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AN IMPLEMENTATION PLAN FOR SUSPENDED PARTICULATE MATTER IN THE PHOENIX AREA VOLUME IV - CONTROL STRATEGY FORMULATION

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

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by

George Richard

Environmental Engineering Division of TRW, Inc.
One Space Park
Redondo Beach, California

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EPA Project Officer: Dallas Safriet

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1.0 INTRODUCTION AND SUMMARY

This report is the fourth of four documents associated with a project to develop an air pollution control strategy for total suspended particulate matter in the Phoenix area. The previous documents include a review and analysis of air quality data (Volume I), documentation of a particulate emissions inventory (Volume II), and development of the relationship between emissions levels and air quality. The present report (Volume IV) characterizes alternative control measures and documents the synthesis of these candidate measures into a control strategy. The data base and methodology developed in the project have been extended to provide a general guideline document for application to areas with fugitive dust problems similar to those in the Phoenix area.

A principal goal of the project was to develop a control strategy based on "reasonable and achievable controls" that would minimize TSP concentrations in the study area to the extent practicable. Such a plan has been formulated and is described in this report. The strategy deals solely with fugitive dust sources, the main cause of high TSP levels in Phoenix today. Complete attainment of the standard is predicted with application of reasonable and available controls.

The present section of this report introduces the study and summarizes the major results and conclusions. Section 2 characterizes various candidate dust control methods for major fugitive dust sources causing high levels of TSP in the Phoenix area. Section 3 discusses the factors involved in reasonable control selection, and formulates a control strategy based on these selection considerations. The impact of the control strategy on emissions levels and air quality is evaluated, and the cost and implementation problems associated with each of the control measures are documented.

1.1 RESULTS

A review of the emissions inventory developed earlier in the study[10] showed that local fugitive dust sources are the most substantial contributor to TSP levels in the Phoenix area. By 1985, after planned development changes the distribution and magnitude of the various sources, it is forecasted that three fugitive dust source categories will alone contribute to over 90% of the TSP levels in the study area. These sources are unpaved roads, street dust on paved roads, and construction activities. Because of the domination of TSP levels by these sources, the investigation of alternative controls deals exclusively with their treatment.

Control methods to reduce dust emissions from unpaved roads consist of: 1) paving, 2) chemical stabilizers, 3) watering, 4) graveling, and 5) traffic related controls. Characterization of these controls shows that as a long term cost effective measure, paving of roads is the most suitable control approach, as well as a relatively effective one. In addition, road paving is compatible with planning objectives of local agencies, and provides numerous cost benefits to many sectors of the community. The effectiveness of chemical stabilizers as a road dust control has improved in recent years, but the high annualized cost of this measure for only partial reduction of road emissions is a major drawback to its use. The same shortcomings afflict watering and graveling controls. Traffic controls such as speed restrictions are effective as interim control approaches, reducing dust emission rates significantly at very low cost, but causing substantial inconvenience in areas where unpaved roads serve as major travel routes.

Dust entrained from paved streets may be best controlled by either eliminating sources of street dust, or by more frequent and efficient removal of street dust loadings. Dust sources, consisting primarily of exposed soil areas near the streets, are substantially reduced when unpaved road shoulders are upgraded with curb and sidewalks. Further elimination of sources is attained by providing soil cover (e.g. vegetation or aggregate materials) or stabilization of adjacent soil areas. These measures are relatively cost effective, and consistent with general improvement plans in any community. Frequent street sweeping is an equally cost effective measure, provided the suspendable fines are removed by a suitable cleaning approach such as vacuum sweeping.

Control methods to reduce dust arising from construction activities consist of: 1) watering unpaved areas subject to traffic, 2) stabilization of cleared areas of exposed earth, and 3) sweeping nearby public streets. Enforcement of these measures, particularly wetting of unpaved access routes, provides significant reduction in dust emissions, and reduces the temporarily localized effects of construction activities on air quality.

In establishing the reasonableness (technological and economic feasibility) of control measures, several area-specific factors must be considered. These factors include: 1) the compatibility of the controls with general planning of the area, 2) the timetable for implementation, 3) the degree of control required, and 4) the financing mechanisms available for implementation of the control. Based on the characterization of available control methods and a consideration of the above selection factors, most of the measures for control of fugitive dust appear to be both technically and economically feasible (reasonable) in the Phoenix area. Control selection, therefore, reduces to a determination of the most cost effective and least disruptive measures which will provide attainment of air quality standards.

Table 1-1 summarizes the reasonable control strategy proposed for the Phoenix area. The strategy has been formulated by evaluating successive trials of specific combinations of cost effective measures until attainment of air quality standards was predicted at each of the monitor sites. The strategy was designed to minimize "overkill" at any given monitor site, and to provide special attention where needed for attainment in "hot spot" areas. The strategy is aimed at attainment over a reasonably achievable time frame, beginning in 1978 and reaching complete attainment at all monitor sites by 1975. Cost of the strategy is estimated at $4.4 million per year.

The measures comprising the strategy are consistent with long term planning goals for the Phoenix region, and are also effective as dust controls. The strategy is implementable in a technical and economic sense, however, substantial social resistance may likely develop against its execution. A special feature of the overall strategy is a demonstration model to develop social acceptance for the strategy approach. This portion of the strategy is discussed in Section 3.7. Another special proposal concerns the extension of the current monitor network to establish baseline air quality in specific locations identified by the study as potential non-attainment areas after strategy implementation.

The reasonable control strategy formulated for the Phoenix area is selective for the three major sources affecting TSP levels. The control

TABLE 1-1. SUMMARY OF REASONABLE CONTROL STRATEGY FOR PHOENIX AREA
NOTE: THE DEMONSTRATION STRATEGY IS PREREQUISITE TO IMPLEMENTATION OF THIS PROGRAM[b]

SOURCE CATEGORY	CONTROL MEASURE	EMISSIONS REDUCTION FROM 1985 BASELINE LEVEL tons/day	EMISSIONS REDUCTION FROM 1985 BASELINE LEVEL percent	ANNUALIZED COST OF MEASURE (Millions of Dollars)
Unpaved Roads	1. Chip Seal all section line roads by 1995, and one half by 1985.	298	19.2%	2.5
	2. Reduced speed limit to 20 mph for all interior unpaved roads (private and county) by 1985	256	16.5%	0.2
Entrained Dust Off Streets	1. By 1985, sweep major city roads to attain a 60% reduction in assumed street dust loading in designated areas.[b]	18	5.6%	.36[a]
Construction	1. Effective 1980, wetting of site access roads twice daily at .5 gal/yd^2.	77	5.0%	0.7
	2. By 1980, sweep roads to remove visible dust loads caused by construction activities. Sweeping shall be daily if necessary.	--	--	0.6
	3. By 1980, stabilization of exposed earth at construction sites when operations cease on this land for more than 2 months.	--	--	--
Other Sources	No additional measures are recommended as other sources are already controlled (either by direct pollution regulations or by other restrictions which affect dust control) or have insignificant impact on TSP levels.			

[a]Based on the required sweeping program indicated by the existing data base. This would consist of cleaning major roads three times weekly, alternating from vacuum sweeping to broom sweeping as appropriate.

[b]Three field programs are proposed as prerequisites to implementation of the control strategy. First, a demonstration project would involve application of the strategy measures within a limited selected area, and promotional aspects to shape public acceptance for the eventual overall strategy. Second, a field measurement program to determine street dust loads and effects of various sweeping alternatives should be conducted to reconcile current sweeping controls indicated necessary by the limited existing data base. Third, the air quality monitor network should be extended to establish baseline TSP levels at potential non-attainment areas which may require additional controls in 1985.

measures for unpaved roads exert the greatest impact on overall emission levels. These controls reduce total baseline particulate emissions in the study area by 35% in 1985. Figure 1-1 shows the impact of the control strategy on emission levels. Overall, the total change in emission levels in 1985, due to the strategy and to anticipated development in the study area, amounts to a 31.6% reduction from the 1975 level. Emission reductions attained by the year 1980 are less dramatic as only roughly two sevenths of the strategy will be implemented by then.

Equally important as the emission level magnitudes are the distribution of the reductions. Emissions are reduced substantially in the areas near the monitor sites. Because the major portion of ambient TSP levels are caused by local sources in the near vicinity of the receptor, the impact of the control strategy in areas near the monitors is substantial. Air quality improvements at monitor sites in the specially designated control area are dominated primarily by reductions in entrained street dust. However, sites outside the metropolitan influence or bordering the city tend to be more affected by control measures proposed for unpaved roads. Figure 1-2 shows the effect of the strategy on air quality at several of the monitoring sites. By 1980, significant improvements in air quality are predicted at many of the sites. However, these gains are minor compared to the effect of the strategy by 1985, when baseline TSP levels are reduced by about one third at most sites, and all but two sites are forecasted to attain (or very nearly attain) the primary air quality standards by 1985. Air quality at the two exception sites was found to be unrepresentative of the general area; hence, more stringent controls in the vicinity of these monitors may be needed. However, before extensive site-specific plans are implemented, more detailed analysis of the sites in question with regard to monitor location, etc., should be completed. Additional air quality monitoring data may also be necessary in order to further assess the problem and evaluate the impact of the proposed strategy once it is implemented. TSP levels at the Sun City and Glendale sites are substantially lower than the standards level, but this is due to a low baseline concentration of TSP and unavoidable impact of the strategy throughout the remainder of the area, rather than an overkill control plan at these sites.

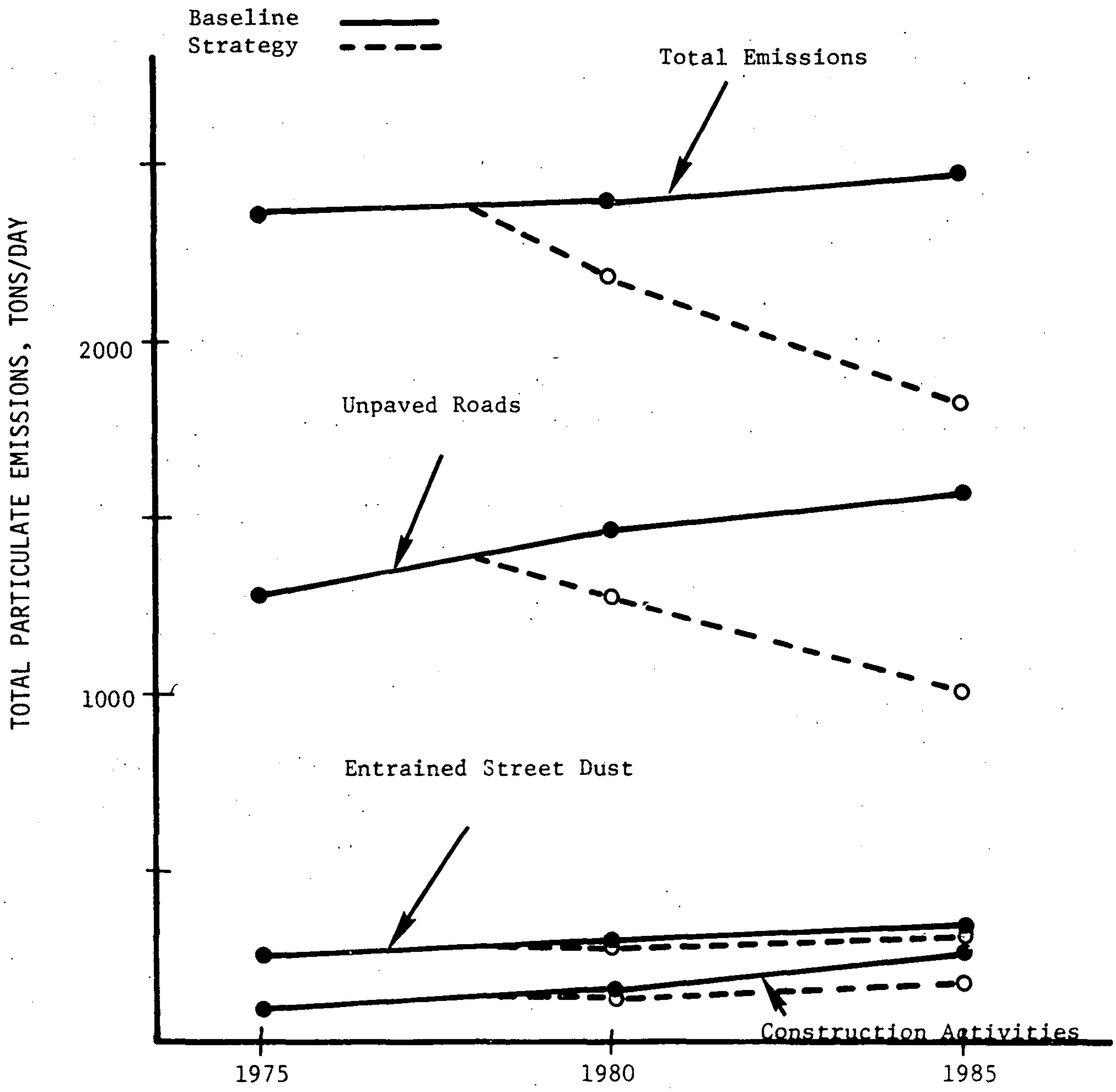


Figure 1-1. Impact of Dust Control Strategy on Emissions Levels

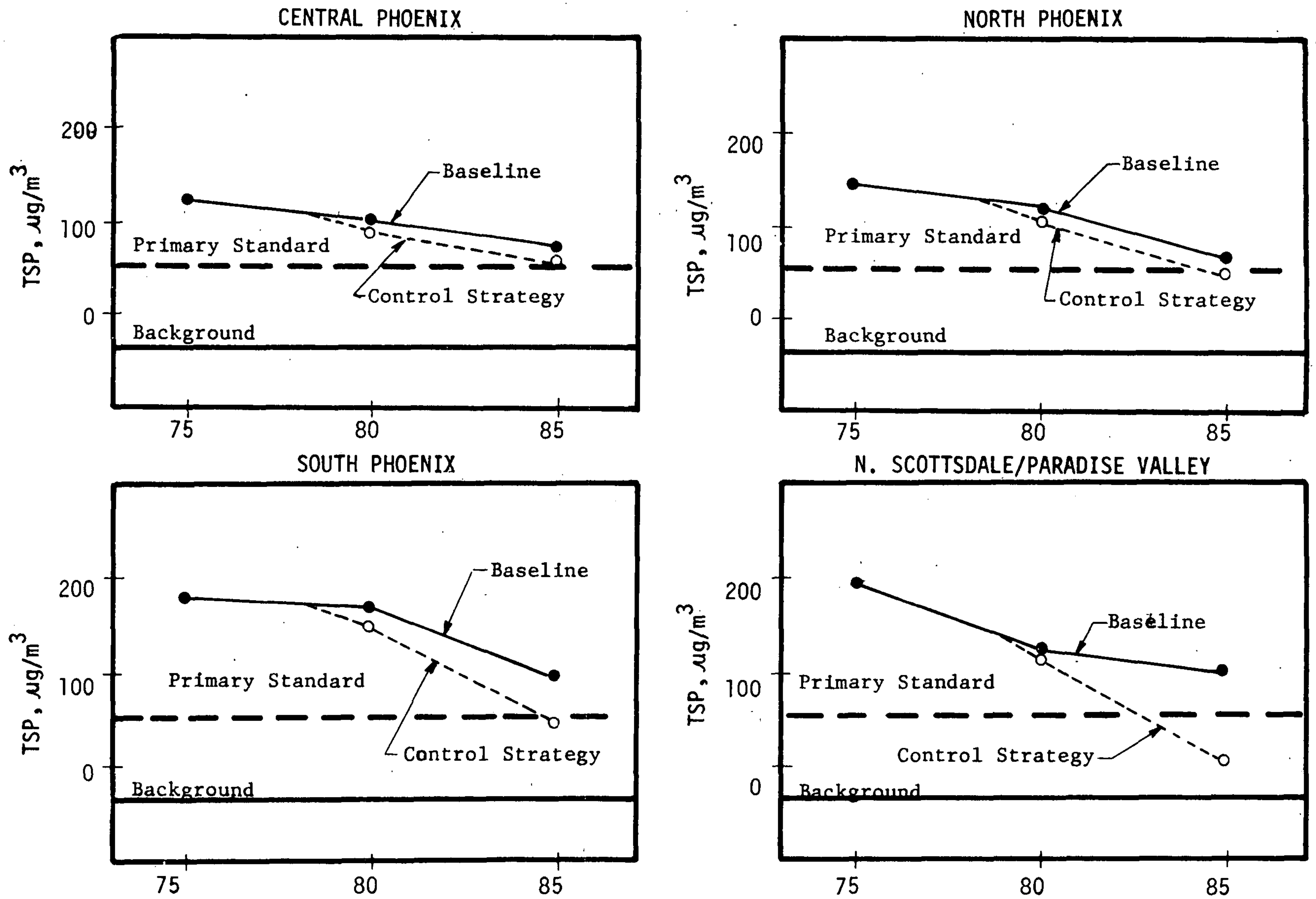


Figure 1-2. Impact of Dust Control Strategy on Suspended Particulate Levels at Monitor Sites in Phoenix Area.

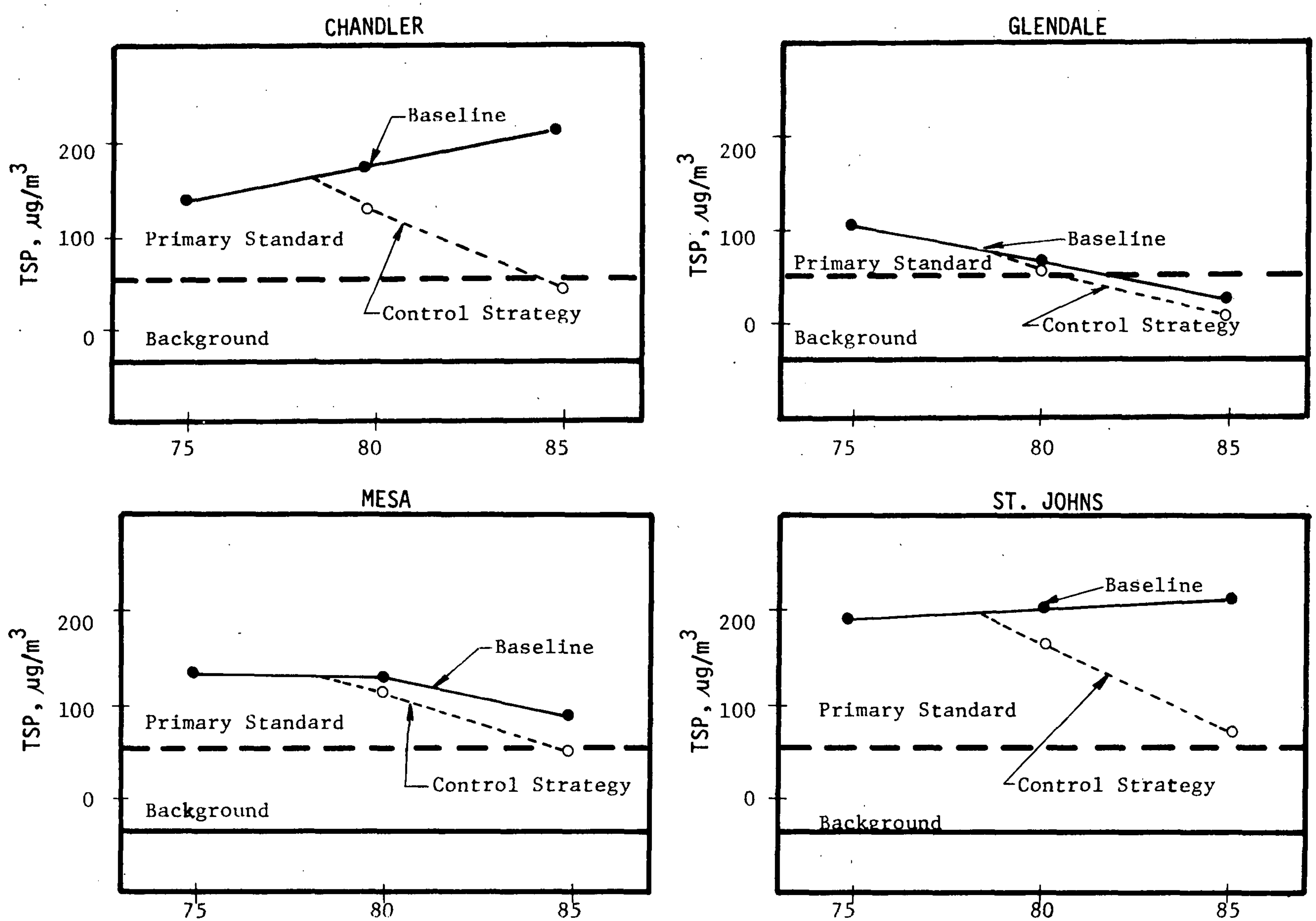


Figure 1-2. (Continued) Impact of Dust Control Strategy on Suspended Particulate levels At Monitor Sites in Phoenix Area

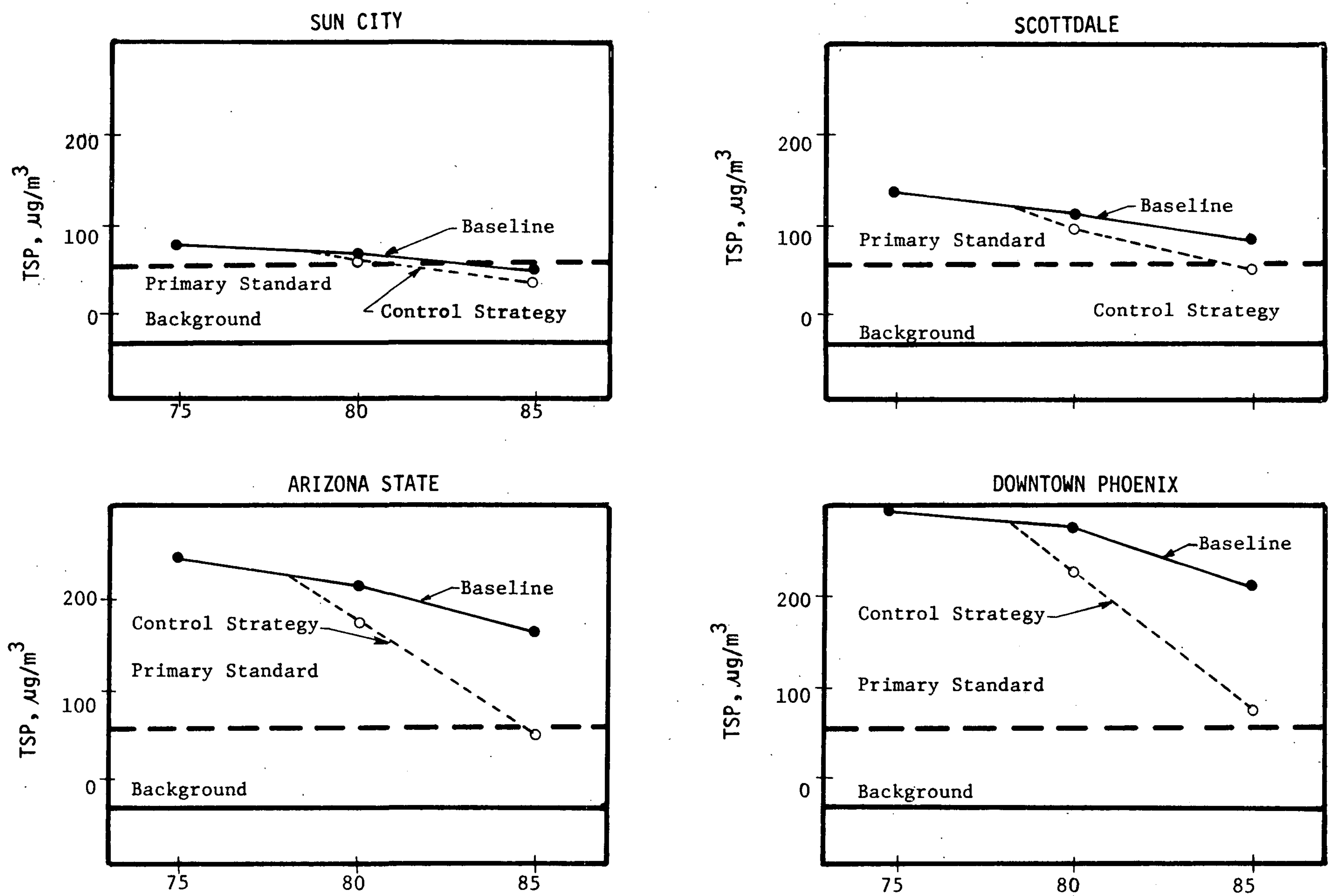


Figure 1-2 (Continued). Impact of Dust Control Strategy on Suspended Particulate Levels at Monitor Site in Phoenix Area

1.2 CONCLUSIONS AND RECOMMENDATIONS

- A reasonable control strategy can attain substantial improvements in ambient air quality in Phoenix. Measures which are technically and economically feasible can achieve the emission reductions required for attainment of the primary air quality standards for TSP.

