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VOLUME III. MODEL SIMULATION OF TOTAL SUSPENDED PARTICULATE LEVELS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
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Research Triangle Park, North Carolina 27711

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VOLUME III. MODEL SIMULATION OF TOTAL SUSPENDED PARTICULATE LEVELS

by

George Richard, Jim Avery, and Lal Baboolal

TRW Environmental Engineering Division
One Space Park
Redondo Beach, California 90278

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EPA Project Officer: Dallas Safriet

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1.0 INTRODUCTION AND SUMMARY

Under contract to the Environmental Protection Agency, TRW Environmental Engineering has developed control strategies for total suspended particulates in the Phoenix area. The data base and methodology developed for Phoenix have been extended into a general technical support document for application to areas with fugitive dust problems. This report is the third of four technical support documents prepared for the project.

The relationships between ambient total suspended particulate, (TSP) and emission levels were established in this study. An air quality model, comprised of the CDM and a simple rollback relation, was used to forecast suspended particulate levels for small and larger particle sizes. Present (1975) and future (1985) suspended particulate concentrations arising form individual source categories were simulated. Controls were established after several iterations of air quality forecasts which were necessary in order to attain standards.

The present section (Section 1) introduces the study and summarizes the major results and conclusions. Section 2 discusses the choice of model. Section 3 identifies factors affecting the representiveness of the emissions and air quality data base, and discusses how the bias in the data base might be eliminated. Section 4 details the model parameterization procedure, including assignment of empirical coefficients for each of the monitor sites. Section 5 presents the modeling results for 1975 and 1985.

1.1 RESULTS

Particulate concentrations in the Phoenix area were simulated using a superposition model which combined the results of the Climatological Dispersion Model (CDM) with those of linear rollback (LR). It was assumed in this study that particulates smaller than 20μm aerodynamic diameter could be adequately modeled with the CDM model, and those greater than 20μm could be adequately treated in the context of the LR

modeling concept. In the latter, ambient particulate levels in a given grid square are assumed proportional to the average emissions within that grid.

The mathematical relation underlying the superposition principle is of the form

$$X_i = \alpha_{1i} C_i + \alpha_{2i} E_i + B$$

where X is the estimated TSP concentration at receptor i, C_i is the CDM simulated level of particulates in the size range 0-20 microns at receptor i, E_i is the emission level of particulates greater than 20 microns in the grid square containing receptor i, B is the background level of TSP, and α_{1i} and α_{2i} are empirical coefficients obtained by comparing the simulated values with the measurements.

Microscopy analyses of hi-vol filters were used to establish the contribution of each particle size range to the TSP levels. These analyses, although limited, confirm the substantial effect of large particles on TSP levels. Seventy percent (70%) of the particulate mass found on hi-vol sampler filters throughout the study area was comprised of particles greater than 20 micron in diameter. This finding, along with the model baseyear TSP simulations and observed TSP levels was used to establish empirically the α's at each of the sampler site.

An analysis of the representativeness of air quality data revealed that the TSP measurements could be significantly biased because of three major factors: 1) variation in monitor heights at the different sites; 2) site-specific sources affecting the monitor in a manner atypical of the general area, and 3) incompleteness of measurements. The first factor can result in substantial understatement of TSP levels for monitors higher than the standard exposure height; the second factor can result in significant overstatement of the air quality in the general area, and the third factor can result in a bias of variable nature depending on the site and annual meteorology. Sufficient information is not available in Phoenix to assess the quantitative relationship between these

factors and measured TSP levels. Hence, air quality adjustments are not possible.

Uncertainties associated with the emissions data base compound the probable bias entering the model parameterization. It is not within the scope of this study to evaluate the sensitivity of the air quality simulation to the numerous influence factors affecting the data base. This study has sought to identify some of the major sources of bias, and to indicate areas where the model results could be used while at the same time recognizing some shortcomings due to data bias.

TSP was estimated at the various sites for 1975 and 1985 with the empirical model using the compiled emissions inventory. The results (Table 5-1) show that in 1975 four particulate sources dominated: unpaved roads, entrained street dust, construction activities and wind erosion. By 1985 (Table 5-2), only the first three sources are likely to dominate. Wind erosion will not be a major source then because of less available open soil surfaces. By 1985, most of the monitor sites will be affected more by entrained street dust than by any other source. Exceptions will occur at the more rural sites (St. Johns, Chandler, N. Scottsdale, S. Phoenix) where unpaved road emissions will cause the greatest impact on TSP levels.

As a result of the net changes in emission source magnitudes and distribution, TSP levels in 1985 will decrease significantly at 11 of the 13 monitoring sites considered (Table 5-2). These TSP levels will be 16 to 50% less than the corresponding 1975 levels, depending on the site. In most cases, the air quality improvements will be due primarily to the forecasted regional development. This development will reduce the proportion of open surfaces and diminish the magnitudes of several local sources which currently affect certain samplers. At two of the monitors, TSP levels will increase due to persisting sources which will be unchanged by expected development plans.

The modeling method used shows good simulation capability. CDM is on firm theoretical ground and applies strictly to the smaller particles. Linear rollback is on weaker theoretical grounds. Considering the difficulties inherent in modeling particulates over the entire range of particle sizes, the superposition scheme used in this study is recommended for particulate modeling until such time as better methods are developed.

1.2 CONCLUSIONS

The CDM adequately characterizes the transport and diffusion of smaller particulates (<20μm) in the atmosphere but is inadequate in the study of larger particulates for which gravitational settling is an important factor. A proper treatment of this problem must consider gravitational settling.

Microscopy analysis of high volume filter samples can provide useful data for model improvement. Particle size distribution data at the various sites may be used to determine size dependent empirical constants (model parameterization). This technique is especially suitable for larger particle regimes where the effect of large particle emissions are so localized that only very site specific adjustments are appropriate.

In Phoenix, the particle size distribution observed at the various monitor sites appears to be very similar. Within a small variation (about 10%), particles 20μm and larger comprise 70% of the TSP by mass for each of the hi-vol sites and filters examined.

Various influence factors (i.e., height of monitor, completeness of data) may affect the representativeness of the air quality data base and therefore its utility for model application. Although the data base examined is small, it appears that height of the monitor may affect values of observed TSP dramatically. Exposure concentrations at ground level may be 30 to 40% greater than those recorded at monitors 5 or 6m above the ground.

In areas where TSP levels are caused principally by fugitive dust, normal growth patterns may have significant impact on future TSP levels

and distributions primarily because fugitive dust is a short range problem which tends to be diminished by local development. The localized effect of fugitive sources and the changing distribution of TSP levels due to regional development suggest the importance of air monitor placement and the need for "hot spot" monitoring. Emissions density maps may be useful in identifying these TSP maxima.

Considering the state-of-the-art of particulate modeling the superposition approach of combining CDM with linear rollback appears adequate. As emissions become better defined the modeling approach must be likewise refined. This study suggests the need for developing source-receptor models which will incorporate dry and wet deposition and gravitational settling.

2.0 FORMULATION OF SOURCE RECEPTOR RELATIONSHIP

This chapter discusses the choice of a suitable air quality model for total suspended particulates in the Phoenix area. Available diffusion models are reviewed to evaluate their potential applicability for emissions sources in the study area. A standard diffusion model is selected, and modifications to the model are proposed to account for the diverse spectrum of dispersion characteristics exhibited by fugitive dust sources. Major inputs required to parametize the formulated model are discussed.

2.1 SELECTION OF THE AIR DIFFUSION MODEL

Averaging time is an important consideration in model selection. The federal air quality standards define both a short term (24-hour) and long term (annual) concentration. However, there is reasonable cause to restrict our analysis to only the long term levels. First, considerably greater control is required to attain the primary annual standard at each station than is required to attain the primary 24-hour standard, provided episodes due to duststorms are excluded (see Table 2-1). Second, uncertainties with the data base also affect model selection. Uncertainties are introduced at several stages of the air monitoring measurements, emissions inventory compilation, and model formulation. The analytical limitations inherent in the modeling of short term averages do not warrant the additional effort at this time.

The discussion of the following sections includes a review of four air diffusion models considered as potential tools for estimating annual concentrations in the Phoenix area. The Phoenix Multiple Box (Berman and DeLaney, 1975), the Denver Brown Cloud (Middleton and Brock, 1975) and Hanna's Urban Model (Hanna, 1971) are reviewed and assessed to be inapplicable for particulate modeling in the Phoenix area. The Atmospheric Transport and Diffusion Model, (Culkowski and Patterson, 1976) ATDM, is reviewed and deemed applicable provided certain modifications are made. Recommended is the Climatological Dispersion Model (CDM) for the long-term (annual) averages. Some modifications to the CDM are required for an accurate representation of air quality from all particle size ranges.

TABLE 2-1. SUMMARY OF 1973-1975 AIR QUALITY VIOLATIONS FOR TSP IN PHOENIX AREA

Stations Reporting	TSP Concentration $\mu g/m^3$		Percentage Emission Reductions to meet primary Standards[b] based on linear rollback	
	Annual	Expected Second Highest 24-Hr[a]	Annual	24-Hour
Central Phoenix	139	370	58.7	32.3
South Phoenix	170	320	67.8	20.6
Arizona State	156	390	64.1	36.1
Glendale	97	220	32.8	--
North Phoenix	127	340	53.6	25.8
N Scot/Paradise	143	450	60.1	45.2
Scottsdale	110	225	43.7	--
Mesa	124	250	52.1	--
Downtown	199	450	73.3	45.2
St. Johns	145	630	60.8	61.6
Sun City	84	200	16.6	--
Paradise Valley	191	480	72.0	48.8
Chandler	136	320	57.5	20.6
Carefree	41	135	--	--

[a]Based on statistically computed expected concentrations (from distributions derived from historical data for 1973 to 1975 [23] and assuming 60 measurements per year).

[b]Annual primary standard = 75 $\mu g/m^3$
24-Hour primary standard = 260 $\mu g/m^3$

The model used, with modifications, is discussed in Section 2.2.

2.1.1 Phoenix Multiple Box Model

To study transport and diffusion of air pollutants over the greater Phoenix area, Berman and DeLaney (1975) selected a multiple box model. In particular, Gaussian concepts with a single wind field could not be used because of the spatially varying wind field which exists in the area. In their model, which is based on the method of Reiquam (1970), the wind field is an input in the basic equation.

Mass of Pollutant in each box	= Mass Imported from Adjacent Box	+ Mass Emitted in the Box	+ Mass Remaining in the Box

And, when the boxes are of constant height, the concentration, X, in a grid square (i,j) at time, t, is given by

$$X(i,j;t) = [R1(i,j;t)Q(i,j;t) + R2(i,j;t)\ S(i,j;t)]\ V(i,j;t) + \rho(i,j;t)\ X(i,j;t-1) \qquad (2\text{-}1)$$

where Q and S are the advective and emission rates, respectively, V the volume of the (i,j) cell, and R1, R2, and ρ are the residuals of Q, S and X remaining at time t.

Stated more compactly, the above equation may be written as

$$\text{Mass of Pollutant in each box} = \Sigma(\text{residual})(\text{rate})$$

The residuals are functions of the mean horizontal winds in a given cell. The above equations do not account for vertical diffusion. To include this, the residual terms were divided by a dilution factor. These factors were obtained from Slade[14] and Ragland[15].

