8 tons	Same
Wind erosion	NA	NA
-- coal loading areas	NA	NA
-- overburden loading areas	NA	NA
-- haul roads		
Caballo Rojo	(See haul trucks)	(See haul trucks)

NOTES:

d = drop height (ft)
L = surface silt loading (g/m^2)
M = moisture content (%)
s = silt content (%)
S = mean vehicle speed (mph)
U = mean wind speed (mph)
w = mean number of wheels
W = mean vehicle weight (ton)
NA = not applicable, i.e., no default values

[a]Silt analysis results from the on-site measurements are presented in Appendix F; moisture analysis results are presented in the Phase I report (EPA, 1994), Table 5-8, pg. 5-33.

The Set 3 emission factors are the same as the Set 2 factors with the exception of the emission factors for heavy-duty vehicles and light-duty vehicles traveling on haul roads. The Set 3 emission factors for heavy-duty vehicles (haul trucks and water trucks) and light-duty vehicles traveling on haul roads were developed from direct source testing of these sources at the Cordero mine during Phase I. Rather than deriving emission factor equations for these sources, representative values of the Phase I source measurements for uncontrolled conditions were used directly in calculating adjusted hourly emission factors. This was accomplished by multiplying the representative (geometric mean) uncontrolled emission factors by the fractional mitigative values that accounted for hourly precipitation and shift-resolved watering activity. Details about this calculation procedure are provided in Appendix A.

The hourly emission factors based directly on emission measurements are more reliable than those that could be derived using even the new emission factor equation for haul roads (Equation 2), because the hourly factors have been adjusted for the effects of hourly rainfalls. If equation 2 were to be used to obtain calculated rates of a comparable level of reliability, large numbers of representative road surface samples would be required to derive highly resolved moisture and silt correction parameters.

For wind erosion, the Set 3 emission factor provides for hourly calculation of particulate emissions (for any hour with winds that exceed the threshold velocity). The Set 3 emission factor assumes that the full erosion potential of a surface is restored when it is disturbed by stationary or low-speed equipment operations. Because moderate-spaced traffic on haul roads releases most of the fines generated by each vehicle pass, the Set 3 emission factor is multiplied by 0.1 when applied to roads.

3.3 SOURCE ACTIVITY

At a surface coal mine, source activity relates to the movement of vehicles, the transfer of excavated materials, and the exposure of disturbed surfaces to high winds. For vehicle traffic, source activity is measured as vehicle-distance traveled. For material transfer, the activity is simply the quantity transferred. For wind erosion, activity should be measured in terms of (a) the amount by which the wind speed exceeds the erosion threshold for the exposed material in question, and (b) the frequency of mechanical disturbances of the erodible surface.

Although documentation of hourly variation in source activity is usually not feasible, shift averages can be determined by multiple observations during each shift, coupled with examination of shift records. This was accomplished as part of the ambient monitoring program at the Cordero mine, using three observation periods that corresponded closely to mine work shifts. The source activity data in the observational data base from the study are detailed further in Section 4.

In preparing emission inventories for model evaluation, source activity will be represented by two levels of resolution—"shift averages for each day" and "60-day shift averages" calculated from the daily shift values. In the first case, the shift-average activity levels vary based upon the specific source observations for the respective source category. In the second case, the daily values for each shift are averaged for the 60-day period that encompasses the ambient monitoring program. Table 4 provides the rationale for selecting these two levels of activity.

TABLE 4. ACTIVITY RESOLUTION

Terminology	Description	Rationale
"Shift averages for each day"	• The activity for each source category follows a variable diurnal cycle (3 shifts)	• Constitutes the most time-resolved representation of source activity
	• The cycle for each day is based on daily Cordero observations of that same category	• Takes into consideration daily changes in location and level of activities (e.g., north versus south pit mining)
"60-day shift averages"	• The activity for each source category follows a fixed diurnal cycle (3 shifts) • The 60-day average activity for each of the three shifts is based on Cordero observations for that source category	• Constitutes potentially more suitable representation of source activity when predicting concentrations that are not paired in time with measured values • Appropriate means for projecting source activity cycle that reflects reasonable use of mining equipment

3.4 CONTROL EFFICIENCY

In the calculation of the emission rates, uncontrolled emissions must be reduced to account for the effects of road watering and natural mitigation (rainfall). In the case of road watering, a control efficiency will be assigned to each road segment where water truck activity was noted during the observation period, except when using the Set 2 emission factor equation for heavy duty trucks traveling on unpaved haul roads (Equation 2). In the later case, the effects of road watering (and rainfall) are reflected in the road surface moisture content as a correction parameter. The control efficiencies used for road watering will be as follows:

	Watering control efficiency		
	Set 1	Set 2	Set 3[a]
Heavy-duty vehicles	50 percent	b	60 percent
Light-duty vehicles	50 percent	50 percent	60 percent

[a]See Appendix A.
[b]Effect of watering reflected in moisture correction parameter.

The 50 percent estimate for watering control efficiency is consistent with past estimates for western surface coal mines. In addition, 50 percent approximates the average control efficiencies for watering of haul roads found in the 1992 testing program (Muleski et al., 1994):

	Watering control efficiency	
	PM-10	TSP
Coal haul roads	52 percent	56 percent
Overburden haul roads	55 percent	21 percent
Both	53 percent	52 percent

Note, however that slightly higher efficiencies are obtained when only those controlled emission tests that were performed within an hour of water application are included; hence, the 60 percent value for the Set 3 factors. This is discussed further in Appendix A.

The mitigative effect of rainfall will be assumed to apply only to unpaved haul roads (heavy duty vehicles, light duty vehicles, graders, and wind erosion) and scraper travel. In most cases, the effect of rainfall will be taken into account by assuming that emissions are negligible for any hour with measurable precipitation (precipitation greater than or equal to 0.01 inch). However, a more complex treatment of rainfall mitigation was used in the development of the Set 3 emission factors for heavy duty and light duty vehicles traveling on haul roads as addressed in Appendix A.

No mitigation due to rainfall will be assumed for the dragline or for truck loading or unloading of bulk materials (coal and overburden), because of the inability of rainfall to quickly penetrate the bulk materials that are being handled.

3.5 GEOMETRIC REPRESENTATION

For ISCST2, roadway emissions are most appropriately represented as a string of volume sources. The ISC User's Manual (EPA, 1992b) recommends using no fewer than N/2 volume sources to represent a line source where N is defined as

$$N = \frac{\text{length of the line source}}{\text{width of the line source}}$$

The ISCST2 accommodates square (N-S)/(E-W) oriented area sources to represent more diffuse working areas of the mine where mined material is transferred. Considerable latitude in choosing the size of the area sources is available to the modeler.

Because ISCSTM allows rectangular area sources of arbitrary orientation, elongated area sources are appropriate to represent roadway emissions, but a string of volume sources can also be used as before. Use of elongated area sources for roads is more convenient because it requires far fewer source elements.

Table 5 lists the geometric representations that will be used for each source category. In the case of haul roads, two "explicit" representations will be used: (a) strings of volume sources (ISCST2 and ISCSTM) and (b) elongated area sources (ISCSTM). For haul truck loading and associated bulldozing activity and wind erosion, upright square area sources will be used with ISCST2, and tilted rectangular area sources (i.e., areas rotated in relation to the system of coordinate axes used in the modeling) will be used with ISCSTM. All other source activities will be represented as upright square area sources, both for ISCST2 and ISCSTM. Table 6 lists the area source grid sizes used for each emission source category.

The representations for vehicle travel on haul roads, haul truck loading (coal and overburden) and associated bulldozing and wind erosion, and haul truck dumping (coal and overburden) are illustrated in the following figures:

Figure 1—Representations for ISCST2
Figure 2—Representations for ISCSTM with haul roads as volume sources (Explicit 1)

TABLE 5. SOURCE REPRESENTATION

Source category	Operating characteristics	Representation	
		ISCST2	ISCSTM
Haul roads (haul trucks, water trucks, light vehicles, graders and wind erosion)	Fixed routes	Explicit—Volume sources (nominal 100 ft spacing); see Figure 1	Explicit 1—Volume sources (nominal 100 ft spacing); see Figure 2 Explicit 2—Rectangular area sources oriented to road segment direction; see Figure 3
Haul truck loading and associated bulldozing and wind erosion, and haul truck dumping	Mobile within definable areas that are fixed at ends of ramps to haul roads	N-S/E-W square area sources; see Figure 1[a,b]	Fixed sources oriented to bench direction; see Figures 2 or 3[b,c]
Dragline	Mobile within definable area that migrates from day to day	Migrating N-S/E-W square area sources; see Figure 4	Migrating N-S/E-W square area sources; see Figure 4
Scraper travel	Mobile within definable area that migrates from day to day	Migrating N-S/E-W square area sources; see Figure 4[k]	Migrating N-S/E-W square area sources; see Figure 4[k]
Wind erosion	Definable areas of surface disturbance where excavation/transfer and traffic are occurring	Same as haul truck loading and haul roads (above)	Same as haul truck loading and haul roads (above)

[a]Figure 1: a1, a2, b1, b2, c1, c2 = North pit coal loading.
[b]Figure 1 for ISCST2 and Figures 2 and 3 for ISCSTM:
d = North pit overburden loading.
e = North pit overburden dumping.
f = Coal dumping.
g = South pit overburden loading.
h = South pit coal loading.
i = South pit overburden dumping.
[c]Figures 2 and 3: a, b, c = North pit coal loading.
[k]Referenced to A1...G9 and V1...Z4 (see Figure 4) grid areas. (Note that only topsoil and scoria mining operations will be modeled.)

TABLE 6. AREA SOURCE GRID SIZES

Source category	Figure	Identifier	Operation	Size (m)	Model	
					ISCST2	ISCSTM
Haul roads (haul trucks, light duty vehicles, graders, and wind erosion)	Figure 3	Roads A...Z	Coal and overburden haulage, access to work areas and road maintenance	305 m x 305 (max)[a]		x
Haul truck loading and associated bulldozing and wind erosion, and haul truck dumping	Figure 1	a1, a2, b1, b2, c1, c2	North pit coal loading	200 × 200	x	
	Figures 2 and 3	a, b, c	North pit coal loading	200 × 400		x
	Figures 1, 2, and 3	d	North pit overburden loading	200 × 200	x	x
		e	North pit overburden dumping	200 × 200	x	x
		f	Coal dumping	200 × 200	x	x
		g	South pit overburden loading	200 × 200	x	x
		h	South pit coal loading	200 × 200	x	x
		i	South pit overburden dumping	200 × 200	x	x
Scraper travel	Figure 4	A1...G9	North pit operation	305 × 305	x	x
		V1...Z4	South pit operation	305 × 305	x	x
Dragline	Figure 4		North pit overburden removal	Variable	x	x

[a]Each straight line road segment (30 5 m [100 ft] width) must be broken into rectangular unit areas having a maximum aspect ratio of 10. Actual road lengths are available in the supporting data files (See Appendix D).

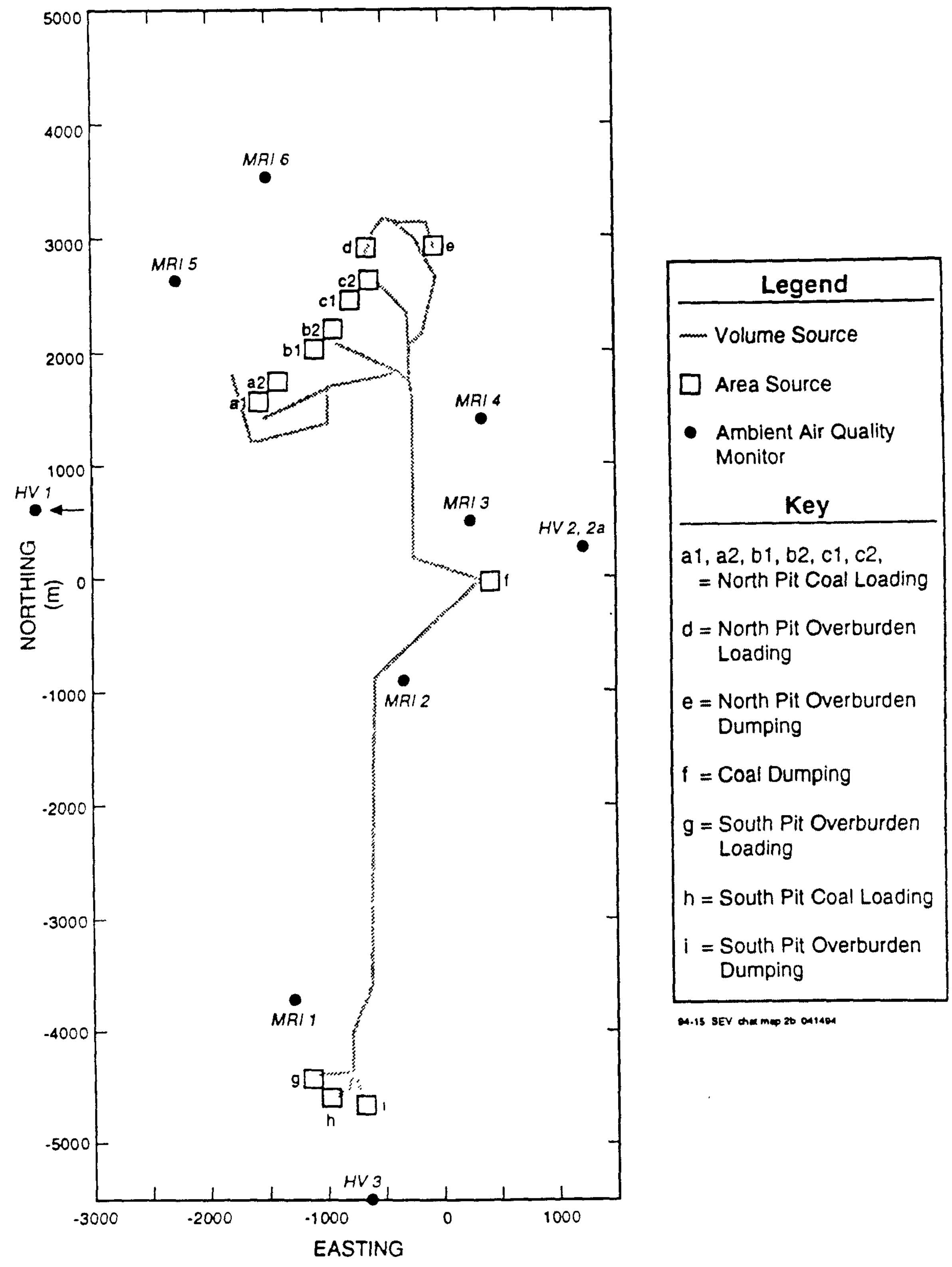

Figure 1. Source representations for ISCST2: haul roads, haul truck loading and dumping.