- The cost of clean air in Phoenix appears economical. Compared to cities experiencing TSP non-attainment due to conventional emission sources (e.g. Los Angeles), the cost effectiveness of lowering TSP from fugitive dust in Phoenix is an order of magnitude less.

- Successful implementation of the control strategy may be jeopardized by social resistance (about 70% of the strategy costs must be financed by public funds). A demonstration strategy should be instituted to promote social acceptability for the strategy concept.

- A local demonstration strategy is particularly appropriate for areas experiencing widespread fugitive dust problems because of the dominant local influence of these sources. A substantial portion of the particle sizes from thse sources are greater than 15 microns, and are limited in travel distance. However, because of their widespread distribution throughout the Phoenix area, these sources play a major role in measured TSP levels at many sites. The feasibility of improving air quality by eliminating such local sources could be readily demonstrated by institution of a modest local control program which is closely monitored.

- The uncertainties involved in the analysis of dust pollution sources makes justification of extensive control strategies untenable. More precise demonstration is needed to warrant implementation of the costly measures which are predicted to improve air quality. The short term local model strategy is an appropriate vehicle for this demonstration.

- A special feature of the fugitive dust measures comprising the strategy is their compatibility with overall planning objectives for the area. Dust control for unpaved roads and paved city streets are merely intensified extensions of current local programs (e.g. paving of roads).

- The consistency between the major elements of the proposed control strategy and planning objectives of local governmental agencies permits a workable approach to implementation of dust controls. The measures may be instituted and conducted as on-line operations of the various local agencies, as opposed to the more conventional procedure employing regulatory actions.

- Because of uncertainties in the data base available for assessing street dust loadings and street equipment sweeping efficiencies, it is not possible to specify a definite street sweeping program to accomplish the targeted emission reductions. A field measurement program should be instituted to establish baseline loadings for various streets and to determine by test the actual sweeping programs needed to obtain the allowable dust levels.

- This study has identified nine potential non-attainment areas (Figure 3-10) which may require additional control attention in 1985. It is recommended that monitor sites be installed at the indicated locations to establish baseline TSP levels for use in air quality simulation and prediction of future TSP levels there. The timetable for completing the expanded monitor network should be immediate to permit appropriate adjustment of the proposed control strategy (if necessary) before required deadlines.

- To insure maximum effectiveness of the demonstration strategy as a persuasive tool, implementation should include a public relations program to promote awareness of the economic and air quality benefits inherent in dust control plans. Opinion surveys should be conducted to develop an understanding of the value forces which must be shaped.

2.0 CHARACTERIZATION OF ALTERNATIVE CONTROLS

In the Phoenix area, formidable reductions in fugitive dust emissions must be achieved if air quality is to be upgraded to the National Ambient Air Standards for suspended particulates. Therefore, the success of the air pollution control plan will depend greatly on the effectiveness of controls proposed for the major fugitive dust sources. Examination of the 1975 and 1985 emission inventories reveals the dominance of 5 major source categories in the total emissions tabulation. Table 2-1 shows a listing of the major particulate emissions expected from these sources in 1985. Five sources are responsible for all but 17% of the particulate emissions in 1975, and by 1985 these sources are estimated to account for all but 7% of the total particulate emissions in the study area. During the air quality modeling task of this study [17], it was shown that three of the major sources are almost entirely responsible for the high levels of suspended particulates monitored throughout the study area. These sources are fugitive dust arising from unpaved roads, dust off paved streets, and construction activities.

The dominance of fugitive dust emissions in the particulate emissions inventory (Table 2-1) is confirmed by microscopic analyses of the Hi-Vol filters. Approximately 70% of all mass deposited on the filters consists of particles greater than 20 micron diameters. [35] In areas where conventional sources are already controlled (such as Phoenix), particles greater than 10 micron diameter are generally of fugitive origin. In the Phoenix study area, one third of the fugitive dust emissions are estimated to be greater than 20 micron diameter. The local impact of large particles is substantial. Gravitational settling of the larger particles confines them to short range transport, and limits their dispersion significantly. Controls which treat these sources on a local basis may improve local air quality substantially. However, because the sources are widespread throughout the study area, the effective control of these local sources must be area-wide to reduce the local impact of particle deposition at many separate locations.

This chapter provides a general characterization of alternative control methods which are applicable for prevention of fugitive dust emissions from the three major source categories.

TABLE 2-1. PARTICULATE EMISSIONS FROM MAJOR SOURCES* IN THE PHOENIX STUDY AREA, 1975 AND 1985.

	EMISSIONS, TONS/DAY							
	1975				1985			
EMISSIONS SOURCE CATEGORY	0-10µ	10-20µ	20-100µ	TOTAL	0-10µ	10-20µ	20-100µ	TOTAL
1. Unpaved Roads	537	144	600	1281	637	171	745	1553
2. Resuspension off paved roads	164	57	27	248	213	74	35	322
3. Construction activities	66	23	11	100	169	59	28	256
4. Wind Erosion-undisturbed Desert	200	65	29	294	58	19	8	85
5. Off road vehicles	29	8	23	71	44	12	50	106
6. All other categories	258	70	49	386	105	16	19	140
Sub-total for 5 categories	996	297	690	1974	1121	335	866	2322
Total emissions	1254	367	739	2360	1226	351	885	2462
Percentage of all emissions generated by 5 fugitive dust categories	79.4	81.0	93.5	83.7	91.5	95.5	98.0	94.3

* The five sources listed above are the largest emitting sources of particulates projected to exist in 1985.

2.1 CONTROL OF DUST EMISSIONS FROM UNPAVED ROADS

Control methods to reduce dust emissions from unpaved roads consist of (1) paving roads, (2) application of chemical stabilizers, (3) watering, and (4) traffic related controls. Both the city of Phoenix and Maricopa County have considered these alternatives as candidate measures in their respective improvement program.

In 1960, the City Transportation Department rejected use of measures which are temporary or of short term nature and adopted an overall plan to provide a high standard for roadways throughout the city. The city program, forecasted for completion by 1985, will provide for paving of all unpaved streets and general upgrading of the city link network. The program has already accounted for a decrease in unpaved road mileage in the city from 550 miles in 1960 to 191 in 1976.

The County Roadway Program includes a modest street paving effort amounting to approximately 50 miles per year (including those streets paved by private development). The County Highway Department is presently engaged in a modest test program to evaluate highway alternative chemical stabilizers as dust retardants and as preparation bases for asphaltic composition road surfaces. Cement stabilization, lime, enzymes, and tree sap have been tried as dust palliatives, without success, and also appear to show little promise as stabilizer bases for bituminous asphaltic surfaces. The stabilizers wear quickly under the abrasive action of motor vehicle travel and retain their effectiveness only briefly before repeated application is necessary [1]. The cost of effective dust control using road soil stabilizers varies with the average vehicle traffic. An initial application may cost from $2000 to $4000 per mile, depending on the type of stabilizer and the surface preparation provided.

The Arizona Department of Transportation has recently funded a study [13] in which various chemical stabilizers were tested for dust control on unpaved roads. The stabilizers were applied to sections of an unpaved road with an average daily traffic of 140 vehicles and a surface soil silt content of 28%. Some of the chemicals were applied by spray, while others were mixed to a three inch depth after ripping the roadbed surface. Hi-Vol and dust collector measurements were utilized to evaluate the dust suppressing ability of the stabilizers with the road subject to normal traffic conditions. The performance of the stabilizer products is shown in Tables 2-2 and 2-3. As a spray treatment, dust control oil demonstrated the highest degree of dust control on the road surface both after the 5 month and 14 month observation periods. This palliative also was superior in terms of least cost. As a stabilizer which is mixed into the roadbed, the Redicote E52 Asphalt Stabilizer Emulsion provides superior dust control, especially for the longer observation period. The stabilizer exhibiting the best performance for dust control also performed significantly better in terms of road surface preservation. The dust palliatives tested are available commercially and can be applied at costs ranging from $4,300 to $10,300 per mile of 2 lane roadway. Since these palliatives must generally be applied once annually (for roads carrying 150 ADT), it is clear that the substantial annual cost of this measure should be carefully evaluated against alternatives before it is applied.

The city of Phoenix is currently engaged in a modest program to treat a limited number of unpaved roads where dust emissions have been particularly offensive. Dust control stabilizers are applied with the use of a boot truck equipped with a spray bar. The street surface is prepared prior to application by surface blading or by ripping, depending on whether the application is a surface treatment or a soil penetration mix. After application of the stabilizer, the street surface is compacted using a roller.

The city of Phoenix is currently using Dust Control Oil (RD-1000) supplied by Standard Oil as it has proven to be a satisfactory dust palliative in the past. The State Department of Transportation is also using the Dust Control Oil in the Phoenix area to stabilize 400 acres of cleared right of way for the future Maricopa Freeway. This treatment was applied in 1974, yet the soil still exhibits a crust and has been observed to be stable during heavy winds. Because the oil application was very light (.1 to 25 gal/yd^2), the crust is easily disturbed by pedestrian or vehicle traffic.

TABLE 2-2. PERFORMANCE RATING AND ROAD CONDITIONS FOR SELECTED ROAD DUST PALLIATIVE, SPRAY ON APPLICATIONS [13]

Chemical	Cost of Chemical & Application[a] $/mt.	After 5 Months		After 14 Months and Several Bladings		Cost Effectiveness[b] $/ton of dust Emissions Prevented
		Percentage Control[c]	Description of Road Condition	Percentage Control[c]	Description of Road Condition	
Dust Control Oil Mixture of petroleum resin and light hydrocarbon solvent. Applied at .6 gal/yd.^{2}	5280	95.2	Black, very hard surface, some potholes near shoulders, minimal loose material, extremely light dust behind traffic.	54.3	Dark brown, hard surface, scattered potholes, moderate loose material but from outside the road, light dust behind traffic.	9.3
Curasol AE A polymer dispersion diluted in water by 6 to 1. Applied in 4 passes at .25 gal/yds^2 each.	8130	86.9	Dark brown, medium hard surface, rutted with few potholes, loose coarse particles on surface, moderate dust behind traffic.	9.4	Brown, several ruts and potholes, large amount of loose particles, very heavy dust behind traffic.	23.8
Aerospray 70 A polyvinyl Acetate resin diluted 6 to 1 with water. Applied using 4 passes at .25 gal/yd each.	8080	82.6	Brown, medium hard surface, medium wear and ruts, few potholes, loose coarse particles on surface, moderate dust behind traffic.	44.3	Lt. Brown several ruts and potholes, large amount of loose particles, heavy dust behind traffic.	18.0
Dust Bond 100 + F-125 Mixture of lignin sulfate and other chemicals. Applied non diluted in first pass at 1 gas/yd^2 then at 1 to 1 dilution plus 2.5% formula 125 on next pass. Surface compacted intermittently for several hours after application	8420	88.0	Brown, medium hard surface, moderate wear, few potholes, smooth surface, slippery when wet, moderate dust behind traffic.	17.6	Lt brown, few patches of treated surface, several ruts, large amount of loose particles, heavy dust behind traffic.	22.4
Foramine 99-194 A urea-formaldehyde resin in water solution. Diluted 1.6 to 1 by water application at 1 gal/yd^2	10300	46.6	Natural color, worn and rutted surface, large amount of loose particles, poor riding quality, heavy dust behind traffic.	8.9	Natural color, similar to untreated (water) section.	52.2
Water	400	0	Natural color, soft when wet, worn and rutted surface, large amount of loose particles, heavy dust cloud behind traffic.	0	Natural color, worn, numerous ruts and potholes, large amount of loose particles, heavy dust cloud behind traffic.	---

a. Based on State cost figures [13] for chemical stabilizers, adjusted 15% upward to reflect current (1976 costs, and another 10% to include cost of surface preparation and applications. Correction for adjustment to current costs is based on personal communication with a principal supplier [14]. Costs include shipping expenses for supplier to Phoenix.

b. Cost effectiveness is based on the ratio of the cost and the average emissions reduction attained for the period indicated. This reduction is estimated by applying the control figures above to the uncontrolled dust emissions corresponding to an unpaved road with ADT of 140, soil silt content of 28%, and average vehicle speed of 35 mph (see reference [10]. The uncontrolled emissions are 254 tons per mile of road for the 5 month period, and 712 for the 14 month period.

c. Control effectiveness is based on dustfall measurements conducted at various distances from road.

TABLE 2-3. PERFORMANCE RATINGS AND ROAD CONDITIONS FOR SELECTED ROAD SOIL STABILIZERS, MIXED INTO SOIL[a] [13]

			After 5 Months		After 14 Months	
Chemicals	Cost of Chemical and its application[b] $/mi	Percent Control[d]	Description of Road Condition	Percent Control[d]	Description of Road Conditions After Several Bladings 9/29/75	Cost effectiveness[c] $/ton of dust emissions Prevented
Redicote E52 Asphalt Emulsion A cationic asphalt emulsion (7.4% in water) applied at 2.4 gal/yd^2.	10810	94.7	Black, very hard, asphalt like surface, little wear, smooth no loose material, no dust behind traffic.	84.4	Black very hard, asphalt like surface, little wear, good riding quality, some loose coarse material, very little dust behind traffic.	17.0
Dust Bond 100 + F-125 A misture of lignin sulfonate and other chemicals plus formula 125. Applied at 1 gal/yd^2.	8440	86.6	Brown, hard surface, smooth, little wear, some loose material, very light dust behind traffic.	44.7	Brown, few hard spots, numerous ruts and potholes, heavy dust concentration behind traffic.	18.1
Dust Control Oil Mixture of petroleum resin and light hydrocarbon solvent. Applied at .5 gal/yd^2.	4370	80.5	Black, hard at spots, few ruts and potholes, loose course material moderate dust behind traffic	11.5	Dark brown, hard at few spots, numerous ruts and potholes, heavy dust cloud behind traffic.	13.4
Water	600	0	Natural color, rutted, several potholes substantial loose material, heavy dust behind traffic.	0	Natural color, rutted, numerous potholes, substantial loose material, heavy dust cloud behind traffic.	---

a. Mixing of the chemical stabilizer into the road bed is accomplished as follows: 1) the surface is first ripped to a depth of 3 inches; 2) the surface is sprayed with water; 3) the chemical is sprayed on the surface; 4) the chemical is mixed into the soil surface with a series of successive bladings; 5) the road surface is compacted by rolling.

b. Based on state cost figures [13] for chemical stabilizers, adjusted 15% upward to reflect current (1976) costs, and, adjusted another 10% to include cost of surface preparation and chemical application.Correction to current costs are based on communication with a principal supplier [14]. Costs include shipping expenses from supplier to Phoenix.

c. Cost effectiveness is based on the ratio of the cost and the average emissions reduction attained for the period indicated. This reduction is estimated by applying the control figures above to the uncontrolled dust emissions corresponding to an unpaved road with ADT of 140, soil silt content 28%, and average vehicle speed of 35 mph (see reference [10]. Roadway dust emissions without control are 712 tons for the 14 month period.

d. Control effectiveness is based on dustfall measurements conducted at various distances from road.

This crust is, however, re-established after rainfall provided the soil is not disturbed by frequent traffic.

The tests by the State Department of Transportation show clearly that chemical soil stabilizers may be used as an effective control for unpaved road dust emissions. In some cases the stabilizer also serves to preserve the road surface, resulting in lower road maintenance cost. Of the various chemicals tested by the state, the Dust Control spray application is by far the most cost effective in terms of dust control. The most effective performer was the mix-in application of Redicote Asphalt Emulsion, which was controlling dust emissions by 85% after a 14 month period. The main drawback to use of the effective stabilizer is cost. Repeated applications of the chemicals, even at reduced rates, impose costs which approach or exceed the annualized cost of a paved road.

In addition to chemical road stabilizers, the county and city have each considered low-cost paving alternatives. The most widely used low cost pavement is the bituminous asphaltic chip seal over a granular base or a stabilized soil base. Figure 2-1 shows a profile of this chip seal construction. A penetration stabilizer (liquid asphalt MC-250) is applied to the 6 to 8 inch base, followed by a chip seal.

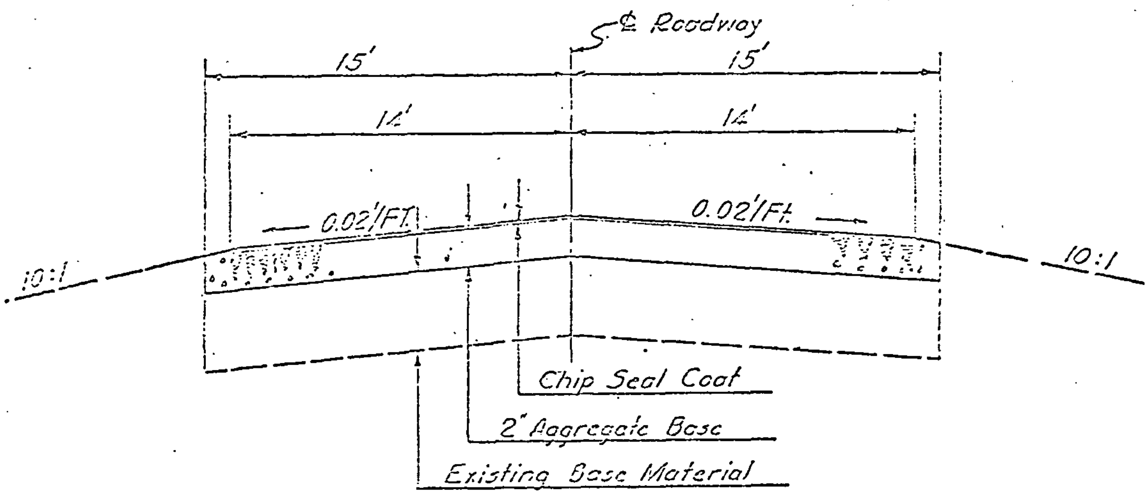


Figure 2-1. Profile of Typical Section for Chip Seal Road Surface Construction.

TABLE 2-4. COST OF CITY STREET MAINTENANCE IN PHOENIX, 1974-75 FISCAL YEAR [2]

MAJOR:	Miles	% of Total City Miles	City Cost For Period	% of Total City Cost	Cost Per Mile For Period
Fully improved	397	15.3	$1,296,027	52.7	$3,265
Bituminous Surface Treatment	13	0.5	42,743	1.7	3,288
Oiled Roadway	5	0.2	13,531	0.5	2,706
No Surface Treatment (graded)	5	0.2	19,690	0.8	3,938
Total	420	16.2	$1,371,991	55.7	$3,267
COLLECTOR					
Fully improved	200	7.7	$ 182,737	7.4	$ 913
Bituminous Surface Treatment	28	1.1	45,688	1.9	1,632
Oiled Roadway	8	0.3	2,427	0.1	303
No Surface Treatment (graded)	1	-	8,702	0.4	8,702
Total	237		$ 239,554	9.8	$1,011
LOCAL:					
Fully improved	1,772	68.3	$ 541,499	22.0	$, 306
Bituminous Surface Treatment	15	0.6	44,570	1.8	2,971
Oiled Roadway	35	1.3	40,503	1.7	1,157
No Surface Treatment (graded)	116	4.5	222,663	9.0	1,920
Total	1,938	74.7	$ 849,235	34.5	$ 438
GRAND TOTAL	2,595	100.0	$2,460,780	100.0	$ 948

Note: Above figures do not include cost of Preventive Maintenance by Contract.

The city has rejected the chip seal approach on the basis of its high annual maintenance costs and poor performance characteristics. Table 2-4 shows the high maintenance costs incurred during 1974-1975 for the four major types of road construction in the city of Phoenix. However, the county is experimenting with the bituminous chip seal for roads with low vehicle traffic counts (100 vehicles/day), and finding it satisfactory in applications throughout the county. Maintenance requirements depend on vehicle traffic and locale, but generally include a second chip seal after one year, followed by another seal in approximately 5 years.

A study conducted by the city of Seattle Engineering Department has shown the most cost effective method of dust control on roadways is a chip seal when the average daily traffic is 150 vehicles. This dust control option is also economically beneficial, considering the estimated annual savings of $2,665/yr/mi in maintenance costs resulting from the measure. A Duwamish Valley study [3] has shown annual maintenance costs of various types of roadways diminishes appreciably with the quality of the road surface. Table 2-5 shows the annual maintenance costs derived from this study. The study also includes a cost analysis of benefits gained by dust control for Duwamish roadways. These benefits were estimated to translate to over $3.88 million/year to the community, and demonstrate clearly that paving of roads is a good investment.

TABLE 2-5. ANNUAL MAINTENANCE COSTS FOR VARIOUS ROAD[a] SURFACES [3] IN DUWAMISH VALLEY

TYPE OF ROAD	COST IN $/MI
Gravel Road	2900
Oiled Surface	1100
Seal Coat	245
3 inch Asphalt	245
6 inch Concrete and Curbs	100

a. Costs are given for standard 2-lane road

While it is possible to show the high cost of roadway dust control programs is economically beneficial, the most cost effective control measures are difficult to determine. The Duwamish Valley Study estimated that oiling of unpaved roads with an average daily traffic over 15 vehicles is the least cost way to reduce dust levels. As traffic increases, maintenance costs required to sustain dust control throughout the year increases until the least cost dust control consists of a chip seal surface at 150 ADT, and with still more vehicle traffic, an asphalt surface. Typical cost estimates for initial construction and maintenance of the different road types in Phoenix are shown in Table 2-6. It is apparent that maintenance costs contrast sharply with those reported in Phoenix City (Table 2-4) and the Duwamish Valley (Table 2-5). This is due to the diversity of maintenance practices and requirements from one region to another, and the differing cost of resources.

TABLE 2-6. INITIAL COST AND MAINTENANCE COST OF ALTERNATIVE ROAD SURFACES APPLIED BY MARICOPA COUNTY HIGHWAY DEPARTMENT [1, 13]

TYPE OF ROAD	COST ($/MI)	ANNUAL MAINTENANCE ($/MI)
Gravel Road	16,000	600
Oiled Surface (Low Cost Application)	2000-3000	2000-3000
Oiled Surface Dust Control Oil	5,300	5,300
Chip Seal Coat	35,000	800
3" Asphalt	55,000-100,000	160

Control efficiency estimates for the various dust measures are tabulated by considering the effect of altering a road which is presently an unpaved dirt surface having a silt content about twice that of a gravel road (representative of the Phoenix area). Cost effectiveness is then estimated by considering the annualized cost of the measure in the given study area and the resulting emissions reduction. Efficiencies and cost effectiveness estimates are shown in Table 2-7. The chip seal surface appears to be somewhat more cost effective than the other road surfacing dust control measures, and of those measures providing the best control, the chip seal is significantly more cost effective. These findings are consistent with the Duwamish Valley Study [3] where it was found that the least cost control was a chip seal surfacing when ADT is over 100. However, for lower ADT, lighter applications of the road dust palliatives may be used to attain a certain level of dust control and cost effectiveness of the palliative in this instance becomes competitive with the chip seal paving approach.

TABLE 2-7. EFFECTIVENESS OF ALTERNATIVE ROAD SURFACES IN REDUCING DUST EMISSIONS FROM AN UNPAVED ROAD IN MARICOPA COUNTY

ROAD TYPE	EMISSION RATE LB/VEHICLE MI.	ANNUAL EFFICIENCY	COST EFFECTIVENESS[c] $/TON OF DUST
Dirt Surface	22[a]	---	---
Gravel	11[a]	50%	11.0
Oil Surface (Dust Control Oil)	5[f]	75%	19.5
Oiled Surface (Low Cost Application)	11[b]	50%	13.5
Chip Seal	0[e]	100%	10.8[d]
Asphalt	0[e]	100%	19.6[d]

a. Based on MRI emission factor [6], and road silt content of 24% and average vehicle speed of 35 mph.

b. From reference [4].

c. Computations based on assumption of ADT of 100, maintenance costs of Table 2-6, and annualized cost of indefinite period at 10% interest.

d. These figures do not incude the dust reductions attained by inducement of traffic off unpaved roads to the newly paved surface.

e. This emission rate does not include entrainment of dust loadings off the pavement. Entrained dust emissions are discussed in Section 2.2.

f. Based on field test conducted by Arizona Department of Transportation [13].

Traffic controls also offer potential for dust emissions reduction from unpaved roads. Dust emissions increase exponentially with vehicle speed up to 30 mph [5,6]. Table 2-8 illustrates the dust emission rate at different speeds for a vehicle traveling over a dirt road characteristic of the Phoenix area. Based on an average speed of 35 mph, the reduction achieved by restricting vehicle speed to 20 mph would be 62%.