However, there are several problems with this model. First, it would be strictly inapplicable to particulates since it does not take into account particle size. Second, it is essentially a short term

model from which long term averages may be obtained by aggregating ('brute force' method) the hourly simulation -- a process which is both time consuming and costly. Third, it employs factors (dilution) which are derived from data gathered elsewhere. For these reasons this model cannot be applied to the present problem.

2.1.2 Denver Brown Cloud Model

Another approach which did take into account the changing particle sizes is the Denver Brown Cloud Model (Middleton and Brock, 1974). In this model, the evolution of the particle size spectrum, assuming some initial distribution, is investigated as an air parcel traverses over a given source distribution. The primary physical mechanisms modeled are coagulation, condensation and deposition. Neglected in the model are the urban "heat island effects," the "chimney effect" and complex air circulations other than drainage flows.

In this model, the evolution of the density function $n(x,r,t)$ for an aerosol with convective transport is described by

$$\begin{aligned}\frac{\partial n}{\partial t}(x,\vec{r},t) + \nabla\cdot\vec{v}n(x,\vec{r},t) &= \nabla\cdot\bar{\bar{K}}\cdot\nabla n(x,\vec{r},t) \\ &+ \frac{1}{2}\int_0^x dx'\, b(x-x',x)\, n(x-x',\vec{r},t)\, n(x',\vec{r},t) \\ &- n(x,\vec{r},t)\int_0^\infty dx'\, b(x',x)\, n(x',\vec{r},t) \\ &- \frac{\partial}{\partial x}[\Psi(x)\, n(n,\vec{r},t)] + \frac{\partial}{\partial x^2}[\alpha(x)\, n(x,\vec{r},t)] \\ &+ \vec{G}(x)\cdot\nabla n(x,\vec{r},t) + \sum_p \dot{\nu}_p(x,\vec{r},t) + \sum_j \dot{\nu}_{Nj}(x,\vec{r},t)\end{aligned} \tag{2-2}$$

where $n(x,\vec{r},t)$ represents the number of aerosol particles of mass, x, between the mass interval x and x+ dx and at position $\vec{r}$ at time t; and $\vec{V}$ velocity of the air mass, $\bar{\bar{K}}$ the eddy diffusivity tensor, G(x) the sedimentation velocity of a particle of mass x, $\dot{\nu}_p(s,\vec{r},t)$ the rate of production of particles of mass x at $\vec{r}$,t from primary sources, $\dot{\nu}_{Nj}(x,\vec{r},t)$ the rate of production of particles of mass x at $\vec{r}$,t by homogeneous

nucleation of the j th chemical species, $b(x,x)$ the coagulation coefficient and $\Psi(x)$ and $\alpha(x)$ the condensation coefficients which account for heterogeneous nucleation.

The first term on the right-hand side of the equation accounts for the turbulent dispersion of the aerosols, the second and third terms account for coagulation, the fourth and fifth terms treats the heterogeneous nucleation involving the j-th chemical species.

To be applied to the problem at hand, the above equation must be averaged over time and space. In this process, the volume average of the density function then becomes

$$\langle n(x) \rangle = \int n(x,\vec{r},t)d\vec{r} \tag{2-3}$$

where the time dependence is dropped on the left-hand side in the interest of brevity.

If, subsequent to the above averaging, the above volume integral is converted to a surface integral the evolution of the density function becomes

$$\begin{aligned}\frac{\partial}{\partial t}\langle n(x)\rangle \quad &= \frac{1}{2}\int_0^x b(x-x',x)\ \langle n(x-x')\rangle\ \langle n(x')\rangle\, dx' \\ &- \langle n(x)\rangle \int_0^\infty b(x,x')\ \langle n(x')\rangle\, dx' \\ &+ \frac{\partial^2}{\partial x^2}\ \langle\alpha(x)\rangle\ \langle n(x)\rangle - \frac{\partial}{\partial x}\ \langle\Psi(x)\rangle\ \langle n(x)\rangle \\ &- \langle\sigma(x)\rangle\ \langle n(x)\rangle + \sum_p \tau_i\, W_i\,(x)\end{aligned} \tag{2-4}$$

In this equation, the homogeneous nucleation term has been omitted because it is small compared to the contribution from the other terms, $\langle\sigma(x)\rangle\langle n(x)\rangle$ treats the removal of aerosol from a given cell viz. this term replaces that involving $\vec{G}\,(x)$ in the previous equation, while the last term accounts for the direct production of aerosols from all

primary sources. These factors depend strongly on the local mixing conditions and as such are terrain dependent. Therefore, these factors could be expected to be site specific.

The next stage in the model development involves specifying the coagulation coefficient, $b(x,x')$. It is assumed that the particles interact through Brownian coagulation only. In the treatment of condensation, the effects due to particle size dispersion are ignored relative to diffusional transfer of chemical species to the surface of a particle. Furthermore, it is assumed that the only significant mechanism for secondary source input involves the conversion of H_2SO_4.

The deposition coefficient, $\langle\alpha(x)\rangle$, is expressed in terms of the deposition velocity, $V(x,t)$, and the mixing height, $H(t)$, as

$$\langle\alpha(x)\rangle = V(x,t)/H(t)$$
$$\text{where} \quad V(x,t) = v(x,t) + V_0(x). \tag{2-5}$$

The gravitational settling velocity, $V_0(x)$, of particles of effective radius R and density ρ, is given by

$$V_0(x) = \frac{4}{3}\,\Pi\, R^3\, \rho g/6\Pi\mu R \tag{2-6}$$

where g = acceleration due to gravity and μ = viscosity of air; and, $v(x,t)$ is related to the wind speed, $U(x)$, by means of

$$v(x,t) = U(x)L(t)$$

where $L(t)$ is a time factor which specifies the diurnal variation in the mean flow.

Five different source types (traffic dust, construction dust, point sources, stationary combustion sources and transportation) were used to construct the source term. Furthermore, since no information on source size distribution was available, a log normal distribution in the mass was assumed. An empirical relationship for the time dependent vertical mixing was used in the model. Advection was accounted

for in a valley flow factor in the source term. A typical night-time aerosol distribution derived from actual measurements was used for the initial size distribution.

From the various simulation runs, the following conclusions were drawn for Denver:

1. The ambient particle size distribution is very sensitive to the choice of dry deposition and primary source input rate parameters.

2. The episode aerosol is strongly source dominated with photochemistry acting only as a minor secondary source; hence, the submicron particles increase mainly by source injection and by coagulation, while the large particles are influenced by source injection, by deposition as well as, by coagulation with combustion nuclei.

3. The wavelength dependent light scattering ability of the episode aerosol has been shown to be a possible contribution to the "brown cloud" effect.

The model, as presented above, is only a preliminary one. Even so, its complexity and data input requirements make it impractical for present application to the Phoenix area. However, this type of modeling approach offers much hope provided the prescribed data becomes available in the future.

2.1.3 Climatological Dispersion Model, CDM

CDM was also considered for application to this study. This model was developed by Busse and Zimmerman (1973).[2] Essentially, it is a regional model which accepts the emissions inventory in the form of gridded input. Long term concentrations are obtained by inputting the joint frequency distribution functions of the surface winds. Turbulence is parameterized in terms of the standard Pasquill-Gifford Scheme. Recognition of the diurnal variation in mixing layer height is made by an algorithm which

assigns a separate height for each stability class. Also, the variation in the horizontal wind with height is modeled according to the wind power law. Pollutant removal, by whatever means such as coagulation, sedimentation, Brownian diffusion, is handled only in a gross way through an exponential decay term. The equations describing the average concentration and relevant parameters are in general quite complicated and are not repeated here in great details especially since the model has been in existence for a relatively long time and is a commonly used model.

In the CDM model the average concentration X_a due to area sources at a particular receptor is given by

$$X_a = \frac{16}{2\pi} \int_0^{\infty} \left[\sum_{k=1}^{16} q_k(\delta) \sum_{\ell=1}^{6} \sum_{m=1}^{6} \Phi(k,\ell,m) S(\delta, z; u_\ell, P_m) \right] d\delta \qquad (2\text{-}7)$$

where k = index for wind direction sector

$$q_k = \int Q(\delta, \theta)\, d\theta \qquad \text{for the } k \text{ sector}$$

$Q(\delta, \theta)$ = emission rate of the area source per unit area and unit time

δ = distance from the receptor to an infinitestimal area source

θ = angle relative to polar coordinater centered on receptor

ℓ = index identifying wind speed class

m = index identifying Pasquill stability category

$\Phi(k,\ell,m)$ = joint frequency function

z = height of receptor above ground level

u_ℓ = representative wind speed

P_m = Pasquill stability category

$S(\delta, z; u_\ell, P_m)$ = dispersion function

For point sources, the average concentration X_p due to n point sources

$$X_p = \frac{16}{2\pi} \sum_{j=1}^{n} \sum_{\ell=1}^{6} \sum_{m=1}^{6} \frac{\Phi(k_j, \ell, m)\ Q_j\ S(\delta_j, z; u_\ell, P_m)}{\delta_j} \qquad (2\text{-}8)$$

where k_j = wind sector appropriate to the jth point source

Q_j = emission rate of the jth point source

$_j$ = distance from the receptor to the jth point source

For a ground level receptor, z = 0, S becomes

$$S(\delta, 0; u_\ell, P_m) = \frac{2}{\sqrt{2\pi}\ u_\ell\ \sigma_z(\delta)} \exp\left[-\frac{1}{2}\left(\frac{h}{\sigma_z(\delta)}\right)^2\right] \exp\left(\frac{-0.692\delta}{U_\ell\ T_{1/2}}\right)$$

for $\sigma_z(\delta) \leq 0.8L$ and (2-9)

$$S(\delta, o; u_\ell, P_m) = \frac{1}{u_\ell L} \exp\left(\frac{-0.692\delta}{u_\ell T_{1/2}}\right) \qquad (2\text{-}10)$$

for $\sigma_z(\delta) > 0.8\ L$

where $\sigma_z(\delta)$ = vertical dispersion function

h = effective emissions height

L = afternoon mixing height

$T_{1/2}$ = assumed pollutant half life, hours

2.1.4 Atmospheric Transport and Diffusion Model, ATDM

The ATDM (Culkowski and Patterson, 1976)[17] was also reviewed for this project. It is based on the standard Gaussian equation which

has been modified to include the effect of aerodynamic roughness on dispersion. The ATDM also models terminal and deposition velocities, incorporates a tilting plume for the heavy particulates, and includes an episodic calculation of exposure maxima. Wetfall and dryfall deposition rates are both included in the model.

Equations (2-7) through (2-10) apply to the dispersion and transport of small particles ($\leq$ 5 m aerodynamic diameter). The equations may be modified to account for the larger particles. These modifications will assume that plume dilution takes place through dry deposition, and washout.

Dry Deposition

Dry deposition rate is given by

$$D = v_g \, S \, (\rho \, , z; u_\ell, p_m) \qquad (2\text{-}11)$$

where v_g is the deposition velocity.

