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Technical Report

An Investigation of Future Ambient Diesel Particulate Levels Occurring In Large-Scale Urban Areas

By

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NOTICE

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I. Introduction

EPA proposed a particulate standard for diesel-powered light-duty vehicles in February, 1979, and is in the process of promulgating this standard. One of the prime inputs to this process is the effect of diesel particulate emissions on air quality. The purpose of this report is to determine the diesel's effect on ambient particulate levels over large urban areas. Past studies will be examined and combined with original projections to arrive at the best estimate of ambient diesel particulate levels in U.S. cities. A companion study is being conducted to determine the diesel's impact in smaller, local areas where the impact may be significantly larger (e.g., street canyons).

The original calculations of future regional impacts from diesel particulate emissions will be based on past ambient lead measurements in various urban areas. Almost all of ambient lead prior to 1976 can be traced to lead-containing particulate from automobile exhaust emissions. By relating future particulate emissions from diesels to past lead emissions from gasoline-fueled vehicles, ambient lead concentrations of the past can be used to project ambient diesel particulate concentrations in the future.

General Motors (GM), in their comments to the proposed light-duty diesel particulate standard, did just this, they projected ambient levels of diesel particulate for the year 1990 using ambient lead concentrations found in two major cities, Toledo and Chicago. However, GM did not document their methodology to support their calculations. Since it is desirable to project the ambient impact of diesel particulate in as many cities as possible, GM's work will be repeated to confirm their results and then expanded to other cities using a documented methodology. The results from this work will then be compared to two studies performed by PEDCo Environmental examining the impact of diesel particulate emissions in 1) Kansas City and 2) New York, Chicago, and Los Angeles.

The rest of this report has been divided into five sections. The first section contains the development of a reasonable scenario which includes future diesel sales, future traffic levels, and diesel particulate emission factors. The second section contains 1) a survey of the three studies which have already examined the air quality impact of the diesel and 2) modifies the results of these studies to conform with the scenario developed in the previous section. In the third section, the lead surrogate approach (GM) is outlined and extended to many other cities. The fourth section contains a comparison of the results of the three studies (including the extention) while the final, fifth section contains the conclusions of the analysis.

II. Development of Scenario

Whenever two studies predicting the same phenomena are compared, differences can result because of two factors. One, the input data may differ. Two, the methodology may differ. This study is primarily concerned with differences in methodology. The study's goal is to arrive at the best estimate of the ambient impact of a specified level of diesel particulate emissions. In order to compare methodologies from one study to another the same input data must be used in every case. This input scenario will consist of projected emission factors, growth rates for vehicular traffic and the breakdown of this traffic by vehicle class.

EPA estimates that by 1990 the uncontrolled particulate emission factor from light-duty diesels will be 1.0 gram per mile (g/mi).1/ This emission factor anticipates an increase in particulate exhaust emission due to a more stringent NOx emission standard being implemented by 1985. The heavy-duty particulate emission factor is presently estimated to be 2.0 g/mi.1/ It will be assumed that these emission factors would not change by 1990 without regulation. A summary of emission factors corresponding to vehicle class is shown in Table 1. Because this report is only concerned with diesel particulate emissions, particulate emissions from future gasoline-fueled vehicles will be assumed to be zero.

The breakdown by vehicle class of total urban vehicle miles traveled (VMT) by 1990 is also shown in Table 1. Two different breakdowns are shown: a "low estimate" and a "high estimate" based on a range of projected diesel sales. When engine type (gasoline or diesel) is ignored, the breakdown by class is the same in both cases and was based on DOT data.2/ EPA's latest projection of diesel penetration into the 1990 light-duty vehicle and truck fleet was the basis for the breakdown of the first two classes of Table 1.3/ That projection only included a single best estimate. To indicate the error possible in such projections, a range of plus and minus 25 percent of the best estimate was used. The estimate of diesel penetration into the heavy-duty fleet was taken from the Regulatory Analysis for EPA's proposed light-duty diesel particulate regulations.1/ Knowing the emission factors and the fraction of VMT for each class, an average weighted emission factor of 0.17 g/mi for the "low estimate" case and 0.27 g/mi for the "high estimate" case can be calculated. These figures were obtained by summing the product of each urban VMT fraction and its corresponding emission factor. From examining the contributions of each class to these average emission factors it can be seen that light-duty diesels contribute 56.7 percent and 60.6 percent of total diesel particulate emissions, low and high estimates, respectively.

Finally, an estimate of urban traffic growth is necessary to obtain a complete picture of future vehicle emissions. An annual growth rate of 1 percent will be used here. This should be suitable as it has been EPA's policy to use a 1 percent per year growth rate for projections of CO emissions, which, along with diesel

Table 1

Fraction of Urban VMT by Mobile Source Category in 1990

Classification	Fraction VMT (1990) Low	High	Emission Factor
LDV-G	0.745	0.689	0
LDV-D	0.085	0.141	1.0
LDT-G	0.096	0.089	0
LDT-D	0.012	0.019	1.0
HDT-G	0.025	0.010	0
HDT-D	0.037	0.052	2.0

LDV = Light-duty vehicles.
LDT = Light-duty trucks.
HDT = Heavy-duty trucks.
G = Gasoline.
D = Diesel.

particulate, is primarily an urban core problem.3/ This increase should be compounded between the last year of traffic or ambient pollutant measurement and the year being examined (1990). Including traffic growth in future projections is necessary as it alone will cause an increase in ambient particulate concentrations, if other factors are left unchanged.

III. Survey and Modification of Previous Studies

A. PEDCo-Kansas City

PEDCo Environmental recently performed a study on the impact of diesel particulate emissions on total suspended particulate (TSP) concentrations in the atmosphere.2/ Specifically, the Air Quality Display Model (AQDM) was used to predict the diesel's impact on the air quality of Kansas City, Missouri. The city was broken down into 165 sections using a grid of 2 x 2 kilometer squares. The average diesel particulate concentration in each square was determined. EPA requested and examined PEDCo's grid data sheet for one case and determined the fraction of the population exposed (by residence) to various levels of diesel particulate in 1990.4/ These results are shown in the second column of Table 2.