Restriction of use of unpaved roads may also be employed to reduce dust emissions. Unpaved roads may be closed to travel when alternative paved routes are available. The potential of this dust control measure is not encouraging since almost all roads provide needed access to at least a limited segment of the population, and it is not plausible to restrict traffic to only this limited sector. It should be noted, however, that traffic volume on the remaining interior unpaved roads will be diverted significantly after addition of paved routes to the road network. Such traffic inducement should be considered in assessing the total effectiveness of the road-surfacing measures. For example, a plan to pave half the section line roads in Maricopa County (Arizona) by 1985 would reduce expected traffic on remaining interior unpaved roads by 15%. This analysis is made by considering the trip alternatives in a representative section of the road network for the "before and after" paving control measure (Section 3.3).

TABLE 2-8. DUST EMISSION RATES AT DIFFERENT VEHICLE SPEEDS

SPEED OF VEHICLE	EMISSION RATE[a] LB/VEHICLE MI.	DEGREE OF EMISSIONS REDUCTION
35	22	---
30	19	14%
25	13	41%
20	8.5	62%

a. The emission rate is based on the MRI emission factor [13] for vehicle speeds of 30 mph and over. For speeds from 0 to 30 mph the emission rate increases exponentially with speed and is calculated as follows: $e = .0211\ S^2$, where e = emission rate (lb/vehicle mi.), and S = vehicle speed (mph). The baseline emission rate (35 mph) was calculated assuming a typical dirt road silt level of 24%.

2.2 CONTROL OF ENTRAINED DUST OFF PAVED STREETS

The amount of entrained dust entering the atmosphere from paved streets is proportional to the traffic volume and the street surface dust loading [20]. Both of these parameters vary substantially from region to region, as well as within the region itself. Figure 2-2 illustrates street dust loadings measured [8] in various cities differing in age, size, locale, meteorology, and land use patterns. The average dust loadings of the cities sampled was 1500 lb/curb mile, and for Phoenix, 780 lb/curb mile.

The variation of dust loadings by different land use categories is illustrated in Figure 2-3. Streets in industrial areas tend to be most heavily loaded, while commercial streets are least heavily loaded. This pattern is consistent with land use and street sweeping practices. Commercial areas are swept frequently while industrial areas receive less cleaning attention. These patterns suggest the control of entrained dust by two methods: 1) control of the street dust origins, and 2) modification of street sweeping practices.

Control of the Dust Origins

One obvious means of reducing street dust loadings is by controlling the dust sources. Significant origins consist of carryout of dust from dirt surfaces by motor vehicles, atmospheric fallout of airborne particulates, and transport from adjacent exposed land areas. In Phoenix, the major sources of dust originate from dust fallout of local source emissions and from transport of exposed soil areas near the streets. There are presently 470 miles of city streets with unpaved shoulders in the cities of the study area. Over half of these roads are major streets experiencing substantial traffic volume. Dust from the exposed road shoulders is transported to the street surface by air turbulence from passing vehicles, wind erosion, tracking by pedestrians and vehicles, and water runoff. In addition, there are numerous exposed vacant lots throughout Phoenix which contribute to dust transport on nearby street surfaces.

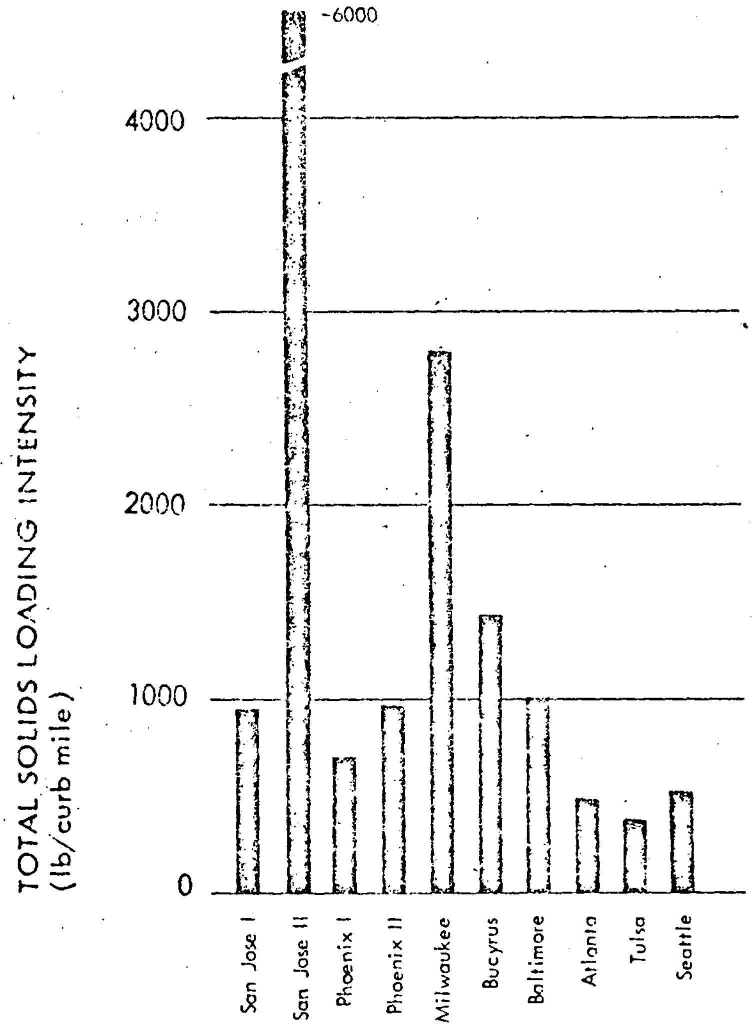


Figure 2-2. Street Dust Loadings for Various Cities in U.S. [8].

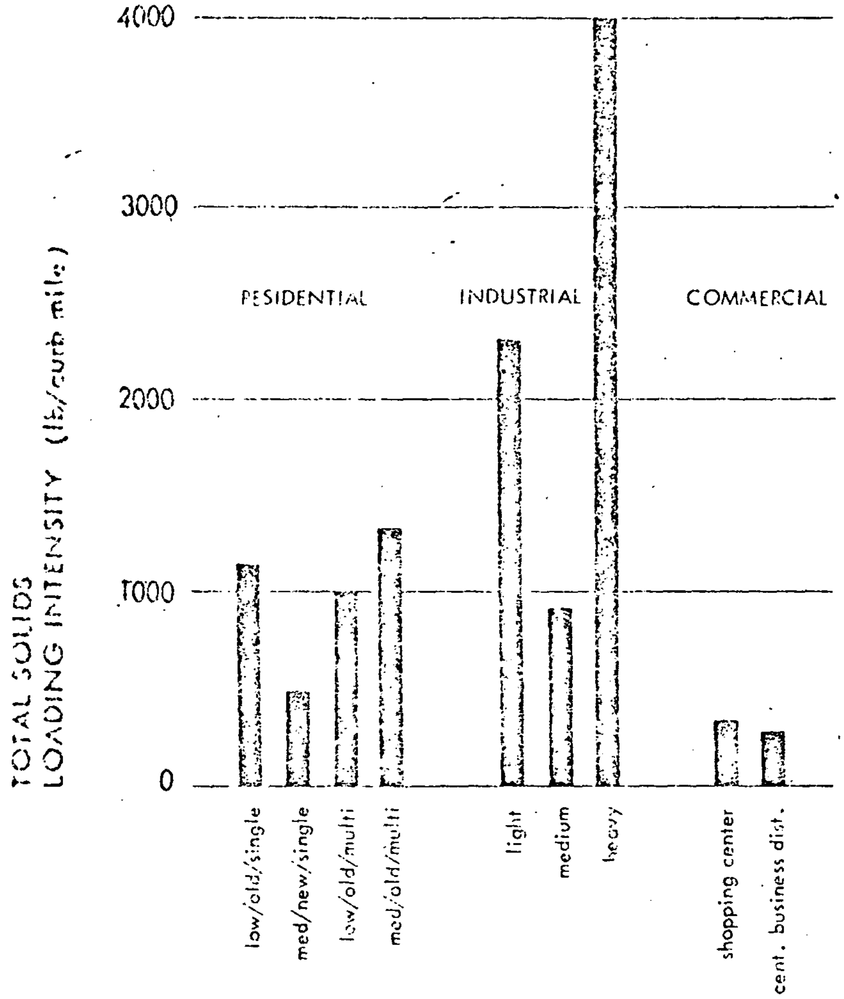


Figure 2-3. Street Dust Loadings for Various Land-Use Categories, Summary of Several Cities in U.S. [8].

Roadway improvements anticipated over the next ten years will result in significant impacts on street dust loadings. The mileages of uncurbed streets in the cities of the study area will change as follows:

ROAD TYPE	MILES OF UNCURBED CITY STREETS		
	1975	1980	1985
Local	142	72	0
Collectors and Majors	329	260	191

Source: Support Document #2 [10].

These improvements are important because dust loadings for streets with uncurbed shoulders are estimated to be four times greater than that observed for curbed streets [9]. While local roads play a minor role in total dust resuspension (due to low VMT on those roads) the improvement of road shoulders for collectors and major streets is expected to decrease the city-wide entrainment emission factor from 11.1 g/vehicle mile in 1975 to 8.7 g/vehicle miles in 1985, [10]. Table 2-9 summarizes the reduction in area-wide dust resuspension factors which would occur with an intensified city program to curb all major roads and collectors by 1985. While this emission factor applies only to city traffic, the substantial portion of vehicle miles traveled in the study area are concentrated within the cities. Hence, reductions in street dust loadings in the cities would have far greater impact on TSP levels than would similar reductions in the county road network.

TABLE 2-9. EFFECT OF ROAD SHOULDER IMPROVEMENTS ON DUST RESUSPENSION FACTORS FOR CITY STREETS

	TOTAL UNCURBED MILES IN CITY	WEIGHTED DUST SUSPENSION RATE gm/VEHICLE-MI.
Baseyear 1975	329	11.1
Baseline, 1985	191	8.7
After Program to Curb all Roads (Major & Collector by 1985)	0	5.3

Based on present city construction costs of $5/curb foot [11], the additional cost of improving all remaining unpaved road shoulders with curbs in the city by 1985 would be approximately $5 million. This compares to the projected plan of the city of Phoenix to spend $57 million on local street improvements and $167 million on major streets [11, 12] by 1985.

To increase the effectiveness of street curbings as a dust control measure, the adjacent soil should be stabilized or covered to prevent wind erosion or tracking of this soil onto the street. Clearly, the most effective means of soil protection at the curb is a sidewalk. The current city policy is to include sidewalks whenever curbs are constructed on major streets. The cost of sidewalk construction is $6 per running foot of the standard 5 foot wide sidewalk. Quantification of the effectiveness of this measure is not possible but it is clear that transfer of exposed soil to adjacent road surfaces will be decreased significantly.

Street Sweeping

There are three main types of machine street sweepers currently in use. Broom sweepers utilize a rotating gutter broom to sweep debri from the gutter into the main pickup broom which rotates to carry the debris into the truck hopper. The broom sweeper is by far the most commonly used class of sweeper. A second type of sweeper, called the air broom uses an air blast to direct debris into a collection hopper. A third type of sweeper utilizes a broom and vacuum system to collect debris. Each of the sweepers employs a water spray to control dust emissions during sweeping. A number of operational and equipment factors have an appreciable impact on street sweeping effectiveness.

These factors include operator performance, forward speed, type of sweeper, and condition of broom. The most important operational factor in sweeping efficiency concerns level of effort. Level of effort in cleaning the road (expressed in terms of cleaning time per area) is related to the weight of material collected by:

$$M = M^* + (M_0 - M^*)\, e^{-kE}$$

Where M_0 is the initial street loading, M^* is the loading unremovable by any amount of sweeping, k is an empirical constant dependent on sweeper characteristics, and E the amount of sweeping effort [8].

The exponential effect of sweep effort on collection efficiency for a broom sweeper is illustrated in Figure 2-4. For the normal street sweeping operation, a single sweep pass is performed, yielding approximately a 50% collection efficiency (for typical operating speed). Adding a seocnd pass to the cleaning operation, or doubling the effort, improves efficiency to 75%. For the vacuum sweeper, collection efficiency is relatively constant regardless of level of effort for vehicle speeds 6 mph and less [18].

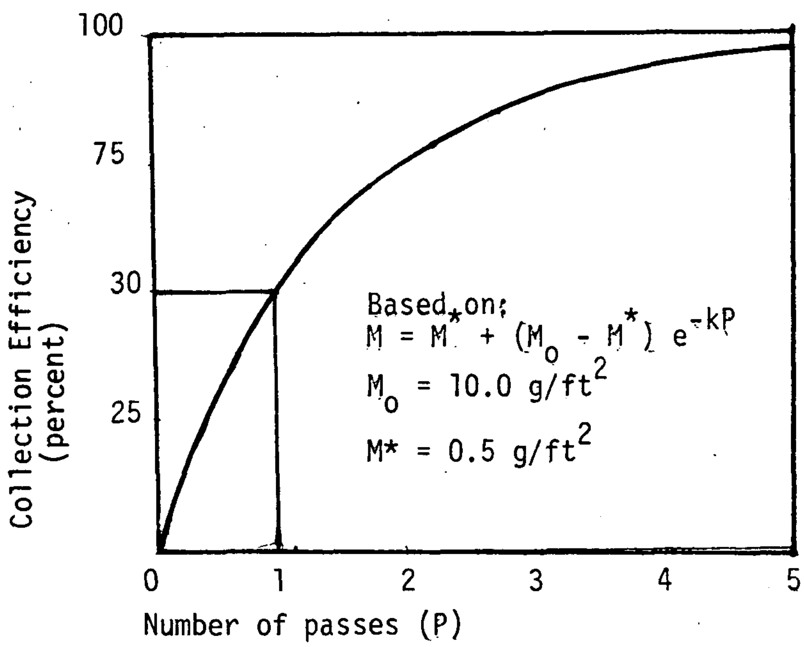


FIGURE 2-4. Effect of Level of Effort on Collection Efficiency of Broom Sweeper [8].

Sweeper collection efficiency is also related to particle size of the street load. Table 2-10 shows the efficiency of a broom sweeper for different particle size ranges. It is clear that the broom sweeper is ineffective in removing those particles which are most likely to become airborne (<100μ) by passing vehicles. In fact, the broom sweeper tends to fracture aggregated fines causing slight increases in the concentration of smaller particles after sweeping. In addition, the sweeper tends to redistribute the remaining dust over the surface of the street, making it more susceptible to atmospheric reentrainment by passing vehicles. While limited studies of the vacuum type sweepers have been conducted, these controlled experiments demonstrate a dramatic difference in the performance of the vacuum broom sweeper for collecting smaller particles. Table 2-11 shows the vacuum sweeper will collect roughly twice the small size material of the broom sweeper (when the broom effort is equivalent to about a 2 pass operation). The vacuum sweepers are most effective under dry conditions for loose dust.

TABLE 2-10. EFFICIENCY OF BROOM SWEEPER FOR VARIOUS PARTICLE SIZES [8]

PARTICLE SIZE (μ)	IN SITU TEST	EQUATION	COMPOSITE (estimate)
>2,000	78.8	--	79
840 - 2,000	66.4	--	66
246 - 840	69.5	49.2	60
104 - 246	47.7	48.7	48
43 - 104	< 0	22.2	20
<43	< 0	15.8	15

TABLE 2-11. COMPARISON OF REMOVAL EFFECTIVENESS FOR MOTORIZED SWEEPING AND VACCUMIZED SWEEPING [9].

MACHINE TYPE	RELATIVE EFFORT	20 g/ft^2 177-300μ (%)	100 g/ft^2 74-177μ (%)	600 g/ft^2 74-177μ (%)
Motorized	2.17	92.5	58.0	46.0
Vacuumized	2.88	95.0	94.5	89.5
Motorized	4.32	94.5	-	62.6
Vacummized	5.83	98.5	-	91.4

NOTE: Tests conducted on asphaltic concrete. Results are for 1 pass in 2nd gear and 1 pass in 3rd gear.

g/ft^2 = Initial mass level.

μ = Particle size range of simulant.

% = Removal effectiveness = $\frac{(M_o - M)}{M_o} \times 100$

Relative Effort = effort (time spent by sweeper covering a given area) relative to the minimum level of effort attainable by the sweeping equipment. For the tests above, unit relative equipment effort corresponds to a forward speed of 1200 ft/min. Therefore, relative effort = 1200/forward speed (ft/min.).

The city presently operates 23 motorized broom sweepers on a full time all day basis. The sweepers generally perform a single pass during cleaning. Major streets and collectors receiving heavy traffic are generally swept by night, and low-use major collectors, and local streets are cleaned by day. The local streets are swept monthly, most collectors every 2 weeks, the major streets every 7 days. Some of the high-use streets are cleaned 3 times per week, and a limited number are swept daily. The cost of this program is $1.0 million per year.

The effect of street cleaning frequency on street dust loadings is illustrated hypothetically below (Figure 2-5). The loading intensity increases rapidly approaching an equilibrium level after sweeping. The accumulation rates on typical city streets have been studied carefully under funding by the Environmental Protection Agency [8]. Typical accumulation rates after a complete cleaning are shown in Figure 2-6.

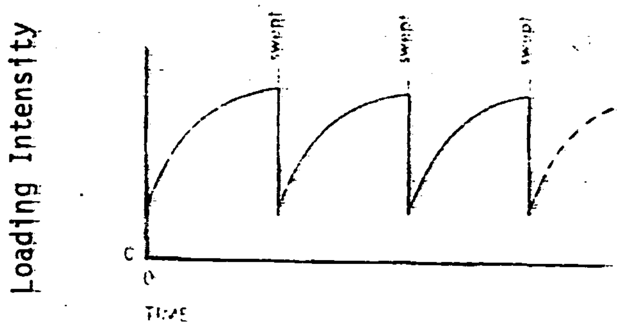


Figure 2-5. Accumulation of Particulates (Shown with Periodic Sweeping)

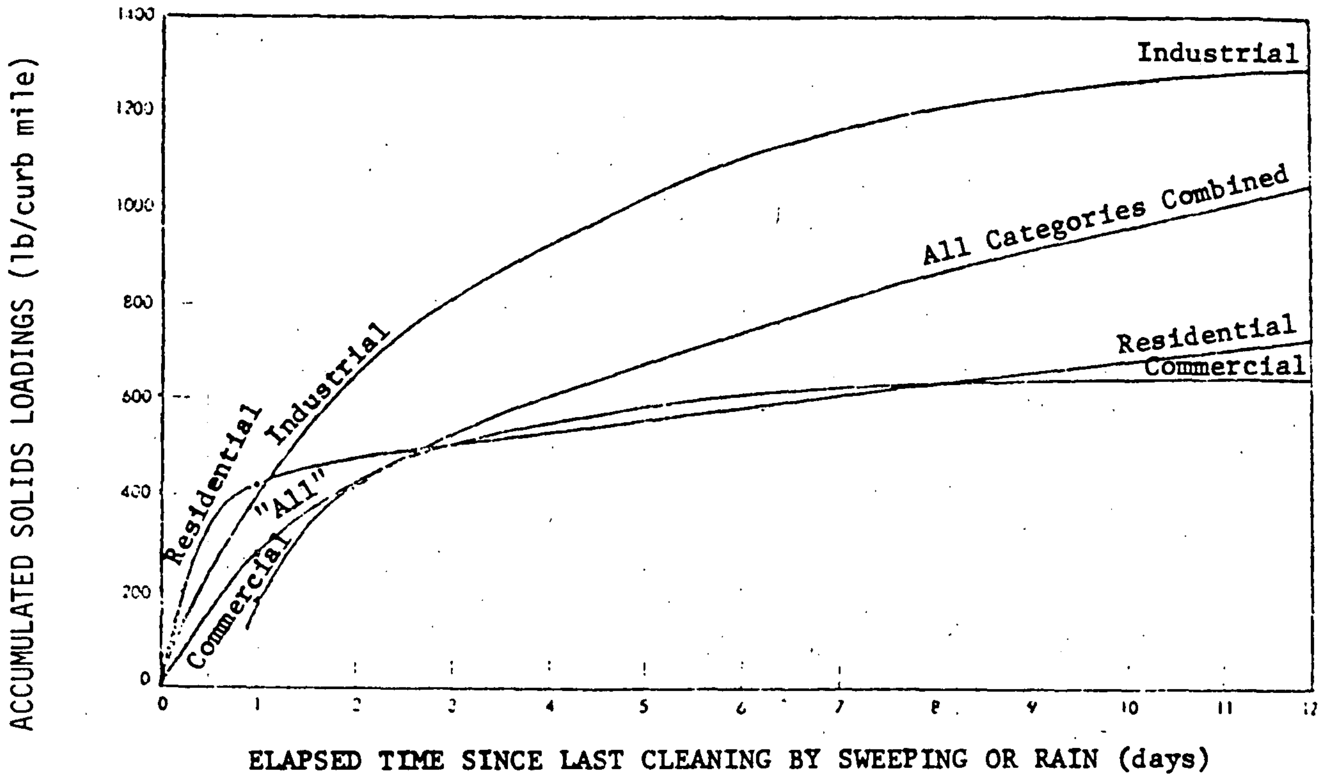


Figure 2-6. Street Dust Loading Versus Time Since Last Sweeping [8]

Figure 2-7 shows the effect of frequent sweeping with a broom sweeper on a street with typical dust loading levels. The diagrams of Figure 2-7 have been formulated by applying a collection efficiency of 50% to the accumulation schedule in Figure 2-6. When broom sweepers are used, a 48% total dust loading reduction would occur by shifting from a 10 day cleaning cycle to a 3 day cycle. In combination with a double pass of the broom sweeper, the increased cleaning frequency would reduce average total street dust loadings still more. Figure 2-8 shows the effect of frequent sweeping with vacuum sweepers on a street with typical dust loading levels. These curves are based on collection efficiency data shown in Table 2-11 and reported in reference [18], and the average street accumulation rates shown in Figure 2-6. A 58% total loading reduction would occur by shifting from the current sweeping cycle to a 3 day cleaning cycle.

The information from Figures 2-7 and 2-8 are presented in summary form in Figure 2-9 to permit extrapolation of total street dust loadings associated with any given street sweeping schedule.

The reduction in street dust loadings affects entrainment of dust by motor vehicles according to the relation developed by MRI [20].

$$E = KLS$$

Where E = suspended dust per vehicle mile
K = an empirical proportionality factor
L = street dust loading
S = silt content of dust (percentage of particles less than 75μ).