The rate of change of effective sources strength as a function of downwind distance from the source is

$$\frac{dQ}{dx} = -\int D d\delta \qquad (2\text{-}12)$$

Equation (2-12) may be substituted in (2-11) to give

$$Q = Q_o \exp \left[- \sqrt{\frac{2}{\pi}} \left(\frac{v_g}{U} \right)^{-V} \int_o^x S'(\; ; z; u_\ell, P_m) \right] dx' \qquad (2\text{-}13)$$

Washout

Washout may be described by the equation:

$$\frac{dQ}{dt} = - \lambda Q \qquad (2\text{-}14)$$

where λ is the washout coefficient. Equation (2-14) may be integrated to give

$$Q = Q_o \, e^{-\lambda \frac{x}{u}} \tag{2-15}$$

where the time of flight, t, is set equal to x/u.

The results given in equations (2-14) and (2-15) may be incorporated in equation (2-7). Dry deposition may be estimated from the expression

$$D = F_D \, v_D \, X_a \tag{2-16}$$

where: F_D = fraction of time in which only dry deposition occurs
v_D = deposition velocity
and X_a is given by equation (2-7)

Similarly washout may be estimated by

$$W = F_w \boldsymbol{\lambda} \, X_A \tag{2-17}$$

where F_w = fraction of time in which both washout and dry deposition are occurring

$\boldsymbol{\lambda}$ = washout coefficient

Dry deposition and washout may be incorporated into the basic Gaussian, equation as prescribed in equations 2-7 and 2-8. This was actually done in ATDM. However, in its present state the model is most suitable for point sources and would have to be rewritten for regional application involving aggregates of sources. This would involve substantial amounts of time and resources and was not pursued any further.

2.1.5 Hanna's Urban Model.

A "Simple Method of Calculating Dispersion from Urban Area Sources" was proposed by Hanna (1971).[6] In this model, the surface concentration

was assumed directly proportional to the local area source strength and inversely proportional to the wind speed when all source strength are approximately the same. Or,

$$X = C \frac{Q_o}{u} \qquad (2\text{-}18)$$

where X = surface concentration

Q_o = source strength

u = wind speed, and

C is a function of atmospheric stability.

This model gave good results for sulfur dioxide simulation in the Chicago area. It has also been applied in a recent study of the TSP problem in Reno and Las Vegas[13]. Relatively high correlations between observed and predicted TSP levels were obtained, with the model tending to over-predict measured levels. The model is unable to account for gravatational settling and deposition of particulates.

2.2 MODIFICATIONS TO CDM

Even though CDM was found to be most applicable for the Phoenix particulate problem, there were still some serious shortcomings which had to be addressed. One study[4] of high-vol filters in the Phoenix area showed that large particles (greater than 20 microns) accounted for roughly 70% of the particulate mass by weight. This implies that only 30% of the particulate matter at receptor level could be treated as a dispersive gas; and, the other 70% would have to be treated differently. Moreover, the experimental data supported the observation that the large particles were directly associated with local nearby sources while the smaller particles were derived from the region as a whole.

It was,therefore, necessary to treat emissions from local sources in the air quality modeling effort differently from those area

wide sources with smaller particle sizes which CDM could represent accurately. To facilitate this modified modeling approach, the emissions model was altered so that it would prepare a gridded inventory for each of four particle size ranges. The particle size ranges were selected based on approximate cutoff points in dispersive behavior. The four size ranges are as follows: 0-10 microns; 11-20 microns; 21-70 microns; and greater than 70 microns.

The CDM is useful for the first two ranges governed primarily by dispersion forces but not useful for the latter ranges where gravitational settling becomes the dominant force. Figure 2-1 illustrates the settling effect for different wind speeds. For the CDM, the effect of gravitational settling in the smaller size ranges was approximated with the assignment of concentration decay constants. The decay rate for the 11-20 micron range is significantly larger than that of the 0-10 micron range. The assignment of decay rates for incorporation to the CDM is discussed in Section 2.3.1

Particles greater than 70 microns in size are ignored in the air quality model. The diffusion of these particles will be determined almost exclusively by gravity effects. Their travel distance is only a few meters and generally not enough to impact the air quality monitors, except for a few cases where nearby local sources may be situated very near the monitor.

The modeling of air quality for particles in the 21-70 micron range was accomplished by a simple rollback scheme which assumed that concentration within a given grid is directly proportional to emissions within that grid. In this scheme the mathematical relation is of the form

$$X = \alpha E$$

where X is the concentration of particles larger than 20μm at a receptor in a given grid, E the emissions of particles larger than 20μm within the grid and α an empirical constant.

The overall air quality model now assumes the form:

$$X = \alpha_1 C + \alpha_2 E + B$$

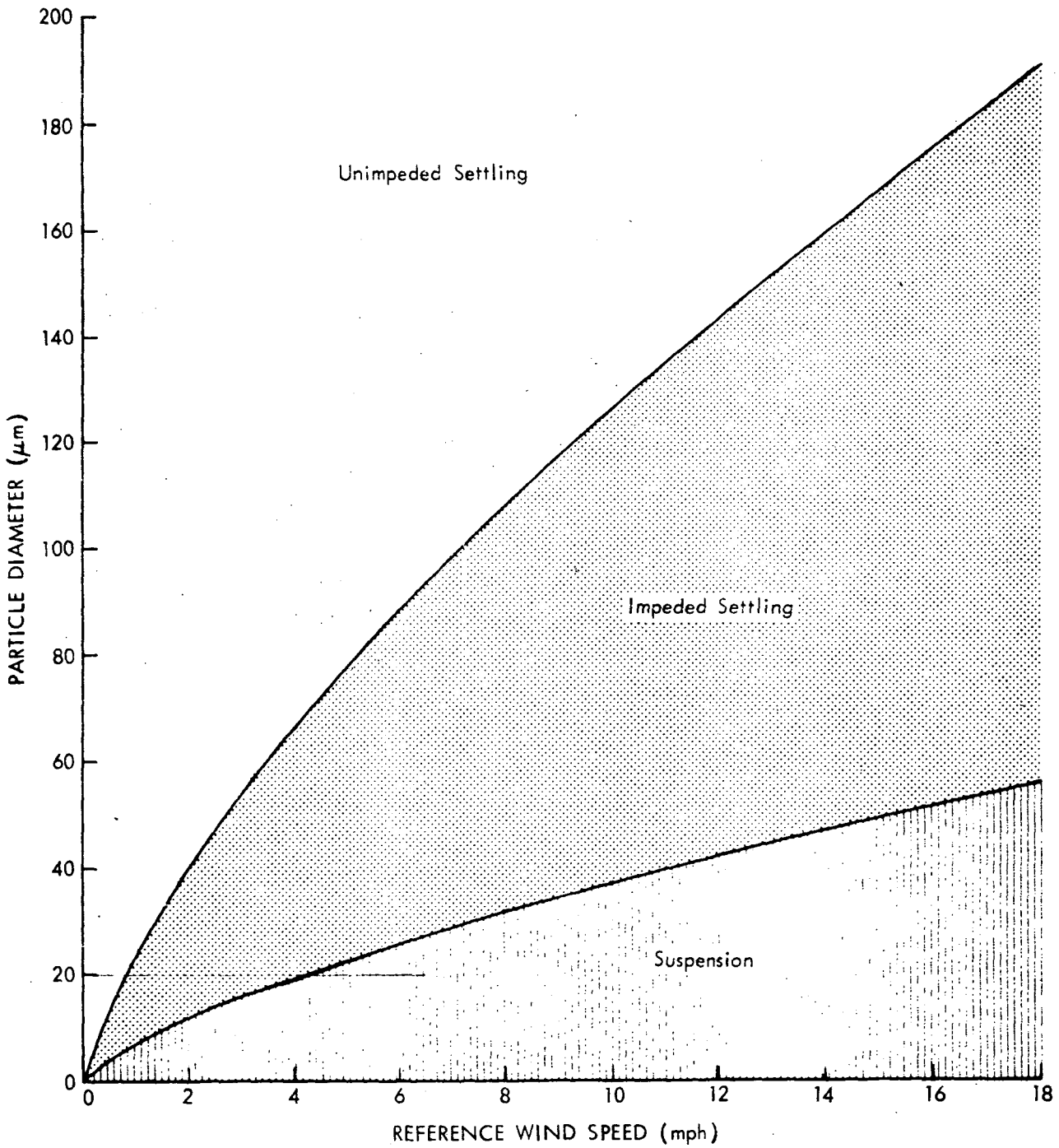

FIGURE 2-1. PARTICLE SETTLING/SUSPENSION REGIMES (MRI, 1974)

where: X = Total suspended particulate concentrations

C = CDM concentration estimates for 0-10 and 11=20 micron ranges

E = Emissions of particles >20 micron in grid containing receptor

B = Background TSP level

α_1 = Empirical coefficient for CDM

α_2 = Empirical coefficient for rollback model

The background term in the above equation derives from two different sources. The first is due to suspended matter advected into the Phoenix area from other regions. The second is due to natural local sources which have been neglected from the emissions inventory.

The Carefree site showed the same 70% large particles as the other sites, while TSP levels there were only about one third larger than those of the background stations ($42\mu g/m^3$ vs. $30\mu g/m^3$). There are some anthropogenic sources near Carefree to account for the larger TSP levels, but not enough to account for the 70% observed. Therefore, some fraction of the background must be due to particles greater than 20 microns. Unfortunately, microscopy analysis[4] was not performed on any station which could be considered purely natural background, so there are no data to indicate what percent of the background is large and what is small. Hence, it was assumed that 50% of the background was less than 20 microns, and 50% greater than 20 microns.

With the nature of the background thus defined, and the particle size distribution on the filters known, it is a straightforward task to estimate α_1 and α_2 in the above equation. Since 30% of the total suspended particulates measured are less than 20 microns, and 50% of the background particulates are less than 20 microns, the following relationship must hold:

$$0.3X = \alpha_1 C + 0.5B$$

Also, since 70% of the measured particulates are greater than 20 microns:

$$0.7X = \alpha_2 E + 0.5B$$

and,

$$\alpha_1 = (0.3X - 0.5B)/C$$

$$\alpha_2 = (0.7X - 0.5B)/E$$

The numerical procedure for the assignment of α_1 and α_2 and their empirical values are presented in Section 4.2. The determination of α_1 and α_2 must be performed individually for each receptor, so that for the ith receptor:

$$X_i = \alpha_{1i} C_i + \alpha_{2i} E_i + B$$

2.3 MODEL INPUTS

The CDM requires various meteorological and source emissions input data which must be prepared in forms suitable for model application.

2.3.1 Meteorology Data

Meteorology data for the study were obtained from the National Climatic Center (NCC) in Asheville, North Carolina. The NCC provided both the joint frequency function and mixing height data. The joint frequency function is a combined frequency of occurrence for three meteorological parameters as defined by CDM: six stability classes, six wind speed classes, and sixteen wind directions. A monthly annual (day/night) star program run was made by NCC for both 1975 and for the entire 1973-1975 period. The 1975 data were used for model parameterization (i.e., to determine the empirical α coefficients) while the 1973-1975 averaged data were used for 1980 and 1985 particulate simulation.

The mixing height data were prepared from two different sets of NCC inputs using both surface observations and upper air data. The mixing heights were calculated form upper air data collected at Tucson

(the nearest upper air station to Phoenix), and the surface observations at Phoenix. Mean mixing heights used are shown in Table 2-2, and mean daily temperature in Table 2-3.