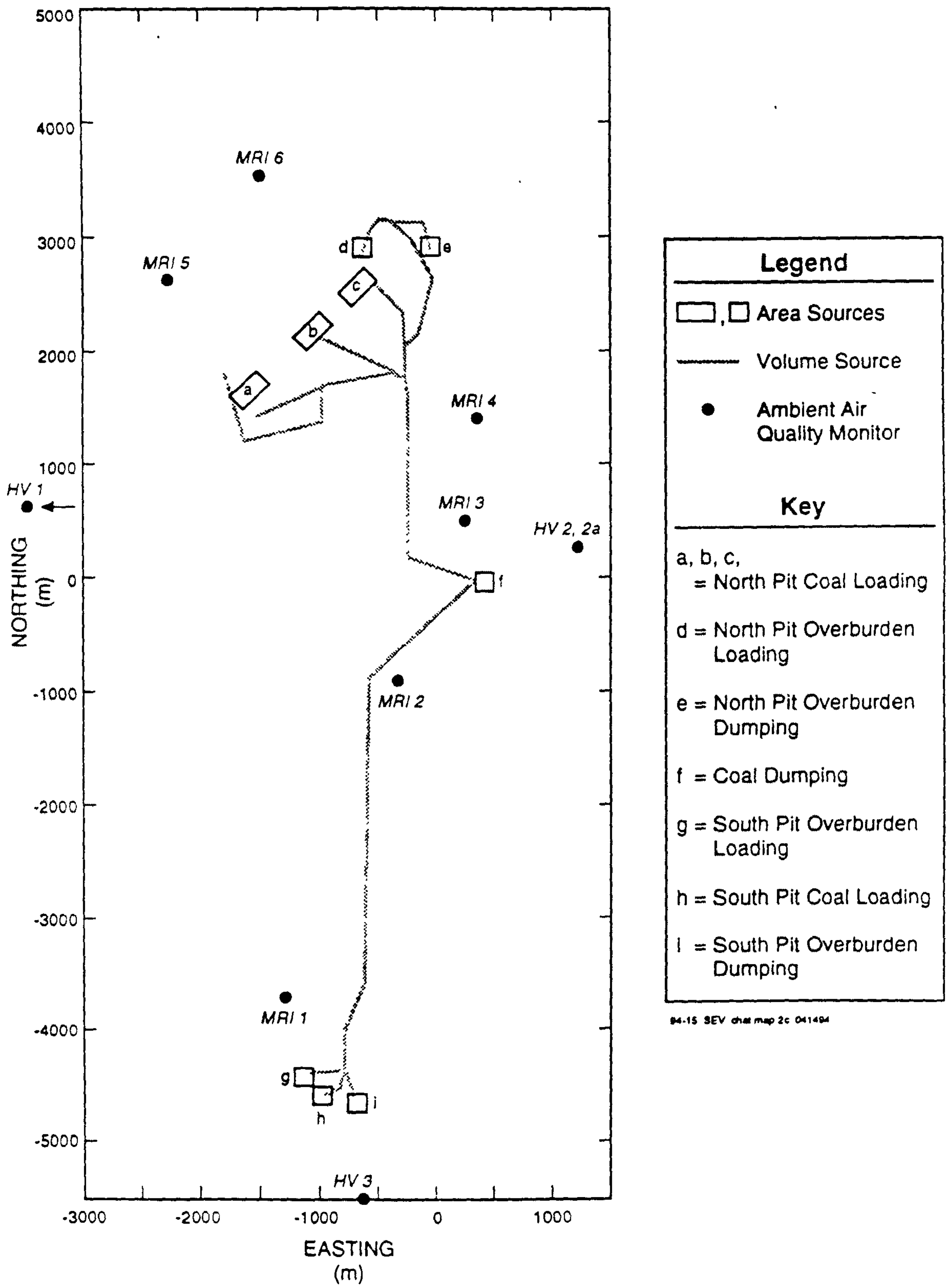

Figure 2. Source representations for ISCSTM: haul roads, haul truck loading and dumping—Explicit 1 (volume source for haul roads).

Figure 3—Representations for ISCSTM with haul roads as elongated area sources (Explicit 2)

For dragline and scraper operations, the source locations are shown in Figure 4. The dragline is represented by one or more squares of varying size and location for each day of operation. These squares lie within the boundary of the irregularly shaped area (shaded) shown along the northwest portion of the north pit. Scraper operations are represented by the square areas in the figure. Because the State of Wyoming coordinate system (1,000 × 1,000 ft) was used to document dragline and scraper activity during the monitoring program, a matching metric area source grid size (305 m × 305 m) was defined.[b] The north pit grid system is assigned letters A...G for the columns and numbers 1...9 for the rows. The south pit grid system is assigned letters V...Z for the columns and 1...4 for the rows. The specific grids that were active on any given day are contained in the observational data bases.

For days when the threshold velocity for wind erosion is exceeded, wind erosion emissions will be added to the grids where truck loading is occurring and to the active haul roads. The traffic in these areas generates pulverized surface material that is far more erodible than exposed surface material containing significant nonerodible fractions (particles larger than about a centimeter in diameter) in areas undisturbed by traffic. With regard to hourly wind erosion of the loading areas, it is assumed that 10 percent of an 80,000 m^2 coal loading area is disturbed in any hour and 15 percent of a 40,000 m^2 overburden loading or unloading area is disturbed in any hour. Because the exact location of an hourly activity within a loading area is unknown, the emissions are assumed to be equally distributed over the entire area.

Not shown in Figures 1, 2, and 3 are the volume sources or elongated area sources that will be used to represent the Caballo Rojo haul road to the north of the Cordero property. The emission rate from this potentially significant source will be calculated using the same techniques as applied to the Cordero haul roads. Daily average source activity data for the Caballo Rojo haul road will be used for this purpose, as described in Appendix B.

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[b]The origin of the metric coordinate system in terms of the Wyoming coordinate system is as follows: 454,000 ft easting; 1,226,000 ft northing.

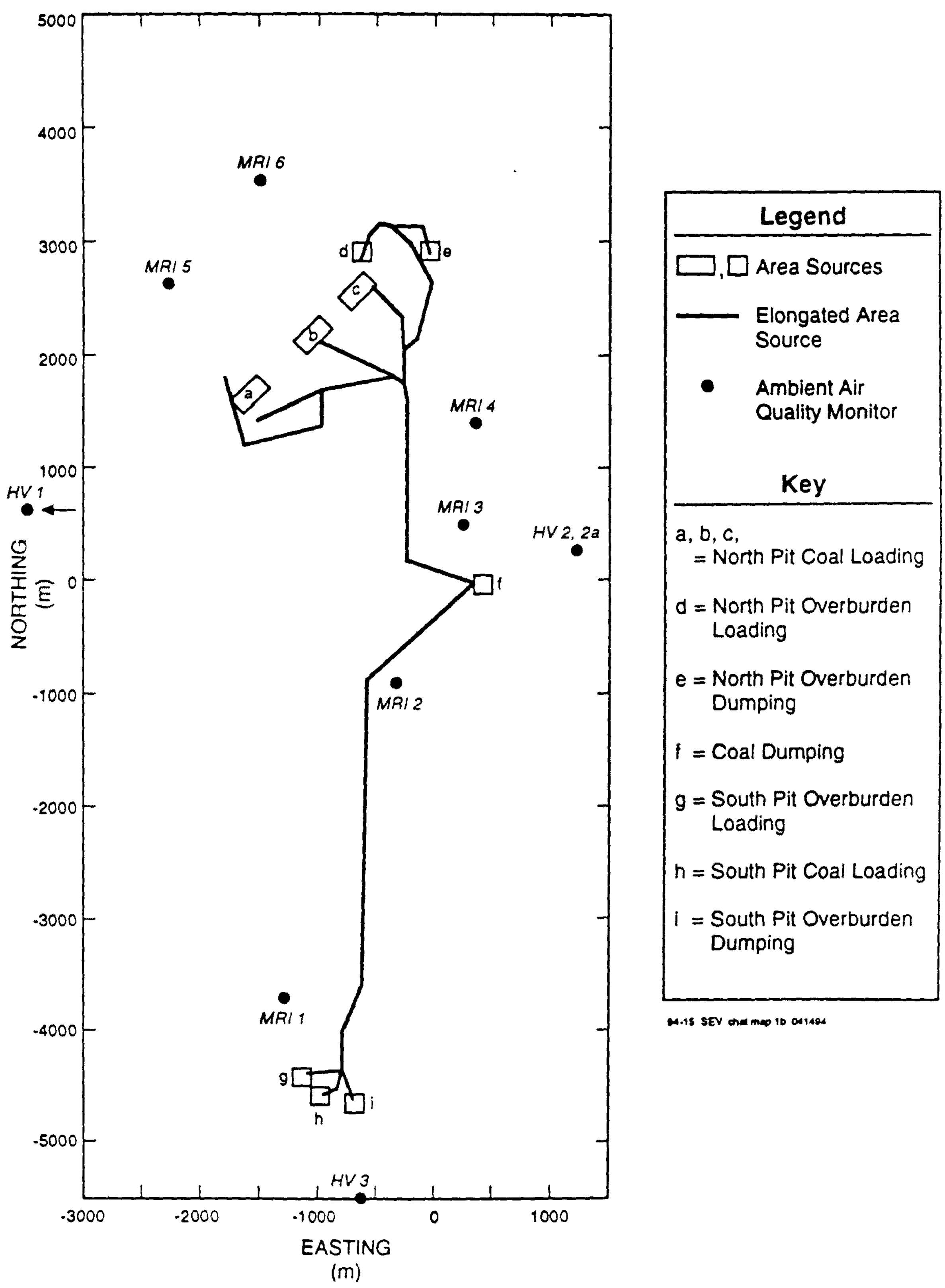

Figure 3. Source representations for ISCSTM: haul roads, haul truck loading and dumping—Explicit 2 (area sources for haul roads).

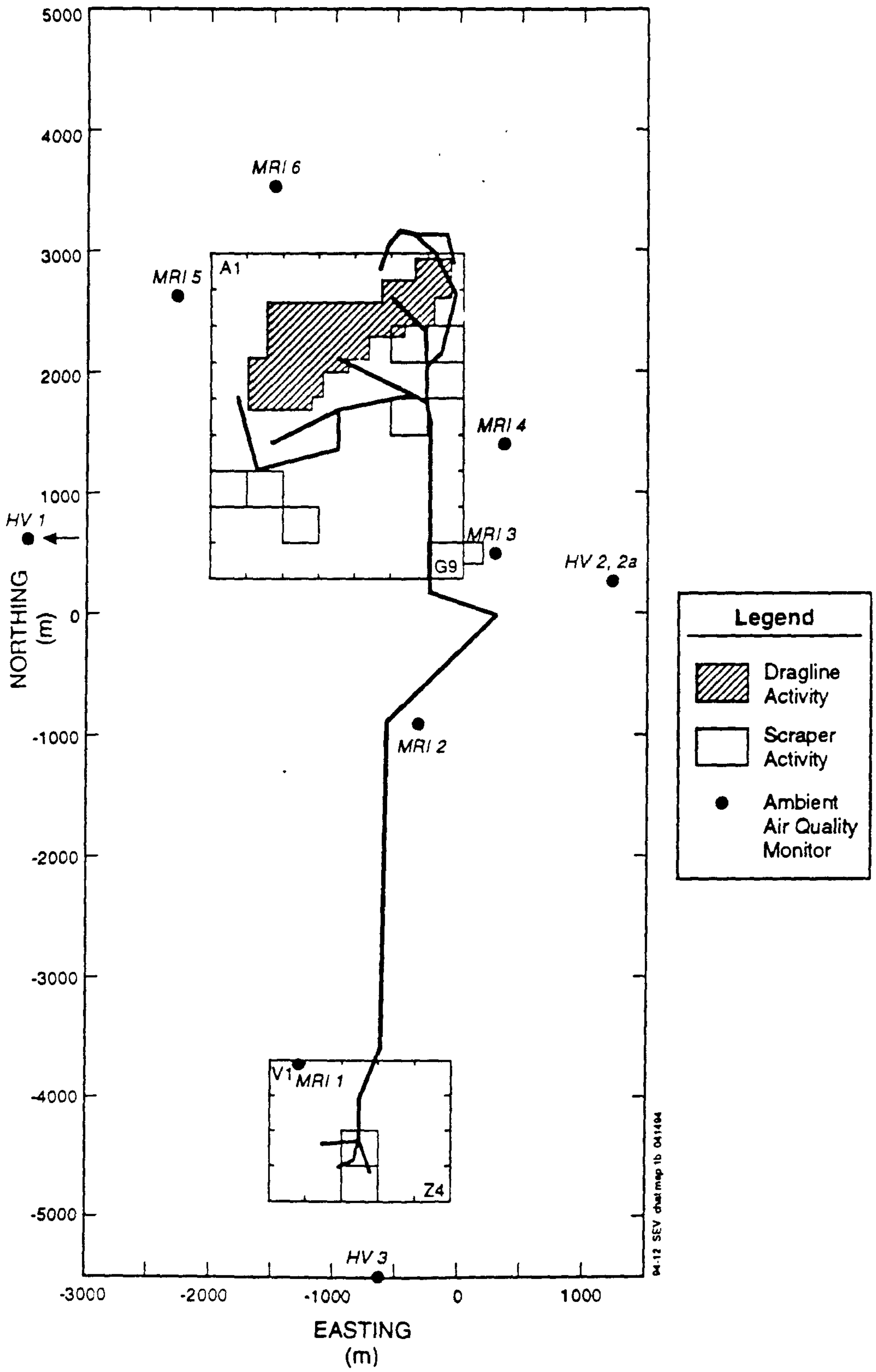

Figure 4. Migrating source representation for dragline (shaded area) and scraper operation (squares)—ISCST2 and ISCSTM.

3.6 RELEASE HEIGHT AND INITIAL VERTICAL DISPERSION

With regard to source elevation, only coal loading and coal dozing occurred at the full pit depth of approximately 50 m during the Cordero monitoring program. The haul road ramps that extended from grade to the pit floor will be assigned a source reference height of 25 m. These ramps are identified by the darkened road segments shown in Figure 5. All other operations will be assumed to occur at grade.

In using volume sources to represent haul roads, a release height of 2 m and an initial vertical dispersion term (σ_{zo}) of 3 m will be used. Both values are based on results from the 1992 source testing program at the Cordero mine. The same values are applicable to area sources.