Emissions of street dust decrease with total street dust loading reductions accomplished by street cleaning programs. However, intensification of street sweeping will probably raise the average silt content of the street dust. Immediately after sweeping, the remaining dust is comprised of a higher percentage of fines as most of the heavier larger particules are removed during sweeping. Tables 2-10 and 2-11 show that the broom sweeper is far less effective at collecting smaller particles than the vacuum sweeper. For a single pass of the broom sweeper, only 20% of the particles smaller than 100 micron were expected to be removed, and during field tests [8], it

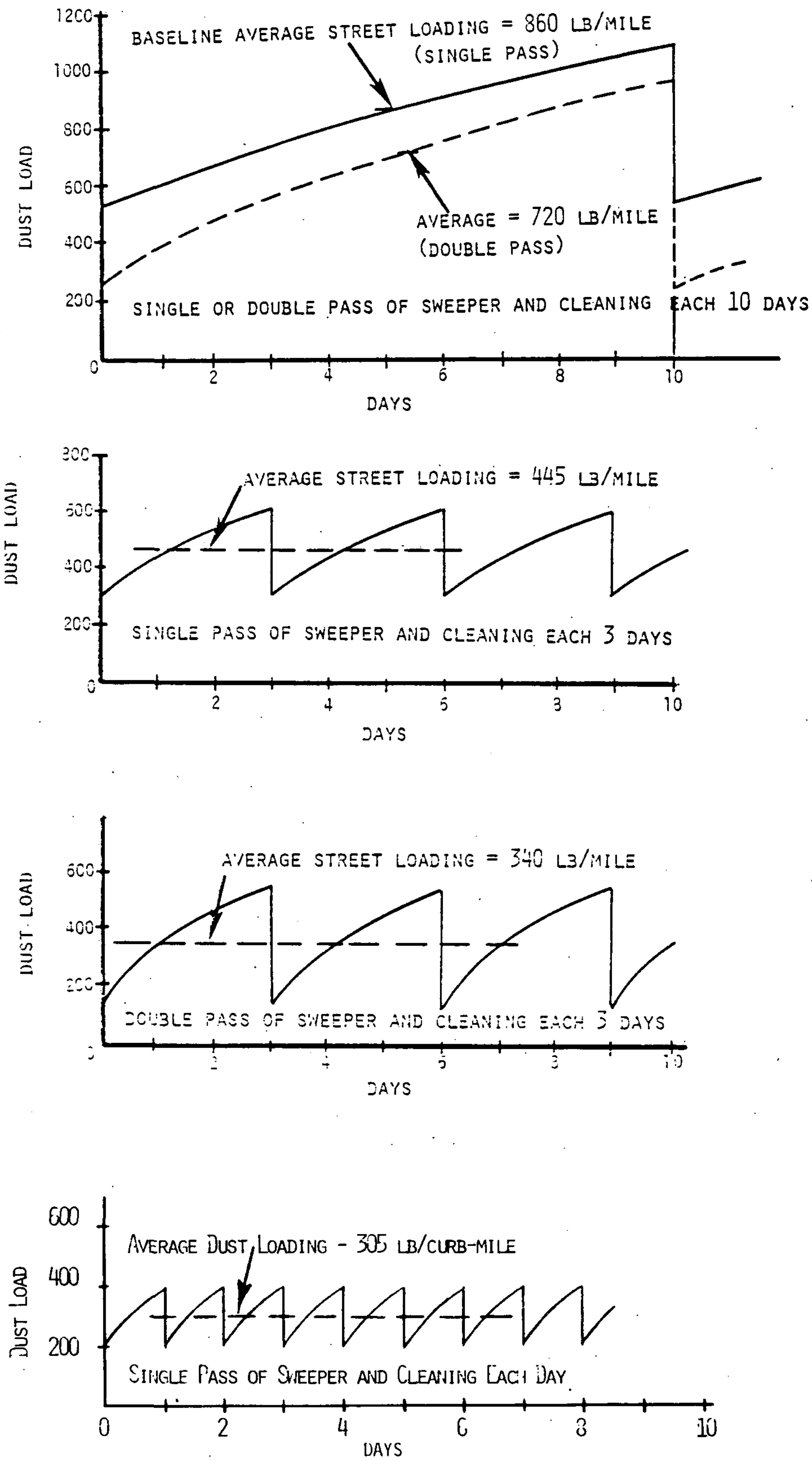


Figure 2-7. Effect of Intensification of Broom Sweeping on Street Dust Loadings

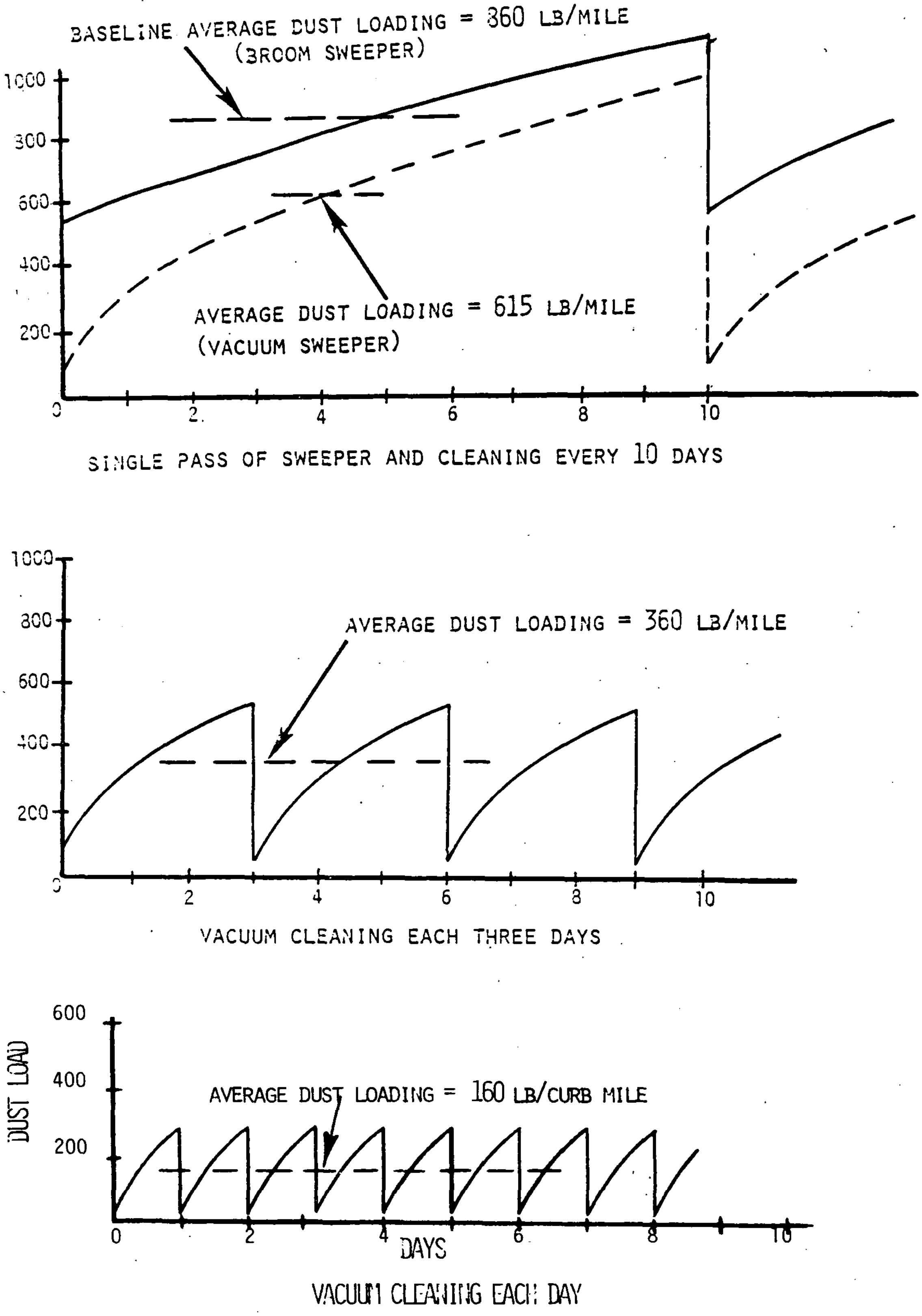


Figure 2-8. Effect of Intensification of Vacuum Sweeping on Street Dust Loadings

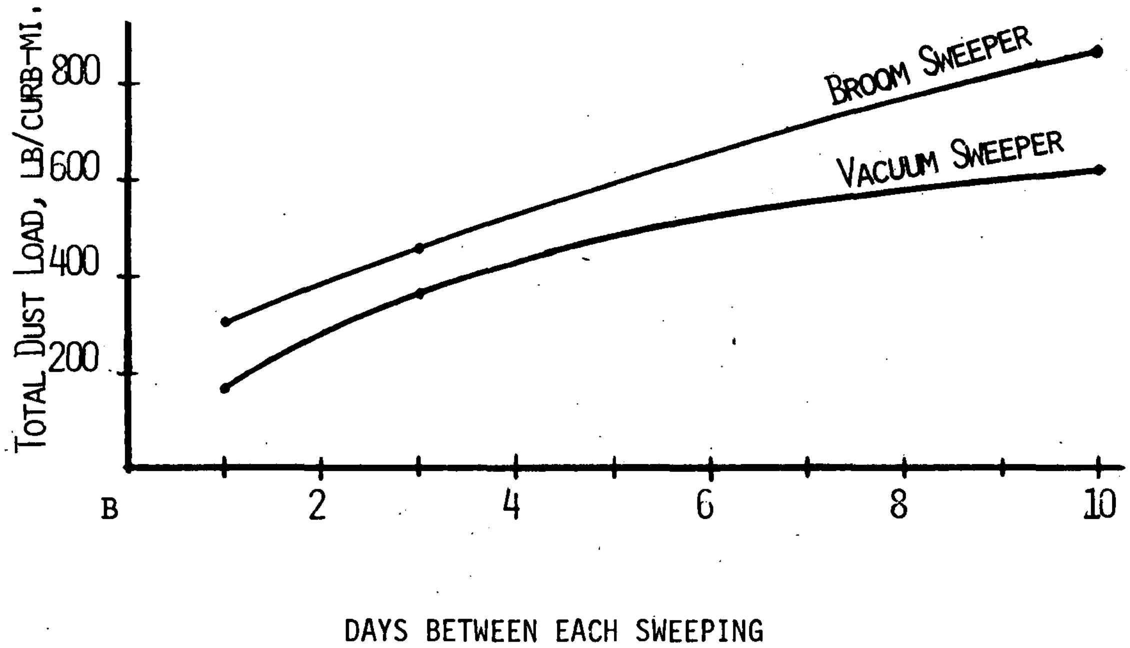


Figure 2-9. Effect of Sweeping Frequency on Average Total Street Dust Loadings

was found that a street cleaning by the broom sweeper actually increased loading concentrations of the particles smaller than 100 micron. This caused substantial shifts in the silt content of the street dust, as shown in Table 2-12. The higher silt values, increasing in some instances immediately after sweeping by factors of 2 to 6, partially cancell, at least temporarily, the dust control benefits achieved by broom sweeping cleaning operations. As accumulation of new materials occurs, equilibrium between deposition rates and traffic related removal rates is once again achieved, returning the silt levels within the range of 10 to 15%. However, with frequent sweeping, the average silt levels of street dust may be significantly higher than for normal street sweeping. It is not possible, using available data, to assess the effective silt value occurring with more frequent street sweeping. Studies now underway by the Environmental Protection Agency should reveal more information on this subject.

TABLE 2-12. COLLECTION EFFICIENCY OF BROOM SWEEPER FOR VARIOUS PARTICLE SIZES [8].

PARTICLE SIZE RANGE (micron)	ATLANTA		TULSA		PHOENIX		SCOTTSDALE	
	INITIAL LOADING (g)	RESIDUAL LOADING (g)	INITIAL LOADING (g)	RESIDUAL LOADING (g)	INITIAL LOADING (g)	RESIDUAL LOADING (g)	INITIAL LOADING (g)	RESIDUAL LOADING (g)
>2,000	175	76	1,438	142	535	240	217	43
890-2,000	103	14	418	181	308	107	439	124
246-890	375	56	690	588	2,190	224	915	415
104-246	231	29	544	595	1,273	331	421	287
43-104	66	136	415	549	425	614	213	134
<43	43	187	324	431	175	493	87	14
Total (g)	993	498	3,829	2,486	4,906	2,064	2,292	1,017
Overall Eff. (%)		50		35		62		56
>104	884	175	3,090	1,506	4,306	952	1,992	869
<104	109	323	739	980	600	1,112	300	148
% silt*	11	67	19	39	12	54	13	15

* Because of the form in which the measurements were reported, silt is defined here as the percentage of all particles smaller than 104μ, rathern than the customary breakoff at 75μ.

Increased levels of silt content resulting from frequent broom sweeping operations can be reduced substantially by employing vacuumized sweepers. Table 2-13 shows the effect of vacuum sweeping for various particle size ranges. The data is based on claims of Ecolotec, Inc., manufacturer of commercial vacuum sweepers. For a street loading similar to that found in Phoenix (768 lb/mi) the vacuum sweeper collects approximately 80% of the particles smaller than 45μ. Therefore, the vacuum sweeper would have only minor effects on the average silt level of road dust, while at the same time this sweeper would reduce total street dust loadings substantially. Consequently, the street dust loading reductions attained by a vacuum sweeper program (Figure 2-9) will translate directly into emission reductions.

TABLE 2-13. EFFECT OF VACUUM SWEEPER OPERATIONS ON STREET DUST LOADINGS [18].

OPERATING CONDITIONS			DEBRIS REMAINING			
Vehicle Speed MPH	Air Velocity MPH	Dirt Loading #/mi.	Overall %	>841μ %	44-840μ %	<43μ %
3	115	768	7.3	4.8	8.4	21.8
3	115	1536	6.4	3.2	7.8	16.7
3	115	3072	5.5	1.5	7.1	19.2
3	134	768	8.9	6.4	10.0	24.8
3	134	1536	5.0	3.4	5.5	16.7
3	134	3072	2.1	1.1	2.4	9.2
3	186	768	6.1	5.4	6.1	20.0
3	186	1536	4.0	3.7	3.8	12.1
3	186	3072	2.4	1.5	2.7	8.6
1	134	3072	3.2	3.4	2.9	4.6
1	147	3072	2.4	-	-	-
1	171	3072	2.8	-	-	-
6	147	3072	2.5	-	-	-
6	171	3072	7.0	-	-	-

Caution should be exercised in applying the evaluation procedures developed here for entrained street dust emissions control. The available data base for existing street dust loadings and sweeper efficiencies are very limited. While an average dust loading and silt level was assumed based on limited field data, it is known there is substantial variation from street to street. The information for sweeper efficiency is unclear, particularly with respect to the impact of the sweeper types on the temporal and average distribution of the particle sizes. As more information becomes available, it may be possible to develop software to compile emissions estimates for each link of the transportation network, using traffic volume tapes,street-specific dust load levels, and sweeper efficiency values as inputs to the procedure. However, a field approach would be preferable to the complex analytical procedure. For example, the control objective would be specified in terms of an allowable dust load target, and street sweeping would be adjusted by reasonable trials to obtain the objective. Field measurements would provide the basis for determining the amount of actual sweeping required, rather than uncertain analytical estimates.

The control effectiveness of various schedules of vacuum and broom sweeping outlined above can be used only as a useful guideline in specifying tentative and potential street cleaning requirements associated with an allowable street dust emission rate.

The cost of street sweeping varies widely from city to city. Because the full scale street vacuum sweeper has been marketed for a limited time in the United States (beginning in 1971), nearly all cost data available pertain to the conventional broom sweeper. The American City Survey [26,27] showed sweeping costs varying from $2.18 to $8.42 per curb mile sweep. This cost range is due to differences in maintenance practices, operators pay, and accounting reporting practices. The average cost of sweeping streets in the city of Phoenix (using broom sweepers) is $4.80 per curb mile [15].

Street maintenance departments of various municipalities [30,31,32] are presently reserved about the potential utility of the vacuum sweepers.

It is generally agreed the vacuum sweeper is not capable of collecting heavy loads (e.g., high piles of leaves or debri) or loads which adhere to the street surface (e.g., mud or sticky substances). Added reluctance to purchase the vacuum sweepers stems from the higher initial cost of the sweeper, and the general viewpoint that it reflects new state-of-art development. However, it is also widely acknowledged that the broom sweeper has its drawbacks: 1) it is inefficient as a collector of dust and small particulates, and 2) it is characterized by high maintenance costs, excessive downtime, and short lifetime.

Few cities have experimented with the vacuum sweepers, but there is indication from those that have that it may provide satisfactory performance at overall costs roughly equivalent to that of the broom sweeper [28]. The initial cost of a broom sweeper suitable for city street maintenance is about $32,000 to $40,000 depending on the manufacturer and type of engine. Because many cities find the diesel engine more attractive economically, the capital cost is often close to $40,000. Initial cost of the vacuum sweepers varies from about $49,000 - $58,000, depending on manufacturer and engine type. Maintenance costs for the broom sweeper are acknowledged to be higher. In one study performed by the city of Columbus (Ohio), the vacuum sweeper was reported to be operating at an average cost of $6.60 per cubic yard of collected material versus $26.00 per cubic yard reported for the broom sweepers [28]. Since the vacuum sweeper is new on the market, it is not possible to factor in equipment lifetime values to compute annualized costs. Manufacturer claims indicate the vacuum sweeper may be extended to a 7 to 10 year life [29,33], while experience has shown the broom sweepers are usually scrapped after a 5 to 6 year term. Based on these claims, the manufacturers are promoting the vacuum sweep as the least cost street cleaning method.

While the available cost data are unclear in the comparison of vacuum versus broom sweep technology, there appears to be little doubt these alternatives are competitive. For the purposes of this study, the annualized cost of these two street cleaning approaches was considered equivalent.

Table 2-14 summarizes cost estimates and emission reductions for various scenario street sweeping measures applied throughout the city of Phoenix. City-wide costs are shown here for illustrative purposes only, while any actual control program would probably focus on specific areas where entrainment of dust must be controlled to attain air quality objectives. The cost of intensifying street cleaning operations in the city of Phoenix (Table 2-14) have been estimated based on a review of the existing budget and performance, and a projection of that base data for more intensified operations.

2.3 CONTROL OF DUST EMISSIONS FROM CONSTRUCTION ACTIVITIES.

Construction activities are temporary and variable in nature. Fugitive dust is emitted both during the activities (e.g., excavation, vehicle operation, equipment operations) and as a result of wind erosion over the exposed earth surfaces. Earth moving activities comprise the major source of construction fugitive dust emissions, but traffic and general disturbance of the soil also generate significant dust emissions.

Emissions of dust from construction activities are already controlled by the Maricopa County Bureau of Air Pollution Control Rules and Regulations. Rule 31[a] states:

> ...."No building or its appurtenances, a utility or open area may be used, constructed, repaired, altered, or demolished without taking all reasonable precautions to prevent particulate matter from becoming windborne or airborne. Dust and other types of particulates shall be kept to a minimum by such measures as wetting down, covering, landscaping, paving, treating or by other effective means."

Similarly rule 31B requires that reasonable precautions also be taken to prevent particulate emissions during roadway construction activities.

TABLE 2-14. COST EFFECTIVENESS OF VARIOUS CITY-WIDE STREET SWEEPING PLANS

Control Measurement	Annual Cost of Entire Motorized Sweeping Program in Millions of dollars	Reduction of Average Street Dust Loading Expected	Reduction of Dust Emissions Expected[c]	Cost Effectiveness $/ton of dust emissions prevented[e]
1. Existing Motorized Sweeping Program	.87 [a]	---	---	---
2. Intensified Broom Sweeping				
a. Sweep all Majors & Collectors each 3 days	2.6	48%	29%	79
b. Double pass with Sweeper on existing cycle	1.7	16%	16%	67
c. 2 and 3 above	5.1	60%	45%	95
3. Vacuum Sweeper Program				
a. Sweeps on existing schedule	.87 [b]	29%	29%	0 [d]
b. Sweep each 3 days	2.6	58%	58%	39

[a] Based on budget for 1975 [15]. Cost estimates of more intensified sweeping measures above are expanded proportionally from this base.

[b] Based on assumption that annualized cost of vacuum sweeper is approximately equivalent to that of broom sweeper. This is predicated on the tradeoff between higher initial cost of a vacuum sweeper ($50,000) versus 40,000 for broom sweeper) and lower annual maintenance and longer lifetime of vacuum sweeper.

[c] Dust emission reductions for broom sweeping have been estimated based on assumption that silt content(percentage of particles <75μ) of street loading reaches equilibrium level within one day of sweeping. The silt level varies from 10% to a level 4-1/2 times greater (based on Table 2-12) immediately after sweeping. The equilibrium silt value is taken as 10% [20].

[d] This measure does not incur additional costs because the vacuum sweepers can replace broom sweepers on a phase out program at no charge

[e] Emissions preventions are based on 322 tons of resuspended dust originating in the cities of the study area each day. 204 tons/day are estimated to originate off the streets of the city of Phoenix.

While the construction regulations do not specify a definite amount of control which must be applied, construction contractors are currently employing water trucks and appear to be complying with the intent of the rule [11, 16]. The rule was tested in court following a challenge by a contractor, who had been cited in violation of the rule. The court upheld the rule, deciding that the contractor had not taken reasonable precautions (i.e., wetting down soil) to prevent the dust from becoming airborne. However, despite the support given by the court, the rule is enforced rather loosely, especially on construction sites removed from populated areas.

Wetting the surfaces of unpaved access routes for construction vehicles and trucks is an effective control for dust emissions provided the surface is maintained wet. In the arrid Southwest this generally requires appreciable water. A study on the effect of watering on construction sites [4], indicates that extensive wetting of the soil may reduce dust emissions at up to 60 to 70%. However, this result was far from consistent, as the watering control caused no apparent effect on several occasions, resulting in an average efficiency of only 30%. PEDCO [4] suggests that wetting of access roads twice a day with an application of .5 gal of water per square yard will suppress dust emissions by 50%. Another study [25] has shown emissions from unpaved roadways are reduced by 30% when the surface was maintained moist.

It is not clear what degree of compliance is presently being exercised with respect to dust control on construction sites. Baseline calculations for emissions from construction sites were based on emission factors derived from a study of a construction site in the Phoenix area where some degree of dust control measures were being employed. The effect of more extensive wetting practices on baseline estimated dust emissions is entirely speculative, although such a practice would surely incur significant additional prevention of dust emissions off the construction site. For the purpose of this study, it was conservatively assumed that dust emissions would generally be reduced by 30% with strict enforcement and awareness of the construction dust regulations, including the added provision that watering be conducted twice a day at a rate of 1/2 gal/sq.yd.

A negative tradeoff associated with watering controls at construction sites concerns the carry-out of mud onto adjacent streets. The carried out dust is susceptible to suspension by passing vehicles. If the construction site is frequented by appreciable traffic and watering controls are amply employed, mud carryout will be significant and should be controlled.

Presently, rather minimal control is provided by loose enforcement of Rule 31D (this rule requires materials deposited on public roads be removed by the responsible party). One means of removing the dust carryout from construction activities is street sweeping. Street sweepers may be employed daily to clean those paved public roads where visible dust has accumulated due to construction activities. To reduce cleanup costs, good housekeeping measures (cleaning construction vehicles before leaving site) may be employed as a cost effective alternative to street sweeping. It is not possible to generalize an effectiveness for these actions.

An additional dust source at construction sites consists of exposed earth which is susceptible to wind erosion, and to dust emissions from infrequent traffic disturbance. While the suspended dust from this source is generally significant, there are brief periods (i.e., during wind gusts or traffic bursts) when the resulting dust levels may create a nuisance to nearby inhabitants. Dust emissions from these sources may be reduced by combining two approaches. First, a soil stabilizer, such as a chemical palliative or vegetation cover may be applied. A second approach would involve a stipulation that cleared earth be exposed for a limited period before subsequent operations on this land begin. This would prevent the frequent practice of clearance of vast plots of land where subsequent construction operations are not scheduled to begin for several months. Such clearance may be allowed only if accompanied by soil stabilization measures within two months of the clearning. The effectiveness of these measures in reducing dust emissions is unknown.

The cost of the alternative dust control measures for construction site dust emission is shown in Table 2-15.

TABLE 2-15. COST OF ALTERNATIVE DUST CONTROL MEASURES FOR CONSTRUCTION EMISSIONS

DESCRIPTION OF MEASURE	CONTROL EFFICIENCY	COST
1. Wetting of site access roads twice/day at .5 gal/yd^2, and strict enforcement by Building Department and County Health Department	30%	$6/acre[a]/day
2. Daily (if necessary) cleanup of public roads to remove visible dust or mud deposits resulting from construction activities.	Unknown	$25/sweeping/site[b]
3. Stabilization of all exposed earth on the construction site wherever operations cease on that land for more than 2 months.	Unknown	$200-300/acre[c]

a. Based on 3 hours labor and equipment cost. Unlimited water is provided from irrigation canals to contracting for a single annual permit cost.

b. Based on typical sweeping service rates ($25/hour) [34], and assumed sweeping effort of one hour. Sweeping requirements will vary substantially depending on the magnitude and nature of construction activities. Good housekeeping practices can keep sweeping requirments to minimum.

c. Based on cost of Dust Control Oil application as reported by State [13] and supplier [14].

3.0 FORMULATION OF REASONABLE CONTROL STRATEGY

This chapter discusses the selection and evaluation of a reasonable control strategy for reducing suspended particulate levels in the Phoenix area. Since the objective of the strategy is attainment of primary air quality standards for TSP, the strategy selection necessarily involves an iterative process where the impact of trial strategies are evaluated successively until the desired result is obtained.

Section 3.1 describes general factors affecting the selection of reasonable control measures. Based on the general characterization of alternative controls described in Section 2.0, and the general considerations of Section 3.1, specific reasonable measures are selected to formulate an overall strategy (section 3.2). For each selected measure, the reduction in emissions of fugitive dust is estimated (Section 3.3) and the air quality impacts of these reductions are calculated (Section 3.4) using the source-receptor model developed earlier in the study [17]. The cost and implementation problems associated with the strategy are also evaluated (Section 3.5 and 3.6).

A special feature of the control strategy includes a demonstration model to promote social acceptance for the main strategy. This concept is appropriate because of the significant funding required for implementation of the strategy, and the probable social resistance to be encountered. Section 3.7 describes the features of this demonstration strategy.

3.1 FACTORS AFFECTING SELECTION OF REASONABLE CONTROL MEASURES

Reasonable control measures are defined as those which are technically and economically feasible to implement, and attain significant benefits in air quality. The technological and economic feasibility of various controls will differ depending on several factors indiginous to the study area. General factors affecting the reasonableness of a control measure in Phoenix include:

- The compatibility of the controls with general plans of the area
- The time-table for implementation
- The degree of control required

- The financing mechanisms available for implementation

The extent to which proposed control measures are compatible with planned development affects the cost and technological feasibility of the measure. For example, the paving of roads for dust control is entirely compatible with long term city development objectives to improve the transportation network. Similarly, the improvement of road shoulders to reduce street dust loadings and reentrainment of this dust to the ambient air is completely consistent with city objectives to improve the quality of life in the city. This compatibility lends to greater general technical and economic feasibility for the dust control measures because of the other desirable benefits they provide.