2.3.2 Emissions Parameters and Pollutant Half Life

The CDM requires as input the emissions and their diurnal behavior, plume heights, source configuration; and pollutant half life.

Diurnal Assignment

The diurnal distribution of emissions must be specified in the CDM. To estimate this distribution, the five largest sources were analyzed for their emission patterns. A weighted average of these patterns produced a 78-22 percent day-night split for 1975 and an 81-19 percent split for 1985. The 1985 daytime figure is larger primarily because of greater emissions due to construction activities forecast to occur then.

Plume Height of Sources

Plume heights for all point sources were given in the NEDS data. An assumed plume height of 10 meters was used for all area sources.

TABLE 2-2

MIXING HEIGHTS FOR PHOENIX, 1975.

QUARTER	AVERAGE AFTERNOON (METERS)	AVERAGE NOCTURNAL (METERS)
1	1685	269
2	3287	463
3	4363	743
4	2688	366
Annual Average	3006	460

TABLE 2-3.
MEAN DAILY TEMPERATURE AT PHOENIX

QUARTER	1975 (^{o}F)	1980-85 (Historical Data) (^{o}F)
1	55	56
2	75	76
3	91	88
4	63	61
Annual Average	71	71

Determination of Pollutant Half-life

The pollutant half-life is required for the estimation of the decay term used in the CDM diffusion model for the 10-20 μm range. Half-life refers to the time elapsed before the ambient concentration of a given size particulate is reduced by one-half due to physical removal mechanisms (e.g., dry deposition and gravitational settling). The following derivation of half-life is based upon the IITRI[4] study in Phoenix; however, the procedure can be readily applied to other areas. The computational technique is based on Van der Hoven's dry deposition formulation (given in Slade, 1968). First, it is assumed that a 15 μm diameter particle is representative of the 10-20 μm range. Then for an average wind speed of 2.41 m/s (annual mean value for Phoenix) and a terminal fall speed of 1.69 cm/s (corresponding to a 15 μm diameter particle), Van der Hoven's expression for reduction of the source strength due to dry deposition may be used to determine the distance at which the effective source strength has been reduced to half its original value. The time that it takes a parcel of air, embedded in the mean flow, to travel that distance may then be used as the half-life for

particles in the 10-20 μm size range. This half-life value may then be used in the exponential decay term of the CDM.

The results of the calculations, using the technique outlined above, are shown in Table 2-4.

Table 2-4. Half-life for Physical Removal Mechanism in the CDM for a 15 μm Particle and a Mean Wind Speed of 2.4 m/s.

Stability	Half-life (minutes) T_i
A	∞*
B	∞*
C	691.2
D	62.2
E	42.2
F	27.7

*Not calculated, but can graphically be shown to be essentially infinite.

Because half-life (and the resulting decay term in CDM) varies with both stability and wind speed, the user must decide whether to use separate values for the various wind speed/stability categories of CDM or to use a single composite value. For Phoenix, a single composite value was used on the basis that since this is only an approximate technique, a more complex analysis is not justified. The composite value was derived from a weighted average of the half-life times given in Table 2-4.

The weights used to determine the composite value were a function of two factors: (1) the percent frequency of each stability and (2) the relative contribution to the predicted concentration given by the model for each stability class. The latter contribution to the weighting term was approximated from $\chi u/Q$ curves (for example, those given by Turner, 1970). Table 2-5 gives numerical values associated with the two factors that determine the weights. The weighting factors themselves, given in column 4 of this table, are the product of columns 2 and 3.

Table 2-5. Annual Weighting Factors

Stability Class	Annual Frequency of Occurrence	Stability Class Contribution to Concentration at 500m Relative to Class F	Half-life Weighting Factor-W_i
A	0.02	0.02	0.0004
B	0.11	0.08	0.0088
C	0.18	0.18	0.032
D	0.22	0.40	0.088
E	0.18	0.60	0.108
F	0.29	1.00	0.290

The mean value for the half-life term in the decay constant was then evaluated using

$$\left(\overline{\frac{1}{T_{1/2}}}\right) = \frac{\sum_{i=1}^{6} \frac{W_i}{T_i}}{\sum_{i=1}^{6} W_i}$$

where the W_i are from Table 2-5 and T_i are the half-life values given in Table 2-4. The inverse half-life time was used because the physical removal mechanism in the CDM is proportional to this expression (see Section 2.1.3). Based on these data, the composite half-life was found to be approximately thirty-seven minutes.

Emissions by Particle Size Categories

Particle size distributions of the various emission source categories are documented in a previous phase of the study (TRW, 1976b). Owing to the general lack of information available to characterize the particle size of the various sources, substantial uncertainty is associated with the size distribution estimates. Figures 2-2, 2-3, and 2-4 are approximations for the particle size distributions of various source categories, drawn as probable fits to the limited data. The curves assembled for these plots were utilized to compile the particle size distributions corresponding to the size regimes selected for input to the CDM. The distributions for the various sources are summarized in Table 2-6.

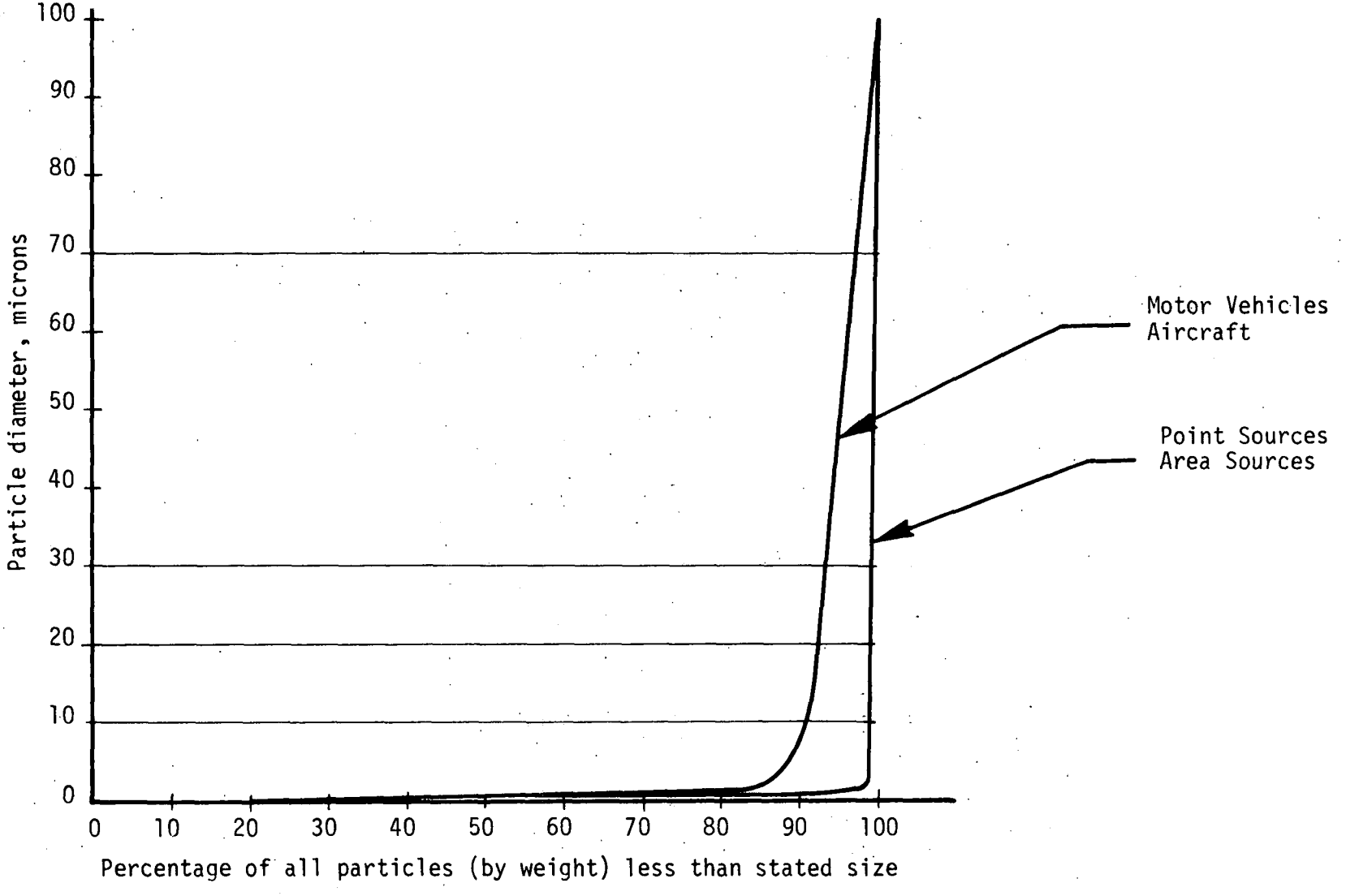

Figure 2-2. Particle Size Distribution of Conventional Emission Sources

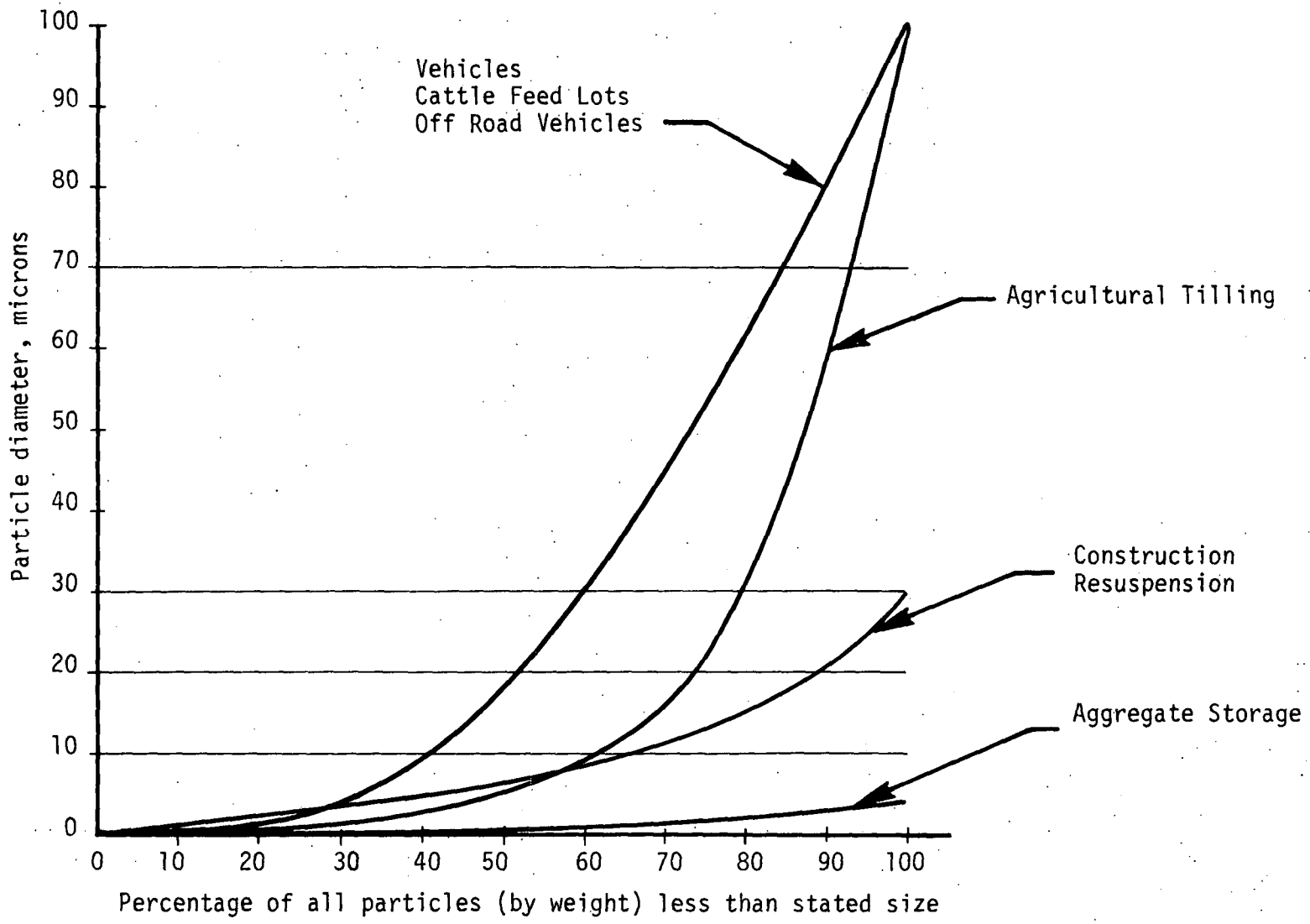

Figure 2-3. Particle Size Distribution of Anthropogenic Fugitive Dust Emission Sources