A release height of 2 m approximates the level in the dust plume that equally divides the mass flux. The 1992 source testing program (Muleski et al., 1994) found that the maximum particulate matter concentration in the profiled haul road dust plumes typically occurred at a height of approximately 1.5 m. However, the mass flux (i.e., the product of concentration and wind speed) occurred at a height of approximately 2 m.

In general, the receptors of interest in the evaluation lie far enough from the volume sources such that adjustments to the release height have only a slight effect on the resulting concentration estimates. For example, changing the release height by a factor of two causes no more than a 3 percent change in modeled concentrations (using ISCST2) at the typical source-monitor distances.

The initial vertical dispersion (σ_{zo}) of 3 m was estimated using guidance contained in the ISC2 user's guide. The guide suggests setting σ_{zo} equal to the height of the source divided by 2.15. The 1992 source testing program (Muleski et al., 1994) found 7 m to be a reasonable estimate of the height of haul road emission plumes at a distance of 5 m downwind from the edge of the road.

As was the case for the release height, changes in σ_{zo} have only a slight effect on the modeled concentrations for the receptor locations of interest. For example, doubling the value of σ_{zo} reduces the predicted concentrations by no more than

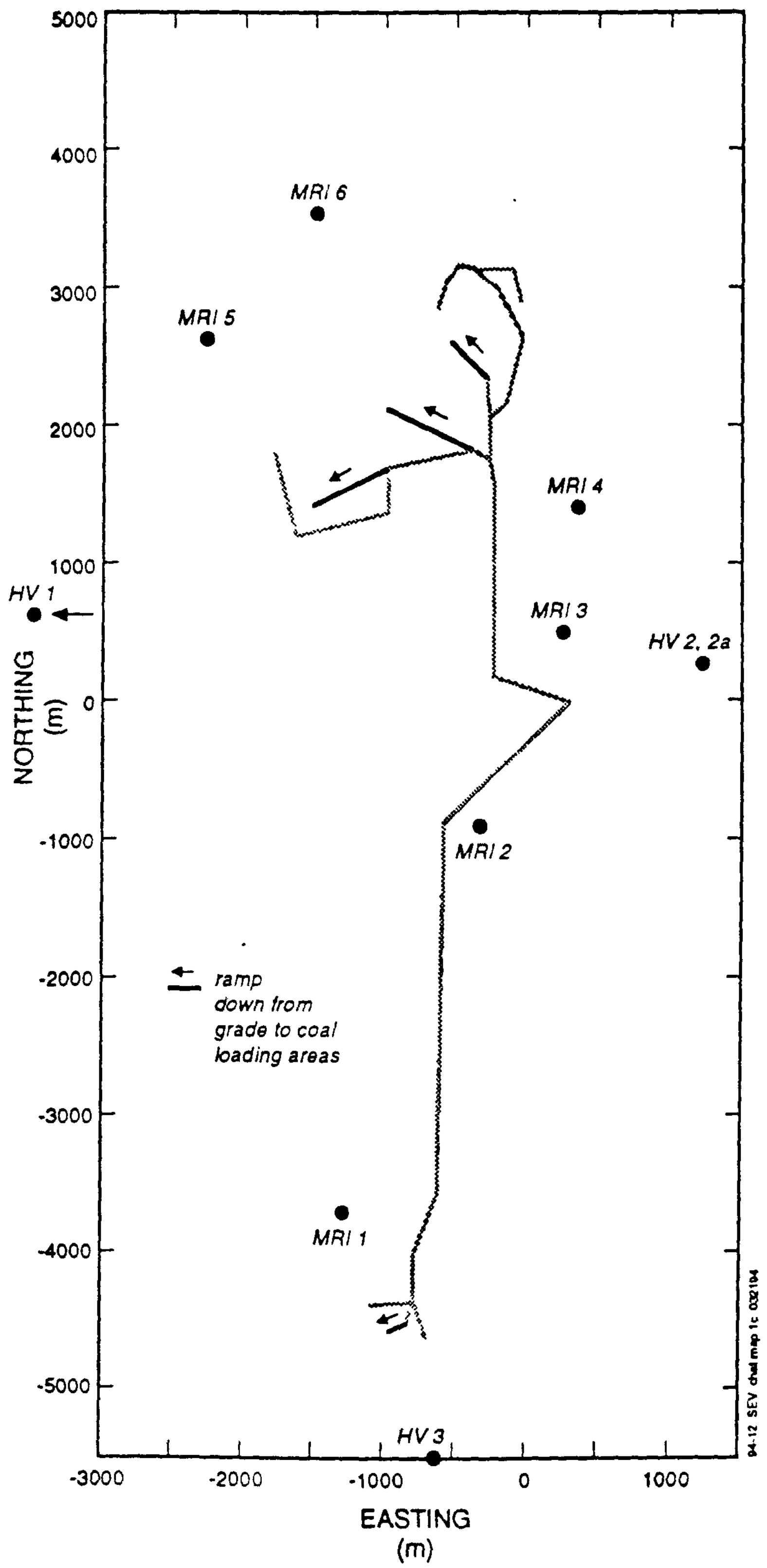

Figure 5. Haul road ramps from grade to pit floor.

10 percent (using ISCST2) at the typical source-monitor distances for the Cordero mine.

3.7 PARTICLE SIZE DISTRIBUTION

The particle size distribution of source emissions is required to develop the necessary inputs to the deposition algorithms within both ISCST2 and ISCSTM. In the case of ISCST2, the inputs are expressed in terms of the gravitational settling velocity distribution and the surface reflection coefficient distribution, both of which can be calculated from the particle size distribution.

The determination of the particle size distribution that will be used for mining source emissions was based entirely on particle sizing data collected during the Phase I source testing program (Muleski et al., 1994), as discussed in Appendix C. A total of four tests for coal haul roads and one test for an overburden haul road were conducted during the course of the field exercise. For each of the five particle sizing tests, cyclone/cascade impactor combinations were operated at 1- and 3-m heights (and at a nominal distance of 5 m from the roadway), providing a total of 10 measured aerodynamic particle size distributions.

The 10 measured particle size distributions were (geometrically) averaged to develop the composite aerodynamic particle size distribution, given in Table 7. This composite distribution will be used to characterize emissions from all modeled sources, because (a) haul road emissions account for more than half of the total emissions and (b) various categories of fugitive dust sources have been shown to exhibit similar particle size profiles, as indicated by the emission factor data presented in AP-42 Section 11.2. Note that because the composite distribution is expressed in terms of aerodynamic particle size, unit density (1 g/cm^3) can be assigned to all particle size fractions.

Equations (1-54) and (1-55) in Volume 2 of the ISC2 User's Guide will be used to calculate mass median diameters and settling velocities for each particle size subrange. Reflection coefficients will be obtained from Figure 1-7 (ISC2 User's Guide) and the mass median diameter for each subrange.

TABLE 7. COMPOSITE PARTICLE SIZE DISTRIBUTIONS

	Wt. % < stated diameter		Mass fraction	
Particle diameter (µmA)	TSP	PM-10	TSP	PM-10
32[a]	100	–		
			.39	–
25	61	–		
			.20	–
20	41	–		
			.12	–
15	29	–		
			.08	–
10	21	100		
			.07	.33
5	14	67		
			.05	.24
2.5	9	43		
			.05	.24
1	4	19		
			.04	.19
0	0	0		
			1.0	1.0

[a]The geometric mean of the 20- to 50-µmA range usually associated with the cutpoint of the standard high-volume samples.

SECTION 4

MODELING SYSTEMS FOR EVALUATION

This section describes: (a) the modeling systems (groups of model components) that have been selected for performance evaluation; and (b) the rationale for selecting the sequence of modeling systems.

Each modeling system to be evaluated consists of:

- an atmospheric dispersion model;
- a set of fugitive dust emission factors;
- a set of source locations and activity levels; and
- a geometric method of representation for each source.

Table 8 shows the sequence of model "runs" proposed for evaluation of the various modeling systems. The emission factors (Sets 1, 2, and 3), activity levels (60-day average shift, and daily shift), and geometric methods of representation (explicit, explicit-1, and explicit-2) identified in Table 8 have been presented and discussed in detail in Section 3. Each run builds upon the base case by utilizing the updated dispersion model and emission factors, more refined source activity levels, and more refined source representations. The runs progress from the base case using ISCST2 and the existing emission factors, 60-day source activity resolution and volume source representation for haul roads to the most updated approaches using ISCSTM, the updated emission factors and two alternatives for haul road source representation.

TABLE 8. MODELING SYSTEMS FOR EVALUATION

Run	Dispersion model	Emission factors[a]: Vehicles traveling on haul roads[b]	Emission factors[a]: Other sources	Activity resolution[c]	Source representation[d]	Effect of improved ...
1	ISCST2	Set 1	Set 1	60-day average shift values	Explicit	Base case
2	ISCST2	Set 3	Set 2	Daily shift values	Explicit	Emission factors (measurement based)
3	ISCSTM	Set 2	Set 2	60-day average shift values	Explicit 1	Dispersion model, emission factors
4	ISCSTM	Set 2	Set 2	Daily shift values	Explicit 1	Dispersion model, emission factors
5	ISCSTM	Set 3	Set 2	Daily shift values	Explicit 1	Dispersion model, emission factors (measurement based)
6	ISCSTM	Set 2	Set 2	60-day average shift values	Explicit 2	Dispersion model, emission factors, source representation[e]
7	ISCSTM	Set 2	Set 2	Daily shift values	Explicit 2	Dispersion model, emission factors
8	ISCSTM	Set 3	Set 2	Daily shift values	Explicit 2	Dispersion model, emission factors (measurement based)

[a]Refer to Tables 1 and 2.
[b]Haul trucks, water trucks, and light-duty vehicles.
[c]Refer to Table 3.
[d]Refer to Table 4.
[e]While the area source representation for haul roads may improve the ease of modeling, the effect on model performance is not known.

SECTION 5

OBSERVATIONAL DATA BASES

The observational data bases are those that were generated from the intensive air quality monitoring study conducted at the Cordero surface coal mine. The monitoring program encompassed thirty 24-h periods (midnight to midnight) from May 19 through July 18, 1993. Monitoring was conducted on an every-other-day basis. Air quality was measured at a nine-station network as shown in Figure 6. The data bases are computer files generated during preparation of the final report for the Phase I study (EPA, 1994). A listing and brief description of these files are presented in Appendix D.

The observational data bases were specifically developed for use in evaluating model performance. The monitored parameters fall into three categories:

- Source activity (mostly shift-resolved data),
- Meteorology (hourly data), and
- Air quality (24-h data).

5.1 SOURCE ACTIVITY

Throughout the monitoring program, the field crew collected process information about the mining operations that were to be included in the emission inventory input for model evaluation. Specifically, shift-resolved activity data were obtained for the following operations:

- Haul trucks traveling on unpaved haul roads--vehicle counts
- Water trucks traveling on unpaved haul roads--vehicle counts
- Light-duty vehicles traveling on unpaved haul roads--vehicle counts
- Dragline (bucket dumping—overburden)--location and cycle time

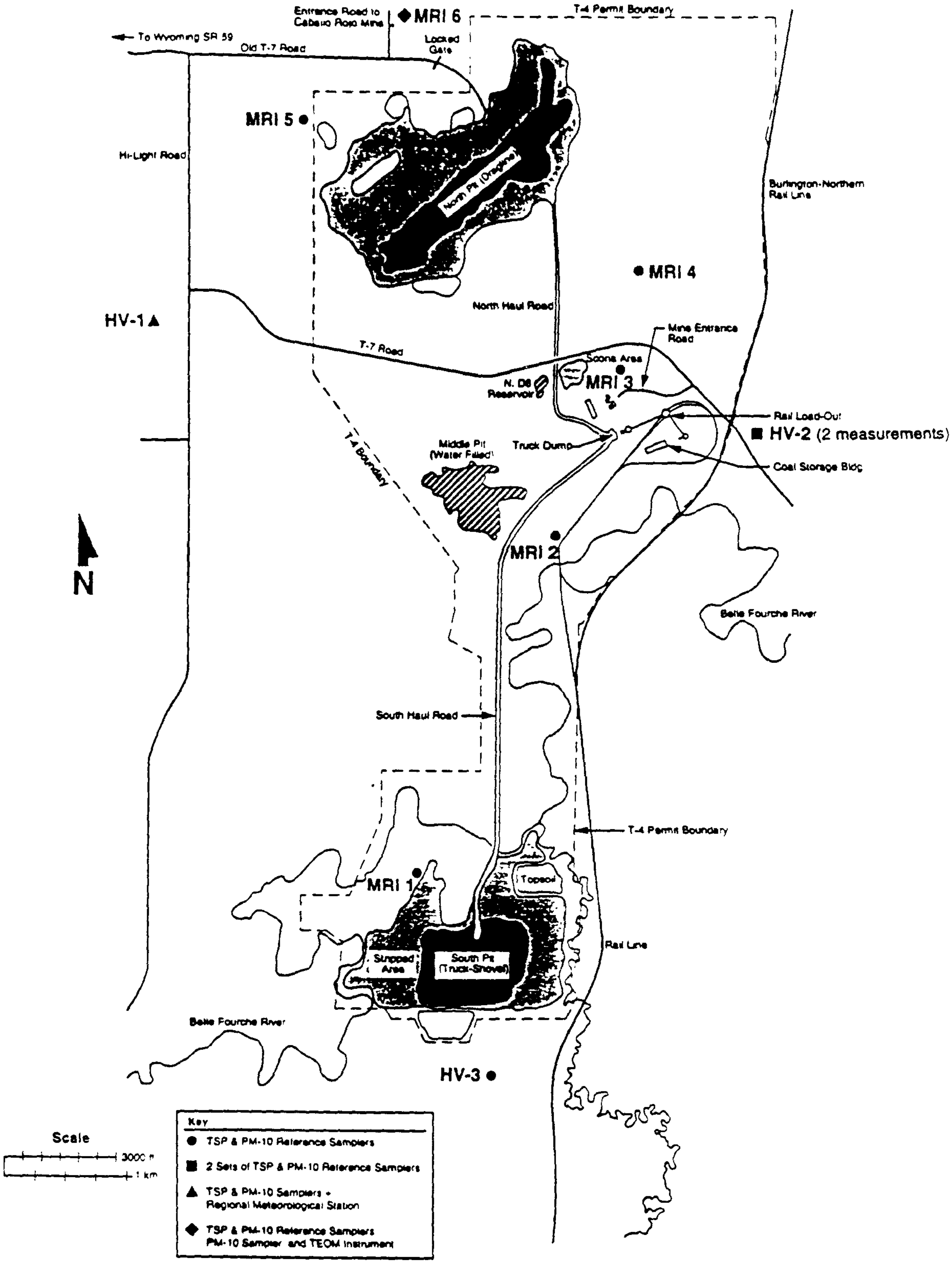

Figure 6. Locations of monitors at the Cordero mine.