In calculating the impacts shown in the second column of Table 2, PEDCo used emission factors of 0.5 grams per mile (g/mi) for light-duty diesels and 2.0 g/mi for heavy-duty diesels with a traffic growth rate of 1.51 percent per year between 1974 and 1990. The traffic breakdown (percentage of total regional travel) used was 19.1 percent for light-duty diesel vehicles, 2.4 percent for light-duty diesel trucks, and 5.2 percent for heavy-duty diesel trucks.

To convert these results to the scenario of Section II, two converting factors must be determined. One is the ratio of the traffic-weighted diesel particulate emission factors and the other is the ratio of future traffic levels between 1974 and 1990. From the figures shown in the preceding paragraph, PEDCo's weighted emission factor was 0.21 g/mi and their overall estimate of traffic growth was 27 percent. From Section II, EPA's weighted emission factors are 0.17 g/mi (low) and 0.27 g/mi (high) and the estimate of traffic growth is 17.3 percent (16 years). The ratios of emission factors are then 0.81 (0.17/0.12) and 1.29 (0.27/0.21), low and high diesel estimates, respectively. The ratio of future traffic levels is 0.92 (1.173/1.27). Combining these two factors, the PEDCo results need to be multiplied by 0.74 and 1.14 to be converted to EPA's low and high diesel scenarios, respectively. This has been done and the modified results are shown in the last two columns of Table 2.

B. PEDCo-New York, Chicago, and Los Angeles

PEDCo performed a second study on the environmental impact of

Table 2

Predicted Population Exposure to Ambient Particulate Levels for Kansas City, Mo, in 1990

% of Population Exposed to Estimated Ambient Levels	Ambient Part. Level (ug/m^3) Diesels (Pedco, "Max Growth")	Ambient Part. Level (ug/m^3) Diesels (EPA, "Low Est.")	Ambient Part. Level (ug/m^3) Diesels (EPA, "High Est.")
2.1	1.732	1.3	2.0
5.9	1.586	1.2	1.9
13.2	1.48	1.1	1.7
17.8	1.386	1.0	1.6
28.6	1.24	0.92	1.5
32.8	1.20	0.89	1.4

diesel particulate emissions,5/ this time based on ambient total suspended particulate (TSP) data taken at fifteen monitoring sites, five each in New York, Chicago, and Los Angeles. TSP data collected from these SAROAD sites were converted to ambient diesel particulate levels using the approximation that motor vehicles contribute a fixed percentage of the TSP levels in each city. PEDCo estimated that particulate emissions from motor vehicles in 1975 and 1976 contributed about 21 percent of the TSP in New York City, 13 percent of TSP in Los Angeles, and 17 percent of TSP in Chicago.5/ These percentages were the result of analyses examining the amount of elemental lead in ambient TSP measurements. It is uncertain whether these percentages as discussed in the original references, refer to leaded exhaust particulate only or to all particulate emissions associated with automobiles (e.g., tire particulate emissions, reentrained dust, etc.). PEDCo assumed that the percentages referred to leaded exhaust particulate. This uncertainty will be analyzed in the Comparison section of this report (V).

Via the above-mentioned percentages, PEDCo was able to determine the motor vehicle contribution to ambient TSP levels in 1975-1976. They then determined future ambient diesel particulate levels by using 1) the ratio of the diesel particulate emission factor to the leaded-gasoline particulate emission factor, 2) the ratio of future diesel traffic to the existing traffic of leaded-gasoline fueled vehicles, and 3) the future overall traffic growth. Through the use of two or more different estimates of the above three factors, PEDCo examined a total of six scenarios. As PEDCo's work involved the same basic assumption as that used in this report, that the air quality impact of a source is proportional to the emissions of that source, only one of PEDCo's scenarios need be modified to the scenario of Section II.

PEDCo's scenario which assumed optimistic growth in diesel use and traffic will be the one examined here (Scenario T_1 D_2 E_1). The particulate emission factors used were 0.5 g/mi for light-duty diesels and 2.0 g/mi for heavy-duty diesels. The breakdown of traffic by vehicle and the traffic growth rates used were different for each city and are shown in Table 3. The weighted emission factors resulting from these growth rates and individual vehicle emission factors for the year 1990 are also shown in Table 3. The resulting ambient diesel particulate levels at all fifteen sites are shown in Table 4 (first column). These results, modified to the scenario outlined in Section II, are shown in the second column of Table 4. The methodology used to modify these original PEDCo results was the same as that used to modify the results of the previous PEDCo-Kansas City study. The ratios of the weighted emission factors and the future traffic levels were multiplied against the original results to obtain the modified results. These results are substantially higher than the PEDCo-Kansas City prediction. An explanation of this will be discussed in Section V.

Table 3

Input Parameters of PEDCo Three-City Study 5/

	T1, D2, E1 Scenario - 1990		
	New York	Chicago	Los Angeles
Overall Traffic Growth (1976-1990)	10.8%	6.4%	22.7%
Vehicular Traffic Breakdown by Class			
Light-Duty*			
Gasoline	50.7%	47.8%	52.2%
Diesel	40.5%	42.2%	41.6%
Heavy-Duty**			
Gasoline	0.3%	0.2%	0.2%
Diesel	8.4%	4.8%	6.0%
Particulate Emission Factors			
Light-Duty	0.5 g/mi	0.5 g/mi	0.5 g/mi
Heavy-Duty	2.0 g/mi	2.0 g/mi	2.0 g/mi
Diesel Particulate Weighted Emission Factors	0.37g/mi	0.307g/mi	0.33 g/mi

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* Light-duty includes autos and taxi's in PEDCo's terminology.