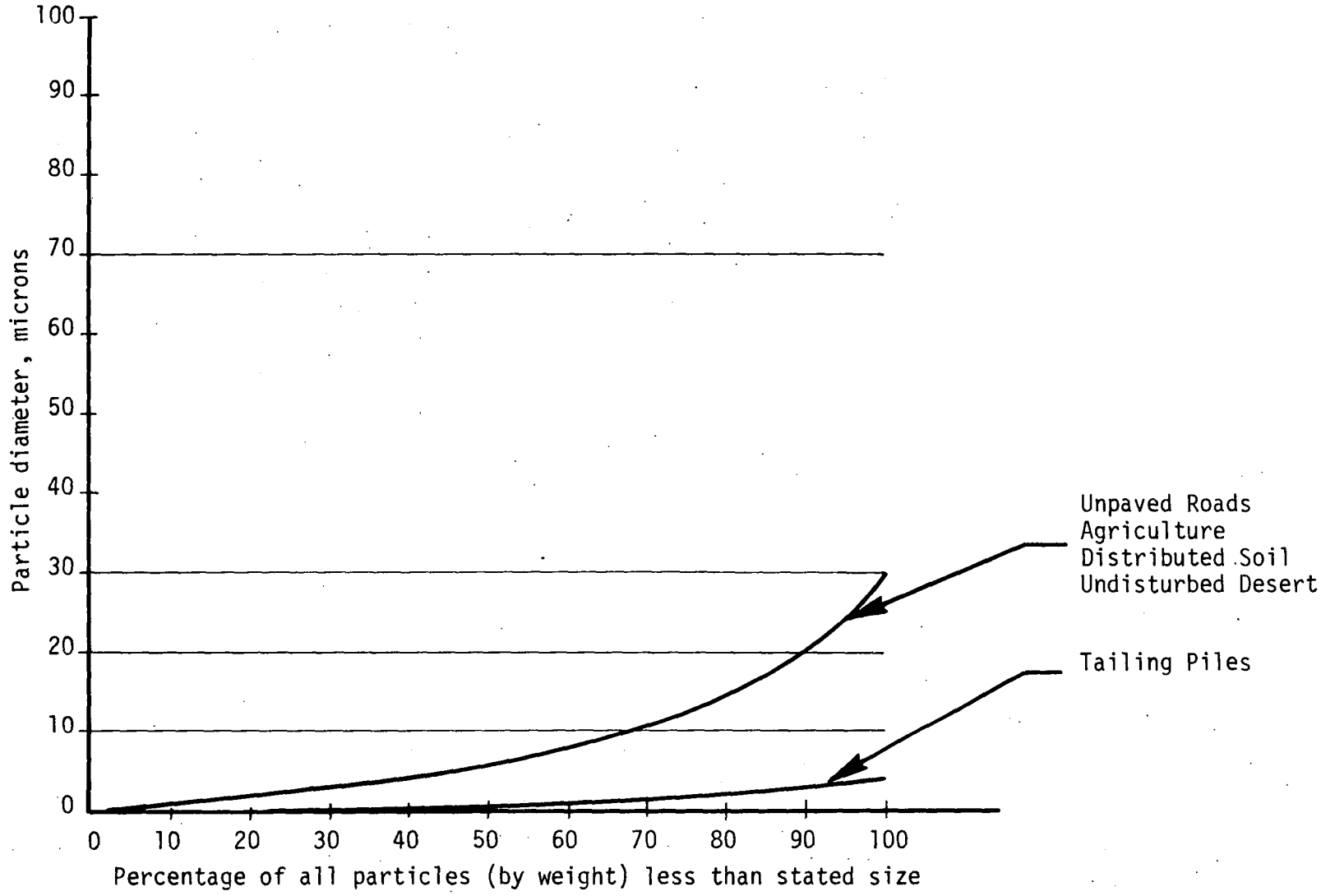

Figure 2-4. Particle Size Distribution of Wind Blown Fugitive Dust Sources

TABLE 2-5. PARTICLE SIZE DISTRIBUTIONS
FOR VARIOUS EMISSION SOURCE CATEGORIES*

Source Category	FRACTION OF ALL PARTICLES IN STATED SIZE RANGE							
	≤10μ	0-10μ	≤20μ	10-20μ	≤ 30μ	20-30μ	≤ 70μ	30-70μ
ANTHROPOGENIC								
Motor Vehicles	.41	.41	.52	.11	.60	.08	.85	.25
Ag. Tilling	.62	.62	.74	.12	.80	.06	.93	.13
Aggregate Sto.	1.00	1.00	1.00	-	1.00	-	1.00	-
Cattle Feed Lots	.41	.40	.52	.11	.60	.08	.85	.25
Off Road Vehicles	.41	.41	.52	.11	.60	.08	.85	.25
Construction	.66	.66	.89	.23	1.00	.11	1.00	-
Resuspension	.66	.66	.89	.23	1.00	.11	1.00	-
WIND BLOWN								
Unpaved Roads	.68	.68	.90	.22	1.00	.10	1.00	-
Agriculture	.68	.68	.90	.22	1.00	.10	1.00	-
Undisturbed Desert	.68	.68	.90	.22	1.00	.10	1.00	-
Tailing Piles	1.00	1.00	1.00	-	1.00	-	1.00	-
Disturbed Soils	.68	.68	.90	.22	1.00	.10	1.00	-
CONVENTIONAL								
Motor Vehicles	.91	.91	.93	.02	.94	.01	.97	.03
Aircraft	.91	.91	.93	.02	.94	.01	.97	.03
Point Sources	.99	.99	.99	-	.99	-	1.00	.01
Area Sources	.99	.99	.99	-	.99	9.	1.00	.01

* Based on interpolation using Figures 2-3, 2-4, and 2-5.

3.0 ADJUSTMENT OF AIR QUALITY DATA

In providing air quality and emissions data as input to the model, a major objective is to obtain the most representative data set for model parameterization. Obtaining such a data set might require several adjustments of the data base. In the limit, data adjustments would be performed as part of an iterative process to be conducted concurrently with succesive trials of the model. However, because of significant uncertainties associated with most of the data base, this iterative process is a costly and impractical task. Within the scope of a practical program, opportunity for adjustment of the data base is limited. Instead, it is more feasible to identify the degree of representativeness of the data set, to determine the factors affecting this representativeness, and to interpret the implications of these findings for the final air quality forecasts. The latter approach has been adopted for the present study.

The following sections document the suitability of the data set for use in the model, and discuss potential adjustments which should be considered to make the data set more representative. Three major considerations are involved in the selection of representative monitoring data; 1) height of the monitor above ground level 2) representativeness of site location, and 3) completeness of the data.

3.1 VARIATION OF TSP WITH HEIGHT OF MONITOR

An aspect of model parameterization related to particle size concerns the variation of TSP with height. A clear dependence of particle size distribution with height would suggest a variation of TSP with height

as well. If the TSP variation can be clearly established, it may be possible to adjust observed levels of TSP at different elevations to a common reference elevation to facilitate a more meaningful parameterization of the particulate model.

Table 3-1 shows the variation of TSP with height as measured during the study conducted by the IIT Research Institute[4]. For the windy day, sampling variation of concentration with monitor height is somewhat erratic, with no consistent trend observed for the five sites considered. For days of more typical wind velocity, a consistent pattern was noted at most of the stations. Concentration of TSP declined significantly with height, the average concentration of all stations decreasing over 40% from 3 meters to 30 meters elevation. This result is consistent with the particle size distribution variation observed for the same monitoring conditions. Table 3-2 shows that the weight percent of particles greater than 15μ in size decreases significantly with height, with the average weight percent of these larger particles diminishing about 30% from 3 meters to 30 meters elevation.

IITRI also conducted particle size analysis of hi-vol filter samples for two selected days in late 1975. One of these days was characterized by typical low wind speeds, while the other (September 27) was characterized by substantial gusts and an average wind speed of 9.8 mph. The overall observed size distributions (Table 3-3) were found to be consistent in some respects with those obtained by the Anderson measurements shown in Table 3-2. For example, a substantial portion of the particulate mass (nearly 70%) is comprised of particles of 20μ diameter or more. However, the hi-vol microscopy examination indicates no clear differences in particle size distributions for the windy and calm days, and there appears to be no significant variation of particle size distribution with monitor height (as noted previously with the Anderson measurements).