- Haul truck loading (with power shovel)--location
  - — coal
  - — overburden
- Haul truck dumping--location
  - — coal
  - — overburden
- Scraper travel on unpaved surfaces (for topsoil removal and scoria mining)--location
- Grader travel on unpaved surfaces (for road maintenance)--location

MRI referenced its source activity observations to three periods. To the extent practical, these periods corresponded to work shifts, as follows:

Observation period	Description
0	Period from midnight to start of day shift (6 or 7 a.m.). This period incorporates part of the preceding day's evening shift.
1	Entire day shift (either 10- or 12-h) for the day that sampling occurred.
2	Period from start of evening shift (either 4 or 7 p.m.) to midnight stop time for the air monitors.

In this document, the term "shift" is used to characterize the observation periods.

A grid scheme based on the Wyoming state coordinate system was used in this study to locate emission sources within the mine, as described earlier in Section 3.5. The major roads were stylized and segmented using aerial photographs, and the endpoints and length of each road segment were identified. Scraper travel associated with either topsoil removal or scoria mining was assigned to the appropriate 1,000- × 1,000-ft grid cell. The dragline location during each work shift was referenced to the nearest quadrant of a 1,000- × 1,000-ft grid cell. The locating coordinates of the area designations for coal loading and unloading, overburden loading and unloading, dragline activity and scraper activity are provided in the data file **AREAS.LOC**.

Four files of source activity data were generated:

- **24HRVPH** contains hourly numbers of haul trucks, water trucks, and other vehicles passing over each of twelve road segments, for each of the thirty 24-h monitoring periods. [The "hourly" numbers represent shift values except when it was noted that activity had ceased for part or all of a shift.]

- **DRAGLINE.DAT** contains (a) the number of dragline load cycles and (b) the grid location of drop, for each shift of the thirty 24-h monitoring periods.

- **SCRAPER.DAT** contains the location of scraper operations by grid, for each shift of the thirty 24-h monitoring periods.

- **GRADER.LOC** contains a listing of the roads on which graders were observed during any shift on any day.[c]

A separate series of files (**ROADA, ROADB, ROADC,...etc.**, one for each road segment) defines one or more line segments for each road and gives the x-y coordinates (Wyoming system) for volume sources used to represent the road.

The amount of coal and overburden loaded into and dumped by haul trucks in a particular area will be set equal to the amount transported by haul trucks over the road that serves that area. Additional information about material flow balance calculations is provided in Appendix D. The source activity for bulldozing (hours of operation) will be determined by assigning one bulldozer to each power shovel used for haul truck loading.

The source activity for wind erosion (Set 2 emission factor) will be obtained from on-site hourly wind speed data coupled with a default value for a threshold wind velocity defined as a fastest mile of 27 mph at a reference height of 10 m above the surface. This value was derived from the typical mode (1 mm) of the size distribution of surface samples collected for silt analysis. The relationship between mode and threshold wind velocity is described in Section 11.2 of AP-42 (EPA, 1985). Assuming

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[c]NOTE: This data file is a new file not included in the original Phase I report data files; the information was taken from the field data sheets from Phase I.

that the ratio of the fastest mile to the hourly mean wind speed is 1.2; an hourly mean windspeed of 23 mph will be assumed to produce a fastest mile of 27 mph.

Throughout the 1993 ambient air quality monitoring program, samples of haul road surface material were collected. During each day when ambient air monitoring occurred, "moisture-tracking" samples were collected from a representative haul road in use on that day. These samples consisted of approximately 10 incremental subsamples of the surface material. Each subsample was collected by broom sweeping a randomly selected 10- × 10-in area on the road. Sampling was repeated every 15 to 20 min, so that a time profile of the surface moisture content could be obtained. Water truck passes were noted, and sampling continued over at least one watering cycle.

During "off days," i.e., days when monitors were not operated, standard material samples of road surface material were collected by broom sweeping a 10-in strip across the full width of the road. Samples were split as necessary to an appropriate size (1 to 2 lb). Roads were selected for sampling based on the current level of usage.

Both types of samples underwent surface moisture analysis by measuring weight loss upon oven drying. The results of the moisture analyses were presented in the Phase I Report, Table 5-8, pg. 5-33 (U. S. EPA, 1994). After drying, sets of "moisture tracking" samples were combined, and all sets were archived for further analysis. Subsequently, the samples from the monitoring days were analyzed for silt content by dry sieving (according to the procedures specified in AP-42). The results of the silt analyses are presented in Appendix F.

5.2 METEOROLOGY

Data characteristics of regional meteorology were collected at Site HV-1. This site was already equipped with a 10-m tower and associated meteorological instruments that meet the criteria specified by EPA (1987). The station collected data that are directly applicable to model implementation. Specified parameters monitored at the station included wind speed and direction, standard deviation of wind direction (σ_θ), temperature, and precipitation. The hourly meteorological data are contained within one file, **IMLMET.DAT**.

The following approach to missing/poor quality meteorological data will be used. Data from the Caballo Rojo mine (on adjacent property to the north) will be substituted for a missing period if Caballo Rojo data are available. Otherwise data from the next closest meteorological station will be used.

The ISC model also requires input data on mixing height and atmospheric stability. Because plume dispersion from the modeled (ground-level) sources should not be influenced significantly by reflection from the top of the mixing layer, a default value of 3,000 m will be used for the mixing height. Calculation of hourly values of atmospheric stability will be based on the "buffered sigma sub-theta" approach, as described in "On-Site Meteorological program Guidance for Regulatory Modeling Applications" (EPA, 1987). The buffering refers to the restriction of not allowing the stability to change by more than one class from one hour to the next.

5.3 AIR QUALITY

Ambient air quality monitors for both TSP and PM-10 were installed at nine permanent monitoring sites in and around the Cordero surface coal mine. The locations of the nine primary ambient air monitoring sites are shown in Figure 6 along with the types of monitors used at each site. All of the sites but one are on Cordero property, and most lie within the permit boundary for mining activity. The "HV" sites were those already operated by the Cordero Mine; HV-1 had been sited in an area generally suitable for measurement of background concentration.

Each station was equipped with an elevated platform and sufficient electric power to support at least one standard high volume sampler for TSP and one PM-10 reference sampler equipped with an inlet manufactured by Wedding and Associates. Collocated PM-10 and TSP samplers were installed at one site (HV-2), bringing the total samplers to ten PM-10 and ten TSP instruments. An additional continuous monitoring instrument was also added at one of the stations (MRI-6) to provide supplemental data on time-resolved (i.e., hourly) PM-10 concentration. The ambient air quality monitors used in this study were operated, maintained, and calibrated in a manner consistent with guidelines established by EPA (1977).

The 24-h air quality data for PM-10 and TSP are contained within 30 files, one for each of the ten pairs of PM-10/TSP samplers and each month of operation (May-July). The files are named **HV1.MAY, HV1.JUN, . . . MRI6.JUN, MRI6.JULY**.

If air quality data (PM-10 or TSP) are not available at a monitoring site, that site will be removed from the model comparison for that sampling day. Substitutions will not be made for missing air quality data.

5.4 BACKGROUND AIR QUALITY

A critical step in this process will be the estimation of background air quality levels, which must be subtracted from observed concentrations before comparing with model-predicted values. A background concentration is needed for each monitored air quality parameter (PM-10 and TSP) for each monitoring period.

There are three components to air quality levels at the monitoring sites:

1. Impacts from sources at the mine and from sources beyond the mine property boundaries that are being modeled;

2. Impacts from sources at the mine which are not being modeled; and

3. "Regional" background: contributions from airborne particles that are incorporated broadly in the air mass covering the region or are transported into the region as a broad, diffuse plume from a far-distant source.

The objective is to modify the observed air quality data so that they reflect only component 1 above, allowing a true evaluation of model performance.

A procedure for estimating regional background concentration was developed and applied to the air quality data base. This procedure focuses on evaluation of the lowest measured concentration for each day to see if it meets the necessary acceptance criteria. If the lowest measured concentration meets the acceptance criteria, it is used as the background concentration. If the lowest measured concentration does not meet the acceptance criteria, the background concentration is estimated. The procedure is described in Appendix E.

The resulting regional background concentrations are shown in Table 9. As indicated, most of the values shown correspond to the lowest measured concentrations for the days of interest. The average ratio of PM-10 to TSP concentration (0.66) is consistent with the findings of the Phase I study (EPA, 1994). Figure 5-8 of that report is a plot of PM-10/TSP ratio versus TSP concentration; it shows that as the TSP concentration decreases, its fractional PM-10 component increases. A PM-10/TSP ratio of 0.66 corresponds to a TSP concentration of approximately 10 $\mu g/m^3$.

5.5 RUNSTREAM PREPARATION

Runstreams for the different modeling systems listed earlier in Table 8 have a common "ancestry." All runs may be viewed as modifications of files of source activity and meteorological data compiled during the 1993 field study (EPA, 1994). Figure 7 illustrates how the different runstreams will be derived. Although Figure 7 addresses only roads and truck/loading/dumping operations, the approach is analogous for all sources.

As illustrated in Figure 7, for roadway and truck/shovel operations, the file **24HRVPH** contains hourly information on the number of haul trucks, water trucks and the vehicle passes on each of 12 roads at the mine. A program, "Program 1" of Figure 7, will take this source activity information and combine it with emission factors to develop an hourly emission inventory for all vehicle traffic on roads as well as truck loading and dumping operations.

As Figure 7 shows, the next step makes use of "Program 2," which will combine the hourly emission inventory with geographic information to produce ISCST2 runstreams with the specified temporal and spatial resolution. The final step in generating runstreams relies on temporal averaging of the runstreams already prepared. This is the goal of "Program 3" in Figure 7. Program 3 will average the daily shift values of emission rates to produce a "typical" shift-based profile of emissions, i.e., the 60-day average shift value for the monitoring period.

TABLE 9. REGIONAL BACKGROUND CONCENTRATIONS

Date	Background concentration ($\mu g/m^3$)	
	PM-10	TSP
5/19	***6*** [a]	***8***
5/21	8.60	***16***
5/23	5.45	7.90
5/25	6.17	7.87
5/27	9.92	31.25
5/29	9.09	***8***
5/31	7.32	13.21
6/2	4.33	***8***
6/4	4.25	5.23
6/6	4.96	7.79
6/8	6.53	6.27
6/10	8.26	9.98
6/12	9.34	20.28
6/14	10.92	21.75
6/16	***6***	***8***
6/18	4.07	4.07[b]
6/22	***9***	16.78
6/24	5.07	8.35
6/26	11.04	***22***
6/28	12.91	34.75
6/30	***6***	***8***
7/2	***10***	21.81
7/4	5.86	7.89
7/6	5.06	***8***
7/8	7.11	17.38
7/10	9.96	16.87
7/12	15.34	***29***
7/14	9.59	17.01
7/16	***6***	***8***
7/18	7.50	***8***

[a]Bold italics indicates that the value is estimated (to the nearest microgram).
[b]TSP value set equal to PM-10 value, because lowest measured TSP concentration (2.51 $\mu g/m^3$)was more than 1 $\mu g/m$ below the background concentration for PM-10.

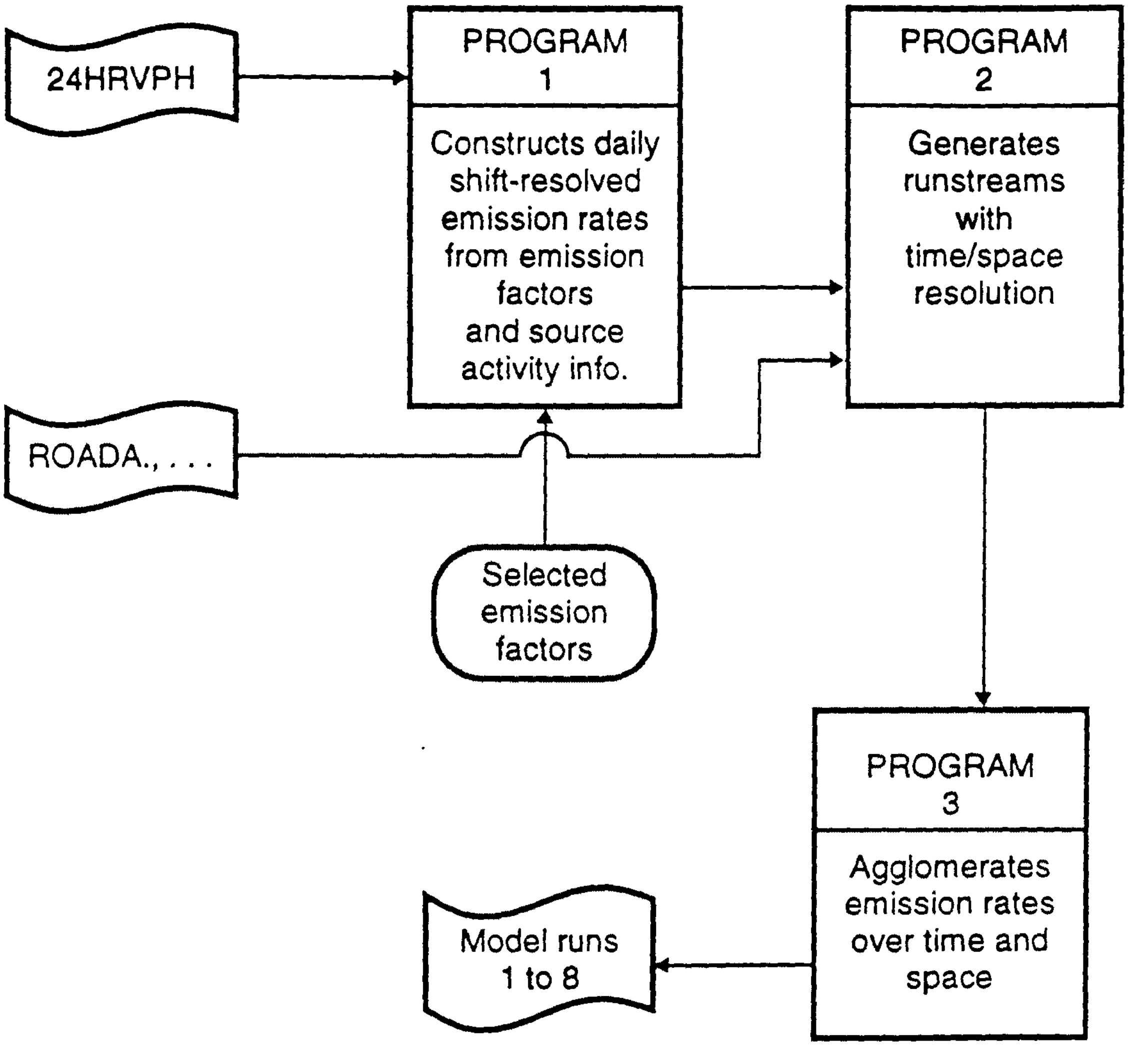

Figure 7. Required source data manipulation for roads and haul truck loading/dumping.