A significant degree of fugitive dust control will occur in the next several years due to normal development and improvement patterns. Table 3-1 shows the expected improvement in air quality due to anticipated development in the Phoenix study 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 area. By 1985, wind erosion emissions are estimated to decrease greatly from 1975 baseyear estimates due to a decrease in wind erosion sources (i.e., vacant property), and the probable occurance of typical meteorology (based on historical averages in 1985. 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 3-1).

Another consideration in the determination of reasonable measures involves the degree of control which is sought. The ultimate goal of the reasonable control strategy would be achievement of the primary air quality standards. Generally, the annual mean for TSP provides the most appropriate target for air quality attainment. Table 3-2 summarizes the extent to which air quality standards were violated in the Phoenix

TABLE 3-1. IMPROVEMENT IN TSP LEVELS DUE TO ANTICIPATED DEVELOPMENT IN THE PHOENIX AREA

MONITOR SITE	TSP, μg/m³ Observed 1975	Forecast 1980	Forecast 1985	Percentage Reduction in TSP 1975 to 1985	Contribution to TSP, μg/m³ Unpaved Roads 1975	1985	Resuspension 1975	1985	Construction 1975	1985	Percentage of TSP Contributed by 3 major sources and background (30μg/m³) 1975	1985
C. Phoenix	112	104	87	22.3	25	8	31	37	4	5	80	92
S. Phoenix	144	139	101	29.8	75	32	20	24	2	9	88	94
Arizona St.	169	157	132	21.9	35	12	59	68	7	9	78	90
Glendale	101	84	65	35.6	30	9	17	20	7	2	83	94
N. Phoenix	121	111	83	30.4	26	8	28	32	7	7	75	93
N. Scott/Paradise	149	111	101	32.2	24	32	8	9	14	25	51	95
Scottsdale	115	105	93	19.1	27	10	33	42	6	5	83	94
Mesa	117	114	95	18.8	32	13	35	45	8	4	90	97
Downtown	200	186	155	22.5	42	15	70	82	8	10	75	89
St. Johns	145	151	157	-8.3	93	116	2	0	2		66	96
Sun City	88	81	74	15.9	15	6	12	17	3	16	68	93
Paradise Valley	184	152	93	49.4	42	14	14	17	17	25	56	93
Chandler	119	139	160	-34.5	64	91	10	12	7	23	93	97

TABLE 3-2. 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 [23] assuming 60 measurements per year).

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

area in 1975. Except for days of dust storms, the severity of 24 hour violations were generally of lesser degree than those for the annual measurements. Table 3-2 also shows that substantial improvements in ambient air quality are needed before the standards may be met. The higher the level of control which is needed for attainment, the greater are the technical and economic demands associated with the attaining control strategy.

Another important consideration in determining what is reasonable strategy involves the time schedule of implementation. Typically, strategies of previous air quality programs have been predicted on meeting objectives within a short term. This requirement has often imposed implementation problems which cannot be reasonably resolved. First, the technological problems associated with the vast resources (i.e., labor and materials) often required for rapid implementation of a regionwide control are generally insurmountable; second, the economic hardships inherent in short term financing and the increased cost associated with intensified program development pose important economic problems for the short term strategy. A reasonable strategy must, therefore, permit execution of control measures over an extended period commensurate with the technological and economic limitations characteristic of the study area.

The economic feasibility of any control alternative is greatly affected by the extent and manner of funding available. Budgets required for implementation of different controls should be compared and expressed in terms of monetary impact on a per capita or consumer basis. The source and ease of funding should be identified and evaluated. Some controls (such as street sweeping, road surfacing) will be funded by taxes or other governmental money-raising mechanisms, while others will be paid by commercial enterprises and then passed onto the private consumer. Either method of financing is reasonable, provided the required resources are available and judged to be within the reasonable range of cost incurred by other existing and pollution controls of similar effect.

Generally, public acceptance of reasonable available controls is important for implementation. It is clear that the lack of social acceptance will impose significant obstacles to the implementation of a reasonable control, and specific measures will be necessary to overcome these obstacles. A demonstration project may be used to generate public support when necessary. The elements of the demonstration project, and its implications for resolving implementation difficulties, are considered in Section 3.7.

There are no absolute guidelines for the selection of reasonable available control technology. A measure which is reasonable in one area may be unreasonable in another. However, in general, most of the measures available for control of fugitive dust are reasonable. Selection, therefore, should be based on the most cost effective measures which will provide air quality improvements needed for standards attainment. For example, it may be necessary to pave all roads to bring about attainment, with any lesser measure being inadequate for attainment. Hence, while other measures may be more technically and economically feasible (i.e., more reasonable), they would not be selected when another reasonable alternative capable of attaining the needed emission reductions is available.

Once a list of reasonable candidate measures have been identified, selection of a control strategy is an iterative process accomplished by means of successive tests of alternatives using the source receptor model [17] to predict resulting air quality levels. As various trial alternative strategies are tested, it becomes clear which areas in the study region may need special attention and which areas will require only minimal controls. The emissions density grid map (Figure 3-3) may be used as an aid in identifying specific problem areas and in formulating preliminary control strategies for test by the source receptor model. Eventually, through a series of iterative trial judgements, a strategy should be established which attains the air quality objective at each of the monitor sites utilizing the most cost effective combination of reasonable control measures available.

3.2 SELECTION OF RESONABLE STRATEGY

Based on consideration of the selection factors discussed above (Section 3.1) and the control characterization presented previously (Section 2.0), trial strategies are formulated and evaluated in an iterative approach to attain the air quality objectives. Table 3-3 presents the final reasonable control strategy selected to meet the objectives.

The measures comprising the strategy reflect the most cost effective measures, are compatible with the long term planning goals for the region, and are also effective as substantial dust controls. The strategy is reasonable in that it is implementable in a technical and economic sense, and accomplishes significant improvements in air quality. However, substantial social resistance is likely to develop against its execution. A special feature of the overall strategy is a demonstration project to develop social acceptance for the areawide strategy approach. This portion of the strategy is discussed in Section 3.7.

The reasonable control strategy is selective for the three major sources affecting air quality. Table 3-2 illustrates the relative effect of these three sources on anticipated baseline TSP levels and demonstrates clearly the justification for focusing attention to these sources. In 1975, unpaved roads contributed the greatest portion of TSP levels at most of the monitor sites. By 1985, after anticipated development, TSP levels at the monitors are affected mostly by entrained dust off streets. Unpaved road emissions are still a dominant contribution of TSP levels at sites in or near rural environments (e.g., St. Johns, South Phoenix, North Scottsdale/Paradise, and Chandler).

It is important to distinguish between the controls needed to attain the standard throughout the region and that needed to attain the standards only at the monitoring stations. Because of the very localized impact of fugitive dust sources, it is possible to attain localized attainment by application of controls in limited areas. (i.e., around

TABLE 3-3. REASONABLE CONTROL STRATEGY FOR PHOENIX AREA*

SOURCE CATEGORY	PROPOSED CONTROL MEASURES
1. Unpaved Roads	<u>County Roads</u> • Chip seal all section line roads with emulsified asphalt by 1995, and one half of section line roads by 1985. Sequence of road selection should be based on ADT volume. • Reduce speed limit to 20 mph for all unpaved roads gradually by 1985, or, where applicable, permit improvement districts to implement equivalent dust control by surface treatments such as graveling, oiling, or paving. Restriction sequence should be based on availability of alternative paved routes and trip lengths. <u>Private Roads</u> • By 1985, restrict speed to 20 mph or require equivalent dust emissions reductions by surface treatments such as oiling, watering, graveling, or paving.
2. Entrained Dust off Paved City Streets	<u>City Streets</u> • By 1980, establish a field measurement program to determine street dust loads and effects of various street sweeping alternatives (using broom sweepers and vacuum sweepers) on street dust loads. • Based on results of field program, formulate sweeping requirements and implement by 1985 a program to attain a 60% reduction in the current assumed average street dust loading of 780 pound per mile [8] in the designated areas (Figure 3-1).
3. Construction Activities	• Effective wetting of site access roads twice daily at .5 gal/yd^2. • By 1980, sweep roads to remove visible dust loads caused by construction activities. Sweeping shall be performed whenever dust loads are apparent, to maximum frequency of once daily. • By 1980, require stabilization of all exposed earth at construction site whenever operations cease on that land for over 2 months.
4. Other Sources	• No additional measures are recommended for other sources. These sources are already controlled (either by direct pollution regulations or by other restrictions which affect dust control) or have minor impact on TSP levels.

* A demonstration project is recommended as a prerequisite to implementation of the overall control strategy. This project would involve application of the strategy measures within a limited selected area. The project should be conducted prior to the deadline date for submittal of State Implementation Plans for fugitive dust control in July, 1978.

monitor sites). This approach should not be used to circumvent the widespread TSP problem in the Phoenix area. It is evident that TSP at other locations may be equivalent or higher than that represented by the monitor network. However, an accurate prediction of the non-attainment problem at these sites is unavailable. Under the circumstances, a plausible policy for control strategy formulation was taken as: 1) apply an area-wide plan which attains standards at the monitors and improves air quality elsewhere, and 2) identify the various locations where additional controls may be necessary, but cannot be justified until air monitoring data are available to confirm high TSP levels there. The latter task may be accomplished by inspection of the 1985 projected emissions grid maps. (see Section 3.3).

Implementation of the overall strategy (Table 3-3) is proposed after the demonstration project is completed. The main element of the overall strategy consists of an intensive road surfacing program in the county for the next 20 years. Road surfacing is to be conducted by applying a chip seal to the section line roads. This approach represents the most cost effective of the alternative road surfacing measures (Table 2-5), and attains maximum source control where applied. Priorities for the paving program would be assigned in the order of those section roads receiving greatest traffic volume, and the county of Maricopa Department of Transportation would administer the program.

In addition to the road surfacing measure, a control is also proposed for existing or future unpaved roads. A speed restriction for unpaved roads is especially cost effective, and is considered reasonable when phased in concurrently with the road surfacing measure. Exceptions to the speed limit would be permitted in instances where accessibility to alternative paved routes is unavailable (e.g., roads connecting remote residence sites to county arterials). Also, other techniques of dust control (e.g., watering, graveling, oiling) would be permitted in place of the speed restriction wherever private groups desire to assume responsibility for improvements.

The overall strategy includes an intensive street cleaning program in designated areas where reduction of entrained street dust emissions is necessary to attain the air quality standards. Figure 3-1 shows the two areas which receive attention under this plan: the area surrounding downtown Phoenix and the area around downtown Scottsdale. It is proposed major streets be swept more frequently, alternating from vacuum sweeping to broom sweeping to attain an overall reduction of 70% in suspendable street dust loadings. The broom sweeper would be used to dislodge material adhering to the road and for collection of larger particles, while the vacuum sweeper would be employed for the efficient and cost effective collection of dust particles of all sizes. The analysis of Section 2.0 indicates that adjustment of typical existing street sweeping programs to obtain a 60% reduction in street dust loadings is probably feasible.

Because of the limited data base available to characterize street dust loadings and sweeping efficiencies, it is not possible to specify a definite street sweeping program to accomplish the targeted emission reductions. A field measurement program is proposed to establish baseline loadings for various streets and to determine by test the actual sweeping programs needed to obtain the required dust levels. Based on the crude data of baseline average dust loadings and street sweeping efficiencies available (Section 2.0), it appears that an adjustment from the existing sweeping frequency (once per week for most major streets) to 3 times per week will produce the targeted emission reductions.

The final element comprising the control strategy entails enforcement of more rigorous regulations for construction activities. The measures are relatively cost effective in terms of total emissions reductions, and produce significant benefits in air quality for those areas affected by construction emissions. The regulations would require: 1) sweeping of nearby roads to remove visible dust loads caused by construction activities (e.g., vehicle carryout from the construction site), 2) wetting of site access roads (when used) twice daily, and 3) stabilization measures for land exposed without construction activity

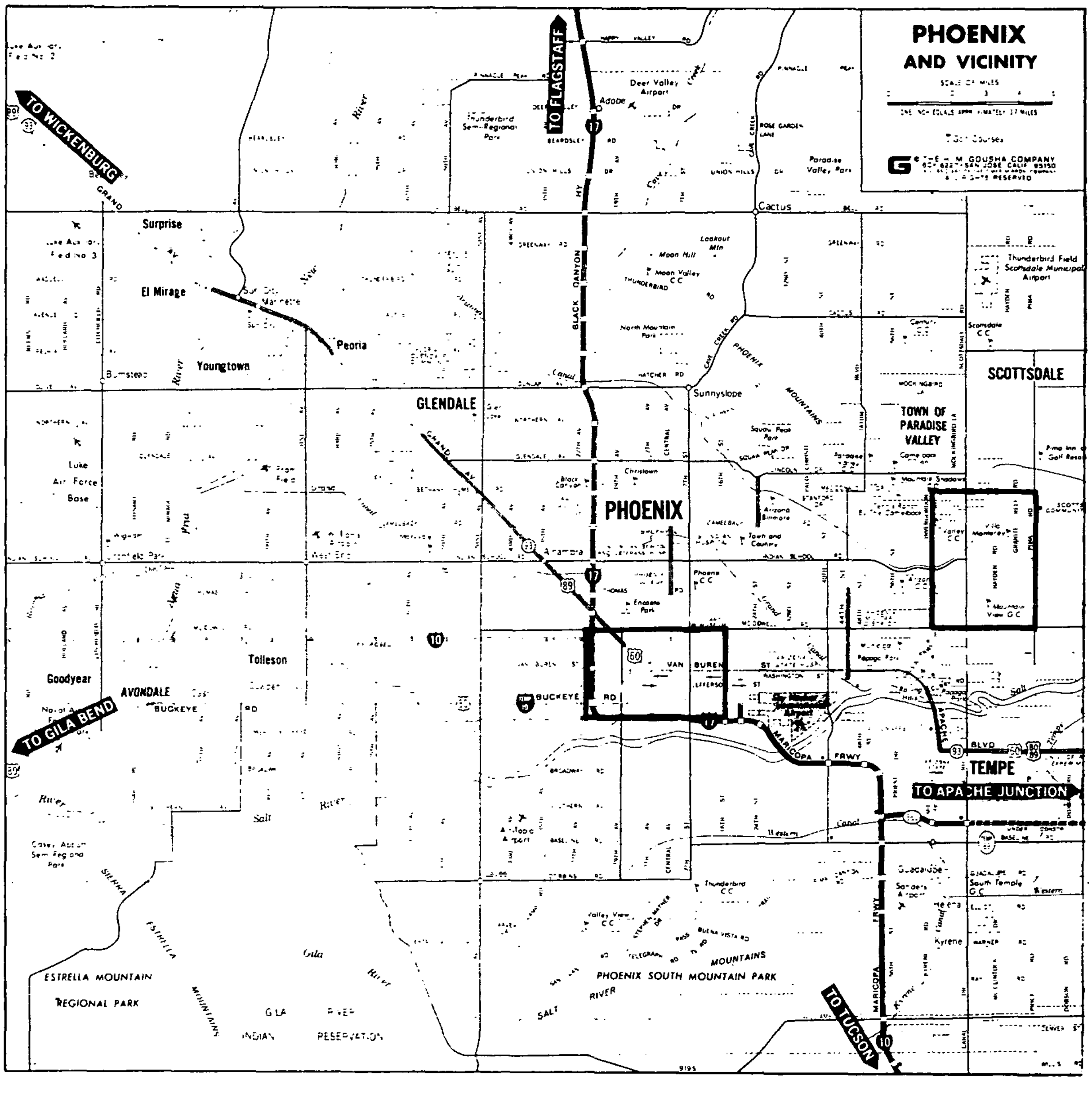


Figure 3-1. Area Map showing Special Areas (Downtown Phoenix and Scottsdale) Designated for Intensified Street Sweeping Programs

for more than two months. These measures would be imcorporated as regulations of the building codes and enforced by the local Building and Safety Department.

Evaluation of the emissions reductions and air quality resulting from the strategy is discussed in Section 3.3 and 3.4. From this analysis nine potential nonattainment areas are identified (see Figure 3-10). There is a distinct likelihood that some of these areas may require special controls (e.g., street sweeping in urban areas). To establish the extent of the TSP problem in these areas, and to simulate future air quality levels there, it is recommended that the current monitoring network be expanded to include representation of air quality in the potential non-attaining areas. The additional monitor sites could be included as part of the control strategy implementation, however, it would be preferable that the new monitors be installed prior to state submittal of fugitive dust implementation plans (July, 1978) so that any additional area-specific control measures which might be required may be efficiently integrated into the overall control plan.

The strategy proposed in Table 3-3 has resulted from a series of trials of different control alternatives applied in varying degrees. Road improvements have been emphasized in the overall plan because of compatibility of this control with the general planning objectives of local agencies, because of the substantial impact of unpaved roads on air quality, and because dust control off unpaved roads is generally more cost effective than other measures. By accelerating this street improvement program (a program which would eventually be implemented on a slower timetable), the intensive street sweeping measure is needed only in isolated areas. Minimizing additional street cleaning requirements is appropriate considering the low priority of this function relative to other programs now receiving competing attention for the city of Phoenix Department of Transportation budget, and the high cost of this measure as a dust control. Curbing for unpaved road shoulders is an effective measure for reducing street dust loads, but was not included in the final control strategy because most streets in the designated vicinities requiring attention are located in downtown areas, and are either presently curbed or will be curbed after planned improvements are carried out through the year 1985. Dust controls for construction activities are not responsible for major long-term gains in air quality but are included to alleviate temporary and localized high levels of TSP surrounding the construction sites.

3.3 IMPACT OF STRATEGY ON EMISSIONS LEVELS

The effect of the proposed strategy on total emissions levels for the entire study area is shown in Table 3-4. The source most affected by the control strategy is unpaved roads. Dust emissions from unpaved roads are reduced by about 36% from the anticipated levels in 1985, and 22% from the baseyear (1975) levels. The reduction in this single category amounts to about 22% of the total 1985 baseline emissions total, and the impact of this reduction on air quality is expected to be substantial because of the local concentration of this source near many of the air quality monitors. Similarly, control of entrained dust emissions off paved roads in the downtown Phoenix area and Scottsdale will incur emissions reductions in areas near monitor sites in these locations. However, total entrained dust emissions in the study area are expected to be reduced only 5.6% from 1985 baseyear emission forecasts. Construction emissions will be reduced by 30% of the 1985 baseyear construction emissions totals, however, this reduction amounts to only 3% of the total baseline emissions forecast in 1985. Hence, construction dust controls are expected to alleviate localized short term TSP levels, but exert only minor effect on monitor annual TSP levels. Due to planned development in the study area, remaining fugitive dust sources not addressed by the strategy are reduced below 1975 levels by a greater degree than those major source categories which are the object of the control strategy. Overall, the total change in emission levels, due both to the control strategy and to anticipated development in the study area, amounts to a reduction of 23% from the 1975 to 1985 forecasted level.

Equally important as the emission level reduction magnitudes are the distribution of these reductions. Figure 3-2 presents the level and spatial distribution of emissions before and after strategy application. It is clear that with strategy, emissions are reduced substantially in the area near the monitor sites, that is, primarily in and bordering the metropolitan Phoenix

TABLE 3-4. IMPACT OF CONTROL STRATEGY ON TOTAL EMISSION LEVELS

Source Category	Baseyear Emissions (1975)	Baseline Projected Emissions (1985)	Emissions After Application of Control Strategy - 1985	Percentage Reduction from Baseyear (1975) in 1985	Percentage Reduction from 1985 Baseline
	TOTAL EMISSIONS IN STUDY AREA, TONS/DAY				
Unpaved Roads	1281	1553	999	22.0	35.7
Entrained Street Dust	248	322	304	22.6	5.6
Construction Activities	100	256	179	-79.0	30.0
Wind Erosion-Undisturbed Desert	294	85	85	71.0	0.0
Off-Road Vehicles	71	106	106	-49.3	0.0
Other Categories	366	139	139	62.1	0.0
Total Emissions	2360	2462	1812	23.2	26.4