** Heavy-duty includes heavy-duty trucks and buses in PEDCo's terminology.

Table 4

Predicted Ambient Particulate Levels for 1990 from Diesels
EPA vs Pedco

City	Site Adress	PEDCo Scenario T_1,D_2,E_1 (ug/m^3)	EPA Scenario (ug/m^3) Low	High
New York	Steinman Hall ,W. 141 St. and Convent Ave.	20.50	9.8	15.1
New York	170 E. 121 St.	21.62	10.3	16.0
New York	Central Park Arsonal, 5th Ave., and 64th St.	19.97	9.5	14.7
New York	240 2nd Ave.	25.62	12.2	18.9
New York	Pier 42, Morton St. and Hudson River	24.82	11.8	18.7
Torrance, Los Angeles	2330 Carson St.	19.78	9.6	15.0
Long Beach, Los Angeles	2655 Pine Ave.	20.45	10.0	15.4
Los Angeles	434 S. Pedro	24.90	12.0	18.7
Pasadena	1196 East Walnut	20.72	10.1	15.6
Pasadena	Kech Laboratories, Cal. Inst. of Tech.	22.59	11.0	17.1
Chicago	3500 E. 114 St.	46.91	28.1	43.6
Chicago	1947 W. Polk	22.91	13.7	21.3
Chicago	9800 S. Torrence Ave.	25.07	15.0	23.3
Chicago	538 S. Clark St.	23.82	14.3	22.1
Chicago	4015 N. Ashland Ave.	19.64	11.8	18.3

C. GM Study

In their response to EPA's proposed standards, GM submitted an air quality impact section in which ambient particulate concentrations from diesel vehicle emissions were calculated from a lead tracer model.6/ A methodology was not presented in this report, but a scenario was given which included a particulate emission rate of 0.2 g/mi with a light-duty vehicle (LDV) fleet of 25 percent diesels for the year 1990. A 1 percent per year traffic growth rate was also used. The GM results are shown in Table 5, as well as the results modified to EPA's scenario. As the GM and EPA traffic growth rates are the same in this case, no adjustment due to this factor was necessary. The GM weighted diesel particulate emission factor was simply 0.05 g/mi (0.25 x 0.2 g/mi), so the only adjustment was converting this to the 0.17 g/mi and 0.27 g/mi weighted emission factors, low and high diesel estimates, respectively.

The regional annual means determined by GM were based on annual lead measurements in Chicago and Toledo taken in 1970 and 1968, respectively. GM claimed that this lead surrogate method is sensible and straightforward and can be reliably applied to major U.S. cities as well.6/ Because of this ease and applicability to many urban areas, this lead surrogate work will be extended to more cities below.

IV. Extension of Lead Surrogate Work to Other Cities

Although GM used the lead surrogate approach to predict future particulate concentrations from light-duty diesels, the exact methodology was not documented. As it would be helpful to extend this work to other cities, a methodology will first be outlined below and then extended using monitoring data similar to that used by GM. This methodology should be very similar to that used by GM and any differences will be examined in Section V.

The basic assumption involved in surrogate work of this type is that the ratio of the ambient level to emissions of one pollutant (in this case lead) is related to that of another pollutant (in this case diesel particulate). Lead has the advantage of being easily separable from other particulate components and the great majority of it is emitted from motor vehicles. It is much more difficult to distinguish diesel particulate from carbonaceous particulate from other sources. Thus, the relationship between ambient lead concentrations and lead emissions from motor vehicles is first determined from actual measurements of both. Second, this relationship for lead is modified as necessary to represent the same relationship for diesel particulate. Finally, this relationship for diesel particulate is coupled with diesel particulate emission data to yield estimates of ambient diesel particulate levels.

Table 5

Results and
Modification of GM Study 6/

	Ambient Diesel Impact Regional Annual Mean (ug/m^3)		
	GM	EPA	
		Low	High
Major Cities (Chicago)	3.2	10.9	17.3
Mid-size (Toledo)	0.9	3.1	4.9

The first step in this process is to express the ambient levels of both diesel particulate and lead in terms of their respective emissions. These relationships are expressed in the following two equations:

$$C(Pb) = E(Pb) \cdot f(Pb) \tag{1}$$
$$C(D) = E(D) \cdot f(D) \tag{2}$$

where:

C(Pb) = concentration of ambient lead levels from mobile source emissions in a particular urban area.

E(Pb) = average motor vehicle emission factor for lead in a particular urban area.

f(Pb) = a function which relates lead emissions to ambient lead concentrations (constant for each monitoring site).

C(D) = concentration of ambient diesel particulate levels from diesel mobile source vehicles in a particular urban area.

E(D) = average motor vehicle emission factor for diesel particulate for a particular urban area.

f(D) = a function which relates diesel emissions to ambient diesel particulate levels (constant for each monitoring site).

As can be seen, the ambient levels of both pollutants have been assumed to be proportional to their emission factor. This is a standard assumption when working with one source of a non-reactive pollutant. Here we are working with many individual sources (i.e., vehicles). If the relative distribution of these vehicle throughout the region were changing, then f(Pb) or f(D) could change if the average emission factor changed. However, for the purposes of this report, the relative distribution of vehicles throughout a region will be assumed to remain constant. The overall breakdown of traffic by class and engine type may change and the overall traffic may increase, however, each subsection of the region is assumed to have the same fraction of the region's total traffic as it had when the lead studies were performed. Under this condition, equations (1) and (2) are quite valid.

Equation (2) can not be used alone to calculate concentrations of ambient diesel particulate levels since f(D) is unknown. However, if equation (2) is divided by equation (1), and solved for C(D), C(D) then becomes a function of C(Pb) and two factors, one related to emissions and one related to dispersion. It may be possible to determine the ratio f(D)/f(Pb) where it would not have been possible to determine f(D) alone. The equation is shown below:

$$C(D) = \frac{E(D)}{E(Pb)} \cdot \frac{f(D)}{f(Pb)} \cdot C(Pb) \qquad (3)$$

In the following three subsections, the three factors shown on the right side of equation (3) will be determined. In the fourth subsection, all three will be combined to yield estimates of ambient diesel particulate levels in a large number of cities throughout the U.S.