SECTION 6

DETERMINATION OF BEST-PERFORMING MODEL

The first stage of the model evaluation process will be to identify one model (or a group of models) as the best performing model through a statistical evaluation procedure that will compare monitored and modeled ambient air quality levels of both TSP and PM-10 using procedures based on the methodology introduced by Cox and Tikvart (1990) and later established as a protocol by EPA (1992a) for determining the best-performing model. This procedure will be implemented via a model evaluation software package recently developed by EPA (1993). The procedure is described in more detail in the four subsections below. The first subsection provides an overview of the evaluation strategy and the rationale for that strategy. The second and third subsections provide details on the test statistic and performance measures that will be used in the evaluation. The final subsection describes the model comparison procedures.

6.1 STRATEGY FOR IDENTIFYING BEST-PERFORMING MODEL(S)

In defining the best-performing model(s), separate and distinct analyses will be conducted for TSP and PM-10, and best-performing model(s) will be selected for each pollutant. For each of the two pollutant-specific analyses, a composite performance measure will be developed using the weighting scheme outlined in Section 6.3.

The decision to conduct separate analyses for PM-10 and TSP is based on both program and analytical considerations. First, because model applications for PM-10 analyses are much more widespread than those for TSP analyses, there is substantial interest in how the performance of the different models compares specifically for PM-10. This interest provided the impetus for a separate PM-10 analysis. More importantly, the different model scenarios handle both emission generation and particle deposition differently. These differences may produce effects in the relative performance of the models that differ for PM-10 and TSP that would be masked by a composite analysis. This potential adverse consequence outweighs possible gains in statistical efficiency that could be gained by combining the PM-10 and TSP data for analyses.

The primary objective in developing monitor-specific weights for the composite performance measure was to place greater weight on those monitors that were most impacted by the emission sources contained in the model assessment. Development of the weights involved two elements. First, personnel experienced in fugitive emission dispersion modeling, who had a thorough understanding of the Cordero site, examined source/receptor geometries at the site to determine whether specific monitoring sites were appropriately sited for source impact under observed wind patterns. Then, average observed concentrations at each monitoring site were used as an indicator of the impact of modeled sources on the site.

6.2 TEST STATISTIC

Because model performance at maximum concentrations is a primary concern, the test statistic that will be used for these analyses is a robust extreme value estimator called the robust highest concentration (RHC) (Cox and Tikvart, 1990). The RHC is preferred for this analysis because it is stable and because the distribution of RHCs obtained via the bootstrap procedure described in Section 6.4 is not artificially bound by the highest observation in the sample. The RHC is based on a tail exponential fit to the upper end of the distribution of ambient concentrations using robust estimates of percentiles calculated from rank order statistics and is calculated as follows:

$$RHC = X(R) + \left[\bar{X}(R) - X(R)\right] \log\left(\frac{3R - 1}{2}\right) \tag{4}$$

where:

RHC = robust highest concentration
$\bar{X}$ = mean of the R − 1 largest values
X(R) = Rth largest value

For these analyses, R will be set equal to 8. This value was selected based on a review of the calculated RHCs for background-corrected observations of both TSP and PM-10 at the nine monitoring sites. For the different sites, the RHC generally stabilized at R values between 6 and 11. The stable range for all sites for both TSP and PM-10 always included eight observations. Six or seven observations also could reasonably have been used, but because some of the analyses will be based on observations from a single sampling station, eight observations are expected to give more stable estimates for the bootstrap analyses than would have been obtained from six or seven observations.

6.3 PERFORMANCE MEASURES

The foundation of the performance measures that will be used to compare the different models is the absolute fractional bias (AFB) of the RHC obtained from the modeled data (RHC_M) relative to the RHC obtained from the monitored data (RHC_O). The AFB is calculated as:

$$AFB = 2\left|\frac{RHC_O - RHC_M}{RHC_O + RHC_M}\right| \tag{5}$$

The AFB will be calculated for each of the nine monitoring sites separately for TSP and PM-10, and a composite performance measure (CPM) based on the nine stations will be calculated for each pollutant as follows:

$$CPM(k) = \sum_{i=1}^{9} w_i \, AFB_i \tag{6}$$

The weights used for the composite performance measure were developed via a combination of an engineering analysis of source/receptor geometries and calculated estimates of source impact using observed concentrations at the monitoring sites. Based on the review of the monitor locations, observed concentration levels and associated wind vectors, and potential for impact of sources external to the modeling framework, two monitoring sites (HV1 and HV2) were assigned weights of zero. HV1 was assigned zero weight because its location provides little potential for source impact and it acts as background on most days. HV2 was assigned zero weight because it has generally low concentrations and does have the potential to be impacted by diesel locomotives that are not a part of the modeling framework.

The remaining seven monitoring stations were assigned weights (w_i) of the form:

$$w_i = \frac{\bar{C}_i}{\sum_{i=1}^{7} \bar{C}_i} \qquad (7)$$

where: $\bar{C}_i$ = mean background-corrected concentration over the 30-day monitoring period at station i

Separate sets of weights were calculated for TSP and PM-10 as shown in Table 10.

TABLE 10. MONITORING STATION WEIGHTS (BACKGROUND ADJUSTED) FOR COMPOSITE PERFORMANCE MEASURES[a]

Monitoring station	TSP		PM-10	
	$\bar{C}_i$	w_i	$\bar{C}_i$	w_i
HV1	3.88	0	0.45	0
HV2	8.49	0	1.42	0
HV3	2.63	0.020	0.99	0.039
MRI1	9.31	0.071	3.65	0.143
MRI2	22.3	0.171	3.45	0.135
MRI3	38.8	0.298	4.73	0.185
MRI4	12.7	0.097	2.38	0.093
MRI5	17.1	0.131	4.00	0.157
MRI6	27.6	0.211	6.31	0.247

[a]These weights are preliminary estimates calculated using the minimum daily concentrations as background. When final background concentrations are determined, average concentrations will be recalculated and weights may change slightly.

Because the purpose of the analysis is to contrast the performance among the possible models, the two composite performance measures (one for TSP and one for PM-10) will be used to calculate differences in performance between pairs of models. These differences in performance between models, called model comparison measures, are calculated as:

$$MCM_{(A,B)}(k) = CPM_A(k) - CPM_B(k) \qquad (8)$$

where: $MCM_{A,B}(k)$ = model comparison measure for Model A versus B for pollutant k

$CPM_A(k)$ = composite performance measure for Model A and pollutant k

$CPM_B(k)$ = composite performance measure for Model B and pollutant k

If $MCM_{A,B}(k)$ is negative, then Model A is "better" than Model B; if it is positive, Model B is "better" than Model A for pollutant k. However, because $MCM_{A,B}(k)$ is a random variable subject to sampling variation, the relative performance of two models must be evaluated statistically as described in the subsection below.

6.4 MODEL COMPARISON PROTOCOL

Because of the inherent sampling variability associated with calculating RHC_O and RHC_M, $MCM_{A,B}(k)$ may be nonzero even if Models A and B perform equally well. Typically, statistical procedures use the standard error of $MCM_{A,B}(k)$ to determine whether these nonzero estimates are statistically different from zero. Because $MCM_{A,B}(k)$ is obtained via a complicated calculation procedure and because the underlying sampling distributions of the observed and modeled ambient concentrations are not fully characterized, its variance and standard error cannot be readily computed analytically. Consequently, a bootstrap resampling procedure will be used to calculate these standard errors. Because monitoring was conducted every second day during the program, each monitoring day can reasonably be assumed to be independent of the other monitoring days. A total of 1,500 bootstrap samples of size 30 will be selected by sampling with replacement from the 30 monitoring days. For each bootstrap sample, $MCM_{A,B}(k)$ will be calculated for each pair of models and each of the two pollutant specific performance measures. Because eight models are being evaluated, a total of 28 paired comparisons will be generated for each of the two composite performance measures. The standard error of $MCM_{A,B}(k)$, which is designated as (se_{ABk}), is simply the standard deviation of the 1,500 bootstrap samples.

For composite performance measure k, the performance of Models A and B are deemed to be different if the 90 percent confidence interval for $MCM_{A,B}(k)$ does not span zero. If the entire interval is less than zero, then Model A performs better than Model B. If the entire interval is greater than zero, then Model B performs better than Model A. If the interval spans zero, the performance of the models is deemed to be equivalent. The 90 percent confidence interval was chosen as a reasonable compromise between achieving an acceptable performance measure specific Type I error rate (α=0.1) and being able to detect differences in models with relatively small sample sizes and the potential of substantial sampling variability. To provide this performance measure Type I error rate, the 90 percent confidence limits (CI) for a specific pair of models for the composite performance measure for pollutant k is calculated as:

$$90\%\ \mathrm{CI}\{MCM_{A,B}(k)\} = c_k se_{ABk} \qquad (9)$$

where the c_k are obtained from the simultaneous confidence intervals for the 28 paired comparisons for each composite performance measure i using the procedure outlined below.

The method of Cleveland and McGill (1984) will be used to calculate c_k. For each composite performance measure k, this method creates a 28-dimensional rectangular hypersolid centered at the 28-tuple $MCM_{A,B}(k)$ for the 28 combinations of A and B obtained from the actual data. The length of the sides is $2c_k \bullet se_{ABk}$. Specifically, c_k is found so that for 90 percent of the 1,500 bootstrap 28 element vectors,

$$\frac{|\Delta_{ABk} - \Delta_{ABj}|}{S_{ABk}} \leq c_k \qquad (10)$$

where:
Δ_{AB} = model comparison difference measure for model pair A,B
Δ_{ABj} = model comparison difference measure for model pair A,B and bootstrap replication j
S_{ABk} = standard deviation for all the Δ_{ABj} values

For this analysis, we find c_k for each performance measure.

$$\frac{|MCM_{A,B}(k) - MCM_{A,B,j}(k)|}{se_{ABk}} \leq c_k \qquad (11)$$

where:
$MCM_{A,B,j}$ = model comparison difference measure for the jth data base, and Models A and B
A and B = 1 to 8 for each model combination
j = 1 to 1,500 for each bootstrap
se_{ABk} = standard deviation of $MCM_{A,B}(k)$ for bootstrap replications 1 to 1,500

In summary, the steps to be taken in providing a scoring of each model analyzed will be as follows:

1. For each TSP and PM_{10} separately, calculate the RHC for the observed and predicted concentrations paired by space over all data. Calculate the AFB of the RHC with confidence limits for each monitoring site.

2. Calculate the CPM for each model for TSP and PM-10. The smaller the CPM, the better the overall performance of the model.

3. Calculate the MCM with confidence limits for each model pair for the composite performance measure for TSP and PM-10.

4. Tabulate the overall performance measure results and significance of the results.

These four steps generate two primary measures that can be used to select a set of one or more best performing models in a two step process. (Note that distinct analyses will be conducted for each of the two pollutants [TSP and PM-10]). First, the CPM values calculated for each model provide point estimates of model performance that can be used to order the eight possible models. Define $CPM_{(i)}$ as the order statistics for the measured CPM values where $CPM_{(1)} < CPM_{(2)} < \ldots < CPM_{(8)}$ and let $Model_{(i)}$ be the model associated with $CPM_{(i)}$. The first step in selecting the set of best performing models provides an ordering of the models from $Model_{(1)}$ (the "best" model in some sense) to $Model_{(8)}$ (the "worst" model). However, for any pair of models $Model_{(i)}$ and $Model_{(j)}$ with $i<j$, the performance of the two models may be indistinguishable statistically. Consequently, the second stage of the process will be to use the MCM for each pair of models to identify those for which the performance can be distinguished statistically. (Those model pairs are the ones for which the confidence interval of the MCM does not span 0.)

The following plots will be generated:

1. AFB with confidence limits for each model as a function of the site and pollutant;

2. CPM and confidence limits for each model as a function of the pollutant; and

3. MCM with confidence limits among the models for each performance measure.

SECTION 7

EVALUATION OF MODEL OVERPREDICTION

The second stage of the model evaluation process is to determine which model or models do not significantly overpredict. The subsections below describe the evaluation strategy.

7.1 OVERALL EVALUATION STRATEGY

Model overprediction is a complex concept. There are many elements to judging whether a model overpredicts or not. Statistical evaluations can be performed which unpair the data in time to determine if the model predicts the range of peak values within an acceptable level of accuracy, but such evaluations are not a complete picture of overprediction. A model can perform statistically well by averaging overpredictions with underpredictions. In an attempt to address these complex concerns, a program of three tiers, or elements, of evaluation has been developed. The first element consists of a statistical evaluation with the data unpaired in time. The second element involves a review of a 5-year historical data base that contains meteorological data and particulate concentrations as seen in the Powder River Basin in an attempt to determine if the concentrations measured in the 1993 field program are representative of long-term trends in the Powder River Basin. Finally, the third tier element is a sensitivity analysis which will determine if the model is running in a reasonable manner for use in regulatory model applications. The subsections below describe each element of the evaluation. More emphasis has been given to the first element, the statistical evaluation, because objective criteria have been developed for this element. The other elements can now only be described in more general terms, but will be specified in more detail at a latter time.

7.2 STATISTICAL EVALUATION OF MODEL OVERPREDICTION

7.2.1 Model Overprediction Evaluation Strategy

The strategy for evaluating statistical model overprediction has elements that are similar to the strategy for identifying the best-performing model in that separate evaluations will be conducted for TSP and PM-10 and statistical inference will be based on bootstrap confidence intervals for the measures of overprediction. However, the statistical model overprediction analysis differs from the best-performing model analysis in four substantial areas. First, the evaluation will focus on model performance at high concentration stations rather than across the network. The analysis will use results for the three stations with the highest observed mean concentration for TSP and the three stations with the highest observed mean concentration for PM-10 for the respective pollutant-specific analyses. This analysis focuses on these high concentration stations because they present the greatest potential for having exceedances. The next two changes are a consequence of model overprediction being a one directional phenomenon. The fractional bias rather than the absolute fractional bias will be used as a measure of performance, and all confidence intervals will be one sided rather than two sided. Finally, the statistical model overprediction analysis will evaluate the potential for overprediction at individual sites rather than averaged across the network. Both the point estimates of bias and confidence intervals for those estimates will be used to define model overprediction.