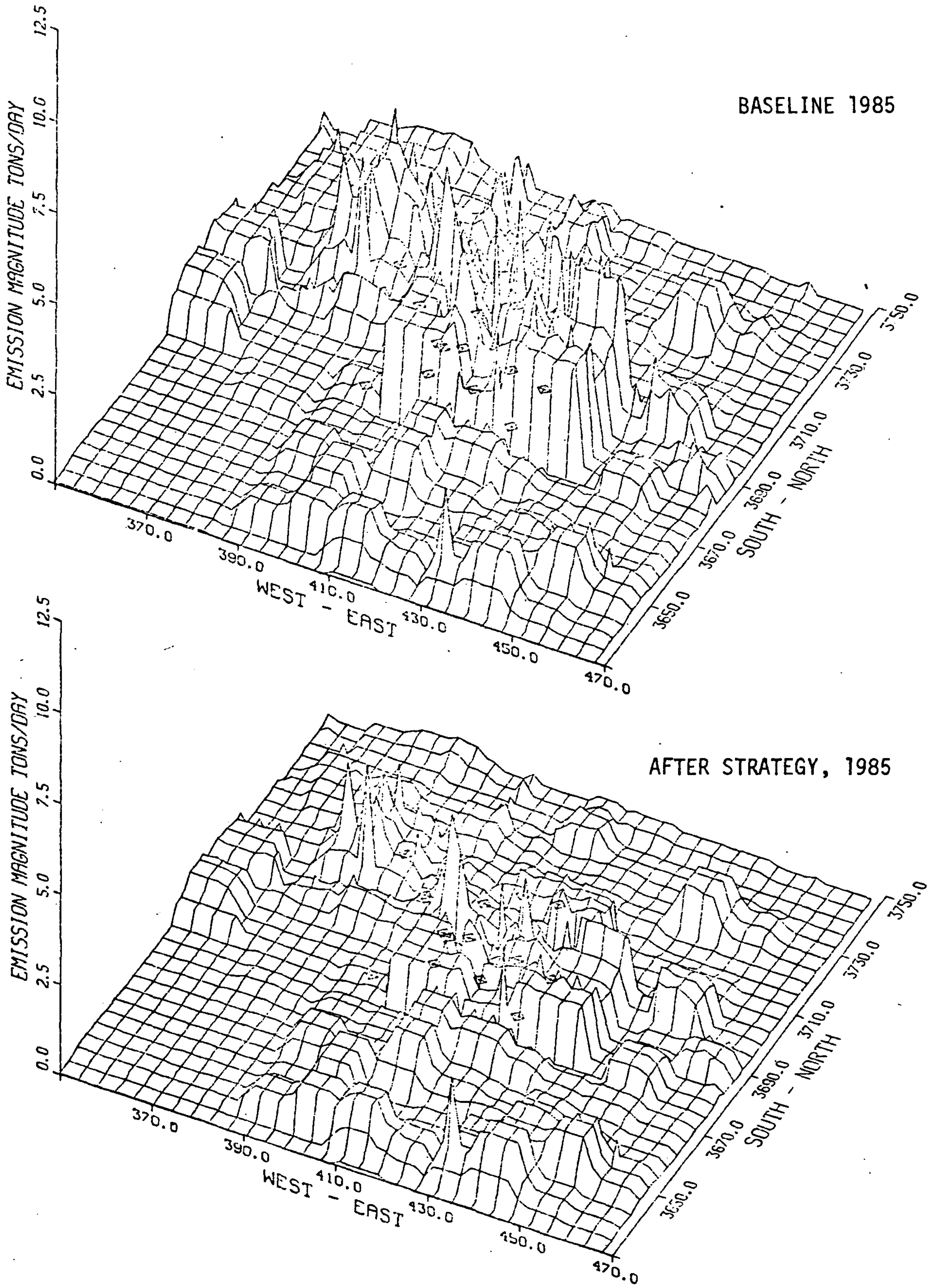
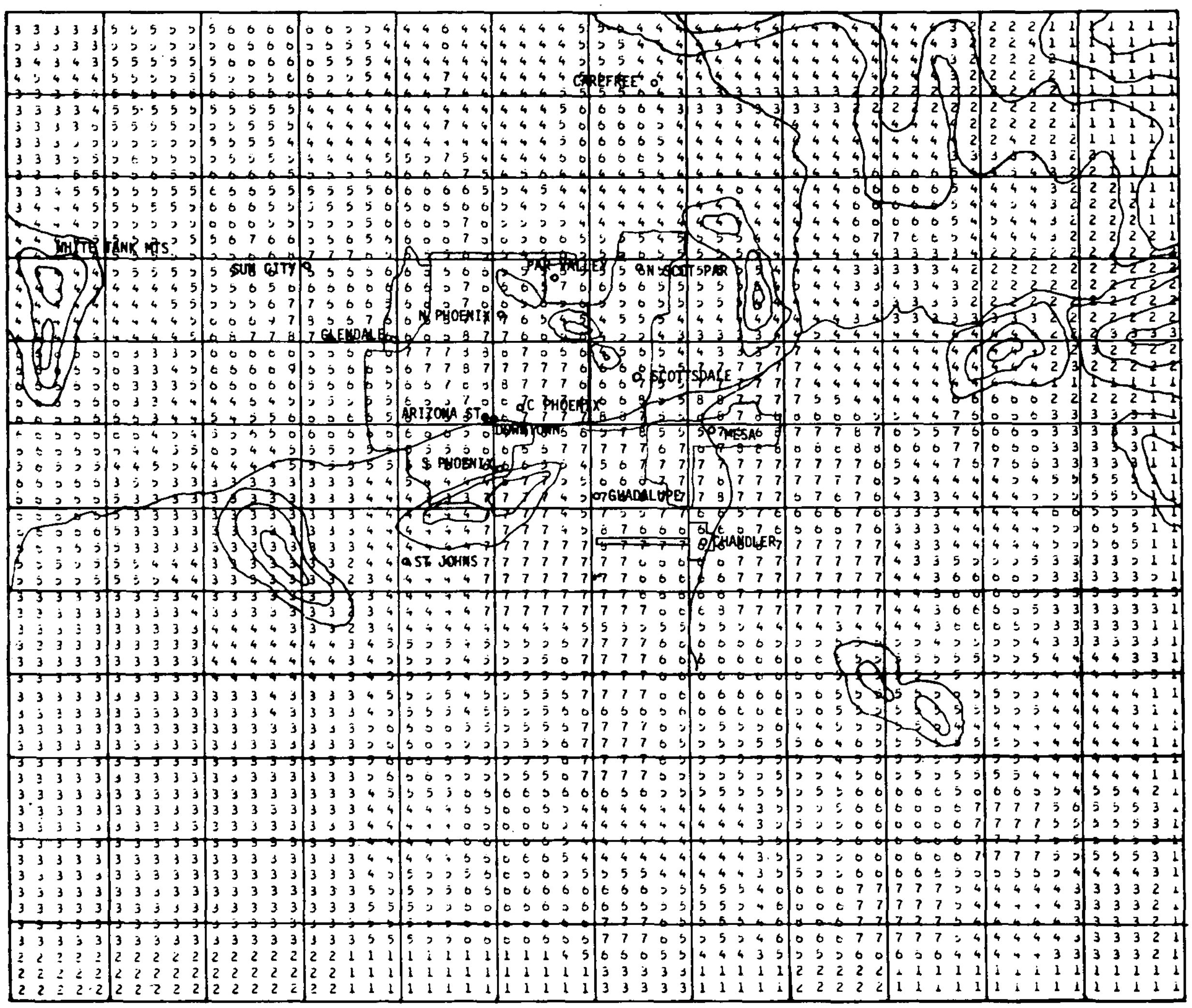
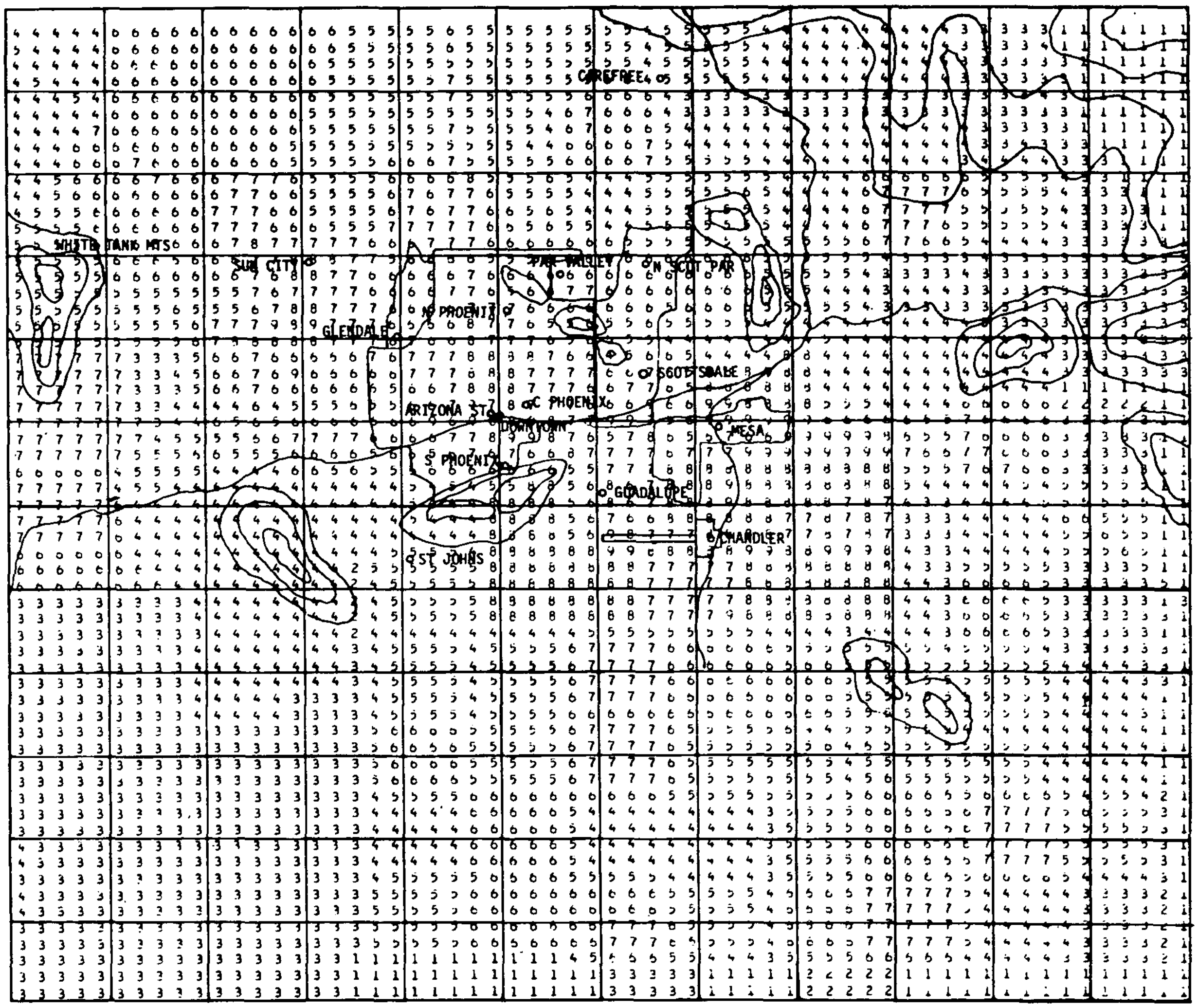


Figure 3-2. Total Particulate Emissions For Phoenix Study Area in 1985. With and Without Control Strategy.



GRID CODE	EMISSIONS TONS/DAY
0	0
1	0 to .01
2	.01 to .04
3	.04 to .13
4	.13 to .32
5	.32 to .67
6	.67 to 1.2
7	1.2 to 2.1
8	2.1 to 3.4
9	3.4 to 5.2

Figure 3-3. Total Particulate Emissions in 1985 After Application of Control Strategy.



GRID CODE	EMISSIONS TONS/DAY
0	0
1	0 to .01
2	.01 to .04
3	.04 to .13
4	.13 to .32
5	.32 to .67
6	.67 to 1.2
7	1.2 to 2.1
8	2.1 to 3.4
9	3.4 to 5.2

Figure 3-3. (continued) Baseline Total Particulate Emissions in 1985.

region. The location of these reductions are consistent with the intent of the control measures comprising the strategy. Entrainment of street dust is prevented by control programs within the designated cities, and roads are paved by priority of vehicle count along section lines closely surrounding the metropolitan area. Figure 3-3 provides a more detailed illustration of the distribution of emission densities in the study area: emission levels for each of the grid squares of the study area network are given for both the baseline and strategy forecasts. Because the major portion of ambient TSP levels are caused by the local sources in the immediate vicinity of the receptor, the emissions grid map of Figure 3-3 serves as a general representation of the TSP distributions as well. However, caution should be employed in this representation, since local effects within a grid square may also cause unsuspected levels of TSP to occur when the receptor is near or in the plume of a nearby source. For example, sources at St. Johns may be very area-specific with respect to TSP values measured there because of the concentration of fugitive dust sources near the monitor. The grid emissions map of Figure 3-3 would not indicate this potential local effect, and assigns instead a lower emissions density based on the distribution of the "hot spot" sources over the entire grid square.

The impact of the strategy on each of the major source categories and the basis for these estimates is discussed in the following sections.

3.3.1 Unpaved Roads

The selected control strategy for unpaved roads is consistent with the County's long-range planning objectives. Under the County's planned development, the number of unpaved interior streets will decrease steadily as road improvements are accomplished according to County priorities. Priority for paving of roads is presently determined mainly by ADT. Table 3-5 shows the projected ADT for various road types in the study area for 1985. By 1985, baseline traffic volumes of unpaved roads is expected to increase by 50%. At the same time, the total mileage of unpaved gravel roads is expected to decrease by 21% (Table 3-6). Gravel roads are the principal target for present planned improvements, since they receive the heaviest traffic activity. Most of these roads are section line streets (1 mile apart) which serve as

TABLE 3-5. TRAFFIC ACTIVITY AND STATUS OF UNPAVED ROADS IN STUDY AREA, 1975 AND 1985

	AVERAGE DAILY TRAFFIC			
	Rural		Urban	
	1975	1985	1975	1985
Dirt Roads (Maintained)	40	60	75	112
Dirt Roads (Not Maintained)	11	16	15	22
Gravel Roads	60	90	100	150

1. Figures are based on data presented in Support Document #2.

TABLE 3-6. UNPAVED ROADS MILEAGES IN STUDY AREA, 1975 AND 1985

	1975			1985		
	Gravel	Dirt-Maintained	Dirt-Not Maintained	Gravel	Dirt-Maintained	Dirt-Not Maintained
Portion of Maricopa County	720	1100	570	579	886	453
Cities in Maricopa	71	106		10	15	
Portion of Pinal County	163	307	598	163	307	598
TOTAL	954	1513	1168	752	1208	1051

major traffic links throughout the country. The net results of the planned improvements and the expected traffic volume increases is an overall increase in unpaved road emissions from 1281 tons/day in 1975 to 1553 tons/day in 1985 (Table 3-4).

With implementation of the proposed Control Strategy, dust emissions from unpaved roads are reduced substantially. Due to road, surfacing of one-half the unpaved section line roads, previously anticipated 1985 emissions arising from one-half the unpaved gravel roads in Maricopa County are essentially eliminated. The road surfacing measure alone may account for a reduction of nearly 50% of the estimated baseline emissions in this source category, depending on the absorption of traffic from the remaining unpaved roads to the newly improved alternates. Transportation of traffic to newly paved streets will be further hastened by the traffic speed control measure of the unpaved roads strategy. Vehicle speed on unpaved roads will be restricted to 20 mph, causing an estimated dust emissions reduction of approximately 40% (assuming vehicles will actually travel at 25 mph) for those vehicles still using these roads. A significant portion of traffic would be expected to switch to the newly paved roads.

In order to predict the reduction in VMT unpaved county roads as a result of paving the gravel section line roads, a representative one-mile rural section of the traffic line network was constructed, and net travel in the link was considered for the "before and after" road paving control. The representative section was constructed using a street map. The map showed that roughly 65% of the section line roads in Maricopa County are presently paved. Travel on unpaved and paved lengths within the section to alternative exit points on the section boundary was estimated by assigning a through trip to the vehicle population expected to reside in the section. The analysis showed that the paving control would reduce expected traffic on remaining interior unpaved roads by 15% in 1985.

Because the strategy includes the paving of all roads within the cities, dust emissions from unpaved <u>city</u> roads are essentially eliminated. For most cities, this involves a modest street improvement program. For the City of Phoenix, no additional strategy is required since the present 10-year program includes improvement of all existing unpaved streets. (New unpaved roads are not anticipated due to a county ordinance which requires paving of all newly developed roads.)

The expected emissions reductions associated with the control measures are applied to the computerized baseline inventory on a grid square basis to determine the emissions levels after controls are applied. The computerized inventory maintains a record of urban and rural road types, mileages, and dirt road silt values for each grid square of the study network. Table 3-4 summarizes the effect of the dust control strategies on total unpaved road emissions for the study area. Over the 10-year period from 1975 to 1985, total dust emissions from unpaved roads would diminish 22% from 1281 tons/day in 1975 to 999 in 1985. The distribution of emissions, both for the baseline case and with strategy applied, is shown in the graphics plots and emission grid maps of Figures 3-4 and 3-5. It is clear that emissions from unpaved roads diminish appreciable from 1985 baseline levels in the vicinity of nearly all the monitor sites.

3.3.2 Entrainment of Dust Off Paved Roads

The selected dust control strategy for entrained street dust on city roads is consistent with city planning goals to maintain clean streets. An effective street cleaning program is needed to maintain acceptable aesthetic standards, to reduce pollution to sewer waters and treatment requirements at sewage plants, and to maintain the condition of road surface. Dust control is an additional benefit to be gained by road cleaning programs, and generally requires more effort than normally expended in typical street cleaning operations. Accordingly, the proposed control strategy for street dust consists of an intensification of the city street cleaning progams in two designated areas where entrained street dust must be controlled for attainment of the standards.

The dust control benefits that can be achieved with various street sweeping operations was discussed in Section 2.2. It was determined that either broom sweepers or vacuum sweepers may be employed to reduce total street dust loadings significantly when the level of street cleaning effort is increased greatly over the normal amount. However, it was also determined that broom sweepers were far less efficient than vacuum sweepers, especially for removal of smaller particles in the suspendable size range. In fact, broom sweepers tend not to remove the smaller particles, but to

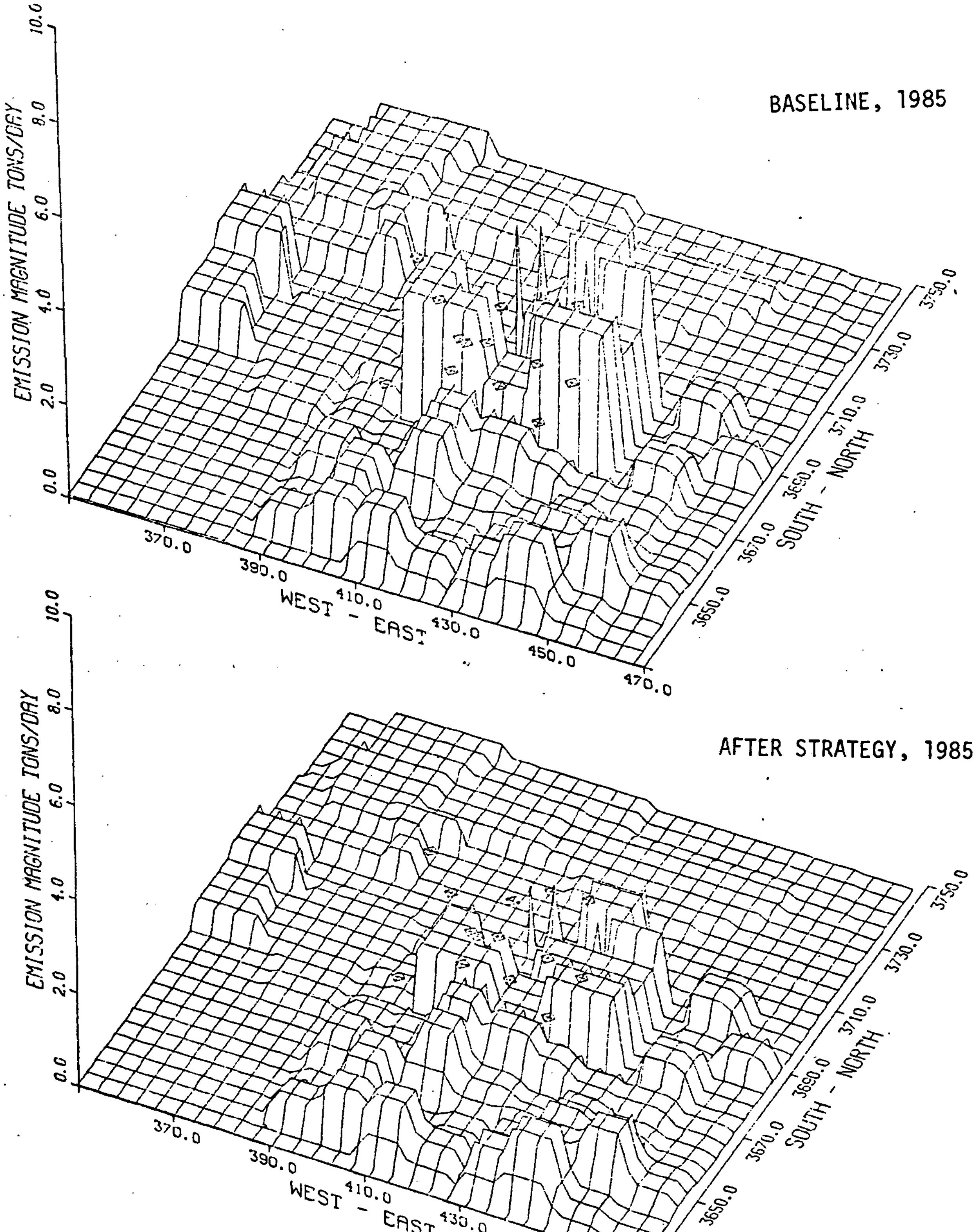
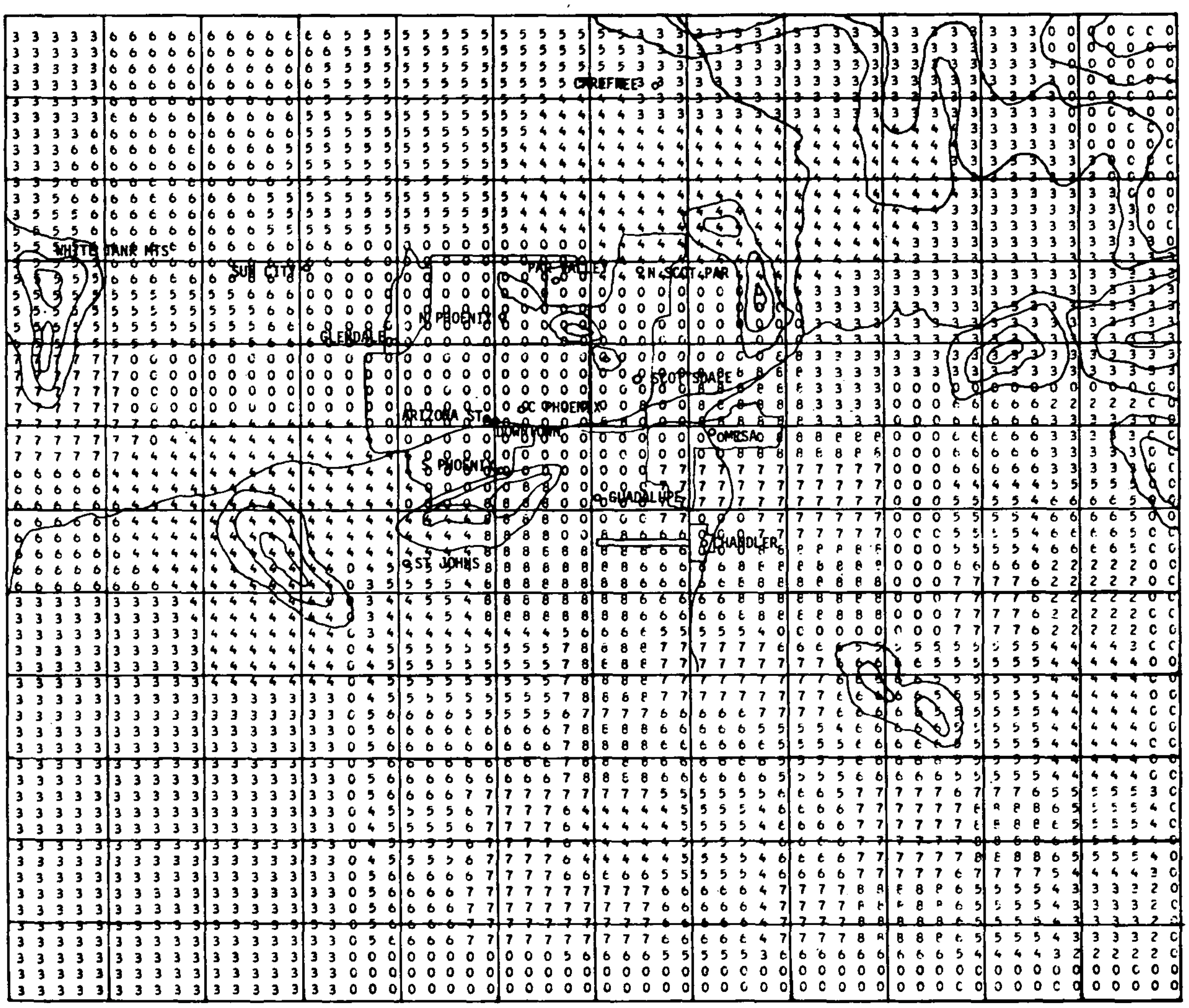
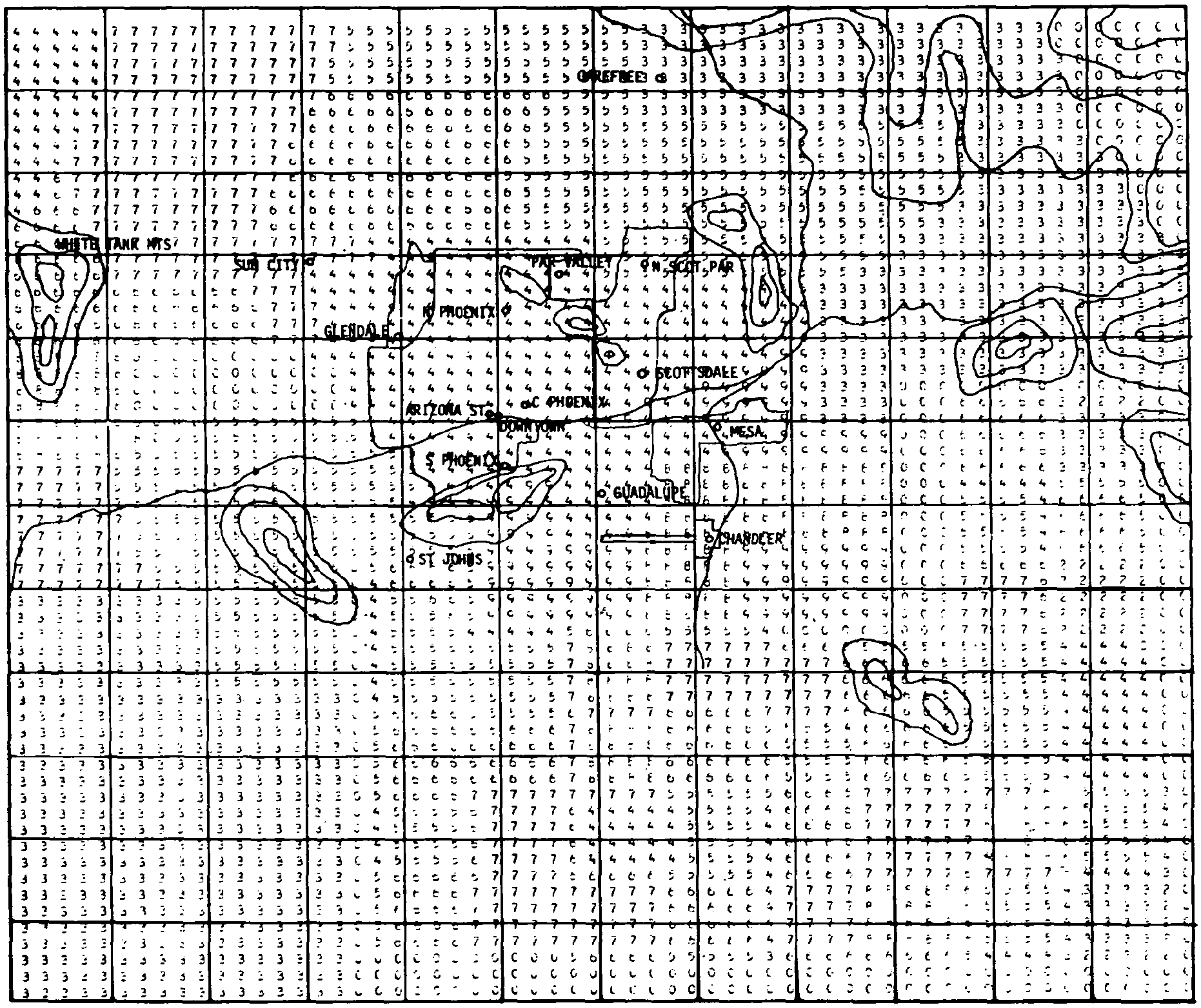


Figure 3-4. Total Particulate Emissions From Unpaved Roads, With and Without Strategy, 1985



GRID CODE	EMISSIONS TONS/DAY
0	0 to 0
1	0 to 005
2	0 to .02
3	.02 to .07
4	.07 to .18
5	.18 to .37
6	.37 to .68
7	.68 to 1.2
8	1.2 to 1.9
9	1.9 to 2.8

Figure 3-5. Total Particulate Emissions from Unpaved Roads in 1985 After Application of Control Strategy.