A. Lead and Diesel Particulate Emissions

The first factor of equation (3) to be determined will be that relating to emissions, E(D)/E(Pb). The average emission factor for diesel particulate has already been calculated in Section II and is 0.17 g/mi for the low diesel estimate case and 0.27 g/mi for the high diesel estimate case. The average emission factor for lead will be determined below.

Lead emission factors for light-duty vehicles (LDV), light-duty trucks (LDT) and heavy-duty vehicles (HDV), can be determined from three pieces of data; 1) the lead content of gasoline, 2) the fraction of the lead entering the engine that is emitted from the exhaust, and 3) the fuel economy of the vehicle. All of these factors will be determined circa 1975, as this is the year of the ambient lead measurements.

The (elemental) lead content of gasoline in 1975 was 1.9 grams per gallon.7/ Past studies have found that approximtely 75 percent of the lead in the fuel leaves through the exhaust.7/ The rest is accumulated in the oil sump and exhaust system. The average fuel economy of light-duty vehicles in 1975 was 13.5 miles per gallon and that for trucks was 8.7 miles per gallon (based on DOC data).7/ No further breakdown was available on the fuel economy of trucks into EPA's light-duty and heavy-duty categories so this figure will be used as the average fuel economy for these two classes.

Combining these figures, the lead emission factor for light-duty vehicles is 0.105 g/mi and 0.164 g/mi for both light-duty trucks and heavy-duty vehicles. These figures and the breakdown of urban traffic in 1974 (assumed applicable in 1975)2/ are shown in

Table 6. Combining the figures of Table 6 yields an average 1975 lead emission factor of 0.11 g/mi.

Only one step remains before the ratio E(D)/E(Pb) can be determined. The average diesel particulate emission factor (0.17 and 0.27 g/mi) is in terms of 1990 miles, while the lead emission factor is in terms of 1975 miles. Between these two years, however, overall travel will increase by 16.1 percent (1.0 percent annual growth compounded for 15 years). Thus, the average diesel particulate emission factor should be increased by 16.1 percent to be on an equivalent basis as the lead factor. With the incorporation of the 16.1 percent increase, the ratios of E(D)/E(Pb) are calculated to be 1.8 (low estimate) and 2.8 (high estimate).

B. Lead and Diesel Particulate Dispersion Characteristics

Automotive lead and diesel particulate emissions have similar properties that would imply that their dispersion would be very similar. These properties are: a) both are emitted in particulate form, b) both are emitted from ground level, and c) both are emitted from vehicles of similar urban driving patterns. However, a major difference between lead and diesel particulate is their relative size. This section will discuss this difference and how it affects the relative dispersion of the two types of particulate.

Diesel particulate is extremely small with well over 90 percent by mass being fine (less than 2.5 micrometers in diameter).8/9/ This is small enough for all of the particulate to be considered suspendable.10/ Lead-containing particulate (lead salts such as PbClBr), on the other hand, is much larger, only 43 percent by mass being smaller than 9 micrometers in diameter.10/ This same study examined the particle size distributions of both ambient and exhaust lead-containing particulate and concluded that only the 43 percent smaller than 9 micrometers was being suspended and the rest was settling out rather quickly after emission.10/ It appeared somewhat simplistic to assume that the cutoff for suspension would be so sharp. However, an examination of the size distributions of both the ambient and exhaust particulate samples revealed that the fraction of the mass smaller than 0.6 micrometer was approximately 2.5 times larger for the ambient sample than the exhaust sample. If it is assumed that all of the particles less than 0.6 micrometers in diameter were suspended, this would imply that about 40 percent of the lead-containing particulates was suspended. As this confirms the 43 percent figure cited above, 43 percent will be used as the percentage of lead-containing particulate that is suspended.

Given that all the other source characterisitics are the same for lead and diesel particulate, the only differences between the dispersion of the two pollutants is that 57 percent of the lead

Table 6

Fraction of Urban VMT by Mobile Source Category in 1974

i	Classification	Fraction of Urban VMT (1974) 2/	Pbi (gr/mi)
1	LDV-G	0.826	0.11
2	LDV-D	0.004	0
3	LDT-G	0.107	0.11
4	LDT-D	0.001	0
5	HDV-G	0.036	0.27
6	HDV-D	0.026	0

G = Gasoline.
D = Diesel.

particulate does not stay aloft long enough to be measured by an ambient air monitor. Thus, the ratio f(D)/f(Pb) is 1.0/0.43 or 2.32.

C. Ambient Lead Levels

The third and last parameter to be determined before equation (3) can be used to predict ambient levels of diesel particulate is the ambient level of lead (C(Pb)). Unlike the other two parameters, this parameter varies from city to city. For precisely that reason, this approach is able to yield diesel impacts in many cities while requiring a minimum of effort.

There are two primary sources of ambient lead data available; that obtained by the National Air Surveillance Network (NASN) and that contained in the National Aerometric Data Bank (NADB).11/ The NASN data will be used here because it has the greater likelihood of being representative of large-scale urban areas and large exposed populations. Many of the lead monitors submitting data to NADB are special purpose monitors located near large sources of lead emissions and would only be representative of locales near those sources.

The NASN ambient lead data is shown in Table 7-A through 7-E for cities divided into five population categories. Data from a few cities known to have large stationary sources of lead emission have been omitted. In general, the lead measured at sites shown in Tables 7-A through 7-E should be nearly all due to motor vehicle exhaust emissions. In 1975, motor vehicles accounted for 89 percent of the 142,000 metric tons emitted nationwide.7/ In addition, much of the 11 percent due to stationary source emissions is concentrated in those areas which have been avoided by this study. However, to be conservative, it will be assumed that only 89 percent of the ambient lead concentrations shown in Table 7-A through 7-E are due to motor vehicle emissions. Thus, these values will be multiplied by 0.89 before being used in equation (3).

