TRUCK TRAFFIC FUGITIVE CONTROL STRATEGY AND MONITORING PLAN

ADM Haul Roads

ADM Corn Processing
Columbus, Nebraska

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I. Objective:

This plan outlines the road silt loading management plan for the new dry mill to be constructed at the ADM Corn Processing – Columbus Facility. .

II. Basis:

All roads that support daily production related traffic are, or will be paved.

III. Control Methods and Frequency:

a. Vacuuming of Facility Roads:

All paved roads that support daily production related truck traffic on site will be cleaned, using a vacuum sweeper, three (3) times a week. Typically this sweeping will be performed once per day on Monday, Wednesday and Friday, excluding holidays or other non-business days.

Facility roads will be cleaned more frequently using a vacuum sweeper, only if heavy construction traffic occurs and facility roads are deemed to warrant such cleaning. Road cleaning/vacuuming as described above may not be done where rain, snow or other adverse weather events are deemed not to warrant such cleaning. These conditions include days where:

- Ambient air temperature drops below 32°F
- A precipitation event of greater than 0.1 inches of rain or snow

b. Paving of New Roads:

Any non-paved roads added to the facility that will support routine daily process traffic will be paved within 6 months after construction has been completed in that area. Roads intended for non-routine traffic (e.g. contractors. plant vehicles) shall not be subject to this requirement. A request for an extension and/or variance must be made to the NDEQ 30 days prior to the end of the 6-month period.

IV. Compliance Demonstration

The basis for the emissions analysis is a silt-loading of 4 g/m^2. It is ADM's understanding that silt loading need not be monitored if the basis for the permit application is at or above 3 g/m^2.

Should silt-loading testing be deemed necessary at some future date, silt-loading will be tested between the months of April and October. ADM will sample silt loading for a one-month period collecting 1 sample per week. Sampling and analysis will be conducted as described in this document and per EPA AP-42, Section 13.2.1, Appendix C.1, Procedures for Sampling Surface/Bulk Dust Loading, July 1993 (Reformatted January 1995) and in addition EPA AP-42, Section 13.2.1 Appendix C.2, Procedures for Laboratory Analysis of Surface/Bulk Dust Loading Samples, July 1993 (Reformatted January 1995). The average of the weekly samples for each location will be compared with silt loading rates determined to ensure compliance with ambient air quality standards.

The purpose of this section is to ensure the quality and consistency of the silt loading data obtained from the production haul roads at ADM Corn Processing. As the sampling site is an industrial paved haul road, the safety of the sampling team shall always be a priority, and team members need to be aware of traffic and other dangerous conditions. If necessary, a spotter can be used to assist the sampler in watching for oncoming vehicles.

Surface samples will be taken once per week no earlier than 24 hours after a sweeping event. Sampling will only be commenced on days that meet the same criteria noted in Section III.a. of this plan. A record of the sweeping events, as well as pertinent details about weather and road conditions and any modifications to the sampling schedule (e.g., because of snow on the road) will be documented.

Surface silt sampling will be performed by in-house personnel using a Hoover or equivalent upright vacuum cleaner at 3 pre-selected locations (Sites A, B, and C). The sampling sites will be marked on the road with paint, as shown in Figure 1. The Site A sampling area measures approximately 6.7 meters (m.) long and 2.24 m. wide, and is located 285 m. north of East 8th Street. Site B measures approximately 21.2 m. long by 0.71 m. wide, and is 28 m. south of Utilities Rd. approaching the corn unloading facility. Site C is located 76 m. south of Utilities Rd. on Jurgenson Drive, and measures approximately 7.0 m. by 2.15 m. Each sample area is approximately 15 m^2. The 3 sample increments will be collected into the same vacuum bag, resulting in a composite silt loading value for the entire haul road.

a. Sampling Procedure

Surface sample identification numbers will follow the format "mmddyy", indicating the date on which the sample was taken. Prior to collecting a surface sample, a Hoover Type A or equivalent bag must be tare weighed, and the weight and sample number recorded on a Silt Analysis Dataform (Figure 2). The sample identification number should also be written on the bag itself. Put the tared vacuum bag into a sealable, plastic bag. Transport the following items to the first sampling location (Site A):

- Vacuum sweeper
- Tared vacuum bag
- Generator (if necessary)
- Extension cord

- Tape measure
- Whisk broom and dustpan
- Extra sealable, plastic bag (for broom swept material)
- Paved Road Sampling Dataform (Figure 3)

Install the vacuum bag into the sweeper at the first sampling site. Fill out the top of the Paved Road Sampling Dataform. If heavy surface loading or large material is present in the sampling area, collect the large material using the whiskbroom and dustpan, and place the material into a plastic bag. Sweep the sampling area with the vacuum sweeper. A recommended method for sweeping is as follows:

- Start at a corner of the sampling area near the curb, facing across the road.

- Vacuum toward the center of the road, using overlapping strokes while moving laterally along the curb to the other corner.

- Note the distance that the vacuum travels across the road on each stroke, it will generally be about a meter, and try to keep this length consistent as you sweep.

- When you reach the other corner, step into the road to the point at which the vacuum has sampled, and resume sweeping while moving laterally back the other way.

- Continue this procedure until you have reached the other side of the road and completely swept the sampling area.

On the bottom part of the data form, indicate the time the sample was taken at Site A, the sampling area dimensions, and whether or not any broom swept material was collected. Also note the number of traffic lanes, the road surface condition, and any unusual situations (e.g., road has been sanded recently because of snow) that exist. Repeat the above collection procedures at Sites B and C.

Carefully remove the vacuum bag from the sweeper. Gently shake the collected material to the bottom of the bag, and fold/roll down the top of the bag so the sample material cannot fall out. Put the bag back into its sealable, plastic bag, and take it to the lab for analysis, along with any broom swept material.

b. Analytical Procedure

The laboratory balance used to weigh the vacuum bags and the sieves is an Ohaus model GT4100 or equivalent. Record the laboratory balance information (make, capacity, smallest division, and date of last calibration) on the Silt Analysis Data Form. An analytical balance calibration check should be performed and documented (Figure 4) prior to each analysis. Weigh the vacuum bag containing the collected sample, and

record this vacuum bag gross weight and the weight of the broom swept material, if any, on the data form.

Select the appropriate 8-inch diameter sieves. Suggested sizes are No. 20, No. 40, No. 100, No. 140, and No. 200. The No. 20 and No. 200 are mandatory; the others can be varied if the recommended sizes are not available. Clean the sieve screens with a soft brush to remove material lodged in the mesh. Weigh the sieves and pan, and record the weights on the Silt Analysis Data Form. Check the balance zero before each weighing. Nest the sieves in decreasing order of mesh size, with the pan on the bottom.

Carefully dissect the vacuum bag by opening it at the top, bottom, and along the side. Brush the collected material into the top sieve, along with any broom swept material. Weigh and record the vacuum bag empty weight on the data form. Calculate the total net sample weight, and record it on the form, as well. Put the cover on the sieve stack, and place the stack in the shaker. Set the dial on the front of the shaker to "8".

Sieve the sample for 10 minutes. Remove and weigh the pan containing the <200-mesh material. Record the weight on the data form. Repeat the sieving at 10-minute intervals until the difference between 2 successive pan weighings (with the pan tare weight subtracted) is less than 3.0% of the total mass collected in the pan. Do not sieve for longer than 40 minutes.