GRID CODE	EMISSIONS TONS/DAY
0	0 to 0
1	0 to 005
2	0 to .02
3	.02 to .07
4	.07 to .18
5	.18 to .37
6	.37 to .68
7	.68 to 1.2
8	1.2 to 1.9
9	1.9 to 2.8

Figure 3-5. (continued) Total Particulate Emissions From Unpaved Roads, Baseline 1985.

redistribute them instead. Consequently, the different effect of each of the sweeper types on dust emission rates off paved roads is appreciable (see Table 2-12).

While the vacuum sweeper attains higher collection efficiency for loose dust loadings under dry conditions, it is not as effective as the broom sweeper for collection of heavy, wet loadings which typically occur after rainstorms. In addition, rainstorms tend to distribute dust loadings across the entire street surface (as opposed to the usual high density of dust found only near the curb), making the broom sweeper, with its wide sweep span, a very appropriate dust collection mechanism under these conditions. The City Maintenance Department has suggested that optimal street cleaning equipment might consist of a battery of both vacuum sweepers and broom sweepers, to be used alternately depending on street loading conditions [11]. Because rains occur infrequently in the Phoenix area, it is feasible that the future expanded sweeper squadron should be comprised predominantly of vacuum sweeper types. As one feasible street cleaning scenario, broom sweepers would be employed at the same frequency as in the baseyear, while vacuum sweepers would be used for street cleaning twice in the interim period. Based on Figure 2-9 and data presented in Section 2.2, this alternating sequence between broom sweepers and vacuum sweepers would attain at least a 60% reduction in entrained street dust emissions off city streets. This sweeping scenario is suggested as a tentative estimate of the sweeping program which may be applied to the designated areas (Figure 3-1) which appears to require additional sweeping effort.

Because of the limited data base available to characterize street dust loadings and the effect of different sweeping alternatives, final selection of the sweeping measures of the control strategy should be deferred until an area-specific field measurement program is conducted. This program would establish baseline loadings for various streets and determine by test the actual sweeping programs needed to reduce entrained street dust emissions to allowable levels. The measurements would include an analysis of dust silt levels resulting from use of the major sweeper types to enable a fair assessment of the efficiency of the sweepers in removing not only total dust loads, but in particular the suspendable fines.

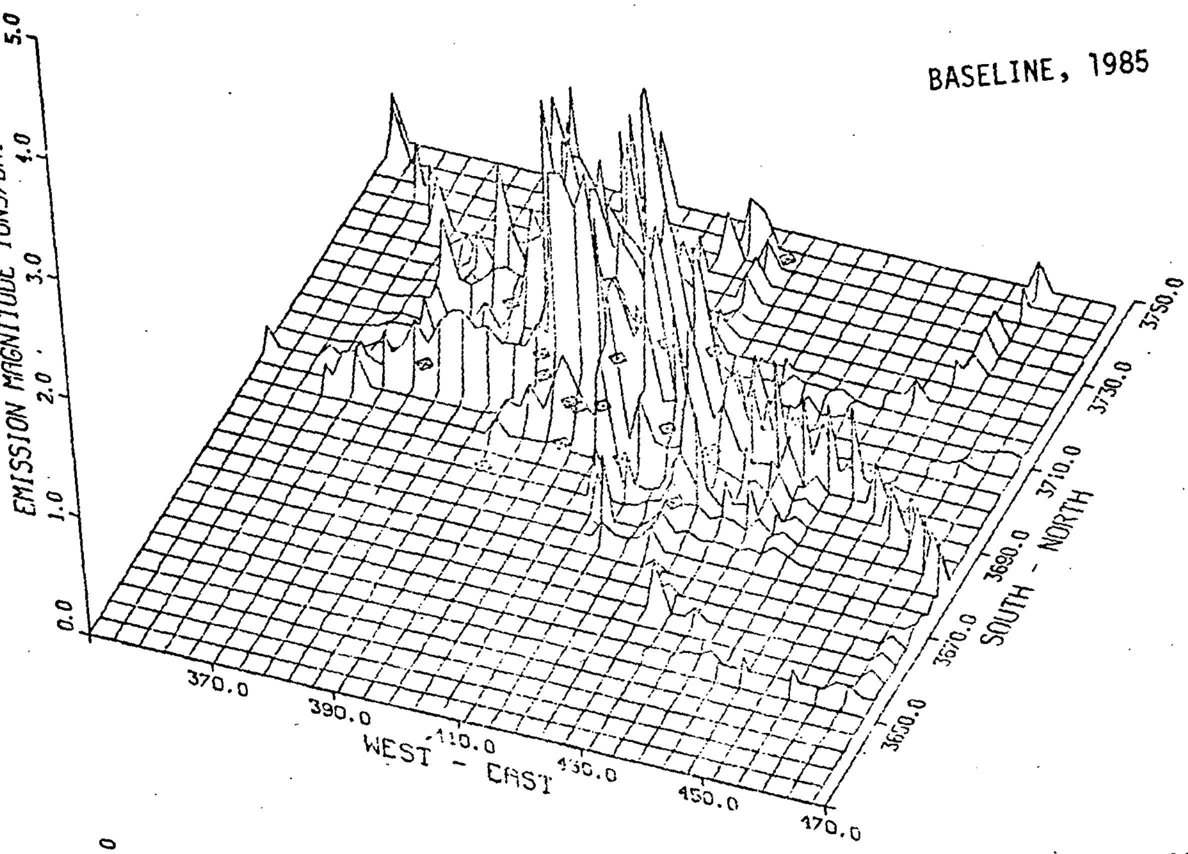
If reconciled to field test data, the proposed street sweeping scenario would reduce total street dust by about 60% in the designated areas targeted for control. This reduction estimate was applied to all streets within the designated control areas (Figure 3-1). Total entrained dust emissions were calculated for each link and assigned to grid squares of the study area grid network by means of simulator software operating on a computer tape of 1975 transportation link data. The variation in emissions density throughout the study area, with and without the strategy in 1985, is illustrated by the graphics of Figure 3-6 and the grid map of Figure 3-7.

3.3.3 Construction Activities

The wetting of construction access roads twice daily is assumed to account for a 30% reduction in construction emissions (see Section 2.3). This reduction was applied throughout the study area to the 1985 baseline projected construction emission inventory. Additional measures, such as nearby road sweeping and soil stabilization will further reduce construction emissions by an undetermined amount. Figure 3-8 and 3-9 show the distribution and magnitude of emissions expected from construction activities after the control strategy is applied by 1985.

3.4 IMPACT ON AIR QUALITY

The emission levels associated with the proposed reasonable control strategy were translated into air quality forecasts using the source-receptor model developed earlier in the study. These forecasts are shown for each of the monitoring locations in the study area in Table 3-7. Substantial improvements in air quality occur at each monitoring site. Baseline TSP levels in 1985 are reduced by about one third at most sites, and some monitor sites experience from 40 to 60% reductions in TSP levels. In many cases, a significant portion of the air quality gains over baseyear levels is due to baseline development planned for the area (see Section 3.1). Between the improvements achieved by development and the strategy together, baseyear TSP levels are reduced by 31 to 76% by 1985.



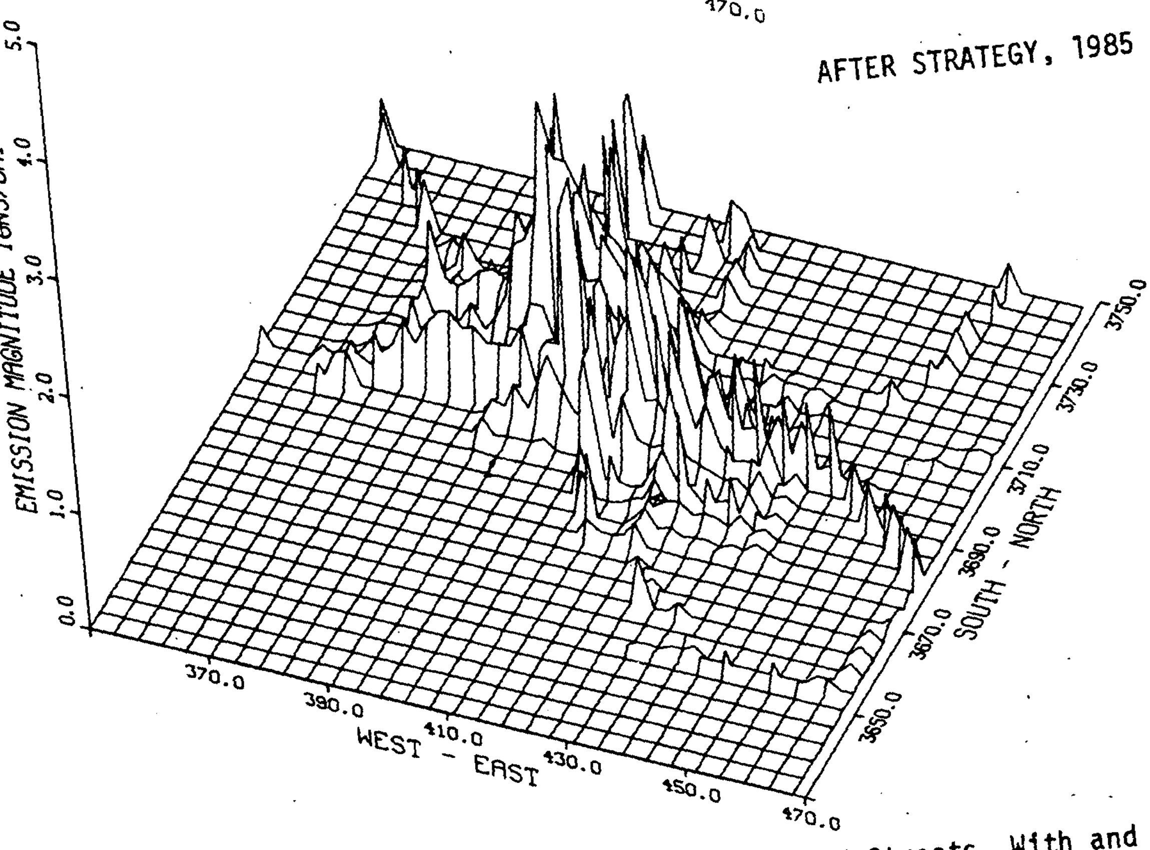
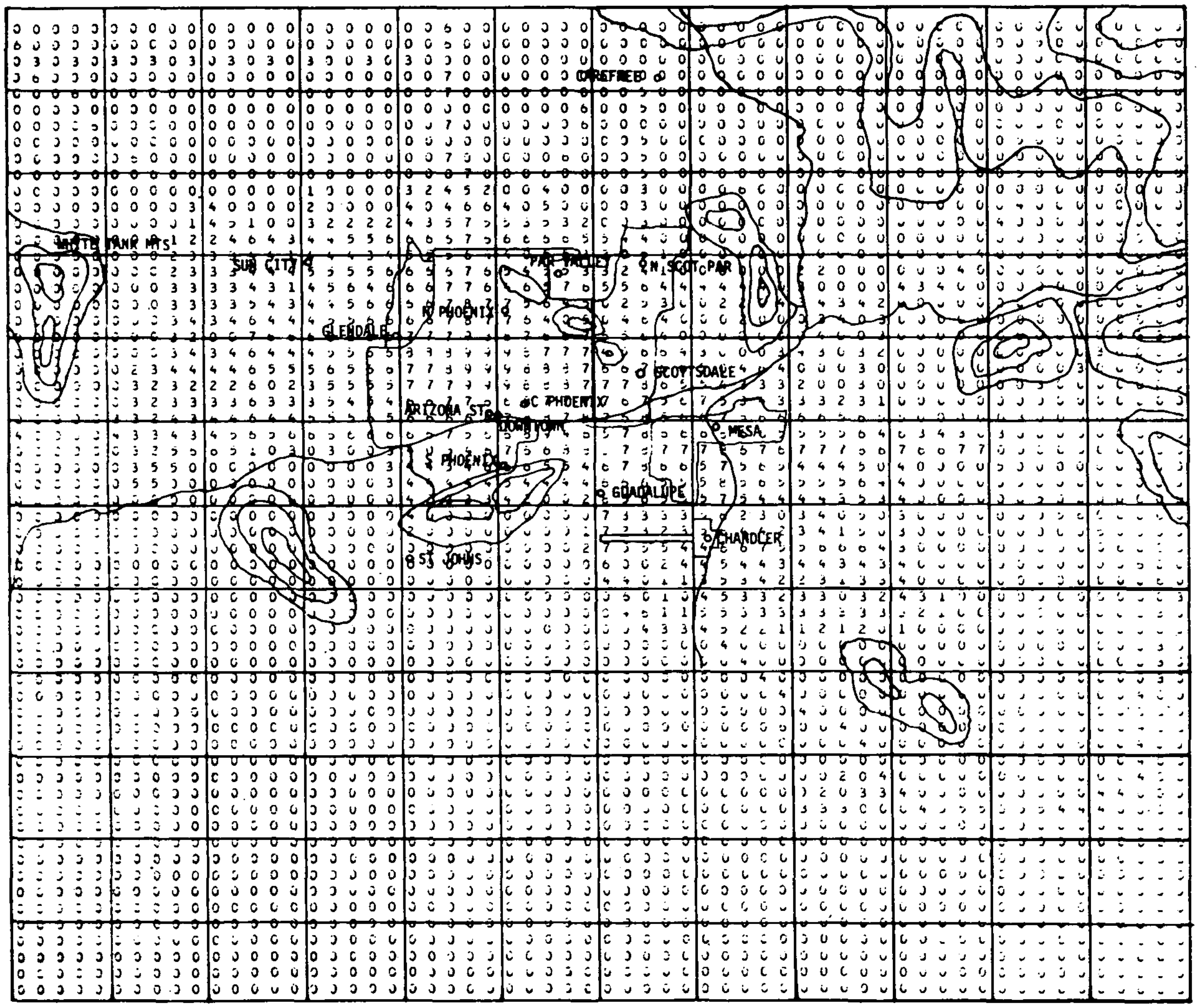
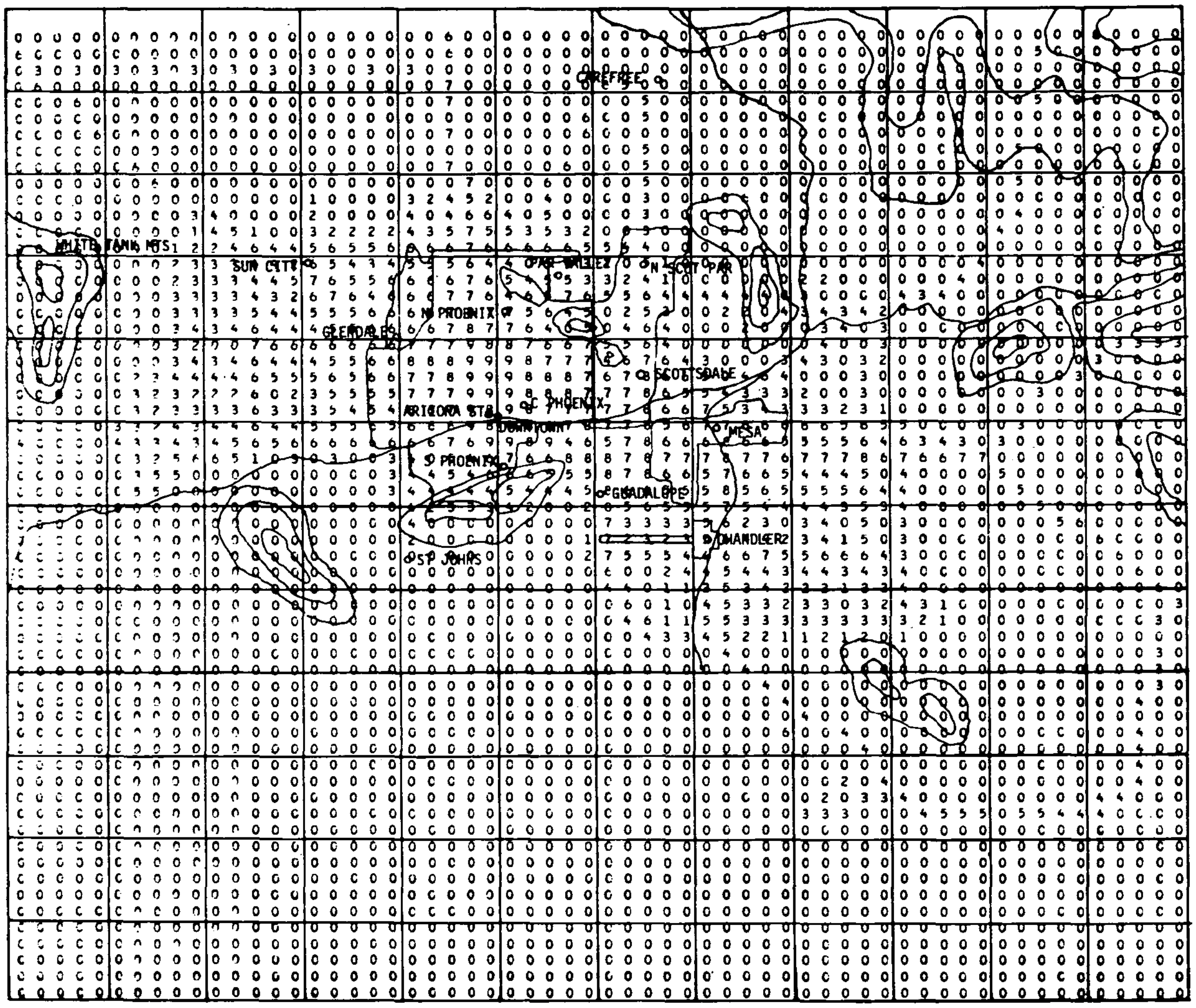


Figure 3-6. Total Dust Emissions From Paved Streets, With and Without Strategy in 1985



GRID CODE	EMISSIONS TONS/DAY
0	0 to 0
1	0 to .004
2	.004 to .02
3	.02 to .07
4	.07 to .18
5	.18 to .37
6	.37 to .69
7	.69 to 1.2
8	1.2 to 1.9
9	1.9 to 2.9

Figure 3-7. Total Dust Emissions (Entrained from Unpaved Roads In 1985 After Application of Control Strategy.



GRID CODE	EMISSIONS TONS/DAY
0	0 to 0
1	0 to .004
2	.004 to .02
3	.02 to .07
4	.07 to .18
5	.18 to .37
6	.37 to .69
7	.69 to 1.2
8	1.2 to 1.9
9	1.9 to 2.9

Figure 3-7. (continued) Total Dust Emissions From Paved Roads, Baseline 1985.

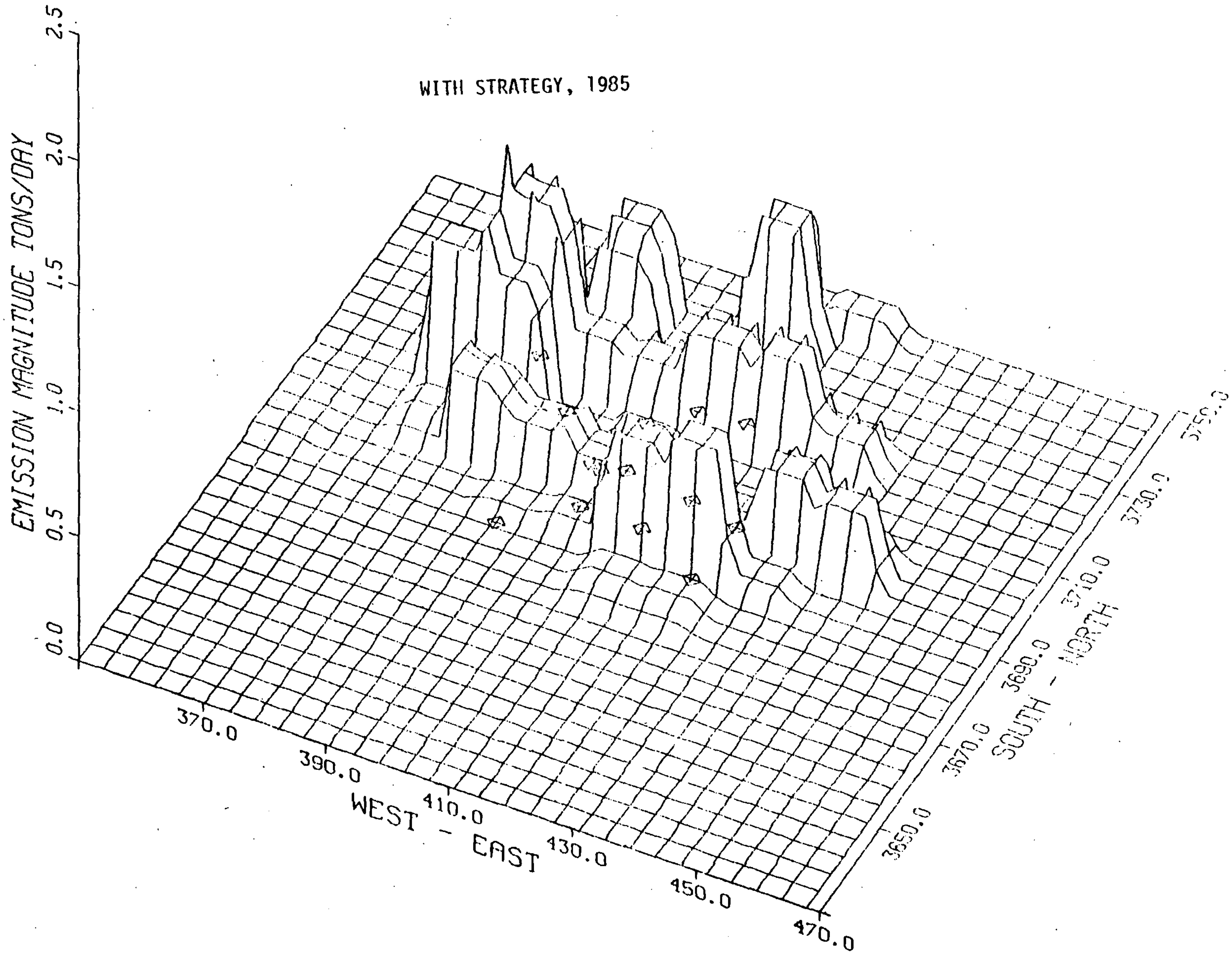
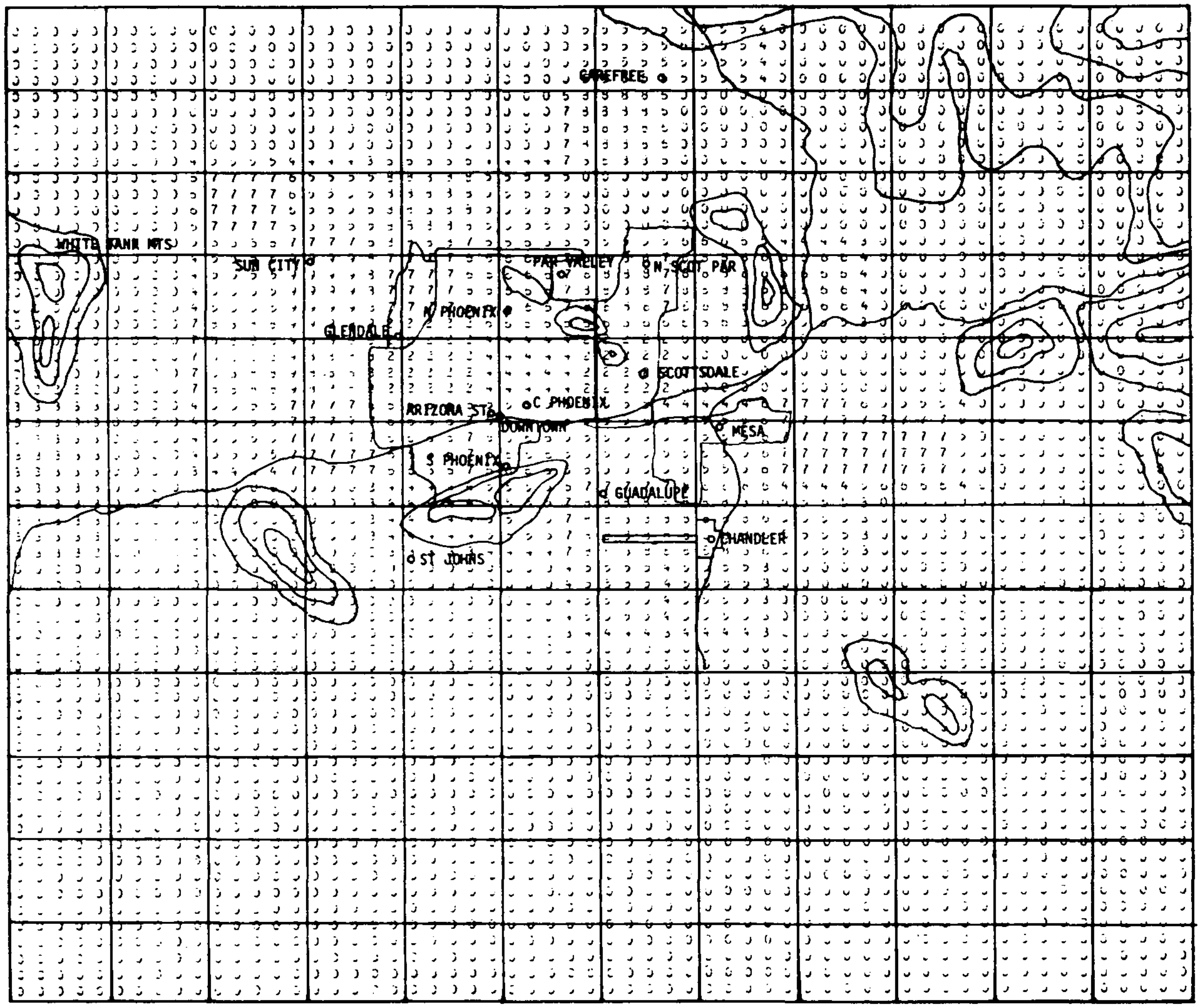


Figure 3-8. Total Dust Emissions From Construction Activities in 1985 After Application of Control Strategy



GRID CODE	EMISSIONS TONS/DAY
0	0 to 0
1	0 to .001
2	.001 to .007
3	.007 to .02
4	.02 to .06
5	.06 to .12
6	.12 to .22
7	.22 to .38
8	.38 to .61
9	.61 to .92

Figure 3-9. Total Dust Emissions From Construction Activities in 1985 After Application of Control Strategy.