D. Calculation of Ambient Levels of Diesel Particulate

The necessary data is now available to calculate ambient diesel particulate levels in 1990. Once again equation (3) is:

$$C(D) = \frac{E(D)}{E(Pb)} \cdot \frac{f(D)}{f(Pb)} \cdot C(Pb) \qquad (3)$$

The ratio E(D)/E(Pb) is 1.8 for the "low estimate" case, and 2.8 for the "high estimate" case. The ratio f(D)/f(Fb) is equal to 2.32 (1/0.43). C(Pb) for each city is equal to the value shown in Table 7 (A through E) multiplied by 0.89. Using these figures,

Table 7-A

Ambinet Lead Levels in Cities with a Population Greater Than 1,000,000 11/

City	AQCR #	Site Number	Address	Station Type	Elev. Above Ground (ft.)	Lead Concentration (ug/m^3)*
Chicago	67	141220001	320 N. Clark St.	Center City-Commercial	10	1.42
	67	141220002	445 S. Plymouth Ct.	Center City-Commercial	10	3.01
Detroit	123	231180001	Public Library	Suburban-Commercial	9	0.99
Houston	216	452560001	810 Bagby St.	Center City-Commerical	50	2.09
Los Angeles	24	054180001	434 S. Pedro St.	Center City-Commercial	100	2.68
New York	43	(Old #) 334680001 (New #) 334680014	170 E. 121st St.	Center City-Commercial	75	1.05
Philadelphia	45	397140002	2031 Race St.	Center City Residential	15	1.34
	45	397140004	1501 E. Lycoming Ave.	Suburban-Residential	17	1.23

* Annual Mean.

Table 7-B

Ambient Lead Levels in Cities With a Population Between 500,000 and 1,000,000 11/

City	AQCR #	Site Number	Address	Station Type	Elev. Above Ground (ft.)	Lead Concentrations (ug/m^3)*
Boston	119	220240001	JFK Bldg., Cambridge St.	Center City-Commerical	85	0.92
Dallas	215	451310002	2100 Young St.	Center City-Commercial	12	3.03
Denver	36	060580001	414 14th St.	Center City-Commercial	43	0.95
	36	060580002	2105 Broadway	Center City-Commerical	9	1.59
Kansas City, MO	94	262380002	Not available			0.80
New Orleans	106	192020002	421 Loyola Ave.	Center City-Commerical	72	1.06
Phoenix	15	030600002	1845 F. Roosevelt	Center City-Commercial	30	2.10
Pittsburg	197	397260001	County Office Bldg.	Center City-Commercial	160	0.85
San Diego	29	056800001	Not available			1.13
St. Louis	70	264280001	1720 Market St.	Center City-Commercial	49	1.18
	72	264280002	215 S. 12th Blvd.	Center City-Commercial	10	1.58

* Annual Mean.

Table 7-C

Ambient Lead Levels in Cities With a Population Between 250,000 and 500,000

City	AQCR #	Site Number	Address	Station Type	Elev. Above Ground (ft.)	Lead Concentrations (ug/m^3) *
Atlanta	56	110200001	99 Butler St. SE	Center City-Commericial	20	1.05
Birmingham, AL	4	010380003	Not Available			1.22
Cincinatti	79	361220001 (A01)	Public Library, Vine St.	Center City-Commercial	550	0.81
Jersey City	43	312320001	Med. Ctr. Garage	Suburban-Industrial	45	1.03
Louisville	78	182380002	2500 S. 3rd St.	Center City-Industrial	80	0.96
Oklahoma City	184	372200015	428 W. California	Center City-Commerical	15	1.66
	184	372200029	Not available			1.02
Portland	193	381460001	State Office Bldg.	Center City-Commerical	170	0.81
Sacramento	28	056580001	2221 Stokton Blvd.	Center City-Commerical	11	1.05
Tucson	15	030860001	24D & Palm	Center City-Commerical	47	0.75
Yonkers, NY	43	337620001 (A01)	87 Hepperman Ave.	Center City-Commerical	100	1.16

* Annual Mean.

Table 7-D

Ambient Lead Levels in Cities With a Population Between 100,000 and 250,000

City	AQCR #	Site Number	Address	Station Type	Elev. Above Ground (ft.)	Lead Concentrations (ug/m3) *
Baton Rouge	106	190280001	3142 Evangeline St.	Center City-Commercial	5	0.93
Jackson, MS	5	251260002	424 N. State St.		12	0.80
Kansas City, KA	94	171800002	Miami & Baltimore	Center City-Industrial	14	0.60
	94	171800012	EPA Lab 25-Furston Rd.	Center City-Industrial	19	0.43
Mobile, AL	5	012380001	O.K. Bicycle Shop	Center City-Commercial	15	0.96
New Haven, CT	42	070700001	270 Orange St.	Center City-Commercial	72	1.15
Salt Lake City	220	460920001	610 S. 2nd East	Center City-Commercial	30	0.98
Spokane, WA	62	492040001	Spokan City Hall	Center City-Commercial	84	0.58
Torrance, CA	24	058260001	2300 Carson St.	Center City-Residential	4	2.35
Trenton, NJ	45	315400001	State House and State St.	Center City Commercial	40	0.88
Waterbury, CT	42	071240001	City Hall 235 Grand Ave.	Center City-Commercial	55	1.88

* Annual Mean.

Table 7-E

Ambient Lead Levels in Cities With Population Under 100,000

City	AQCR #	Site Number	Address	Station Type	Elev. Above Ground (ft.)	Lead Concentration (ug/m3) *
Anchorage, AL	8	020040003	527 E. 4th Ave.	Center City-Commercial	28	1.00
Bethlehem, PA	151	39078002	Public Safety Bldg.	Suburban-Commercial	41	0.57
Helena, MO	142	270720001	Cogswell Bldg.	Center City-Residential	29	0.29
Jackson Co., MS	5	251280001	Jackson Co. Health Dept.	Rural-Near Urban	4	0.47

* Annual Mean.

ambient diesel particulate levels in 1990 can be calculated and are shown in Tables 8-A through 8-E. Now that all the previous studies have been normalized to the same scenario and the GM work has been extended to more cities, the last step of this analysis will be to compare the results of the studies and determine what is the best estimate available of the future ambient impact of diesel particulate emissions.