The presence of substantial portions of larger particles on the hi-vol filters and Anderson samplers, both at lower and higher elevations, indicates the presence of local source influence at each of the various sampling stations. Variability of the particle size distributions from one monitor to another may also be due in part to local source influences. In many cases, the monitor is in the plume of these sources. Because the effect of local sources at a single receptor point is likely to be

TABLE 3-1. TSP AS FUNCTION OF ELEVATION AT VARIOUS MONITOR SITES (IITRI, 1976)[4]

TOTAL PARTICULATES (SUM OF ANDERSON MEASUREMENTS)

	WINDY CONDITIONS NOV. 18, WIND = 4m/sec.						CALM NOV. 17,21,25 WIND = 1m/sec.					
HEIGHT ABOVE GROUND	AMER GRAD SCHOOL	PARKER	PAGE	INDIAN RESERVATION	MESA	AVERAGE	AMER GRAD SCHOOL	PARKER	PAGE	INDIAN RESERVATION	MESA	AVERAGE
3m	163	96	110	59	131	112	173	133	142	133	165	149
10m	96	35	52	84	269	107	93	116	99	86	55	90
30m	79	78	82	216	70	105	76	51	89	99	81	79

TABLE 3-2. PARTICLE SIZE GREATER THAN 15μ FOR SAMPLES AT SELECTED MONITOR SITES IN PHOENIX, NOVEMBER 17, 18, 21, 25 of 1975 [4]

PERCENTAGE OF PARTICLES (BY WEIGHT) GREATER THAN 15μ

HEIGHT ABOVE GROUND	WINDY CONDITIONS NOV. 18, WIND = 4m/sec.						CALM NOV.17,21,25, WIND = 1m/sec.					
	AMER GRAD SCHOOL	PARKER	PAGE	INDIAN RESERVATION	MESA	AVERAGE	AMER GRAD SCHOOL	PARKER	PAGE	INDIAN RESERVATION	MESA	AVERAGE
3m	64	58	29	56	59	54	44	54	42	34	67	48
10m	65	29	85	51	58	58	44	28	44	26	38	34
30m	65	51	73	62	59	62	34	29	37	48	29	34
TOTAL PARTICLES (cm)	211	164	*	*	*	187	247	196	266	203	212	225

TABLE 3-3. PARTICLE SIZE DISTRIBUTION FOR SUSPENDED PARTICULATES MEASURED IN PHOENIX SEPT. 27 & NOV 14, 1975 [4]

	PERCENTAGE OF PARTICLES (BY WEIGHT) IN SIZE RANGE			
	<2μ	2-8μ	8-20μ	>20μ
SEPT 27 (WINDY)				
MONITORS AT 20 FEET	.07	2.8	32.2	65.0
MONITORS AT 15 FEET	.06	2.2	33.0	64.6
MONITORS AT 5 FEET	.05	2.0	28.3	69.7
NOV 14 (CALM)				
MONITORS AT 20 FEET	.14	2.8	32.4	64.7
MONITORS AT 15 FEET	.14	2.5	29.5	67.9
MONITORS AT 5 FEET	.13	2.7	34.9	62.6

highly variable, an average behavior at any one monitor can only be determined by extensive sampling and analyses over a significant period of time. In this study, the data base is probably too small to show any systematic variation of particle size distribution with elevation. It will not be feasible, therefore, to adjust air quality measurements at different elevations to a common level of representativeness. Parametrization of the model must, therefore, be performed with the actual observed values of TSP, whatever the elevation of the observation. Deviations of the observed levels of TSP with the forecasted model values (calculated for a single elevation at all receptors) may be due in part, to actual TSP/height relationships effective at the various monitor sites.

3.2 REPRESENTATIVENESS OF MONITOR ENVIRONMENT

The monitor site review of this study (TRW, 1976a) revealed that air quality at some of the monitor sites was not representative of air quality of the general area surrounding the site. Instead, these sites were influenced by local sources in a manner atypical of the general area, and, therefore, may be only representative of "site specific air quality." Table 3-4 summarizes these latter sites which were determined after reviewing the air quality relative to surrounding sources. Those sites which are representative only of site specific air quality may be deleted from the data base, or they may be included if the significance of the local intervention can be assessed.

TABLE 3-4. SUMMARY OF POTENTIAL MONITOR SITES WITH ONLY SITE SPECIFIC REPRESENTATIVENESS

MONITOR SITE	CHARACTERIZATION OF GENERAL AREA	SITE SPECIFIC SOURCES	SOURCES IN GENERAL AREA	PROBABLE SIGNIFICANCE OF ATYPICAL LOCAL SOURCES
St. Johns	Rural/Residential. Indian Reservation in open desert.	Soil dust from unpaved roads, residence yards, and open fields.	Soil dust from unpaved roads.	Significant impact on monitors measurements.
North Phoenix	Suburban/Residential.	Soil dust from unpaved roadways and unpaved parking lots.	Soil dust from unpaved roadways and vacant lots.	Doubtful if significance of site specific source can be determined without special study. Measurements may have to be deleted from data base.
Mesa	Suburban/Residential-Commercial.	Soil dust from unpaved roadways and parking lots, soil yards.	Soil dust from unpaved parking lots and roadways, disturbed vacant lots.	Impact of site specific sources probably significant, but special study needed to assess the degree of impact.
Downtown Phoenix	Urban/Commercial.	Soil dust from unpaved roads and parking areas, motor vehicle exhaust.	Soil dust from unpaved roads and parking areas, motor vehicle exhaust.	Impact of site specific sources probably significant, but special study needed to assess the degree of impact.

3.3 COMPLETENESS OF TSP DATA

Because of the highly variable meteorology throughout the year in Phoenix, concentrations of TSP also vary substantially. If measurements are incomplete for a significant period of the year, the calculated geometric means may be significantly biased from the acutual mean. Table 3-5 shows the completeness of measurements conducted during 1975 for each of the monitor sites. The sites lacking complete measurements were characterized by absence of data from the second, third and fourth quarters. The general pattern of TSP quarterly variation in 1975 showed TSP minima in the first quarter and maxima in the last quarter. This trend was, however, somewhat indefinite, and it is unlikely that it held at all stations. Because no definite quarterly pattern of TSP can be clearly assigned to any given monitor station (historically the variation changes dramatically due to annual meteorology fluctuations), it is not possible to evaluate the bias of the available data due to the data gaps.

3.4 SUMMARY OF BIAS OF AIR QUALITY DATA

Table 3-6 summarizes the impact of various influence factors on the representativeness of air quality measurements made at the different monitor sites in 1975. The factor of greatest impact on observed TSP levels is monitor height. Nine of the 16 monitors recording in 1975 are situated at elevations exceeding the five foot reference height. TSP levels reported from these nine monitors tend to underestimate the true exposure levels at the five foot level. The factor of next greatest concern for TSP levels is data completeness. Five monitor sites exhibit substantial data gaps for nearly three fourths of the year, placing the measured values reported from these stations in serious doubt. The bias from the data gaps is indeterminate, and probably significant. Four of the sites experience a bias toward high readings because of atypical site specific sources affecting TSP there. The purpose of the determination of probable impact of the various factors on representativeness of air quality data is for interpretation of the final air quality forecasts. Because data are not available to quantify the impact of these

TABLE 3-5. COMPLETENESS OF TSP MEASUREMENTS FOR PERIOD OF 1975

MONITOR		NUMBER OF MEASUREMENTS IN 1975			
		1ST QTR.	2ND QTR.	3RD QTR.	4TH QTR.
2	Central Phoenix	10	14	15	15
3	South Phoenix	9	8	11	12
4	Arizona State	15	15	15	11
5	Glendale	9	9	5	9
6	West Phoenix	0	0	0	0
7	North Phoenix	7	12	14	14
8	Scottsdale/Paradise	14	10	13	16
9	Scottsdale	15	13	15	11
10	Mesa	15	14	14	9
11	Downtown Phoenix	5	0	0	0
12	St Johns	15	15	15	14
13	Sun City	13	0	0	0
14	Paradise Valley	12	0	0	0
15	Carefree	14	13	14	14
16	Chandler	13	0	0	0
17	Guadalupe	14	12	12	15
18	Litchfield	14	11	0	0

TABLE 3-6. MATRIX OF PROBABLE IMPACT OF FACTORS INFLUENCING REPRESENTATIVENESS OF 1975 TSP DATA

	MONITOR	PROBABLE BIAS OF INFLUENCE FACTOR ON ANNUAL GEOMETRIC MEAN MEASURED AT STATION		
		HEIGHT OF MONITOR[a]	REPRESENTATIVENESS OF SITE ENVIRONMENT	COMPLETENESS OF DATA
2	Central Phoenix	Low	---	---
3	South Phoenix	Low	---	---
4	Arizona State	Low	---	---
5	Glendale	Low	---	---
7	North Phoenix	---	High	---
8	Scottsdale/Paradise	---	---	---
9	Scottsdale	Low	---	---
10	Mesa	---	High	---
11	Downtown Phoenix	Low	High	Unclear
12	St. Johns	Low	High	---
13	Sun City	Low	---	Unclear
14	Paradise Valley	---	---	Unclear
15	Carefree	---	---	---
16	Chandler	Low	---	Unclear
17	Guadalupe	---	---	---
18	Litchfield	---	---	Unclear

a. A height of 5 feet is assumed as reference height.

factors, it is not possible to adjust the air quality data to more representative figures. Instead, the qualitative assessment here will be employed to indicate areas where the model parameterization and forecasts should be used with qualifications as to their representativeness.

4.0 MODEL PARAMETERIZATION

The air quality model chosen for this study was discussed earlier in Section 2.0. Quantification of the empirical constants in the model is discussed in this Section. In particular, the background term B is discussed in Section 4.1 and the coefficients α_{1i} and α_{2i} in Section 4.2.

Before assigning numerical values to the constants, it is useful to explain the computer system used in performing the emissions and air quality modeling. Figure 4-1 is a schematic diagram portraying the development of the parameterized model. In the first step, the Emissions Simulator Program (TRW, 1976b) produces both a printed output of total emissions together with a graphical disaggregation of emissions. Next, CDM simulations are made using the 0-10μm and 11-20μm emissions data as well as the appropriate meteorology. The 21-70 micron particle emissions are not used until the final step. The CDM output and the emissions in the 21-70 micron range are input to a parameterization program, which is discussed in Section 4.2. The final product is a parameterized TSP model capable of simulating future air quality given emissions and meteorology.

4.1 BACKGROUND LEVELS OF TSP

Four monitoring sites, sufficiently removed from urban Phoenix, were chosen to determine background levels. This means that only the natural sources in the area affect the readings at these sites, plus whatever suspended particulates are transported from other areas. For the purposes of this study, a background value was interpreted and used as if there were no means of controlling it.

Background levels for 1973, 1974 and 1975 are shown in Table 4-1. The historical data shown for 1973 and 1974 were used to determine a weighted average for 1975 which lacked any TSP data at Grand Canyon and Petrified Forest. A weighted average of 30 μg per m^3 was used for 1975 as well as for 1985, the projection year.