TABLE 3-7. IMPACT OF CONTROL OF MAJOR SOURCE CATEGORIES ON TSP LEVELS

	TOTAL SUSPENDED PARTICULATES, µg/m³					REDUCTION OF:		CONTRIBUTION TO TOTAL SUSPENDED PARTICULATES, µg/m³						
	BASELINE			STRATEGY				UNPAVED ROADS		ENTRAINED ST. DUST		CONSTRUCTION ACTIVITIES		
MONITOR SITE	1975	1980	1985	1980	1985	1985 BASELINE TSP DUE TO STRATEGY	1975 TSP DUE TO STRATEGY & PROJECTED DEVELOPMENT	1985 BASELINE	1985 STRATEGY	1985 BASELINE	1985 STRATEGY	1985 BASELINE	1985 STRATEGY	BACKGROUND LEVEL
1. Central Phoenix	112	104	87	99	77	11.4%	31.2%	8	1	37	35	5	5	30
2. S. Phoenix	144	139	101	126	73	27.7%	49.3%	32	7	24	23	9	6	30
3. Arizona State	169	157	132	138	73	44.6%	56.8%	12	2	68	24	9	6	30
4. Glendale	101	84	65	80	56	13.8%	44.6%	9	1	20	20	2	1	30
5. N. Phoenix	121	111	83	104	73	12.1%	39.6%	8	1	32	32	7	5	30
6. N.Scottsdale/ Paradise	149	111	101	105	78	22.8%	47.6%	32	16	9	9	25	18	30
7. Scottsdale	115	105	93	99	73	21.5%	36.5%	10	2	42	33	5	4	30
8. Mesa	117	114	95	105	74	22.1%	36.7%	13	3	45	45	4	3	30
9. Downtown Phoenix	200	186	155	163	85	45.1%	57.5%	15	2	82	29	10	7	30
10. Sun City	88	81	74	79	64	32.4%	76.1%	6	1	17	17	16	11	30
11. Paradise Valley	184	152	93	138	73	21.5%	60.3%	14	2	17	16	25	17	30
12. Chandler	119	139	160	113	68	57.5%	42.8%	91	5	12	12	23	16	30
13. St. John	145	151	157	130	85	45.8%	41.4%	116	45	2	2	2	2	30

With application of the control strategy, air quality at all thirteen of the monitor sites is forecasted to attain, or come very close to attaining, the primary air quality standard for TSP (75 $\mu g/m^3$). Only the Downtown Phoenix and St. John sites are expected to experience TSP levels (85 $\mu g/m^3$) significantly higher than the standard. However, previous analysis has shown that air quality at each of these sites is probably not representative of air quality in the general area. Each of the two sites is located in a hot spot of fugitive dust sources, and air quality measured there is site-specific and biased towards higher levels than are representative of the general area. Consequently, additional site-specific control measures may be needed. However, before these measures are implemented, it may be advisable to further examine the existing air monitoring network in the areas in question and supplement the network as necessary to further refine the problem and evaluate the impact of the proposed strategy once it is implemented.

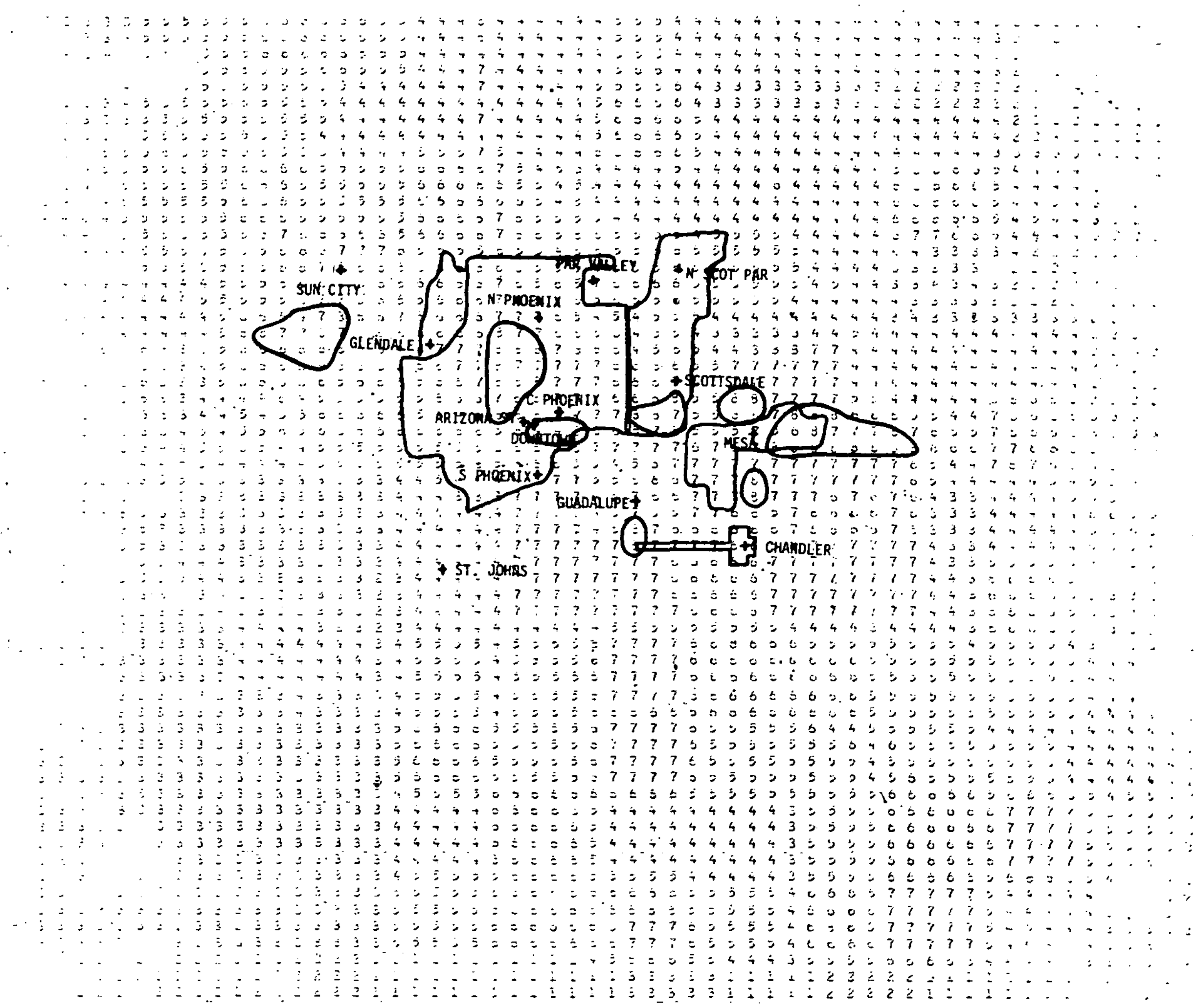
Control strategy air quality improvements are dominated primarily by reductions of dust emissions from unpaved roads. Because controls for unpaved roads are targeted for county areas, monitor sites outside the metropolitan influence tend to be more affected by the control measures proposed for unpaved road emissions. These measures improve TSP levels at Chandler, St. Johns, North Scottsdale/Paradise Valley, and South Phoenix in amounts ranging from 25 to 71 $\mu g/m^3$ in 1985. The effect of controls to reduce entrained street dust emissions off paved roads is evidenced most noticeably at monitors within the designated areas of control (Downtown Phoenix and Scottsdale). The downtown Phoenix monitor experiences the greatest improvement as TSP levels are reduced by 53 $\mu g/m^3$ due to the street dust strategy measures. The effect of construction controls is relatively minor at all monitors, ranging from a resulting improvement of 8 $\mu g/m^3$ at Paradise Valley to no improvement at St. Johns where construction activities are anticipated to be very limited. As discussed previously, other sources do not contribute significantly to TSP levels at the various monitor sites.

As anticipated, the areawide emission reductions are significantly less than the relative improvement in air quality. A 36% emission reduction (Table 3-4) occuring in 1985 from the strategy translated to TSP reductions of 11 to 57%. In view of the relatively high background contributions, which is unaltered by the strategy, the improvement leverage provided by the emissions reductions is appreciable. As discussed previously, this is due to the dominant influence of local fugitive sources on TSP levels at any given location.

The impact of the control strategy by 1980 is also significant, but because the control measures are about only two-sevenths complete by this time, air quality at only one of the monitor sites (Sun City) is forecasted to attain the primary standard.

As discussed earlier, it is useful to distinguish between the control strategy needed to attain the standard throughout the region and that needed to attain the standard at the monitoring stations. Because of the very localized influence of fugitive dust sources, and the limitations associated with current state-of-art air quality simulator techniques, the proposed control strategy cannot assure region-wide attainment. TSP levels at certain locations may be higher than those represented by the monitoring network. The analysis of air quality and emissions levels resulting from the strategy may be combined to indicate potential non-attainment areas where monitor sites should be established and additional controls applied if warranted. Figure 3-10 shows nine potential non-attainment areas which may require additional control attention in 1985. These areas were identified by locating grid squares where emissions densities were greater than those levels predicted at the attaining monitor sites (i.e., all grid squares with grid codes greater than 7). Inspection of the emissions grid maps (Section 3.3) suggests the relative influence of the major sources on air quality at these sites. Some of the potential hot spot grid squares are located within the metropolitan area and are most affected by entrained street dust emissions. Most of the potential problem sites are located in more rural areas outside the metropolitan influence, where unpaved road emissions and dust from construction activities are the major sources of the emissions totals.

Air quality monitors should be installed at the indicated sites to establish baseline TSP levels for use in air quality simulation and prediction of future TSP levels there. The timetable for completing the expanded monitor network should be immediate to permit appropriate adjustment of the proposed control strategy.



GRID CODE	EMISSIONS TONS/DAY
0	0
1	0 to .01
2	.01 to .04
3	.04 to .13
4	.13 to .32
5	.32 to .67
6	.67 to 1.2
7	1.2 to 2.1
8	2.1 to 3.4
9	3.4 to 5.2

Figure 3-10. Potential Non-Attainment Areas in 1985 After Application of Proposed Control Strategy.

3.5 COST OF CONTROLS

The cost of implementing the control measures of the proposed strategy are shown in Table 3-8. The estimates are based on cost data presented in Section 2. The cost effectiveness is expressed in terms of emissions reductions and average air quality improvement. With the exception of the measures to restrict vehicle speed on unpaved roads, there is relatively minor difference in the cost effectiveness of the various measures. The vehicle speed restriction is especially cost effective because of 1) the substantial emission reduction attained, 2) the presumption that the measure can be implemented inexpensively at an annualized cost of $200,000. Costs of the measures vary from about $2 to $55 per ton of dust emissions prevented, or from about $40,000 to $218,000 for each $\mu g/m^3$ of TSP concentration decrease. These costs are significantly lower than those typically required to control particulate emission sources in other regions experiencing non attainment problems due mainly to conventional type sources [21].

The total cost of instituting the control strategy is consistent with the concept of "reasonable" strategy defined earlier. Annual cost of the strategy is about $4.4 million, or approximately $3 per capita in Maricopa County. This compares to an appropriate 1976 total budget of $358 million for the city of Phoenix. Expressed as a tax on automobile gasoline in Maricopa County, the control would cause an increase of 0.8 cents per gallon.

An important aspect in assessing the true cost of the controls concerns cost benefits derived from the measures. The cost effects of air pollution on water treatment, materials, aesthetics, property taxes, vegetation, health, and economic development are significant. It is recommended that the demonstration model, proposed as an integral part of the overall control strategy (see Section 3.7), include a cost benefit analysis for each of the proposed measures.

TABLE 3-8. COST OF IMPLEMENTING CONTROL STRATEGY

SOURCE CATEGORY	CONTROL MEASURES	ANNUALIZED COST INCREASE (MILLIONS OF DOLLARS)	COST EFFECTIVENESS $/TONS OF EMISSION PREVENTED
Unpaved Roads	1. Chip seal all section line roads by 1995, and one-half by 1985.	2.5	23.0[d.]
	2. Reduce speed limit to 20 mph for all interior unpaved roads (private and county) gradually by 1985.	.2	2.1[d.]
Entrained Dust	1. By 1985, sweep major roads in designated areas to attain a 60% reduction in the current assumed average street dust loading. Based on the existing data base, the sweeping program would consist of cleaning major roads three days weekly, alternating from vacuum sweeping to broom sweeping as appropriate.	.36[e.]	54.8
Construction Activities	1. Effective 1980, wetting of site access roads twice daily at .5 gal/yard.^{2}	.72[a.]	25.4
	2. By 1980, sweeping of paved roads used by construction vehicles to remove visible dust resulting from construction activities.	.60[b.]	-
	3. By 1980, stabilization of exposed earth at construction sites when operations cease.	-[c.]	-
TOTAL, OVERALL STRATEGY		4.4	18.6

a. Based on assumption that access roads comprise 10% of all areas involved in construction activity (6590 active acres/month), and watering of these roads is currently performed once daily at $3/acre.

b. Based on assumption an average construction site is comprised of a 2 acre plot and there are some 330 individual sites which must be attended on any day in 1985.

c. It is anticipated that construction practices will be modified to avoid this control requirement by suitable scheduling of activities.

d. Based on emissions reduction of 298 tons/day due to paving measure, and 256 tons/day due to speed limit restriction.

e. This estimate was derived by multiplying the current average cost of street cleaning in Phoenix ($4.80/curb mile [15]) by the number of curb miles of major roads to be swept 3 times weekly in the designated areas. (Total of 474 curb miles based on compilations from traffic volume maps).

f. Cost effectiveness in terms of incremental air quality improvement was computed by dividing the total annual cost of the measure by the average incremental TSP improvement for all monitor sites. Accordingly, this figure reflects the particular cost effectiveness associated with gains at the monitor sites only.

3.6 IMPLEMENTATION PROBLEMS

The difficulty in implementing the strategy depends on political, legal, and socioeconomic obstacles associated with the various control measures. The magnitude of these obstacles depends on the general implementation approach of the strategy, that is, whether it is to be enforced as a series of air pollution control regulations, or as in-line actions to be taken by various agencies in the performance of related projects. As a direct regulatory approach, implementation of the strategy will probably meet with substantial obstacles. There is the legal question of whether the county has the authority to regulate and impose requirements on various agencies or private interests, and whether legislation has actually delegated this specific authority to the county. While local agencies are responsible for the establishment of air pollution regulations, the justification for many local regulations has stemmed from state and federal pollution control requirements. The county could exercise initiative in assuming implied authority, and adopt new regulations for implementing the control strategy, but the risks involved in this approach (e.g., jeopardy of the current control program) would make it an improbable action by the county.

In addition to legal obstacles, political and social acceptance of the proposed measures may pose implementation problems especially if controls are imposed by regulations. Regulations assembled by the County Health Department and justified on the basis of air quality improvements may generate apprehension on the part of agencies and individuals perceiving conflict with their own interests. Productive interaction among appropriate groups would alleviate this problem, but visible enforcement of the measures by an air pollution control agency for questionable health benefits would place support for the strategy in constant jeopardy.

The alternative to the regulatory approach for control measures is a workable approach which provides for integration (when possible) of the control measures into the on-line operations of various governmental agencies. This approach generates greater political and social acceptance to the measures, since the measures are visible not only as dust controls, but as planning and development improvements which will yield several tangible benefits of more popular demand. In view of the types of major fugitive dust emission sources which are typically uncontrolled at present, the integral planning approach is particularly appropriate. Reasonably available controls for unpaved road dust and entrained street dust emissions are entirely consistent with objectives of the local transportation and street maintenance departments.

The major obstacle confronting implementation of a dust control strategy, whether utilizing the integral planning approach or the direct regulatory technique, concerns the socioeconomic acceptability of the proposed actions. Appropriations by the respective local agencies for implementing controls requires financial support of the citizenry, whether by taxes, bonds, or assessment districts. While the funding needed to support implementation of the strategy is relatively miminal (amounting to 1.2% of the annual city budget), there is little chance that the additional expenditures associated with the strategy would be absorbed in the annual budgets without visible justification. Such justification may be facilitated by a persuasive control demonstration project to validate the benefits of the proposed strategy.

While some of the major sources can be controlled with general planning programs within the relevant local agencies, it is clear that all sources cannot be controlled in this manner. For example, commercial point sources of fugitive dust are currently controlled by county regulations under the reasonable control clause requirement, and although other participating agencies (e.g., Building and Safety Department) may be involved in implementation of the present rule, the motivation stems from regulatory mandate rather than planning interest. Such regulatory mandates are subject to test by the courts. In fact, the reasonable control clause, as it applies to construction activities, has already been tested in Phoenix. The state court ruled for the regulation in this case, deciding that a contractor has not taken reasonable precaution to reduce dust emissions during construction activities. The proposed strategy of this study would expand the control regulation for construction activities (requiring watering twice daily and daily street sweeping) in more specific terms,and enlist the participation of the Building and Safety Department in the issuing of construction permit approvals (under their delegated authority) contigent on compliance with the control measure.

Table 3-9 provides a summary of the ranking of implementation difficulties anticipated for each of the control measures comprising the strategy. The rankings are based on the interdisciplinary implementation approach, in which various departments of the local government are active participants in carrying out the strategy. The assessment is estimated for two cases: with, and without the benefit of a demonstration model preceeding implementation of the area wide proposed strategy. The estimates are necessarily somewhat speculative, but are consistent with the foregoing control strategy analysis and interviews with appropriate administrators and staff of pertinent local agencies in Phoneix.

The summary of Table 3-9 shows the relative difficulty of implementing any of the measures is very similar. Without the benefit of a demonstration model to provide general awareness and to support the suitability of the proposed area wide strategy, each of the measures is likely to encounter substantial socioeconomic resistance. Additional annual funding of about $4.4 million would be needed to support the measures, most of which would be generated by increased taxes or direct assessment. Socioeconomic resistance is compounded by the uncertainties inherent in the control strategy development, and the subsequent difficulty in justifying expenditures with minimum risk of expected benefits. None of the measures face difficult technical problems with the possible exception of the intensive street cleaning proposal.

The lower half of Table 3-9 presents estimates of implementation difficulties subsequent to conducting a demonstration model strategy in a limited area of the Phoenix study region. Presuming the model is conducted successfully, yielding a public awareness of the various benefits (including air quality improvements) to be gained from widespread implementation of the model elements, and dismissing speculative uncertainties

TABLE 3-9. IMPLEMENTATION DIFFICULTY OF CONTROL STRATEGY

CONTROL MEASURES	SEVERITY OF IMPLEMENTATION DIFFICULTY				OVERALL SEVERITY
	TECHNICAL	POLITICAL	LEGAL	SOCIOECONOMIC	
WITHOUT DEMONSTRATION MODEL:					
1. Intensive Road Paving	1	1	1	3	6
2. Lower Speed Limit on Unpaved Dirt Roads	1	2	1	3	7
3. Intensive Street Cleaning	2	2	1	3	8
4. Wetting of Construction Site Unpaved Access Roads	1	2	1	3	7
5. Sweeping Paved Access Roads Used By Construction Vehicles	1	2	1	3	7
6. Stablize Cleared Areas of Construction Sites	1	2	2	3	8
AFTER IMPLEMENTATION OF DEMONSTRATION MODEL					
1. Intensive Road Paving	1	1	1	2	5
2. Lower Speed Limit on Unpaved Dirt Roads	1	1	1	1	4
3. Intensive Street Cleaning	2	1	1	2	6
4. Wetting of Construction Site Unpaved Access Roads	1	1	1	1	6
5. Sweeping Paved Access Roads Used by Construction Vehicles	1	1	1	1	4
6. Stabilized Cleared Areas of Construction Sites	1	1	2	2	6

surrounding the appropriateness of the measures, the remaining obstacles limiting the full scale institution of the strategy are expected to be resolvable. The ingredients of the demonstration model are discussed in the following section.

3.7 DEMONSTRATION MODEL

The proposed measures of the control strategy are reasonable in terms of their technical, institutional, economic, and legal feasibility. However, because of substantial socioeconomic resistance associated with the measures, it is proposed that a demonstration model be formulated and included as a prerequisite to implementation of the overall control strategy. The model strategy would be useful in a number of ways. First, the model would be instrumental in generating the public acceptance needed for eventual financial support of the total strategy. Second, the demonstration would promote committment from local agencies as participants in dust control objectives. Finally, the demonstration program is essential as a tool for pollution control analysis as it would yield useful insights for appropriate adjustments of the region-wide strategy.

There is substantial indication the local control demonstration would result in significant air quality improvement. The evidence shows clearly that local sources are affecting the Hi-Vol monitor measurements dramatically. The cost of controlling these sources may well be less than the cost of the air pollution consequencies, and the specific controls are compatible with other city and county planning objectives. Hence, the local control demonstration is a very appropriate vehicle for persuasion, with very little risk involved.

The demonstration model must be formulated carefully, and should consist of the following elements:

- Surveys to establish understanding of pertinent value forces operating among the various social sectors.

- A cooperative task force committee comprised of representatives from the major affected local departments (i.e., Department of Transportation, County Highway Department, Agricultural Extension Service, County Legal Services, Maricopa County Health Department, etc.). The committee would be responsible for the planning of the model strategy.
- A field test to demonstrate the effect of the proposed control measures in a limited area. This test would include institution of all controls proposed for the area-wide strategy. A comprehensive TSP field monitoring program would be implemented.
- A detailed economic analysis to evaluate the economic consequences of particulate air pollution in Phoenix, and the cost benefits of the proposed dust control strategy.
- A public relations program to promote awareness of the benefits of the proposed dust control and to generate support for funding measures needed to implement the measures.

The selection of the specific area for the model demonstration would be dependent on several factors. First, receptibility of the various local agencies to participate in the model test should be assurred. Discussions with various departments of the City of Phoenix and Maricopa County have indicated a positive disposition to participate in both the funding and implementation of a model demonstration program [1, 15, 16, 11, 22]. The position of additional affected agencies should be surveyed, and the disposition of local agencies in unincorporated cities of the study area should be investigated. Second, the test area should be representative of air quality and major emission sources causing high levels of TSP throughout the study area. Controls for the three major fugitive emission sources can then be tested and evaluated during the single demonstration program. Third, it would be preferable if the selected area included a monitor of the existing air sampling network. This would facilitate the comparison between control and after control air quality, and would place the test program within the context of the present study framework. Fourth, since a key to the utility of the test model is its effect on social acceptance, the area selection should reflect a level of social acceptance typical of that characteristic of the region targeted for control strategy application. Another, but not necessarily final consideration in test area selection is the scheduled planning for the area. Desirability for selection of the area is increased when scheduled development is compatible with the specific controls comprising the demonstration model.

Selection of a test area should be based on a prioritized ranking of each of the above (and other) selection factors, and the specific characterization for the various candidate areas being considered.

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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

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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