V. Comparison of Results

The normalized results of the various studies are contained in Tables 2,4,6, and 8-A through 8-E. Because the projections contained in Table 8 (A-E) include most of the cities examined by the other studies, the Table 8 data will be used as a common ruler, against which the results of the other studies will be compared. The comparison will begin with the GM work, as it will be the simplest comparison and will be followed by the PEDCo three city study and the PEDCo-Kansas City study.

A. GM Study

This comparison is the simplest because the methodology used in Section C is most near that of GM. The city examined both by GM and in Section IV is Chicago. Under the low diesel estimate scenario, GM would have projected a level of 10.9 micrograms per cubic meter while Table 8-A shows 11.2 micrograms per cubic meter (for the monitor examined by GM). As can be seen, these projections are less than 3 percent apart. A brief conversation with GM revealed a few sources of the difference, some compensating others.12/ One, GM used a higher average lead emission factor, 0.13 g/mi versus the 0.11 g/mi factor determined in Section IV-A. Two, GM did not try to take into account sources of lead other than motor vehicles. Thus, the 0.89 factor was not used. Three, their original ambient lead level was slightly higher (3.2 versus 3.0 micrograms per cubic meter) as they used 1970 data13/ rather than 1975 data.7/

GM's higher lead emission factor may be due to the earlier date examined, 1970. The lead content in fuel was decreasing in that time frame.7/ The decision to take stationary source lead emissions into account is really a decision to be conservative or liberal and in this study the choice has generally been to be conservative, if possible. In general, then, the methodologies used by GM and in Section IV seem to be nearly identical and the GM results tend to confirm the results of Section IV. As the latter examines many more cities than the GM work, the results in Table 8 should be sufficient for future studies.

B. PEDCo-New York, Chicago, and Los Angeles Study

The basis of this PEDCo study, like that of Section IV, is the

Table 8-A

Ambient Diesel Particulate Levels* for Urban Areas With A Population Above 1,000,000

City	AQCR #	Ambient Lead, 1975 (ug/m^3)(All Sources)	Ambient Paticulate, 1990 (ug/m^3) "Low Estimate"	Ambient Particulate, 1990 (ug/m^3) "High Estimate"
Chicago	67	1.42	5.29	8.36
	67	3.01	11.22	17.73
Detroit	123	0.99	3.70	5.83
Houston	216	2.09	7.76	12.32
Los Angeles	24	2.68	9.96	15.80
New York	43	1.05	3.90	6.19
Philadelphia	45	1.34	4.99	7.90
	45	1.23	4.56	7.25

* Annual Mean.

Table 8-B

Ambient Diesel Particulate Levels* for
Urban Areas With A Population From 500,000 to 1,000,000

City	AQCR #	Ambient Lead, 1975 (ug/m^3)(All Sources)	Ambient Paticulate, 1990 (ug/m^3) "Low Estimate"	Ambient Particulate, 1990 (ug/m^3) "High Estimate"
Boston	119	0.92	3.41	5.42
Dallas	215	3.03	11.27	17.86
Denver	36	0.95	3.53	5.60
	36	1.59	5.91	9.37
Kansas City, MO	94	0.80	2.61	4.13
New Orleans	106	1.06	3.92	6.24
Phoenix	15	2.10	7.81	12.38
Pittsburgh	197	0.85	3.15	5.01
San Diego	29	1.13	4.21	6.67
St. Louis	70	1.18	4.38	6.95
	70	1.58	5.88	9.32

* Annual Mean.

Table 8-C

Ambient Diesel Particulate Levels* for
Urban Areas With A Population From 250,000 to 500,000

City	AQCR #	Ambient Lead, 1975 (ug/m^3)(All Sources)	Ambient Paticulate, 1990 (ug/m_3) "Low Estimate"	Ambient Particulate, 1990 (ug/m_3) "High Estimate"
Atlanta	56	1.05	3.90	6.18
Birmingham, AL	4	1.22	4.54	7.19
Cincinnati	79	0.81	3.02	4.77
Jersey City	43	1.03	3.83	6.07
Louisville	78	0.96	3.57	5.65
Oklahoma City	184	1.66	6.16	9.78
	184	1.02	3.78	6.00
Portland	193	0.81	3.02	4.77
Sacramento	28	1.05	3.90	6.19
Tucson	15	0.75	2.80	4.42
Yonkers, NY	43	1.16	4.31	6.83

* Annual Mean.

Table 8-D

Ambient Diesel Particulate Levels* for
Urban Areas With A Population From 100,000 to 250,000

City	AQCR #	Ambient Lead, 1975 (ug/m^3)(All Sources)	Ambient Paticulate, 1990 (ug/m^3) "Low Estimate"	Ambient Particulate, 1990 (ug/m^3) "High Estimate"
Baton Rouge	106	0.93	3.46	5.48
Jackson MS	5	0.80	2.97	4.71
Kansas City, KA	94 94	0.60 0.43	2.24 1.60	3.46 2.54
Mobile, AL	5	0.96	3.57	5.65
New Haven, CT	42	1.15	4.28	6.78
Salt Lake City	220	0.98	3.65	5.78
Spokane, WA	62	0.58	2.15	3.42
Torrance, CA	24	2.35	8.74	13.85
Trenton, NJ	45	0.88	3.27	5.19
Waterbury, CT	42	1.88	6.70	11.08

* Annual Mean.