7.2.2 Test Statistics and Bias Measure

The primary test statistics that will be used in the statistical model overprediction analysis are the observed and modeled robust highest concentrations (RHC_O and RHC_M) as defined in Section 6.2. For each model, these test statistics will be used to compute the model bias measure, the fractional bias (FB), using the following equation:

$$FB = 2\left[\frac{RHC_O - RHC_M}{RHC_O + RHC_M}\right] \qquad (12)$$

If the FB is negative, then the observed RHC is smaller than the measured RHC indicating that the model overpredicts; conversely, if the FB is positive, then the model underpredicts. The fractional bias has two desirable properties for this analysis. First, it is symmetric and bounded so that positive and negative values of the same magnitude are indicative of equivalent levels of overprediction on a multiplicative scale. For example a FB of 0.4 indicates that the model underpredicts by a factor of 1.5, while a FB of -0.4 indicates that the model overpredicts by a factor of 1.5. Second, because the FB is dimensionless, results are independent of the concentration units selected for analysis, and results obtained for different pollutants present in substantially different concentrations can be compared readily.

7.2.3 Model Overprediction Evaluation Protocol

The protocol used to determine statistical model overprediction is somewhat more ambiguous than the best-performing model protocol outlined in Section 6 because until the set of best-performing models is established, the number of models that will be included in the analysis is unknown. However, this section will describe the general protocol that will be implemented to determine whether each of the models in the set of best-performing models significantly overpredicts. Under this statistical analysis protocol, a model will be deemed to significantly overpredict if it meets two criteria applied sequentially. First, there must be statistical evidence of overprediction at one or more of the three sites examined. If there is statistical evidence of overprediction, the point estimate of overprediction must exceed a level deemed to be scientifically meaningful. Note that the protocol will be implemented separately for TSP and PM-10.

First, RHC_O, RHC_M, and the FB will be calculated for each monitoring station to be used in the analysis and each model in the set of best-performing models. For TSP, the three monitoring stations with the highest background-adjusted mean concentrations are MRI2, MRI3, and MRI6. For PM-10, the stations are MRI3, MRI5, and MRI6. The analysis will be based on the three highest concentration stations because using multiple stations will provide protection against anomalies attributable to the particular geometries of a single station and both pollutants exhibited reasonable separation between the third and fourth highest concentrations. The fractional biases, $FB_{ij}(p)$, for specific combinations of model (i), site (j), and pollutant (p) will be used in the statistical component of the protocol.

Because $FB_{ij}(p)$ are random variables, nonzero values are expected even if specific models provide unbiased estimates at a particular site. To account for this, bootstrap confidence intervals will be developed for the fractional biases using procedures similar to those described in Section 6.4. However, the procedures will be modified to generate only upper confidence bounds to address overprediction.

First, a total of 1,500 bootstrap samples will be selected as described in Section 6.4, and the fractional bias $FB_{ijk}(p)$, where k denotes the kth bootstrap sample will be calculated. These samples will be used to calculate the standard error of the fractional bias, denoted as $se_{ij}(p)$, for each combination of model (i), site (j), and pollutant (p). For each pollutant p, this process yields 1,500 vectors of dimension $3I_p$, where I_p is the number of models in the set of best-performing models for pollutant p. The method of Cleveland and McGill again is applied to calculate the values c_p such that 90 percent of the 1,500 vectors generated by the bootstrap sampling procedures satisfy the system of inequalities:

$$\frac{FB_{11k}(p) - FB_{11}(p)}{se_{11}(p)} < c_p$$
$$\vdots \tag{13}$$
$$\frac{FB_{I_p3k}(p) - FB_{I_p3}(p)}{se_{I_p3}(p)} < c_p$$

These analyses will be conducted separately for the two pollutants. For each pollutant, a model i meets the statistical criteria for significant overprediction if the 3-dimensional 90 percent confidence region bounded by the lines $FB_{ij}(p) + c_p \cdot se_{ij}(p)$, for j=1,2,3 does not include the origin.

This procedure tests the null hypothesis that for each model in the set of "best performing" models, the fractional bias is zero for each of the 3 sites included in the overprediction analysis. The alternative is that the fractional bias is less than zero for at least one site. The null hypothesis will be rejected if the joint confidence region does not include the origin, or equivalently if the lower 90 percent confidence interval for any single site does not include zero. By using all models to develop the initial confidence region, the method provides an overall Type I error protection of α=0.1. At the same time it defines overprediction in terms of the performance of models at specific sites.

The procedure outlined above provides an assessment of statistical significance, but effects can be significant statistically without being scientifically important. The procedure provides overall Type I error rate protection for the general hypothesis of no significant differences. If the overall hypothesis is rejected, the individual model/site combinations can then be examined to identify which combinations resulted in rejection. As a matter of scientific judgement, the model will be defined as overpredicting only if the point estimate for this model/site pair is less than -0.67. This level indicates overprediction by a factor of 2 at a single site. Such a level is deemed to be reasonable for the performance of a model at a specific site.

7.3 HISTORICAL DATA REVIEW

This element of the evaluation will define trends and relationships in the observed concentration values and meteorological data in the five-year historical data base archived during Phase I of the study. This extensive historical data base includes air quality (TSP and PM-10) and meteorological observations at many surface coal mines in the Powder River Basin. A purpose of this element is to determine if the 30-day sampling period is representative of conditions in the Powder River Basin. This element of the evaluation includes three steps: (a) investigation of relationships between meteorology and air quality in the Powder River Basin, (b) investigation of trends in air quality in the Powder River Basin, and (c) comparison of the historical data to the two-month monitoring period data.

Investigation of Relationships between Meteorology and Air Quality in the Powder River Basin: Relationships between meteorology and air quality in the Powder River Basin will be determined by testing several hypotheses: (a) are periods of high concentrations restricted to periods with high wind speed conditions or do they also occur during low wind speed conditions? (b) do periods with high concentrations occur during extended periods when atmospheric conditions are stable? (c) do high and low concentrations occur during periods with similar meteorological conditions regardless of the season of the year? (d) does precipitation cause lower concentrations than otherwise expected?

Investigation of Trends in Air Quality in the Powder River Basin: The existing five-year historical air quality data base will be examined to evaluate annual time trends for the Basin as a whole, seasonal cycles, and spatial patterns of the measured concentrations.

Comparison of Historical Data to Two-month Monitoring Period Data: The meteorological conditions and air quality concentrations measured during the two-month field study will be characterized to determine how representative the sample period is relative to long conditions in the Powder River Basin. For example, do high TSP and PM-10 concentrations observed in the two-month period occur under similar meteorological conditions to those in the historical data base? In the evaluation process, criteria will be developed for judgment of the representativeness of the meteorological conditions experienced during the 1993 2-month field study for characterizing situations which cause maximum concentrations in TSP and PM-10 in the vicinity of large surface coal mining operations in the Powder River Basin. Limitations within the field data sample, correspondingly limit conclusions to be reached in assessing the performance of the air quality dispersion models during such conditions.

7.4 MODEL SENSITIVITY ANALYSIS

A sensitivity analysis will be conducted to assess whether the best performing model (or models) is functioning in a reasonable manner. This element of the analysis will include three steps: (a) examination of model response under various meteorological conditions; (b) examination of source characterization input; and (c) evaluating boundaries of model's use.

Examination of Model Response under Various Meteorological Conditions: Trends, patterns, and relationships of high observed concentrations to various meteorological conditions established during the five-year historical period investigation (see Section 7.4) will be compared with trends, patterns and relationships based on model predicted concentrations. Comparisons will be made to determine whether model predictions of high concentrations occur for similar meteorological conditions (i.e., the right reasons). For example, if the historical data investigation reveals that high observed concentrations in the five-year historical period occurred during high wind speed conditions, then the best performing model should also produce maximum concentrations during such conditions.

Examination of Source Characterization Input: Whether the source characterization information requirements can be simplified without adversely affecting model performance will be examined. For example, if the best performing model used highly resolved source activity data (truck traffic on haul roads collected on a plant shift basis), and an explicit source representation (road segments with specific geographical coordinates), the impact of using less refined source characterizations will be tested.

Evaluating Boundaries of Model Use: In order to eliminate any aberrant behavior, information from steps 1 and 2 will be used to evaluate limits of the models use. For example, if the historical data investigation reveals that low concentrations in the Powder River Basin have been observed to occur under low wind speed conditions but the best performing model is not able to simulate this scenario, then limitations on the use of this model for such conditions will be investigated.

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SECTION 8

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APPENDIX A

DERIVATION OF SET 3 ADJUSTED EMISSION RATES

APPENDIX A

DERIVATION OF SET 3 ADJUSTED EMISSION RATES

The hourly traffic emission rates are constructed with information contained in the source activity file "24HRVPH" generated during preparation of the Cordero monitoring report (EPA, 1994). That file contains the number of vehicle passes per hour by

- Heavy duty trucks (haul and water trucks).
- All other vehicles.

Vehicle-mile-traveled (VMT) results are obtained from multiplying vehicle passes per hour by the road length. Emission rates are calculated by multiplying VMT with the following representative emission factors:

	Emission factors (lb/VMT)	
	PM-10	TSP
Heavy-duty vehicles	6	30
Light-duty vehicles	0.13	0.72

These factors represent the geometric mean uncontrolled emission factors measured for haul roads and light-duty traffic during the 1992 emission testing program (Muleski et al., 1994).

Conventions followed regarding mitigating effects of natural and anthropogenic controls are then applied. First, natural precipitation is assumed to control roadway particulate emissions in the following way:

Precipitation (inches)	Assumed control efficiency for the hour
0.2 or more during present hour	100 percent
0.01 to 0.19 during present hour	75 percent
0.5 or more during preceding 5 hours	30 percent
1 or more during preceding 11 hours	20 percent
2 or more during preceding 23 hours	10 percent

Note that only one control efficiency due to precipitation is included, corresponding to the highest applicable efficiency. The first three efficiencies in the table are consistent with MRI's past findings with road watering programs. The last two efficiencies represent our best judgment as to the effect of rainfall on active roads.

In addition to any mitigation from rainfall, 60 percent control efficiency is applied to roadway emissions whenever water truck passes constitute part of the heavy truck traffic on the road during the observation period. The 60 percent control efficiency approximates the average control efficiencies for watering found in the 1992 testing program when only those controlled emission tests that were performed within about an hour of watering were included in the calculations, because such conditions are more reflective of the normal Cordero watering program:

	Watering control efficiency	
	PM-10	TSP
Coal haul roads	56 percent	57 percent
Overburden haul roads	80 percent	47 percent[a]
Both	63 percent	61 percent

[a]Based on only one controlled emission test.

Note that the control attributed to watering is added to the control attributed to natural mitigation by rainfall. For example, if there are water truck passes on a road (60 percent control) with 1 inch or more of precipitation during the preceding 11 hours

(20 percent control), the controlled emission rate would be found as the uncontrolled rate x (1-0.20) x (1-0.60).

APPENDIX B

ESTIMATION OF EMISSIONS FROM CABALLO ROJO MINE HAUL ROAD

APPENDIX B

Calculation of coal haul truck emissions from the main haul road at the Caballo Rojo mine utilizes the same emission factors as applicable to the coal haul roads at the Cordero mine. Activity levels (i.e., vehicle passes over the 1.17 mi length of haul road) are derived from the daily quantities of coal mined[a] and hauled in trucks having a capacity of 170 tons. Because coal production by work shift is not available, the calculated average hourly emission rates do not vary within each 24-hr period.

Finally, an overall efficiency of 25% is assumed for the combined effects of road watering and precipitation and is applied to all days uniformly. This efficiency, which is approximately half the typical value used for regular road watering, accounts for the fact that (a) water trucks are not operated during all shifts, and (b) other lesser contributions from the haul road, such as the emissions from water trucks, graders and wind erosion, are not calculated separately.

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[a]These data were provided to the project team by the Caballo Rojo mine.

APPENDIX C

PARTICLE SIZE DISTRIBUTION

APPENDIX C
PARTICLE SIZE DISTRIBUTION

The aerodynamic particle size ratios presented in Section 3.6 were derived entirely from the results of the 1992 field testing program at Cordero (Muleski et al., 1994). In the 1992 field testing, the primary device used for particle sizing was a high-volume (20 acfm) sampling train that contained a cyclone precollector and a 5-stage cascade impactor. This sampling train provided direct size separation around the following aerodynamic particle size cutpoints: 15 µmA (cyclone); 10.2, 4.2, 2.1, 1.4, and 0.73 µmA (5-stage impactor). For each of five particle sizing tests, cyclone/cascade impactor combinations were operated at 1- and 3-m heights and at a nominal distance of 5 m from the roadway.

The particle sizing results from the 1992 testing are given in Table C-1, which reproduces Table 11 (page 39) of the Revised Draft Final Test Report *Surface Coal Mine Emission Factor Study* (Muleski, et al., 1994). By averaging (geometrically) the weight percentages in each column, a representative particle size "profile" was generated and graphed on log-probability paper (Figure C-1).

The data point for 32 µmA in Figure C-1 reflects (a) the particle size cutpoint for TSP and (b) the ratio of the coefficients (k) for TSP and PM-10 from the new emission factor equation for haul trucks (Equation 2 in the body of this report). These coefficients reflect the results of Cordero mass emission tests using plume profiling towers equipped with standard high-volume samplers (for measurement of TSP) and with reference PM-10 samplers (for measurement of PM-10), respectively.