When the sieving is complete (either < 3.0 % difference or 40 minutes total time), final weigh each sieve containing sample material and record the weight on the data form. Again, check the balance zero before each weighing. Calculate the net weight for each size fraction, and the resulting percentage of total net sample. After weighing place the sample in a plastic storage bag and label <200-mesh, the date the sample was analyzed and initials. Bag should be saved in a designated location for the entire testing period and thereafter if deemed necessary.

Determine the silt percentage by using the following equation:

$$\% \text{ Silt} = \frac{\text{Net Weight} < 200 \text{ Mesh}}{\text{Total Net Sample Weight}} \times 100$$

Record the silt percentage on the data form. Also calculate and record the total sample area (m^2), the silt loading (g/m^2), and the total surface loading (g/m^2). Silt loading and total loading are calculated as follows:

$$\text{Silt Loading} = \frac{\text{Net Weight} < 200 \text{ Mesh}}{\text{Sample Area}}$$

$$\text{Total Loading} = \frac{\text{Total Net Sample Weight}}{\text{Sample Area}}$$

Results of the monthly sampling will be submitted to the NDEQ within thirty days of the last monthly sampling day. If results of this sampling exceed the aforementioned silt loading factor, within sixty-days of the completion of test, ADM will submit a revised control strategy plan or submit a revised model based on the sampling results which demonstrates compliance with the increment and NAAQS standards. If ADM establishes increment compliance with the revised silt loading factor within that sixty-day period, the exceedance shall not be deemed an enforceable condition.

V. Recordkeeping:

ADM Corn Processing will maintain records for five years of: (1) all road cleaning activities required under section III above; and (2) all monitoring required under Section IV above.

VI. Revision of Plan:

Revisions to this plan. including those based on changed operation of the facility, monitored results. changes to underlying modeling, and evaluation of alternative cleaning methods and frequencies will be submitted to NDEQ 30 days prior to implementation.

FIGURE 1: FACILITY ROAD MAP

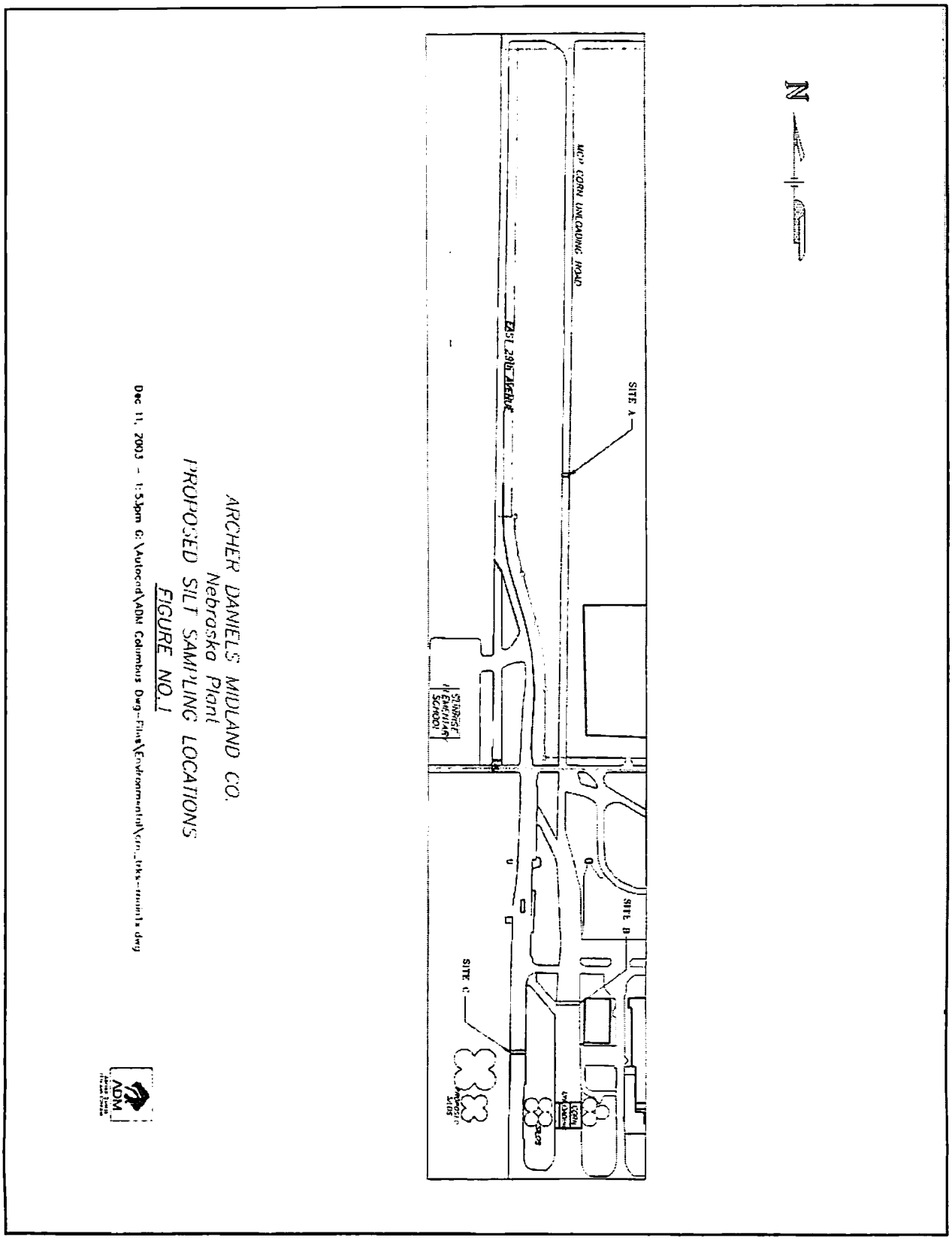

FIGURE 2: SILT ANALYSIS DATAFORM

ADM – Columbus, NE
(all weights in grams)

Analysis Date: _____

Performed By: _____

Vacuum Cleaner Make/Model: _____

Sample No.: _____

Vacuum Bag Tare Wt.: _____

Material: Road Dust

Vacuum Bag Gross Wt. **(A)**: _____

Broom Swept Material Wt. **(B)**: _____

Balance Make: Ohaus GT 4100

Vacuum Bag Empty Wt. **(C)**: _____

Capacity: 4100 g

Total Net Sample Wt. **(A+B-C)**: _____

Smallest Division: 0.01 g

%Silt = $\frac{\text{Net Wt.} < 200 \text{ Mesh} \times 100}{\text{Total Net Wt.}}$ = _____

Date of Last Calibration: _____

Sieving

Start Time:	Weight (Pan Only)
Initial (Tare)	
10 min	
20 min	
30 min	
40 min	

Screen	Tare Wt. (Screen)	Final Wt. (Screen + Sample)	Net Wt. (Sample)	% of Total Net Sample
3/8 inch				
4 mesh				
10 mesh				
20 mesh				
40 mesh				
100 mesh				
140 mesh				
200 mesh				
Pan				

Sample Area (m^2)	
Silt Loading < 200 mesh (g/m^2)	
Total Loading (g/m^2)	

FIGURE 3: PAVED ROAD SAMPLING DATAFORM

ADM – Columbus, NE

Sampling Date: _____ Performed By: _____

Sample No.: _____ Surface Type (e.g., asphalt, concrete): _____

Sampling Method:

1. Sample device: portable vacuum cleaner (broom sweep first if loading is heavy)
2. Sample depth: loose surface material
3. Sample container: tared and numbered vacuum cleaner bag
4. Gross sampling specifications:
    a. 1 sample increment from each of 3 sites (A, B, and C)
    b. Do not sample curb areas
5. Procedure: sweep gross particles into container, vacuum area
6. Samples are retained as follows:
    a. swept samples in plastic bags
    b. vacuumed samples in original vacuum bag sealed in a plastic bag

Indicate deviations from above method:

Sampling Data

Site	Time	Surface Area*		Broom Swept?	No. of Traffic Lanes	Surface Condition
		Width	Length			
A						
B						
C						

* indicate whether units are in feet or meters.