Table 8-E

Ambient Diesel Particulate Levels* for Urban Areas With A Population Under 100,000

City	AQCR #	Ambient Lead, 1975 (ug/m^3)(All Sources)	Ambient Paticulate, 1990 (ug/m^3) "Low Estimate"	Ambient Particulate, 1990 (ug/m^3) "High Estimate"
Anchorage, AK	8	1.00	3.65	4.44
Bethlehem, PA	151	0.57	2.07	2.52
Helena, MO	142	0.29	1.06	1.29
Jackson County, MS	5	0.47	1.67	2.76

* Annual Mean.

use of lead as a surrogate. As such, one would expect the results of the two studies to be similar. However, this is not the case. The PEDCo results for New York are much higher (86-154 percent) than those determined in Section IV as are PEDCo's Chicago results to a lesser extent. A possible reason for this might be the use of different monitors within each city. However, an examination of the actual sites modelled (Tables 6 and 8-A) reveals that two sites, one in New York and one in Los Angeles, were modelled in both studies. In both cases, the PEDCo results were higher, 154 percent (New York) and 18 percent (Los Angeles). The latter error is not large given the type of projections being made here, but the former was too large to ignore and PEDCo's methodology was examined to identify possible sources of the differences.

One primary difference was found between PEDCo's metodology and that used in Section IV. In Section IV, ambient lead levels are modified by two factors, one related to emissions and one related to dispersion characteristics. PEDCo used two similar factors. However, the base ambient lead level was not measured, but calculated from ambient levels of total suspended particulate (TSP). A different constant fraction of TSP levels was assumed to be lead (or lead salts) in each of the three cities, based on referenced studies in New York and Los Angeles. Both of these references were examined.

The Los Angeles study concluded that 13 percent of ambient TSP levels in Los Angeles were automotive-related.14/ It appeared from the wording of the report that this 13 percent only included leaded exhaust particulate and not tire particulate or reentrained road dust.14/ This was also PEDCo's interpretation judging from their use of the 13 percent figure.5/

The New York study, on the other hand, concluded that 20-25 percent of New York's TSP levels were automotive-related.15/ A statistical method was used to correlate ambient TSP levels with ambient lead levels. Rather than express lead levels as a fraction of TSP levels, however, the report's results were actually in terms of an 'x' microgram per cubic meter increase in ambient elemental lead levels coincides with a 'y' microgram per cubic meter increase in TSP levels.15/ This type of analysis would definitely include reentrained dust and other-than-exhaust automotive particulate. However, PEDCo interpretted the report's conclusion to only refer to exhaust (lead-salt) particulate and assumed that 21 percent of ambient TSP levels were lead-containing particulate. This would appear to be the source of the difference between the PEDCo New York results and that of Section IV.

This error can be remedied by determining the actual percentage of TSP levels due to 'exhaust' particulate. A reexamination of the original New York study revealed that about 8 percent of New York TSP levels consisted of lead salts from motor vehicles.15/ As

PEDCo used 21 percent, they overestimated the actual figure by a factor of 2.66. PEDCo's New York results can simply be divided by 2.66 to remove the error and this has been done in Table 9. As can be seen, the modified PEDCo result for the E. 121st St. site is now 6.0 microgram per cubic meter, which compares very well with the Table 8-A result of 6.19 microgram per cubic meter.

Thus, the two studies now compare very well in New York and moderately well in Los Angeles. However, the PEDCo results for Chicago were partly based on the erroneous 21 percent figure used for New York. As no similar study was available for Chicago, PEDCo assumed that Chicago's motor vehicle contribution to TSP levels would be halfway between that of New York and Los Angeles, or 17 percent. Given that the New York percentage is now 8, the same assumption would yield 11 percent for Chicago or a reduction of 35 percent. Thus, the PEDCo results for Chicago should be multiplied by 0.65 to adjust for this error. The adjusted Chicago results are also shown in Table 9. As can be seen by comparing the Chicago results in Tables 8-A and 9, four out of five of the PEDCo monitors fall within the range of the two Table 8-A monitors and agreement can be said to be quite good.

Because this PEDCo study examined a number of monitors in each city, further analysis of the locations of these monitors was performed to determine any possible localized effects due to heavy traffic nearby. Since the modified PEDCo results agree very well with the Section IV results, any conclusion made concerning the PEDCo sites should also apply to the sites modelled in Section IV.

Numerous calls were made to state, local, and EPA regional offices to determine the location of the SAROAD sites modelled by PEDCo. The results are shown in Table 10. EPA guidelines for TSP monitors were published recently and contained minimum distances that a monitor should be located from a road to be representative of large-scale impacts.16/ These minimum distances are 1) 15 meters above and 5 meters away from the road, 2) 2 meters above and 25 meters away from the road, or 3) any point lying on a straight line between these two positions. As can be seen for New York, all five monitors lie well outside these limits. Also, while the traffic counts of the nearest streets are significant, none can be termed 'heavily-travelled' by New York standards. Thus, the projected diesel particulate levels at these sites should be very represenative of large-scale areas and not representative so-called localized impacts.

The Los Angeles sites are generally closer to the road then the New York sites. Two out of four sites for which locations are available meet the EPA guidlines. Again as in New York, none of the nearest roads are exceptionally busy. From an examination of the ambient diesel impacts at these five sites, one finds that

Table 9

Projected Ambient Diesel Particulate Concentrations in 1990
Revised PEDCo Results

City	Site Address	EPA Scenario (ug/m^3) Low	High
New York	Steinman Hall ,W. 141 St and Convent Ave.	3.7	5.7
New York	170 E. 121 St.	3.9	6.0
New York	Central Park Arsonal, 5th Ave., and 64th St.	3.6	5.5
New York	240 2nd Ave.	4.6	7.1
New York	Pier 42, Morton St. and Hudson River	4.4	7.0
Torrance, Los Angeles	2330 Carson St.	9.6	14.9
Long Beach, Los Angeles	2655 Pine Ave.	10.0	15.4
Los Angeles	434 S. Pedro	12.0	18.7
Pasadena	1196 East Walnut	10.1	15.6
Pasadena	Kech Laboratories, Cal. Inst. of Tech.	11.0	17.1
Chicago	3500 E. 114 St.	17.3	26.9
Chicago	1947 W. Polk	8.5	13.2
Chicago	9800 S. Torrence Ave.	9.3	14.4
Chicago	538 S. Clark St.	8.8	13.7
Chicago	4015 N. Ashland Ave.	7.3	11.3