TABLE C-1. PARTICLE SIZING DATA

Source	Run No.	Mean 3-m wind speed (mph)	Sample height (m)	Weight percentage of total particulate less than stated size (aerodynamic diameter)					
				15 μmA	10.2 μmA	4.2 μmA	2.1 μmA	1.4 μmA	0.73 μmA
Coal haul road (site 1B)	100X	4.2	1	30.0	21.1	12.2	8.6	8.1	6.2
			3	41.9	32.6	16.7	8.2	3.0	3.0
	102X	18.8	1	16.9	14.0	8.9	4.3	2.0	1.4
			3	19.7	16.1	9.4	5.5	2.8	1.9
Watered coal haul road (site 1)	111X	18.5	1	18.6	14.1	8.7	5.4	4.3	4.3
			3	20.3	14.5	8.1	8.1	6.7	5.1
	112X	22.2	1	13.7	11.3	9.0	8.3	6.2	4.5
			3	28.2	23.8	18.7	8.5	5.1	3.8
Overburden haul road (site 4)	121X	6.6	1	17.0	11.0	3.9	1.3	0.5	0.5
			3	15.0	8.8	2.3	0.8	0.3	0.3
Geometric mean				20.6	15.5	8.4	4.7	2.7	2.2

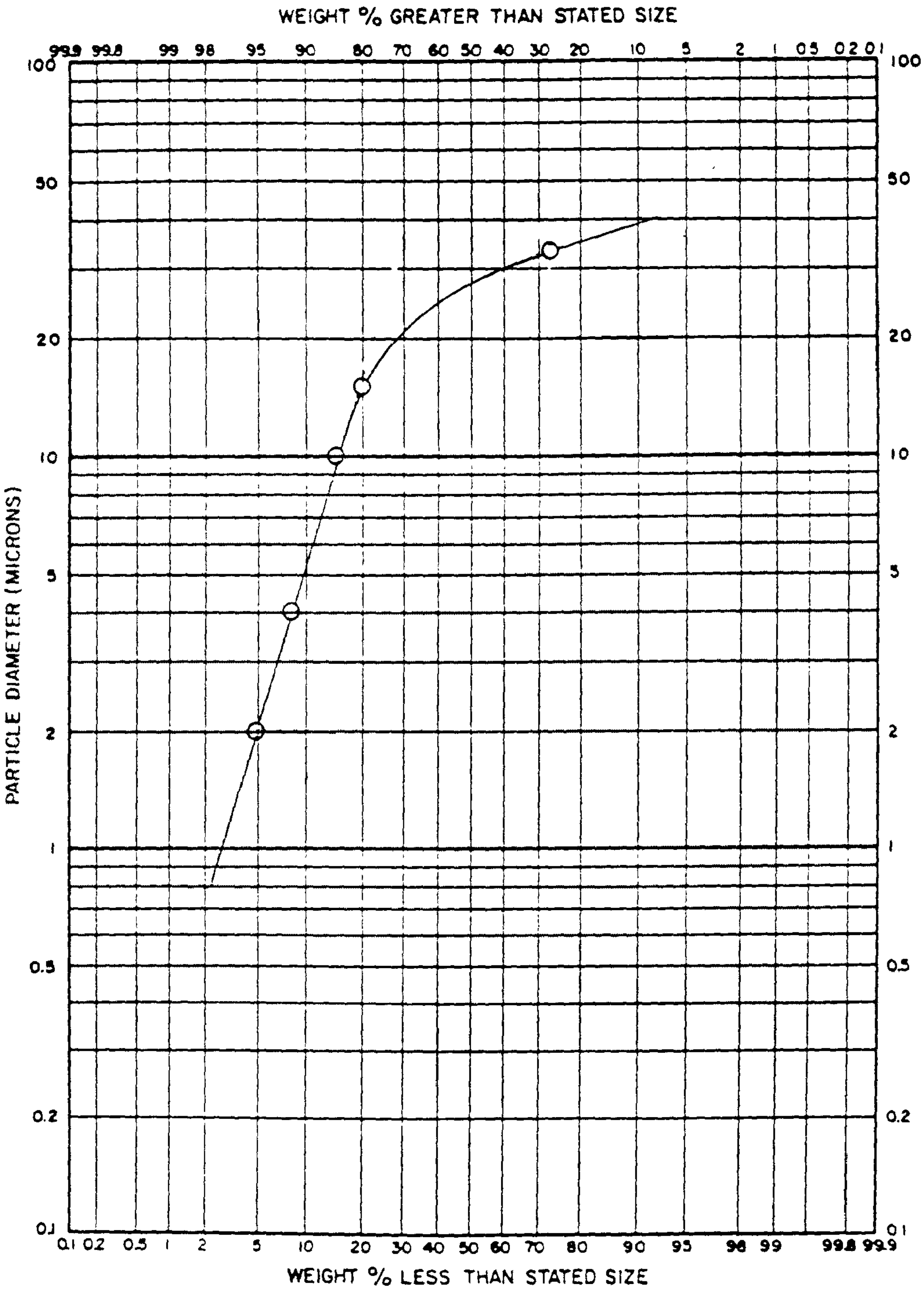

Figure C-1. Aerodynamic particle size profile.

APPENDIX D

SUPPORTING DATA FILES

APPENDIX D
SUPPORTING DATA FILES

Primary Measurements

High-Volume Concentration Measurements

File Name: TABLE.

Description: Spreadsheet used to calculate 24-h high-volume air concentrations at the six monitoring sites. Includes information related to filter number, elapsed time, start and stop flow rates, etc.

Site/Month Concentrations

File Name: HV1.MAY, HV1.JUN, ... , MRI6.JUN, MRI6.JUL

Description: 30 data files containing the site identification, run date, PM-10 and TSP concentrations and status of measurements (i.e., both PM-10 and TSP OK, etc.). One file for each calendar month for each of the ten monitoring sites.

Inter-Mountain Laboratories, Inc. (IML) Meteorological Data[a]

File Name: IMLMET.DAT

Description: File containing hourly surface data collected by the Cordero meteorological station. Data includes wind speed, wind direction, sigma theta, ambient temperature and precipitation.

Time-Resolved Dragline Activity

File Name: DRAGLINE.DAT

Description: Data file containing dragline load cycle information over each of the three observation periods. Also contains information on location of drop, referenced to the 1,000- × 1,000-ft grid system.

---

[a]NOTE: This file has been modified from the data file submitted with the draft Phase I report. The current file includes the data substituted for periods of missing data.

Time-Resolved Scraper Activity

File Name: SCRAPER.DAT

Description: Data file containing information on the use of scrapers during the three observation periods. Also contains information on location of scraper operation, referenced to the 1,000- × 1,000-ft grid system.

Time-Resolved Truck/Shovel Activity

File Name: 24HRVPH.

Description: Source activity data file containing haul truck, water truck, and total vehicle passes per hour on 12 different roads. This file contains information that can be used to develop activity levels not only for traffic on the 12 haul road segments (see Appendix A), but also for coal and overburden truck loading and dumping. This is done by assuming that

1. The number of coal loading operations in areas "a," "b," "c," and "h" in Figure 2 of the text equals one-half the number of haul truck passes on roads A, F, G, and T, respectively. Similarly, the number of overburden truck loadings in "d" and "g" equals one-half the number of haul truck passes on roads D and X.
2. Any loading of trucks (with power shovels) is accompanied by a dozer. Thus, whenever the number of coal or overburden loads in an area is greater than zero, dozer emissions are assumed to be occurring in the area as well.
3. The total number of truck dumps of coal in area "f" in Figure 2 equals one-half the number of haul trucks traveling on the permanent haul roads (M and Z). The number of truck dumps of overburden equals one-half the haul truck passes on roads E and V.
4. All loaded haul trucks are assumed to carry 240 tons of material.

Time-Resolved Grader Activity[b]

File name: GRADER.LOC

Description: Provides a list of days, shifts and road segments on which graders were observed.

Volume Source Representations of Roads

File Name: ROADA., ROADB., ... , ROADZ., ROADX., ROADV

Description: Twelve data files, each corresponding to the 12 roads observed for source activity. Each file consists of one or more straight line segments used to represent the road. Start and end coordinates can be used to depict roads as elongated area sources in the new version of ISC2. File also contains x-y coordinates for volume sources currently used to represent line sources in ISC2. Coordinates referenced to Wyoming state system.

Area Source Location[b]

File name: AREAS.LOC

Description: Provides the coordinates (m) for the Southwest corner (or south corner, as applicable) of the area source designations for coal loading and unloading, overburden loading and unloading, scraper activity, and drag line activity.

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[b]This file is a new file not included in the Phase I report data files.

APPENDIX E

REGIONAL PM-10 BACKGROUND CONCENTRATION

APPENDIX E
REGIONAL PM-10 BACKGROUND CONCENTRATION

A procedure for determining a regional PM-10 and TSP background concentration for each of the 30 sampling periods is described in Figure E-1. Based on the acceptance criteria for allowable wind directions for the station with the lowest measured concentration on a given day, 18 of the 30 sampling days had directly measured PM-10 concentrations and 14 of the days had directly measured TSP concentrations that were acceptable as background values (see Tables E-1 and E-2). Therefore, it was necessary to estimate values of PM-10 and TSP background concentration only for the remaining 12 and 16 days, respectively.

The graphical "model" for estimating PM-10 background concentration is shown in Figure E-2, based on the 18 days with directly measured concentrations that were acceptable as background values. It relates the background concentration to days since significant rainfall, as a surrogate for decreasing surface material moisture content. A "best fit" straight line through the 18 data points is also shown. As a secondary dependent variable, the graph labels each data point with maximum daily temperature as a surrogate for evaporation rate.

Inspection of the graphical model for PM-10 shows that when there have been no (zero) days since rainfall, the concentration is insensitive to maximum temperature. The sensitivity of PM-10 concentration to maximum temperature increases with increased time since significant rainfall. This observation appears to be consistent with the fact that increased evaporation (resulting from higher temperatures) coupled with an absence of rainfall produces dry (dusty) surface conditions.

MODEL DEVELOPMENT

1. Determine which wind directions are allowable at each monitoring station such that impacts of "local" sources (Cordero sources or the Caballo Rojo haul road) are not encountered.

2. For each given day, select the lowest measured concentration value as a candidate regional background concentration.

3. If unallowable hourly average wind directions occur during < 20% of the day in question (i.e., no more than four hourly readings), accent that day's lowest concentration as appropriate for a regional background concentration.

4. For each day with an accepted regional background concentration, determine the number of prior days without significant rainfall (> 0.05 in), not including the day of interest.

5. Plot regional background concentration vs. days since rain and label each data point with the maximum temperature for the day; add "best fit" line to the graph.

MODEL USE

6. ***For PM-10***—If the day of interest occurs immediately after significant rainfall (i.e., occurs ***zero days*** after significant rainfall), use "best fit" line to estimate background concentration to the nearest microgram per cubic meter.

   For TSP—For ***any day*** of interest (without regard to time after rainfall), use the "best fit" line to estimate background concentration to the nearest microgram per cubic meter. Go to Step 9.

7. If the day of interest occurs ***one or more days*** after significant rainfall and has a maximum temperature ***between 60° and 75°F***, use "best fit" line in the "graphical correlation" to estimate background concentration to the nearest microgram per cubic meter.

8. If the day of interest occurs ***one or more days*** after significant rainfall and has a maximum temperature ***outside the range of 60° to 75°F***, estimate a background concentration to the nearest microgram per cubic meter by inspection of the graphical model, i.e., select a value above or below the "best fit" line that best represents the maximum temperature of the day.

9. If the ***measured concentration is less*** than the estimated background concentration of the day, use the measured value as the background concentration.

Figure E-1. Steps to determine regional PM-10 background concentration.

TABLE E-1. QUALIFYING VALUES FOR REGIONAL PM-10 BACKGROUND CONCENTRATION

Date	Station	Regional PM-10 concentration	Wind direction persistence	Wind speed Avg/Max (mph)	Days since rainfall	Temp Avg/Max (°F)
5/21	HV1	8.60	HV	14/26	2	61/78
5/23	HV2	5.45	VS	16/27	0	48/55
5/25	HV1	6.17	MS	8/12	2	68/54
5/27	HV2	9.92	V	10/16	4	59/67
5/29	HV1	9.09	HV	10/20	0	59/72
5/31	HV3	7.32	S	10/20	2	73/61
6/4	HV3	4.25	VS	18/24	0	49/61
6/6	HV2a	4.96	V	10/19	0	53/60
6/8	HV1	6.53	VS	25/34	0	49/57
6/10	HV1	8.26	MS	6/10	1	61/73
6/12	HV3	9.34	HV	10/17	3	58/68
6/24	HV1	5.07	MS	13/20	1	51/60
6/28	HV1	12.91	V	17/27	5	68/81
7/8	HV1	7.11	S	9/14	1	56/66
7/10	HV2	9.96	MS	14/20	3	55/65
7/12	HV1	15.34	HV	15/21	5	65/80
7/14	HV3	9.59	V	23/34	7	57/65
7/18	HV2a	7.50	MS	10/18	0	61/69

Regression output	
Constant	6.19143
Std. err. of Y est.	1.94528
R squared	0.55555
No. of observations	18
Degrees of freedom	16
X coefficient(s)	0.99789
Std. err. of coef.	0.22314

TABLE E-2. QUALIFYING VALUES FOR REGIONAL TSP BACKGROUND CONCENTRATION

Date	Station	Regional TSP concentration	Wind direction persistence	Wind speed Avg/Max (mph)	Days since rainfall	Temp Avg/Max (°F)
5/23	HV1	7.90	S	16/27	0	48/55
5/25	HV1	7.87	MS	8/12	2	54/68
5/27	HV2	31.25	V	10/17	4	59/67
5/31	HV3	13.21	S	10/20	2	61/73
6/4	HV1	5.23	VS	18/24	0	49/61
6/6	HV2a	7.79	V	10/19	0	53/60
6/8	MRI5	6.27	VS	25/34	0	49/57
6/10	HV1	9.98	MS	6/10	1	61/73
6/12	HV3	20.28	HV	10/17	3	58/68
6/14	HV3	21.75	HV	8/19	5	58/71
6/28	HV1	34.75	V	17/27	5	68/81
7/2	HV3	21.81	V	15/24	1	66/77
7/8	HV1	17.38	S	9/14	1	56/66
7/10	HV2	16.87	MS	14/20	3	55/65

Regression output	
Constant	7.728353
Std. err. of Y est.	5.464364
R squared	0.68165
No. of observations	14
Degrees of freedom	12
X coefficient(s)	4.227521
Std. err. of coef.	0.834001