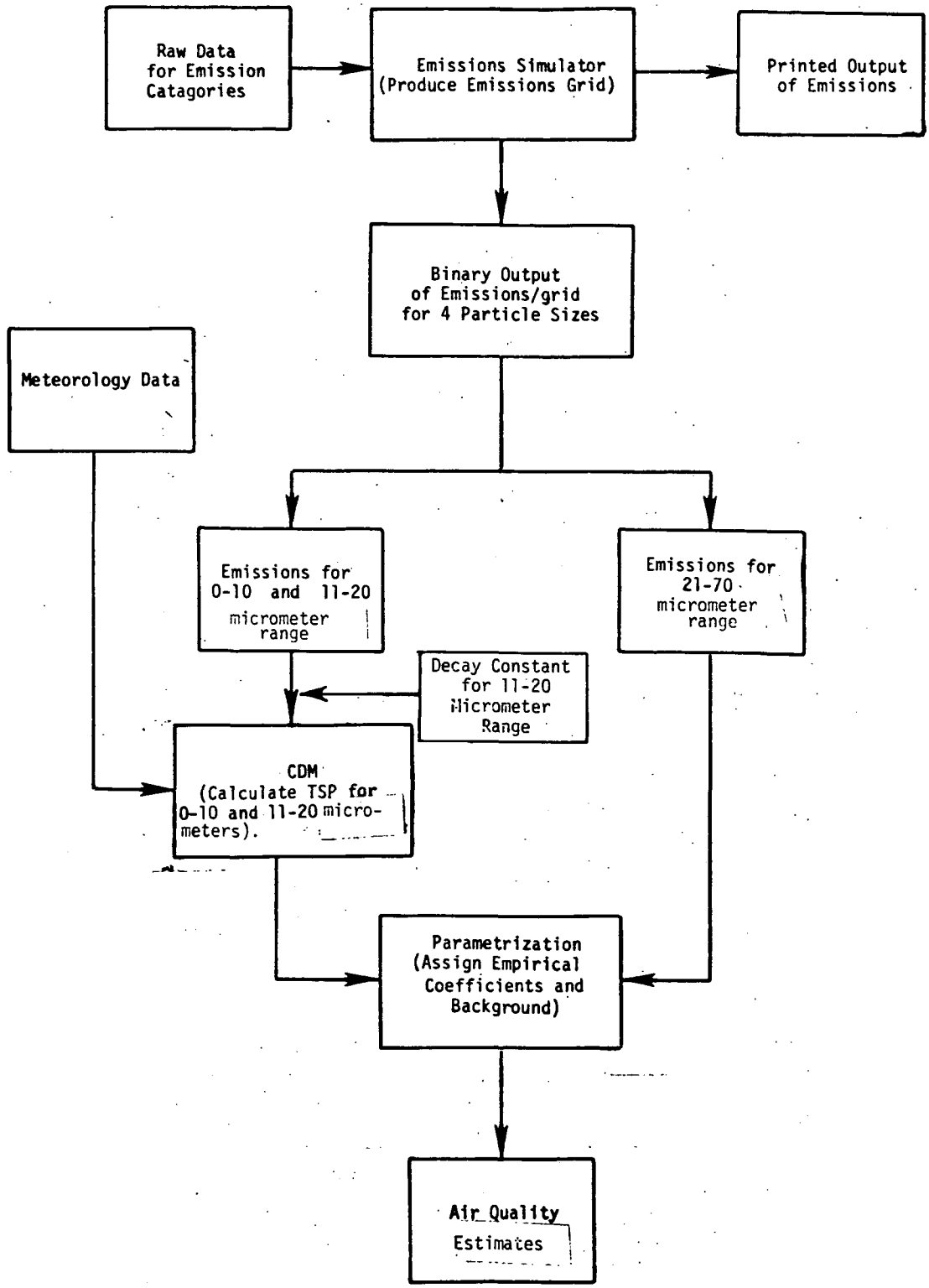

Figure 4-1 Computer Modeling System

TABLE 4-1. BACKGROUND LEVELS OF TSP

SITE	1973 ($\mu g/m^3$)	1974 ($\mu g/m^3$)	1975 ($\mu g/m^3$)
Grand Canyon	22	17	N/A
Petrified Forest	26	23	N/A
Organ Pipe	34	23	31
Montezuma	28	27	34
Average	28	23	32

4.2 ASSIGNMENT OF EMPIRICAL CONSTANTS

The air quality model was presented earlier in Section 2.1, but is restated here for convenience. The basic equation is

$$X_i = \alpha_{1i} C_i + \alpha_{2i} E_i + B \qquad (4\text{-}1)$$

where

X_i = Total suspended particulate concentration

C_i = CDM calculated concentration of 0-10 and 11-20 micron particles

E_i = Emissions of particles >20μ in the grid square of the receptor

B = Background TSP

α_{1i} = Empirical coefficient related to CDM

α_{2i} = empirical coefficient related to rollback model

i = denotes the receptor under consideration

The constants α_{1i} and α_{2i} are defined by:

$$\alpha_{1i} = (0.3\ X_i - 0.5\ B)/C_i$$
$$\alpha_{2i} = (0.7\ X_i - 0.5\ B)/E_i \qquad (4\text{-}2)$$

Table 4-2 summarizes the results of a computer run for 1975, including the emissions model and CDM for the two small particle size ranges. Columns 1, 2, and 3 contain the CDM simulations based on emissions from small particles, column 4 the actual observed air quality, and column 5 the emissions of particle 21-70 microns within the grid square of each receptor. Columns 7 and 9 are the contribution of TSP from particles 0-20μ in size and from particles 21-70μ in size, respectively. The coefficients α_{1i} and α_{2i} are shown in columns 6 and 8 and are computed from equation 4-2 above. X_i is shown in column 11 and C_i and E_i are in columns 3 and 5, respectively.

A plot of observed TSP levels versus those levels predicted by the CDM model is shown in Figure 4-2. The observed levels are defined to be the concentration of sub-20 micron particles measured at the monitor sites, or 30% of the TSP. A linear regression of the plot of Figure 4-2 yields the equation $y = 20 + .49\ X$, where y is the observed level and X the CDM-predicted concentration for particles 0 to 20 micron size. The intercept (20) is found to be relatively close to the background level assumed for sub-20 micron particulates (15), and the slope (.49) is within the range of "usual" calibration for CDM predicted pollutant concentrations. This indicates the modified CDM treats the diffusion behavior of 0-20 micron particles reasonably well.

There are several factors which may cause poor correlation of model predicted values with observed values. First, there is probable bias of the observed values for true representative concentrations due to variations in monitor height, completeness of data, and representativeness of the monitor site environment. Second, there is probable bias in the emissions data base due to numerous uncertainties underlying the development of the fugitive dust emissions inventory. Finally, there are limitations associated with the assumptions of the model itself. While the implications of any one particular limitation on the predictability achieved by the model may be assessed, the simultaneous intervention of many influence factors known to be affecting the model results make any attempt to explain the variations unfeasible.

TABLE 4-2 EMPIRICAL COEFFICIENTS DETERMINED FOR PHOENIX CDM/ROLLBACK MODEL

AIR QUALITY RECEPTORS	1 CDM 0-10μ ($\mu g/m^3$)	2 CDM 11-20μ ($\mu g/m^3$)	3 ΣC CDM ($\mu g/m^3$)	4 OBSERVED AQ ($\mu g/m^3$)	5 EMISSIONS IN GRID (21-70μ) (tons/day)	6 α_{1i}	7 α_{2i} C_i ($\mu g/m^3$)	8 α_{2i} $\frac{\mu g/m^3}{T/day}$	9 α_{2i} E_i ($\mu g/m^3$)	10 B ($\mu g/m^3$)	11 X_i ($\mu g/m^3$)
2 C. Phoenix	43.4	6.4	49.8	112	3.69	0.37	18.6	17.18	63.4	30	112
3 S. Phoenix	23.5	2.3	25.8	144	1.73	1.09	28.2	49.60	85.8	30	144
4 Arizona St.	45.3	7.1	52.4	169	4.35	0.68	35.7	23.75	103.3	30	169
5 Glendale	35.1	4.4	39.5	101	2.59	0.39	15.3	21.51	55.7	30	101
7 N. Phoenix	39.5	6.1	45.6	121	3.81	0.47	21.3	18.29	69.7	30	121
8 N. Scott/Par Va.	33.0	5.4	38.4	149	2.97	0.77	29.7	30.07	89.3	30	149
9 Scottsdale	40.3	5.7	46.0	115	3.71	0.42	19.5	17.65	65.5	30	115
10 Mesa	34.6	5.0	39.6	117	3.28	0.51	20.1	20.40	66.9	30	117
11 Downtown	51.0	7.4	58.4	200	4.35	0.77	45.0	28.74	125.0	30	200
12 St. Johns	14.1	1.0	15.1	145	1.66	1.89	28.4	52.11	86.5	30	145
13 Sun City	29.0	3.6	32.6	88	4.74	0.35	11.4	9.83	46.6	30	88
14 Par. Valley	38.8	6.4	45.2	184	3.92	0.89	40.2	29.03	113.8	30	184
15 Caretree	7.7	0.6	8.3	42	0.71	-.29	-2.4	20.28	14.4	30	42
16 Chandler	23.9	3.0	26.9	119	3.75	0177	20.7	18-21	68.3	30	119

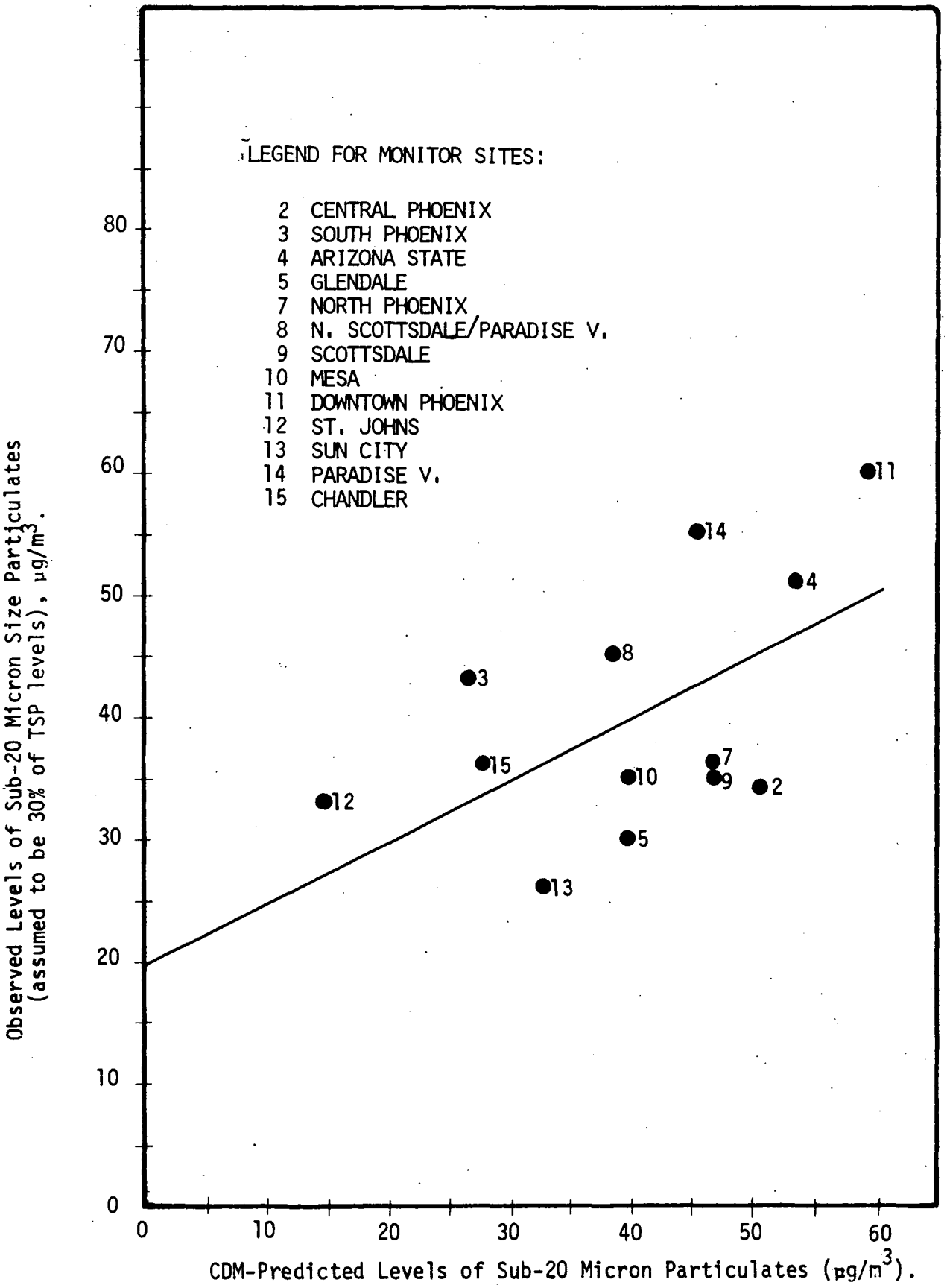

Figure 4-2. Observed Concentration of Sub-20 Micron Particulates Versus CDM-Predicted Concentration of Sub-20 Micron Size Particulates.