Comments:

FIGURE 4: ANALYTICAL BALANCE CALIBRATION CHECK

ADM – Columbus, NE

Ohaus Weight Set	**Ohaus Model GT 4100 Ser. No. 1302**
100g	
200g	
500g	

Analyst: _____ Date: _____

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Resolving Local-Scale Emissions for Modeling Air Quality near Roadways

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ABSTRACT
A large body of literature published in recent years suggests increased health risk due to exposure of people to air pollution in close proximity to roadways. As a result, there is a need to more accurately represent the spatial concentration gradients near roadways to develop mitigation strategies. In this paper, we present a practical, readily adaptable methodology, using a "bottom-up" approach to develop a detailed highway vehicle emission inventory that includes emissions for individual road links. This methodology also takes advantage of geographic information system (GIS) software to improve the spatial accuracy of the activity information obtained from a Travel Demand Model. In addition, we present an air quality modeling application of this methodology in New Haven, CT. This application uses a hybrid modeling approach, in which a regional grid-based model is used to characterize average local ambient concentrations, and a Gaussian dispersion model is used to provide texture within the modeling domain because of spatial gradients associated with highway vehicle emissions and other local sources. Modeling results show substantial heterogeneity of pollutant concentrations within the modeling domain and strong spatial gradients associated with roadways, particularly for pollutants dominated by direct emissions.

IMPLICATIONS
This paper presents a generic, readily adaptable method for developing emission inventories and conducting air quality modeling in an urban area to improve the characterization of pollutant concentrations near roads. Application of this methodology will help assess mitigation strategies to address elevated pollutant concentrations near roads and resultant adverse health effects.

INTRODUCTION
A large body of literature, much of it published in recent years, suggests increased risks for exacerbation of asthma and other respiratory diseases, premature mortality, certain cancers, and adverse birth outcomes from air pollution exposures in populations residing in relatively close proximity to roadways.[1,2] Furthermore, several air quality monitoring studies have revealed the presence of elevated concentrations of pollutants emitted directly by motor vehicles near major roadways when compared with overall urban background levels.[3–8] These elevated concentrations generally occur within a few hundred meters of the road, although this distance may vary depending on traffic patterns, environmental conditions, and the presence of near-roadway urban structures. Pollutants with elevated concentrations measured near major roadways include coarse, fine, and ultrafine particulate matter (mass and particle number), black carbon (BC), polycyclic aromatic hydrocarbons, carbon monoxide (CO), oxides of nitrogen (NO_x), and benzene.

Air quality modeling can provide a linkage between emissions from activity on roadways and resultant air concentrations. Establishing such linkages is critical for transportation planning and developing mitigation strategies. Thus, environmental and transportation planning officials are increasingly interested in developing more accurate geographic representations of highway vehicle emissions in regional and urban-scale assessments, to better identify where air quality is most impacted by traffic as well as populations likely to experience elevated health risks from air pollutant exposure occurring along roadways. Current approaches for characterizing ambient air pollutant concentrations at an urban scale rely on developing a detailed emissions inventory and applying a dispersion model, such as the American Meteorological Society/U.S. Environmental Protection Agency (EPA) regulatory model (AERMOD), which can simulate large

gradients in modeled ambient concentrations of toxic pollutants in urban areas.[9]

In the past, air quality modelers relied on data from national inventories, such as EPA's National Emission Inventory (NEI) for emission inputs to be used with air quality models. These inventories typically rely on a "top-down" approach to estimate highway vehicle emissions. Under a top-down approach, emissions are estimated at the county level, typically starting from more aggregated information (e.g., state or national level). Spatial surrogates, thought a priori to correspond with activities that produce emissions, are then used to allocate emissions to grid cells or Census tracts for modeling. Air quality modeling using such inventories can be useful in elucidating patterns of ambient concentrations across broad geographic areas, and can help characterize air quality trends and potential impacts of controls at a broad geographic scale.[2,10,11] However, such inventories are often inadequate in identifying spatial gradients of pollutant concentrations resulting from highway vehicle activity, and locations where the highest risks are likely to occur. Thus, several recent studies have used "bottom-up" approaches, which rely on more local inputs to estimate better motor vehicle emission factors and vehicle counts or activity data from a metropolitan area's travel demand model (TDM), to develop a more accurate geographic representation of motor vehicle emissions.[12–14]

These bottom-up approaches provide greater power to predict the actual location of emissions. Such approaches use similar traffic data as studies that have predicted ambient concentrations of mobile source-related pollutants using land use regression. These studies report that ambient concentrations of mobile source-related pollutants such as benzene, formaldehyde, fine particulate matter ($PM_{2.5}$), and BC are associated with traffic within several hundred meters of an ambient monitor.[15,16] This suggests that using similar traffic-related variables, such as traffic, population, and industrial land use to predict the location of motor vehicle emissions may improve the predictive capacity of urban-scale air quality models.

In this paper, we present a readily adaptable methodology using a bottom-up approach to develop a detailed highway vehicle emission inventory that includes emissions for individual road links. This method also uses geographic information system (GIS) software to improve the spatial accuracy of the activity information obtained from a TDM model. In addition, we present an application of this methodology to New Haven, CT, a small urban area with typical emission sources. Figure 1 depicts the modeling domain, including locations of major roads. The red dots represent the location of major sources that emit greater than 10 t/yr of any pollutant, and the black dots show the location of the centroids for individual U.S. Census block groups (a Census block group is a combination of Census blocks, which are the smallest geographic areas for which the U.S. Census Bureau collects data.) As shown in Figure 1, there is a dense network of roadways in the New Haven modeling domain, and most of the Census block group centroids are located close to the roads. This illustrates the importance of characterizing the near-road impacts in modeling assessments.

Air quality modeling using this detailed highway inventory was done using a hybrid approach.[17,18] Although numerical photochemical grid models are the model platform of choice for simulation of atmospheric chemistry and fate of airborne pollutants on a larger scale, there are various transport and dispersion models that have been