Table 10

Saroad Monitoring Sites

City	Site Address	SAROAD Code	Elevation Above Ground	Distance From Large Road	Vehicle Count (Vehicle/day)	Comments
New York	Steinman Hall W. 141 St., and Convent Ave.	334680057F01	22.9 m (75 ft.)	91.5 m (300 ft.)	12,100	
New York	170 E. 121 St.	334680014P01	22.9 m (75 ft.)	30.5 m (100 ft.)	16,500	
New York	Central Park Arsonal, 5th Ave., and 64th St.	334680005H01	13.73 m (45 ft.)	30.5 m (100 ft.)	17,900	
New York	240 2nd Ave.	334680010H01	18.3 m (60 ft.)	15.25 m (300 ft.)	26,600	Air Resource Board lists 27.45m (90 ft.) above ground.
New York	Pier 42 Morton St., and Hudson River	?	7.63 m (25 ft.)	91.5 m (300 ft.)	16,800	City lists 4.58m (15 ft.) above ground.
Torrance, Los Angeles	2330 Carson St.	058260001P01	1.22 m (4 ft.)	Not Available	15,000	
Long Beach, Los Angeles	2655 Pine Ave.	05410001F01	7.63 m (25 ft.)	1.83 m (6 ft.)	15,000	
Los Angeles, Los Angeles	434 S. Pedro	054180001I01	27.4 m (89.8 ft.)	5.0 m (16.4 ft.)	13,500	
Pasadena, Los Angeles	1196 East Walnut	055760004I01	5.5 m (18 ft.)	17 m (55.7 ft.)	18,000	

Table 10 (con't)

PEDCo TSP Monitoring Sites

City	Site Address	SAROAD Code	Elevation Above Ground	Distance From Large Road	Vehicle Count (Vehicle/day)	Comments
Lennox, Los Angeles	11408 La Cienega Blvd.	05390000I01	7.0 m (23 ft.)	19 m (62.3 ft.)	25,000	
Chicago	3500 E. 114 St.	14122002H01	9.46 m (31 ft.)	24.4 m (80 ft.)	Not Available	
Chicago	1947 E. Polk	141220033F01	4.57 m (15 ft.)	30.5 m (100 ft.)	4,674	
Chicago	9800 S. Torrence Ave.	141220005H01	4.88 m (16 ft.)	21.35 m (70 ft.)	9,400	
Chicago	538 S. Clark St.	141220005H01	39.9 m (133 ft.)	9.15 m (30 ft.)	11,600	
Chicago	4015 N. Ashland Ave.	141220004H01	19.2 m (64 ft.)	3.6 m (12 ft.)	25,100	

the largest impact is at the San Pedro site, which is the furthest from the least-travelled road. From this observation, it would be difficult to argue that the other sites were overly influenced by heavy traffic. The result for Los Angeles, then, is the same as that for New York, the monitors appear to be very representative of large-scale impacts.

The Chicago monitors are slightly more difficult to analyze. Four out of five are within the EPA guidelines, though two of these four monitors (Polk and Torrence) are quite near lightly-travelled streets. The Clark St. monitor, on the other hand, is well away from a lightly-travelled street. The impact at this monitor (Table 9) is no different than that at the three monitors which are nearer the road. Only the 114th Street monitor has an usually high impact associated with it. This monitor is actually quite far from the street, though the exact traffic count of the street is not known.As PEDCo's methodology was based on TSP levels, the TSP level at this site was twice that of the others in Chicago and upon investigation was found to be 165 micrograms per cubic meter.5/ It cannot be determined whether the motor vehicle contribution at this monitor is also twice that at the other four monitors. However, as the resulting diesel particulate level is almost 50 percent higher than that at any other monitor in any city, it appears likely that something unusual is occurring at that monitor. The use of the 114th Street projection should therefore be used with caution. Otherwise, the results of the other four monitors appear to be free from local impacts like heavy traffic nearby and should be representative of large-scale impacts.

Given that the great majority of the monitors examined by PEDCo appear to be representative of large-scale impacts and the modified PEDCo results closely match those of Section IV, it would seem reasonable to assume that the great majority monitors examined in Section IV are also representative of large-scale impacts. As such, either set of projections could be used to project ambient diesel particulate impacts over large-scale urban areas.

C. PEDCo-Kansas City Study

The final comparison to be performed is between the PEDCo-Kansas City results (Table 2) and the projection for Kansas City developed in Section IV (Table 8-B). As can be seen, the PEDCo projections are less than half those in Table 8-B. Somewhat aggrevating this difference is the fact that the Section IV projection for Kansas City, MO., is the lowest to be found in Tables 8-A, 8-B, and 8-C. In other words, with respect to the impacts in other large cities, the Section IV Kansas City impact appears to be too low rather than too high.

Given this and the fact that the impacts shown in Table 8 are consistent with PEDCo's three city study and GM's work, it would appear that PEDCo underestimated the diesel's impact in Kansas

City. This criticism in fact, has already been made in a previous comparison of carbon monoxide and diesel particulate emissions in Kansas City.17/ The problem most likely lies with the use of AQDM, which would be expected to underestimate line sources, such as motor vehicle.18/ Because of the discrepancy between PEDCo's Kansas City results and that of the other studies, the impacts shown in Table 2 should not be used as valid projections of future diesel impacts.

VI. Conclusions

1. In the PEDCo-Kansas City study, the use of AQDM had probably underestimated future ambient particulate levels from diesel emission in Kansas City.

2. In the PEDCo three-city study, an error was made that overestimated the impacts in New York and Chicago. After correction of this error, however, the resulting impacts appear to be reasonable for further use. In addition, the locations of the monitors modelled were such that the projections should be representative of large-scale urban impacts.

3. The GM work has been repeated, essentially confirmed, and extended to many other cities in the U.S. Along with the PEDCo three-city results, these Section IV projections appear to be among the best available and could be used in further studies.

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