The coefficient α_{2i} has an average value of 27. This is a dimensional coefficient, unlike α_{1i} which is nondimensional, and cannot be expected to assume a value of unity. Also there is no distinct pattern for α_{2i} as there was for α_{1i}, probably because α_{2i} reflects the influence of local emissions on TSP. This influence is undoubtedly different for each grid square because of the numerous variations for local source distributions around a given monitor. Figure 4-3 illustrates the scatter of data for observed versus calculated levels of particulates greater than 20 micron in size.

It can be seen that the most significant contribution to the CDM prediction of concentration is from the 0-10 micron range, while the 11-20 micron range contributes nearly an order of magnitude less (columns 1, 2, and 3 of Table 4-2). This difference is due to the shorter half-life for larger particles (see Section 2.3). Additional analysis showed that CDM predicts neligible contributions to air quality from the 21-70 micron particles.

The empirical constants shown in Table 4-2 were the ones actually used for the air quality projections which are discussed next.

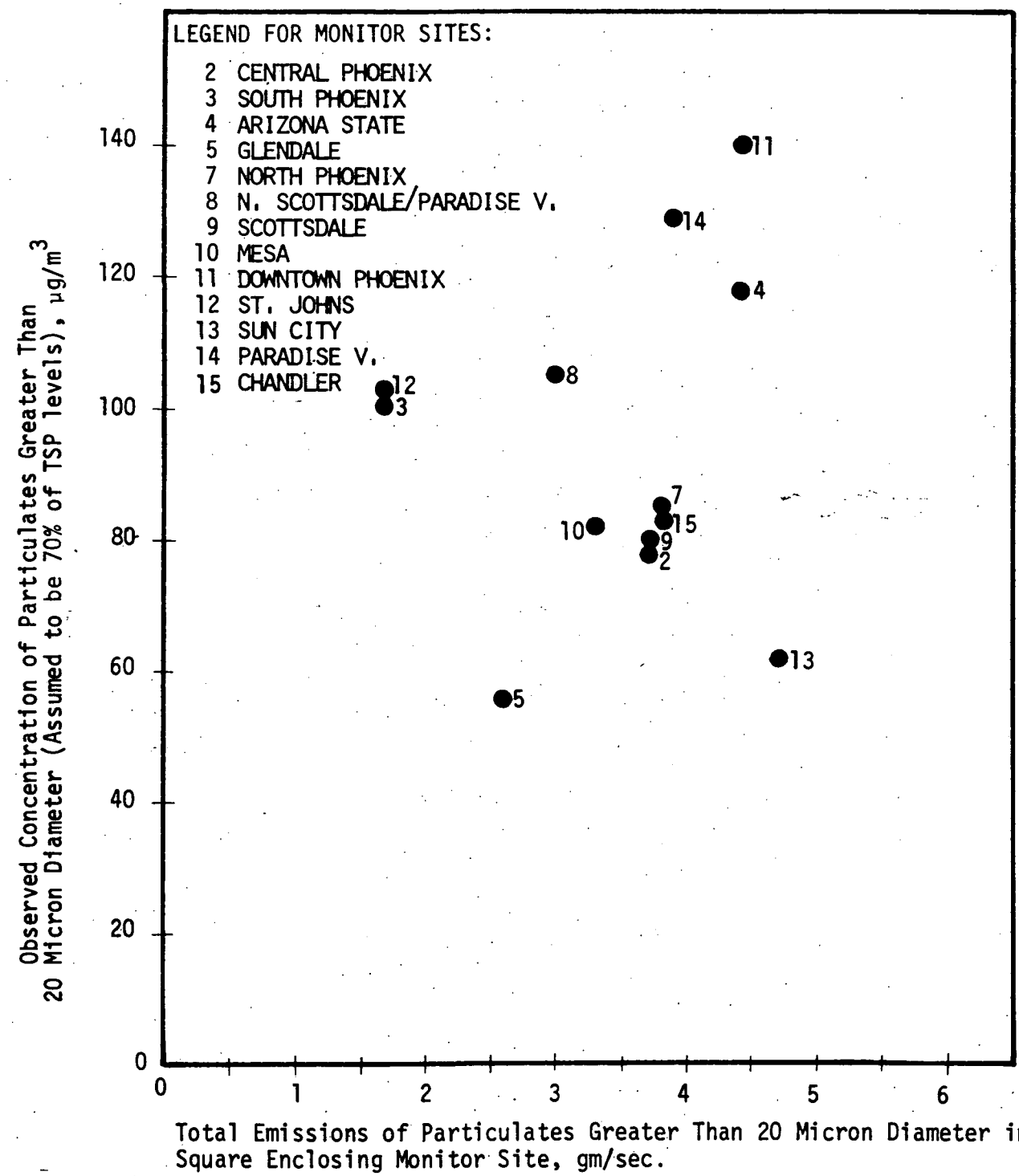

Figure 4-3. Observed Concentration of Particulates Greater Than 20 Micron Diameter in Grid Square

5.0 FORECASTED BASELINE TSP LEVELS FOR 1975 AND 1985

The baseline emission levels corresponding to the baseyear and 1985 are translated into air quality forecasts using the source receptor relationship discussed previously. The model is used to evaluate contributions of each of the source categories to TSP levels, and the impact of source changes on air quality. The 1975 TSP simulation is discussed in Section 5.1 and the 1985 forecast in 5.2.

5.1 BASEYEAR TSP LEVELS

Table 5-1 shows the domination of 1975 TSP levels by the four major emission sources that year. The model predicts that nearly all the TSP level (excluding background) at 12 of the 13 sites monitoring in 1975 was caused by emissions from unpaved roads, entrained street dust, construction activities, or wind erosion. The exception was the Sun City site where off-road vehicles were responsible for most of the TSP levels. Monitors which were most dramatically affected by wind erosion emissions tended to be located in the rural areas under development, such as the Paradise Valley and North Scottsdale/Paradise Valley sites. Other sites within cities were also significantly affected by wind blown dust emissions. These sites were generally surrounded by numerous vacant lots and/or dirt residence yards. Entrained dust also had an impact on urban sites. The sites at Central Phoenix, Arizona State, North Phoenix, Scottsdale, Mesa and Downtown Phoenix were more affected by dust entrained off streets than any other single source. Emissions from unpaved roads contributed significantly to TSP at each of the sites, but were particularly dominant at the South Phoenix, St. Johns, and Chandler sites.

5.2 PROJECTED BASELINE TSP LEVELS

Air quality forecasts were made for 1985 using the projected emissions and annual daily meteorology. The projected emissions were based on anticipated developments in 1985. These forecasts are shown for each of the monitoring locations in the study area in Table 5-2.

TABLE 5-1. IMPACT OF MAJOR SOURCES ON TSP LEVELS

MONITOR SITE	TSP IN 1975	CONTRIBUTION OF SUSPENDED PARTICULATES FROM FOUR MAJOR SOURCES (ug/m^3)				PERCENTAGE OF TSP LEVEL CONTRIBUTED FROM FOUR MAJOR SOURCES & BACKGROUND
		UNPAVED ROADS	ENTRAINED DUST	CONSTRUCTION ACTIVITIES	WIND EROSION	
Central Phoenix	112	25	31	4	19	96.3
S. Phoenix	144	75	20	2	15	98.2
Arizona State	169	35	59	7	33	96.4
Glendale	101	30	17	7	15	97.2
N. Phoenix	121	26	28	7	28	97.8
N.Scotts/Para. V.	149	24	8	14	71	98.3
Scottsdale	115	27	33	6	16	96.5
Mesa	117	32	35	8	10	97.7
Downtown	200	42	70	8	40	94.1
St. Johns	145	93	2	0	18	98.3
Sun City	88	15	12	3	2	55.2
Paradise Valley	184	42	14	17	78	98.1
Chandler	119	64	10	7	5	96.6

TABLE 5-2. FORECASTED IMPROVEMENT IN TSP LEVELS DUE TO ANTICIPATED DEVELOPMENT IN THE PHOENIX AREA

SUSPENDED PARTICULATES, ug/m^3

MONITOR SITE	1975 Observed (TOTAL)	1985 Forecast (TOTAL)	Percentage Reduction in TSP 1975 to 1985	Unpaved Roads 1975	Unpaved Roads 1985	Resuspension 1975	Resuspension 1985	Construction 1975	Construction 1985	Percentage of TSP Contributed by 3 major sources and background 1975	Percentage of TSP Contributed by 3 major sources and background 1985
C. Phoenix	112	87	22.3	25	8	31	37	4	5	80	92
S. Phoenix	144	101	29.8	75	32	20	24	2	9	88	94
Arizona St.	169	132	21.9	35	12	59	68	7	9	78	90
Glendale	101	65	35.6	30	9	17	20	7	2	83	94
N. Phoenix	121	83	30.4	26	8	28	32	7	7	75	93
N. Scott/Paradise	149	101	32.2	24	32	8	9	14	25	51	95
Scottsdale	115	93	19.1	27	10	33	42	6	5	83	94
Mesa	117	95	18.8	32	13	35	45	8	4	90	97
Downtown	200	155	22.5	42	15	70	82	8	10	75	89
St. Johns	145	157	-8.3	93	116	2	0	2		66	96
Sun City	88	74	15.9	15	6	12	17	3	16	68	93
Paradise Valley	184	93	49.4	42	14	14	17	17	25	56	93
Chandler	119	160	-34.5	64	91	10	12	7	23	93	97

Significant improvements in air quality occur at 11 of the 13 monitoring sites. Baseline 1985 TSP levels are from 16 to 50% less than 1975 levels, depending on the site. Two of the 13 sites are forecasted to attain the primary air quality standard (75 $\mu g/m^3$). In many cases, a significant portion of the air quality gains over baseyear levels is due to baseline development planned for the area. This development will change the distribution of emission sources, eliminate local sources near the monitors, and diminish the magnitude of many sources. Although total dust emissions from unpaved roads are expected to increase slightly from 1975 to 1985, the distribution of these emissions changes substantially, such that they are more widely spread in the rural areas, and greatly reduced in the city areas. Wind erosion emissions are estimated to decrease greatly in 1985 due to 1) a decrease in wind erosion sources (i.e., vacant property), and 2) the expectation of typical meteorology in 1985 based on historical averages (the historical data show 1975 to be relatively more windy than other years). Contributions to TSP from entrainment of street dust are expected to increase slightly by 1985, especially at monitors located within the city areas. As a result of the net changes in emission source magnitudes and distribution, TSP levels will decrease significantly at 11 of the 13 monitoring sites under consideration, (Table 5-2).

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16. ABSTRACT

This document is one volume of a four-volume report presenting an implementation plan for control of suspended particulate matter in the Phoenix area.

17. KEY WORDS AND DOCUMENT ANALYSIS

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