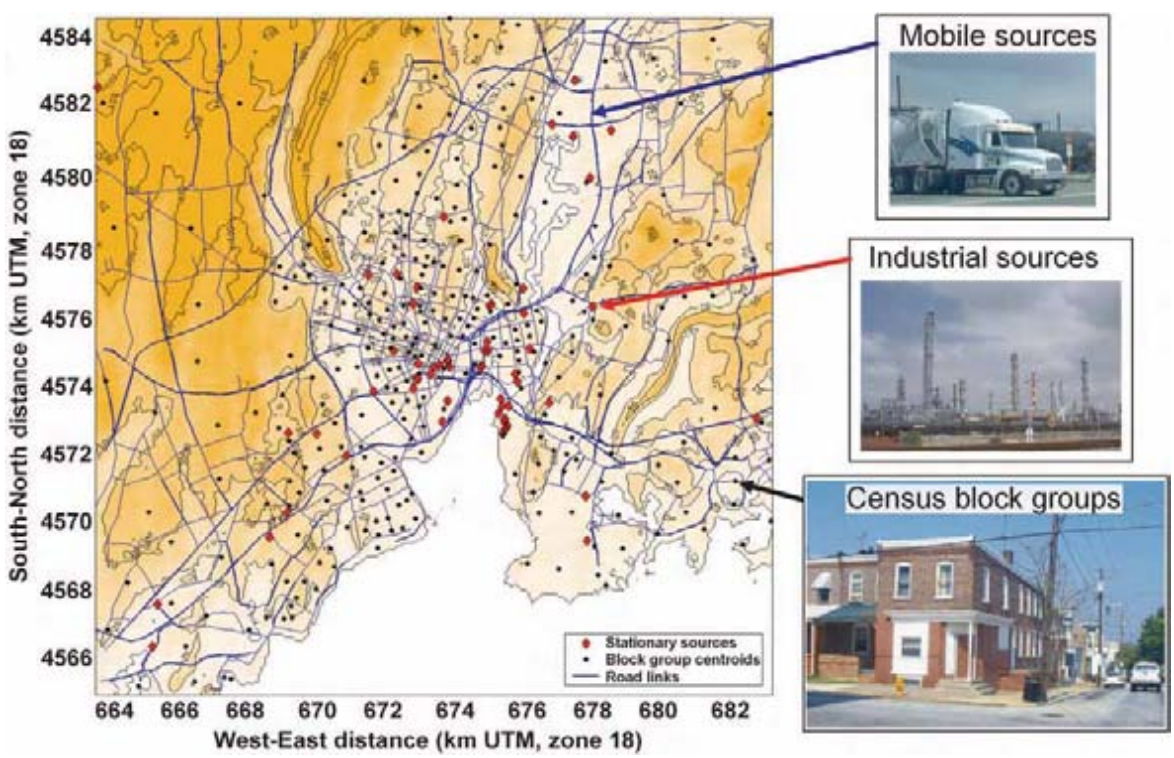

Figure 1. New Haven modeling domain, including major sources and road locations.

developed to simulate the fate of those airborne pollutants that are relatively chemically inert. Although lacking detailed atmospheric chemistry, dispersion models can provide detailed resolution of the spatial variations in hourly-average concentrations of airborne pollutants. To date, local-scale dispersion models have been used to provide the desired detailed description of the concentration pattern. However, local-scale dispersion models cannot properly treat photochemically generated pollutants. Also, an estimate of background concentrations must be provided to local-scale models; these can be provided directly by the grid model. Combining the capabilities of numerical photochemical models and dispersion models into one model is desirable, but this is a yet evolving area of research and development.

In this study, the hybrid approach used existing results from the Community Multiscale Air Quality (CMAQ) grid model and the AERMOD dispersion model to simulate concentration gradients in the modeling domain.[19,20] CMAQ provides volume-average concentration values for each 12- × 12-km grid cell in the modeling domain, given stated conditions that can change hourly. Emissions are assumed to be instantaneously well mixed within the cell where they are emitted. In contrast, AERMOD provides detailed resolution of the spatial variations in hourly-average concentrations of airborne pollutants because of the improved spatial emission allocations. Results of both model simulations can be combined to provide the total ambient concentrations. The study relied on detailed information from the bottom-up inventory for highway vehicle exhaust and evaporative running emissions on roads, as well as local point sources, marine port, and airport emissions data, to provide this resolution. Emissions of area sources and nonroad sources not associated with ports and airports were assumed to be uniformly distributed across grid cells. These emissions are allocated to grid cells using surrogates such as population and land use. However, data that could significantly improve allocations within grid cells were not readily available. Although this study is based in one city, the methodologies developed through this project will have broader application to other urban areas within the United States where vehicle activity data from TDMs are available.

METHODOLOGY TO CREATE LINK-BASED EMISSIONS INVENTORY

This methodology allows us to create a spatially and temporally resolved emissions inventory for mobile sources (i.e., hourly emissions for all pollutants modeled, by vehicle class, by road link).

The total emissions are calculated from emission factors multiplied by traffic activity for each link:

$$E_i(s) = EF_i(s) \times A(s) \tag{1}$$

where $E_i(s)$ is the emission rate (mass per unit of time) for pollutant i from a source (or road link) s, $EF_i(s)$ is the emission factor (mass per unit of activity) for pollutant i from source s, and $A(s)$ is the activity level for source s (e.g., vehicle miles traveled [VMT]) over a given time.

In this process, emission factors are representative for a vehicle class in the study area and are a function of speed, temperature, and road type (e.g., freeway, arterial). Traffic activity level is the VMT by vehicle classes on each link over a given time interval. Therefore, three major inputs are required to develop a bottom-up highway vehicle inventory for exhaust and evaporative running emissions that are primarily emitted on major roadways. These are:

(1) locations of individual road links;
(2) traffic activity by vehicle class on those links; and
(3) emission factors by vehicle class.

Location of Individual Road Links

In this study, the geographic database and associated attribute data used to create the link-level road network for the New Haven area were obtained from the Connecticut Department of Transportation (CDOT). The data were developed using the TRANPLAN (TRANSportation PLANning) four-step travel demand integrated model (www.citilabs.com/tranplan/). This database contains information on all major roads, and roadway activity data is output in the form of average annual daily traffic (AADT) for each road link. Other output from TRANPLAN are average speed for each road link during peak and offpeak periods, coordinates of the segment endpoints (nodes), roadway type, and number of lanes. Speeds from TRANPLAN were used to develop link-specific emission rates.

Although use of TDM data greatly improves geographic representation of emissions over top-down approaches that rely on spatial surrogates, a significant limitation for air quality modeling purposes in populated areas is that TDM data represent curvilinear roads as one or more straight line segments. A single model link may represent more than one road in the actual transportation system and links can intersect where none exist. As a result, misalignments with actual road locations of up to several hundred meters can occur.[21] Because recent research has found strong spatial gradients of pollutants near roads that are localized within a few hundred meters,[22–24] mislocation of roads can result in large errors in estimating ambient concentrations at receptors. Potential misalignment of road locations can be addressed by merging the TDM dataset with a geographic dataset with better spatial accuracy. Merging two geographic datasets to produce an improved target dataset is known as conflation and is used here to combine attributes from the TDM (AADT, speed) with the better spatial accuracy of the U.S. Census Topographically Integrated Geographic Encoding and Referencing (TIGER) 2000 road network. TIGER is readily available from the U.S. Census Bureau.[25] This approach was used in development of the Mobile Emission Assessment System for Urban and Regional Evaluation (MEASURE) under a cooperative agreement between the Georgia Institute of Technology and EPA.[26]

Overlaying the datasets in the GIS (ArcInfo) showed enough spatial similarities existed that a link-by-link assignment could be established. Individual travel model links were selected as source features and the corresponding accurate road segments were selected as target features that then assigned the link attributes to the TIGER road