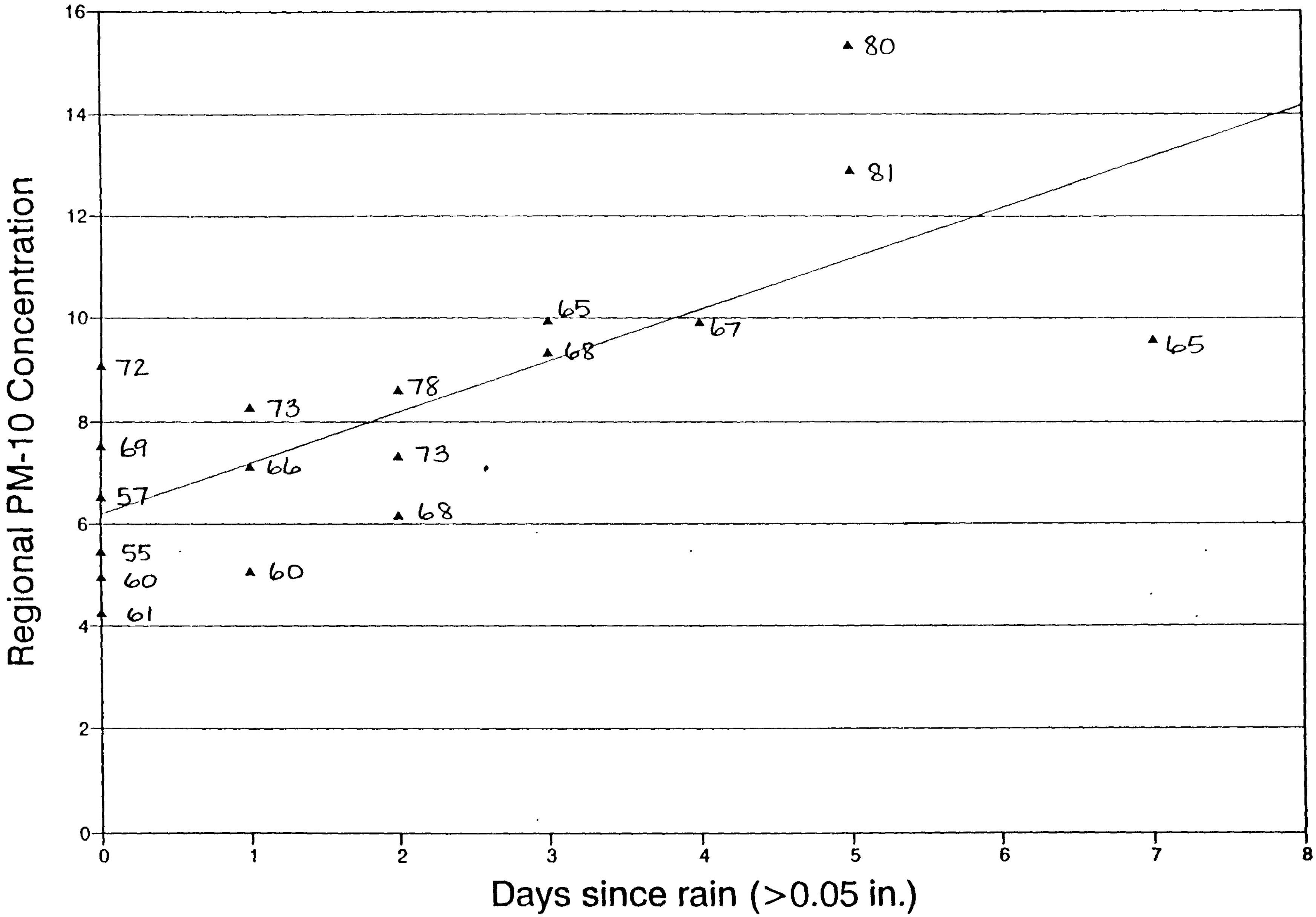

Figure E-2. Regional PM-10 background correlation.

Inspection of the graphical model for PM-10 (Figure E-2) can be used to estimate regional background values for the 12 days in question. The results are shown in Table E-3. It is interesting to note that in all but three cases the estimated background concentration and the measured lowest concentration for the specific day agree within ±2 $\mu g/m^3$, which roughly corresponds to the 95 percent confidence interval for collocated PM-10 measurements. This seems to indicate that suspected local source impacts were not significant on those days. The final column of Table E-3 shows the value of regional PM-10 background concentration actually selected for each of the 12 days.

Similarly, the graphical model for estimating background TSP concentrations is shown in Figure E-3. In this case, however, the concentration appears to be insensitive to maximum daily temperature. Therefore, the best-fit linear relationship is used in all cases to estimate background concentration.

The results of the estimating procedure for TSP background concentration are shown in Table E-4. In all but six cases, the estimated background concentration and the measured lowest concentration for the specific day agree within ±6 $\mu g/m^3$, which roughly corresponds to the 95 percent confidence interval for collocated TSP measurements. The final column of Table E-4 shows the value of regional TSP concentrations actually selected for each of the 16 days.

TABLE E-3. ESTIMATED VALUES FOR REGIONAL PM-10 BACKGROUND CONCENTRATION

				Regional PM-10 concentration ($\mu g/m^3$)			
Date	Station	Days since rainfall	Temp Avg/Max (°F)	Measured	Estimated[a]	Estimated-measured	Selected[b]
5/19	HV1	0	51/61	13.63	6	-7.63	6
6/2	HV2	0	52/59	4.33	6	1.67	4.33
6/14	HV2	5	58/71	10.92	11	0.08	10.92
6/16	HV2a	0	54/60	7.08	6	-1.08	6
6/18	HV2a	0	50/53	4.07	6	1.93	4.07
6/22	HV3	3	61/73	9.74	9	-0.74	9
6/26	HV1	3	64/81	11.04	12	0.96	11.04
6/30	MRI4	0	62/72	7.42	6	-1.42	6
7/2	HV1	1	66/77	11.00	10	-1.00	10
7/4	HV3	3	55/64	5.86	9	3.14	5.86
7/6	HV3	0	55/70	5.06	6	0.94	5.06
7/16	HV1	0	58/69	8.39	6	-2.39	6

[a] Estimated to the nearest microgram.
If there are no days since rain or the temperature is between 60° and 75°F, use the line.
Otherwise, estimate the effect of temperature based on the graph.
Equation for the line: $y = (x)^*(0.99789) + 6.19143$.

[b] The lower of the estimated and measured values was selected.

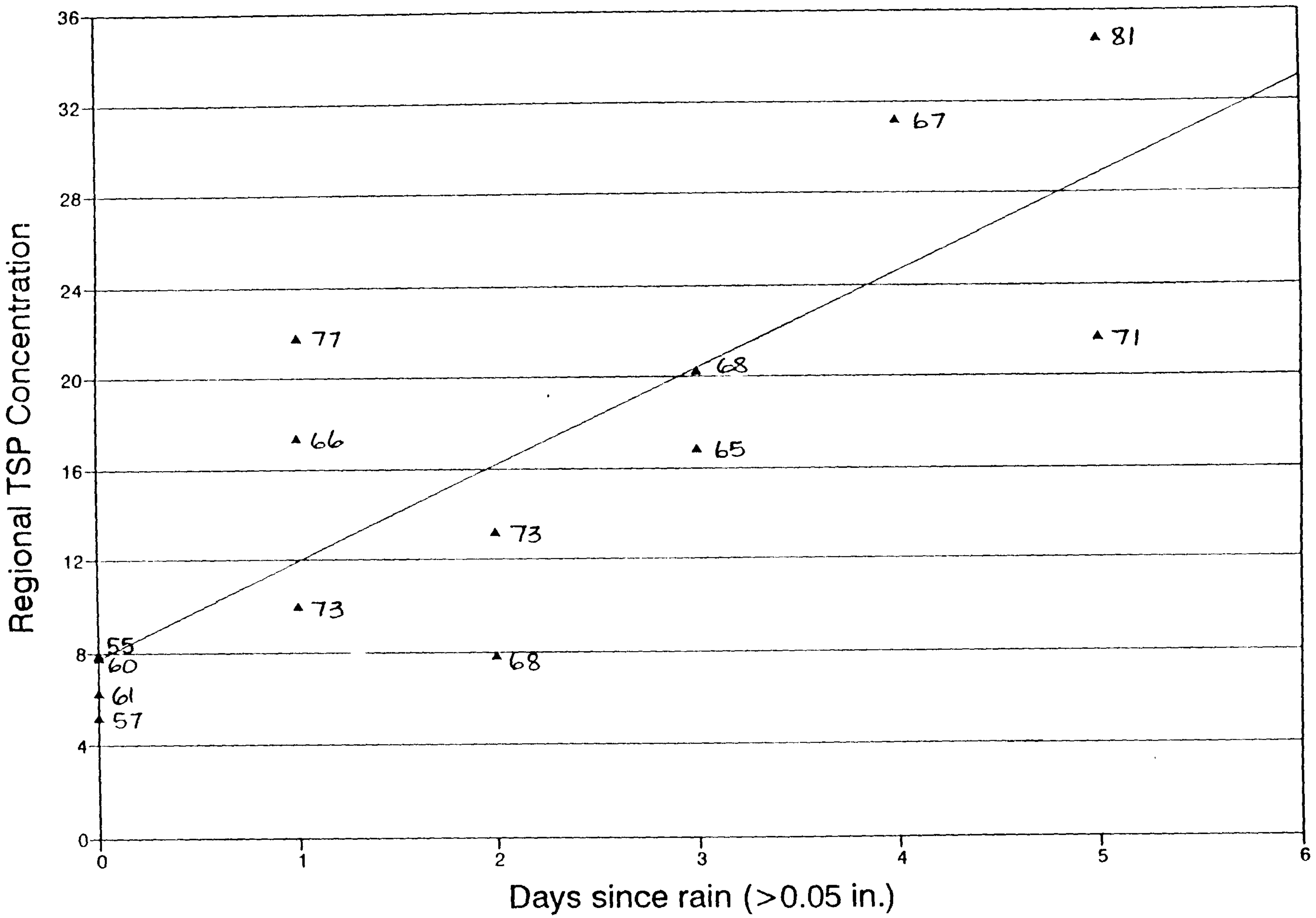

Figure E-3. Regional TSP background correlation.

TABLE E-4. ESTIMATED VALUES FOR REGIONAL TSP BACKGROUND CONCENTRATION

Date	Station	Days since rainfall	Temp Avg/Max (°F)	Regional TSP concentration (μg/m³) Measured	Estimated[a]	Estimated-measured	Selected[b]
5/19	HV3	0	51/61	29.23	8	–21.23	8
5/21	HV3	2	61/78	16.75	16	–0.75	16
5/29	HV3	0	59/72	17.98	8	–9.98	8
6/2	HV2	0	52/59	8.41	8	–0.41	8
6/16	HV2a	0	54/60	11.05	8	–3.05	8
6/18	HV2a	0	50/53	2.51	8	5.49	2.51
6/22	HV3	3	61/73	16.78	20	3.22	16.78
6/24	HV3	1	51/60	8.35	12	3.65	8.35
6/26	HV2a	3	64/81	27.77	22	–5.77	22
6/30	HV1	0	62/72	19.06	8	–11.06	8
7/4	HV3	3	55/64	7.89	22	14.11	7.89
7/6	HV3	0	55/70	8.32	8	–0.32	8
7/12	HV3	5	65/80	34.67	29	–5.67	29
7/14	HV2a	7	57/65	17.01	37	19.99	17.01
7/16	HV3	0	58/69	13.95	8	–5.95	8
7/18	HV3	0	61/69	21.14	8	–13.14	8

[a] Estimated to the nearest microgram.
According to the graph, there does not seem to be the same type of correlation with temperature as there was with PM-10. Consequently, the line was used to estimate values in all cases. The equation is y = (x)*(4.227521) + 7.728353.

[b] The lower of the estimated and measured values was selected.

APPENDIX F

SILT ANALYSIS RESULTS

APPENDIX F

SILT ANALYSIS RESULTS

Category	Silt, %	Date	Site
COAL HAUL RAMPS (G, F, A, T)			
Road A	2.41	7/16/93	A
	3.09	7/6/93	A
	9.24	7/2/93	A
	14.00	6/28/93	A
	9.22	6/26/93	A
	5.46	6/24/93	A
	4.35	5/31/93	A
Average	6.82		
Road T	1.60	7/14/93	T
	1.29	7/2/93	T
	7.51	6/26/93	T
	3.66	6/22/93	T
Average	3.52		
Road G	2.63	6/30/93	G
	3.31	6/14/93	G
	5.54	6/10/93	G
	3.78	6/6/93	G
	9.08	5/27/93	G
Average	4.87		
Road F	9.07	6/12/93	F
	2.91	6/10/93	F
	5.11	5/31/93	F
	6.91	5/29/93	F
	5.56	5/25/93	F (composite)
	5.99	5/23/93	F
	6.42	5/21/93	F
Average	6.00		
Overall average	5.57	Note: This is a weighted average	

TABLE F-1. (continued)

Category	Silt, %	Date	Site
MAIN COAL HAUL ROADS (M, Z)			
Road M	4.76	7/16/93	M
	3.15	7/16/93	M
	2.37	7/6/93	M
	1.30	7/4/93	M
	3.50	6/30/93	M
	3.53	6/12/93	M
	0.84	6/6/93	M
	3.49	5/31/93	M
	1.48	5/29/93	M
	3.05	5/27/93	M
	1.04	5/25/93	M
	2.73	5/23/93	M
	5.92	5/23/93	M
	3.79	5/21/93	M
	2.91	5/21/93	M
	1.20	5/19/93	M
Average	2.82		
Road Z	1.66	7/4/93	Z
	1.58	6/26/93	Z
	3.16	6/24/93	Z
	1.55	6/22/93	Z
Average	1.99		
Overall average	2.65	Note: This is a weighted average	
OVERBURDEN HAUL ROADS (D, E, V, X)			
Road V	3.09	7/14/93	V (100 yds from T intersection)
	3.32	7/10/93	V
	4.57	7/6/93	V
	5.27	6/2/93	V
Average	4.06		
Road D	3.05	7/12/93	D (water tracking composite)
	5.44	7/12/93	D
	1.34	5/31/93	D
Average	3.26		

TABLE F-1. (continued)

Category	Silt, %	Date	Site
Road E	7.78	7/12/93	E
	6.27	6/14/93	E
	1.29	5/31/93	E
Average	5.11		
Road X	3.38	7/8/93	X
	3.47	6/2/93	X
Average	3.43		
Overall average	4.02	Note: This is a weighted average	
ACCESS ROADS (B, C)			
Road C	13.70	7/16/93	C
	3.85	6/14/93	C
Average	8.78		
Road B	9.98	5/27/93	B
Average	9.98		
Overall average	9.18	Note: This is a weighted average	
MISCELLANEOUS			
	5.76	7/16/93	Side of G
	4.70	7/6/93	Bottom of lift A
	7.96	6/28/93	N. pit parting haul area
	7.11	5/13/93	Coal bench by shoven No. 6
	12.10	6/12/93	Travel area on east side of shop
	3.79	7/18/93	Ovb. from S. pit
	4.53	7/16/93	Ovb. dump off E

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Technical Representative: Jawad S. Touma

16. ABSTRACT

This report is the second part of a study designed to analyze the accuracy of the Industrial Source Complex model for application to fugitive dust sources from surface coal mining operations. The first report, EPA-454/R-94-024 described the field monitoring program to collect data on ambient air quality, meteorology and source activity at a surface coal mine in the Powder River Basin in Wyoming. This report defines the procedures that will be used to identify the best-performing model for predicting the impacts of fugitive dust sources at these mines and to assess "significant" overprediction, if it occurs. The report describes the representation of the emission sources in the emission inventory; the modeling systems to be evaluated; the source activity, meteorology, air quality and background air quality data bases to be used; and the evaluation methodology.

17. KEY WORDS AND DOCUMENT ANALYSIS

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