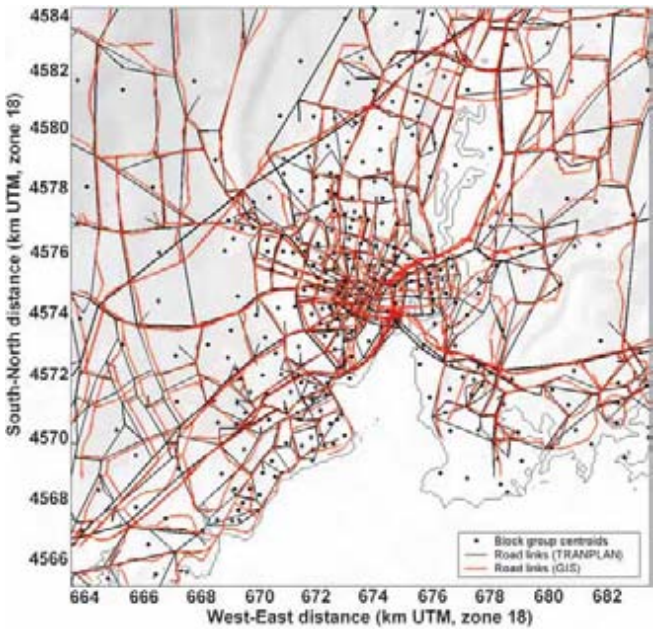

Figure 2. New Haven road links from TRANPLAN vs. TIGER road segments, along with centroids for individual U.S. Census block groups.

segments. Figure 2 compares the locations of the New Haven road links from TRANPLAN and TIGER, along with centroids for individual U.S. Census block groups. If sufficient resources are available, spatial accuracy of an urban scale assessment can be improved even more by transferring activity data to a global positioning system (GPS)-validated network. GPS-derived road network databases have greater spatial accuracy than TIGER. In the Southern California Children's Study, activity data were transferred to a GPS-validated network.[21]

Traffic Activity on Road Links

To determine activity level on each link, we used the TRANPLAN database for calendar year 2002, which consists of a roadway type indicator, directional AADT values, number of lanes, and average speed. Directional AADT values were summed and multiplied by the roadway segment length to obtain daily VMT values. Daily VMT was allocated to eight individual vehicle classes by roadway type using estimated fractions of VMT for each vehicle class obtained from CDOT. These eight vehicle classes are (1) HDDV, heavy-duty diesel vehicles; (2) HDGV, heavy-duty gasoline vehicles; (3) LDDT, light-duty diesel trucks; (4) LDDV, light-duty diesel vehicles; (5) LDGT1, light-duty gasoline trucks 1; (6) LDGT2, light-duty gasoline trucks 2; (7) LDGV, light-duty gasoline vehicles; and (8) MC, motorcycles. MOBILE6.2 estimates emissions for 28 vehicle classes, which can be aggregated into these eight broader classes in the output.

Because emission factors are estimated only on a monthly basis, and activity is estimated by TRANPLAN as annual average daily traffic, activity must be allocated to time of day and time of year. Seasonal temporal profiles were obtained from an ancillary file developed for the Emission Modeling System for Hazardous Air Pollutants (EMS-HAP) database, and were based on data developed for regional emission modeling studies under the National Acid Precipitation Assessment Program (NAPAP).[27] The temporal profiles were specific to vehicle type (across all road types), season, hour of day, and day of week (weekday, Saturday, or Sunday). Multiplying the annual average daily traffic count by the temporal profiles allocated the traffic counts to the appropriate season, hour of day, vehicle, and day of week.

Emission Factors

The two primary emission factor models used for highway vehicles in the United States are MOBILE6.2 and EMission FACtors (EMFAC). The latter model is used in California, and MOBILE6.2 is used throughout the rest of the United States.[28,29] However, EMFAC emission factors represent entire vehicle trips whereas MOBILE6 has more flexibility to estimate link-specific emission rates. Thus, the use of EMFAC presents challenges in modeling emissions at the link level.[30] In this study, we used MOBILE6.2 to generate an emission factor "look-up" table for calendar year 2002 that provides running exhaust and running evaporative emission factors for each of the vehicle classes as a function of speed and temperature. This was done using MOBILE6.2's spreadsheet output option, which produces output from batch runs in a tab-delimited ASCII file. Emission factors also vary by road type (freeway and arterial), so the average emission rate at a given speed and temperature was estimated as an average of emission rates for the individual road types. Nonrunning emissions are not associated with roadway links, and thus were not included in the table. Brake and tire wear particulate emissions for coarse particulate matter (PM_{10}) and $PM_{2.5}$ were included.

Both speed and temperature significantly impact emission rates from highway vehicles. Figures 3 and 4 provide examples for benzene, formaldehyde, CO, and NO_x in calendar year 2002. The impacts of speed and temperature shown in these examples are consistent with those observed in other analyses.[31,32] It should be noted that in MOBILE6.2, there are no speed or temperature effects for PM emissions.

Figure 3 illustrates the variability of emission factors by vehicle class as a function of vehicle speed for four pollutants in New Haven. These factors vary considerably by vehicle class and pollutant. In general, fleet average emission factors for gaseous air toxics are higher at lower speeds. Emissions factors for CO and NO_x increase at both low and high speeds. HDDVs experience a large increase in NO_x emissions at high speeds. Figure 4 shows the emission factors by vehicle class as a function of ambient temperature for various pollutants. Emission factors for gaseous air toxics are high at low and high ambient temperatures. It should be noted that recent research indicates that emissions of gaseous air toxics from gasoline vehicles with advanced emissions control technology are much higher at low temperatures than currently estimated by MOBILE6.[2] CO shows a very large dependence on temperature for gasoline vehicles; in contrast NO_x shows little effect. Temperature has no effect on diesel emissions in MOBILE6.

Input files for MOBILE6.2 for 2002 were obtained from the CDOT. In addition to these input files, modeling

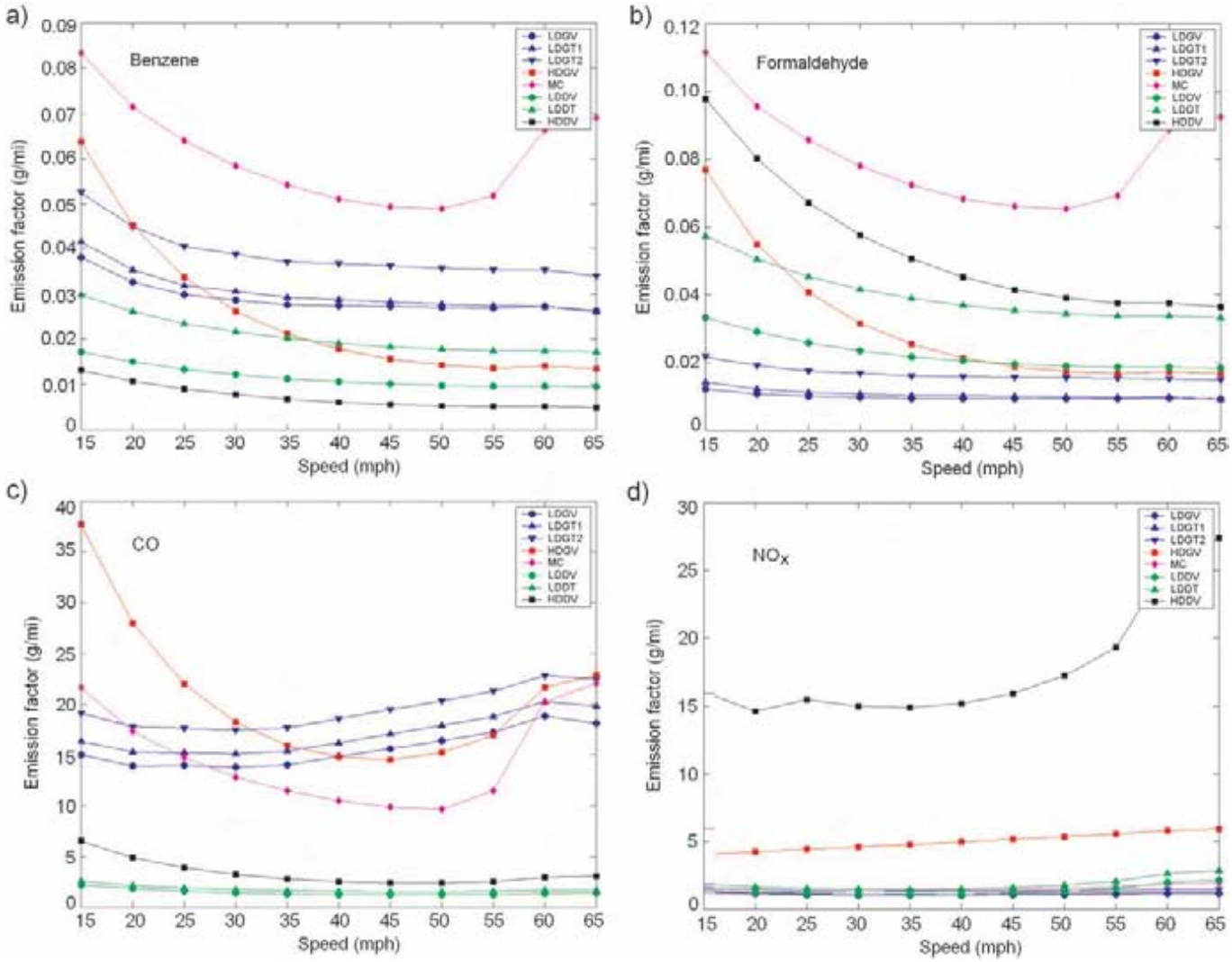

Figure 3. Emission factors by vehicle class as a function of speed for various pollutants—(a) benzene, (b) formaldehyde, (c) CO, and (d) NO_x—for New Haven, CT, 2002.

of air toxics using MOBILE6.2 requires additional fuel parameters not needed for modeling those pollutants for which EPA has the National Ambient Air Quality Standards (NAAQS) for pollutants such as PM_{10}, $PM_{2.5}$, NO_x, sulfur dioxide (SO_2), and CO. These fuel parameters include aromatics level, benzene level, olefin level, and percentage of gasoline evaporated at 200 and 300 °F (E200 and E300). Seasonal properties are available from surveys of gasoline stations. For New Haven, such data were collected as part of the Federal Reformulated Gasoline program.[33]

Calculation of Link-Level Emissions

Using hourly traffic activity and emission factors described in previous sections, the hourly emissions by vehicle class for each of the air toxics for individual links are calculated using eq 1. In this process, emission factors are matched by speed on any specific road link and by temperature for each hour. This procedure is repeated for each of the vehicle classes.

The approach described above can be used in any area of the United States with link-level vehicle activity data. In addition, a tool to obtain the emission rates at the link level has been developed for the Great Lakes Region. This tool, the Consolidated Community Emissions Processing Tool (CONCEPT),[34] is freely available and can significantly reduce the time and resources needed to develop a detailed highway inventory for states in that region as outlined in this paper. Spatial resolution of an inventory developed using CONCEPT could also be enhanced using the GIS approach outlined above.

MODELING APPLICATION IN NEW HAVEN, CT

To illustrate how this methodology can be used to create link-based emissions for near-road modeling applications, we conducted a modeling demonstration of these link-based emission techniques in New Haven, CT. The New Haven modeling effort is part of a broader feasibility study to evaluate impacts of regulatory and voluntary actions to reduce air toxic emissions. New Haven is one of EPA's nationally funded Community Air Toxics projects and has implemented several voluntary air pollution programs aimed at reducing both

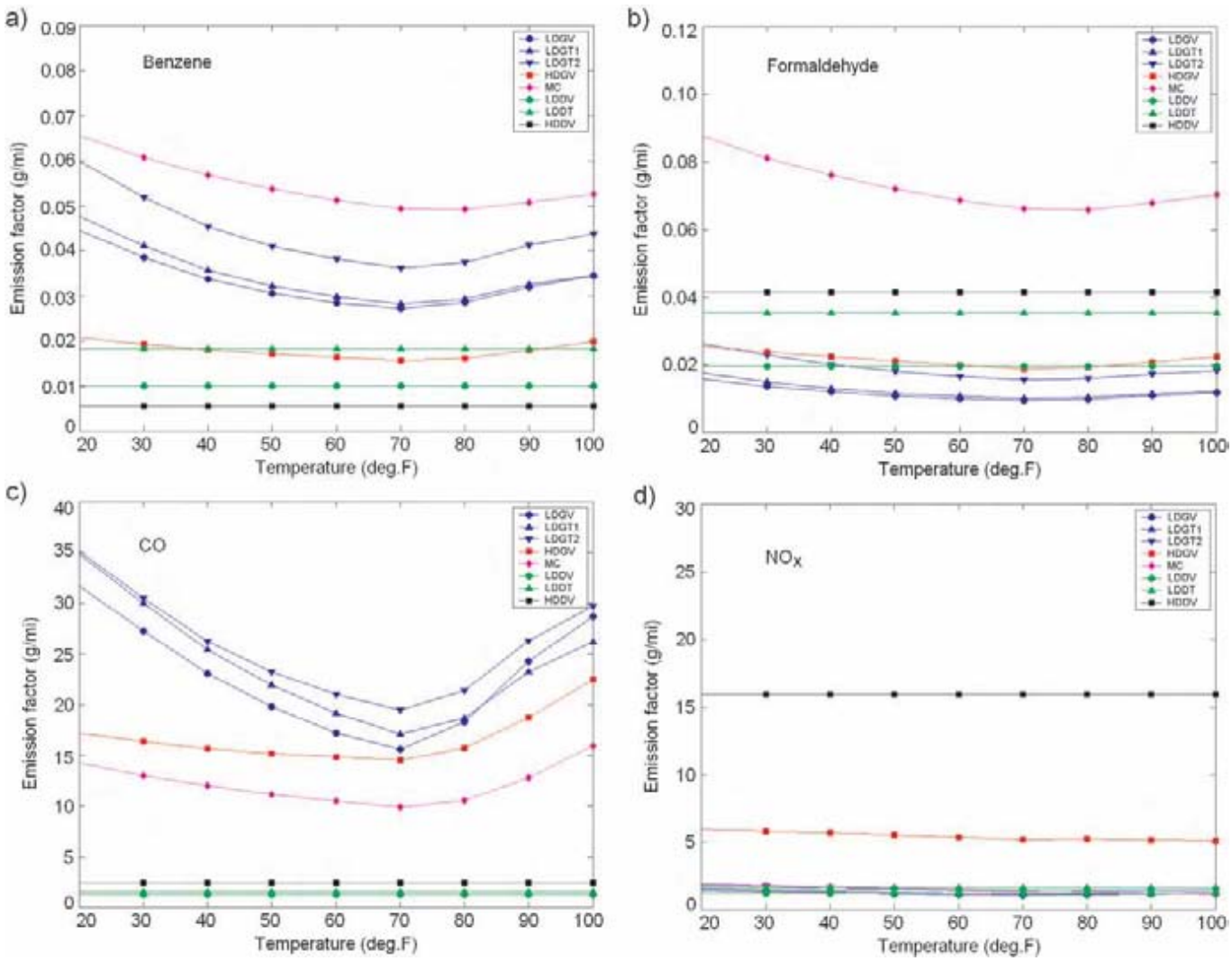

Figure 4. Emission factors by vehicle class as a function of ambient temperature for various pollutants—(a) benzene, (b) formaldehyde, (c) CO, and (d) NO_x—for New Haven, CT, 2002.

criteria and air toxic pollutants. In this study, the AERMOD model was used to estimate concentrations for several pollutants: PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO, benzene, 1,3-butadiene, formaldehyde, acrolein, trivalent and hexavalent chromium (Cr^{3+} and Cr^{6+}), and diesel particulate matter. In this paper, we present results for benzene and CO because these are primarily mobile source pollutants and CMAQ simulation results were readily available.

The AERMOD dispersion model provides detailed resolution of the spatial variations in hourly-average concentrations of nonreactive pollutants associated with highway vehicle emissions and major sources. The AERMOD model provided hourly concentrations at Census block group centroids (~380 receptors in the New Haven modeling domain). The study area includes multiple stationary sources, mobile sources, a marine port, and an airport. Emission rates from sources with sufficient information on source location such as point, on-road mobile, and marine port and airport (nonroad) were directly input in AERMOD. The level of detail to allocate most nonroad mobile and area source emissions was not of sufficient detail for local modeling with AERMOD. CMAQ provides volume-average concentration values for each 12- × 12-km grid cell in the modeling domain, given stated conditions that can change hourly. CMAQ modeled concentrations were assumed to represent the contribution of all remaining emission sources (not directly input into AERMOD): nonroad mobile sources, area sources, and background due to long range transport. Results of both model simulations are combined to provide the total ambient air toxics concentrations.

All point source emissions were extracted from a version of the 1999 NEI inventory. This inventory was thoroughly reviewed when used in the 1999 National Air Toxics Assessment (NATA)[10] and was the most recently available air toxics inventory at the time of this study for illustrative purposes. Because of the desire for accuracy for the local-scale modeling, extensive location quality assurance was performed using Google Earth, EPA's online Facility Registry System (FRS), and in some cases, the 2002 draft NEI. All sources with latitude-longitude coordinates inside a 20- × 20-km modeling domain centered on the city of New Haven are included. These stationary source coordinates as well as stack parameters were input to AERMOD.

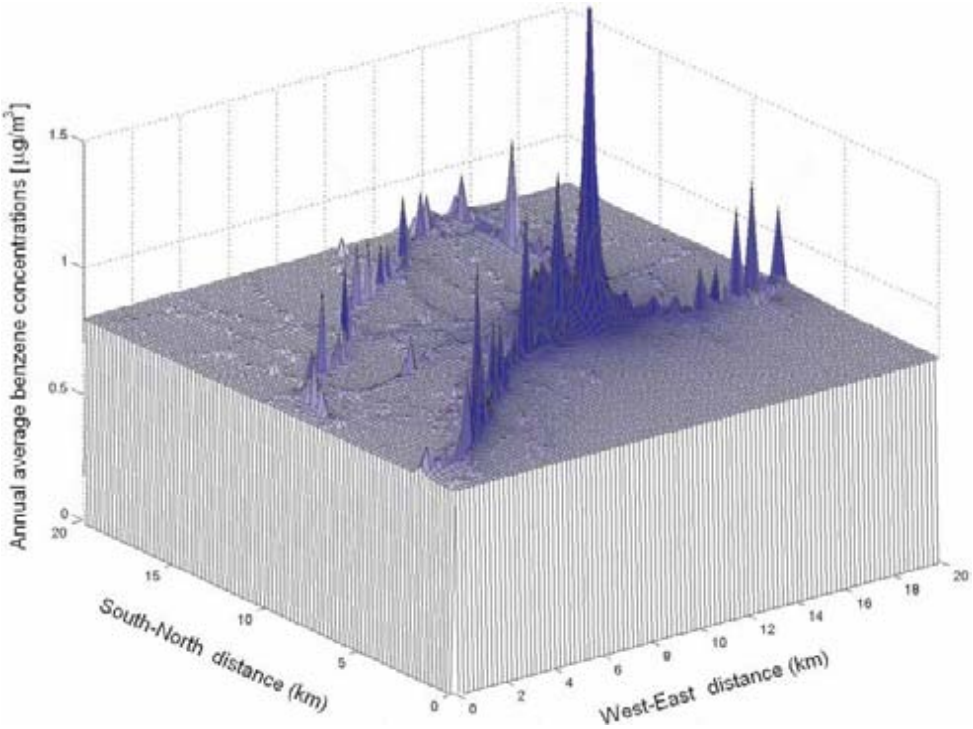

Figure 5. Spatial distribution of modeled annual average benzene concentrations in New Haven, CT.

For the near-road impact of mobile sources, the highway vehicle inventory was developed using the bottom-up versus top-down approach. Locations of individual road links along with link configuration and emission rates were input into AERMOD and modeled as area sources.[35] An extensive discussion of differences between the top-down and bottom-up approaches can be found elsewhere.[12] Also, whereas the highway vehicle inventory used in AERMOD modeling included only the running emissions associated with road links, CMAQ modeling included other types of vehicle emissions such as vehicle start exhaust, evaporative emissions caused by daily temperature changes while a vehicle is parked (diurnal emissions), evaporative emissions produced after a vehicle is

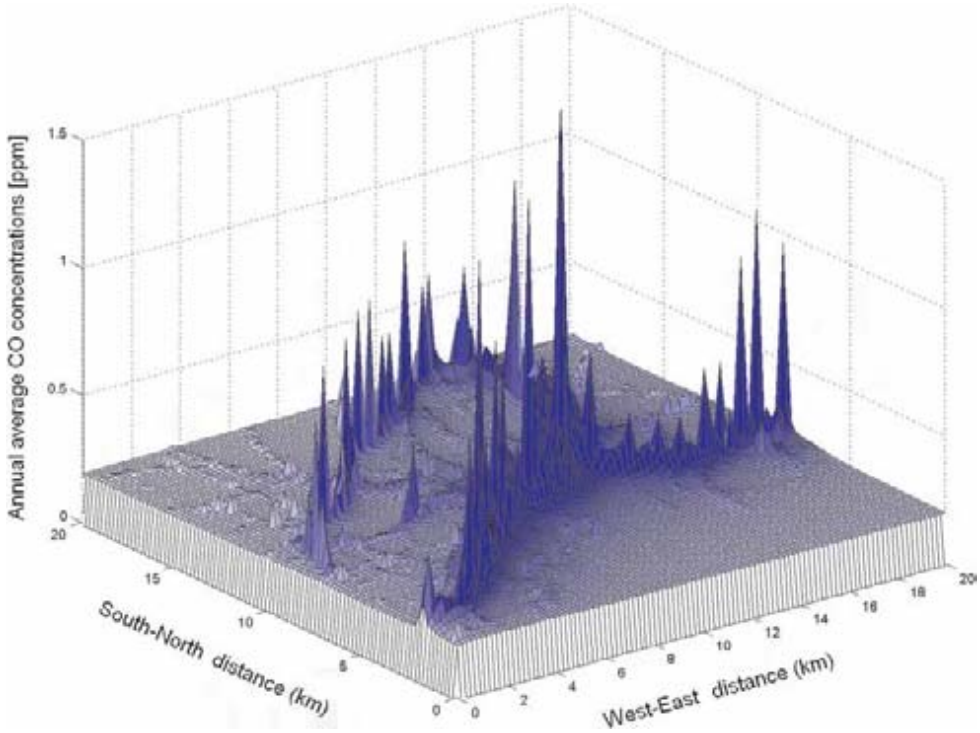

Figure 6. Spatial distribution of modeled annual average CO concentrations in New Haven, CT.

stopped and turned off (hot soak emissions), and emission from leaks or permeation of gasoline from the fuel system while the vehicle is off (resting loss emissions). Whereas the exhaust and evaporative running emissions used in AERMOD were for calendar year 2002, these emissions were obtained from the 1999 NEI.

Figures 5 and 6 show the spatial distribution of hybrid-modeled annual average concentrations in New Haven for two pollutants: benzene, representative of air toxics, and CO, representative of criteria pollutants. For visualization purposes, the model was run with an equally spaced 200-m receptor grid. Both pollutants are mobile-source driven. As shown in Figure 5, benzene concentrations are highest along major roadways and also downwind of the port area

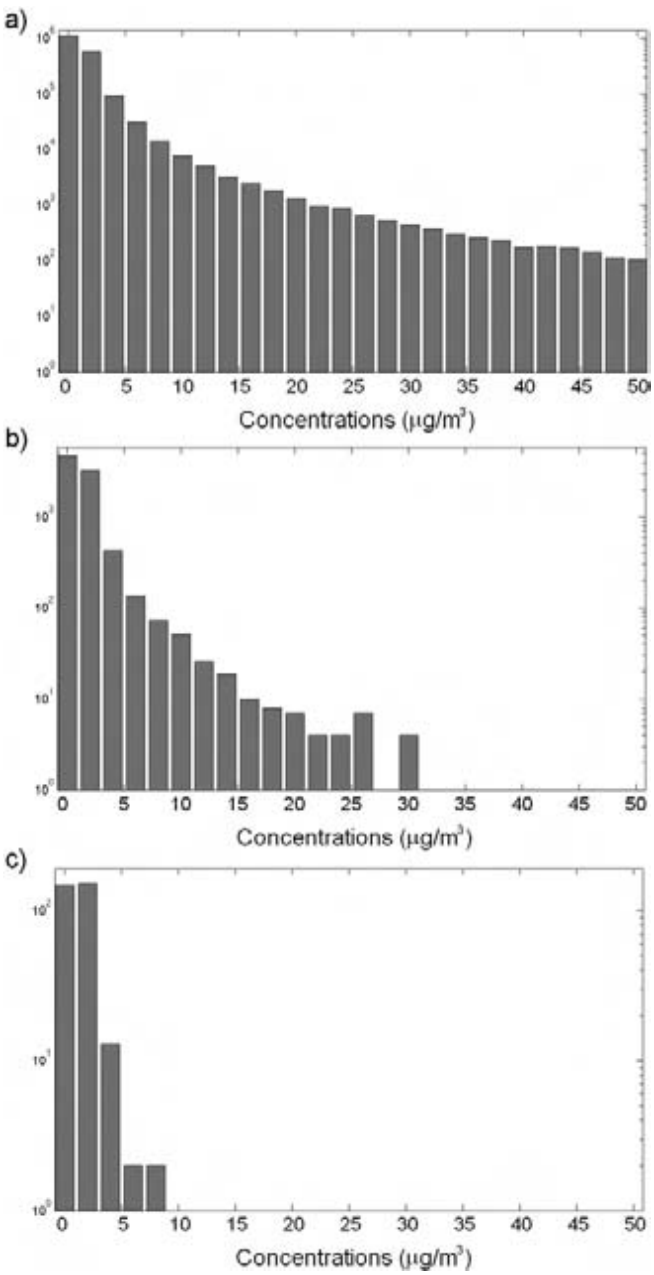

Figure 7. Distributions of modeled benzene concentrations in New Haven, CT: (a) hourly, at each of the 318 block group centroids; (b) hourly, averaged over the entire modeling domain; and (c) annual averages for each of the 318 block group centroids.

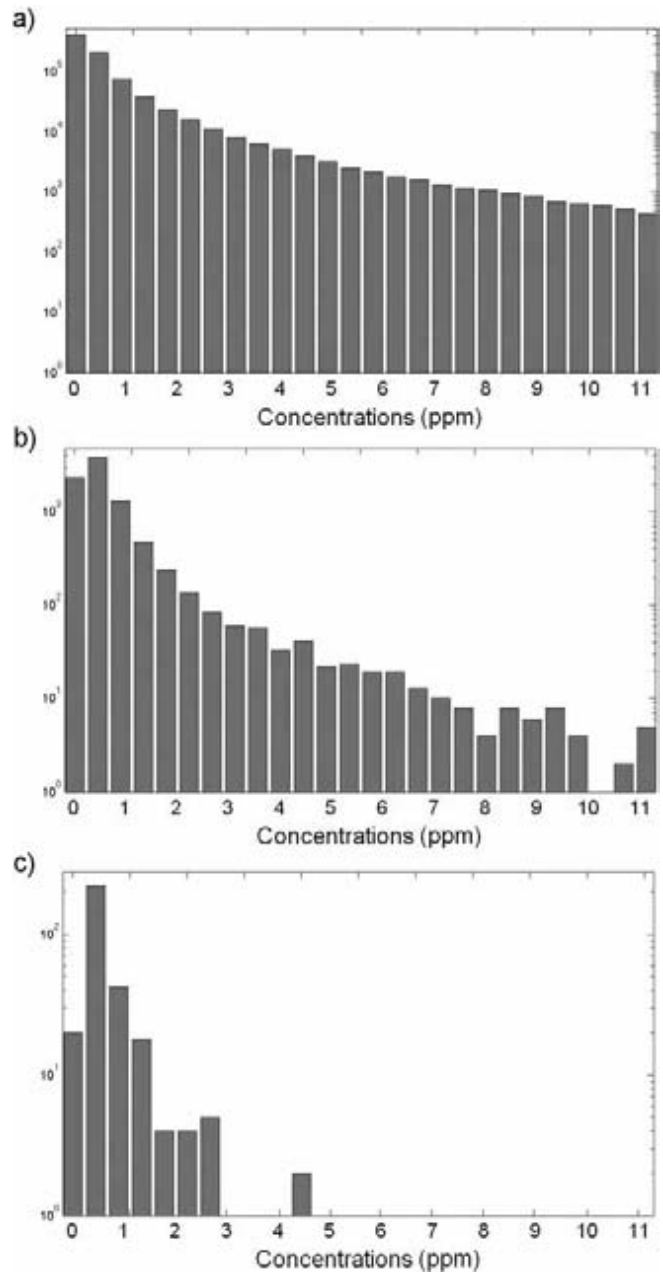

Figure 8. Distributions of modeled CO concentrations in New Haven, CT: (a) hourly, at each of the 318 block group centroids; (b) hourly, averaged over the entire modeling domain; and (c) annual averages for each of the 318 block group centroids.

(highest peak in the figure) where there are large emission sources. Figure 6 shows the spatial distribution of modeled annual average CO concentrations. These figures are similar in that they show high concentrations near major highways because these two pollutants are primarily emitted from mobile sources.

Figure 7 shows the spatial and temporal variations of benzene concentrations in the study area. The top panel (a) shows the frequency distribution of benzene concentrations for all hours in the study period, that is, hourly concentrations at each of the 318 block group centroids in calendar year 2002. As expected, the frequency of occurrence decreases as concentrations increase. Panel b shows the distribution of these hourly concentrations as they are spatially

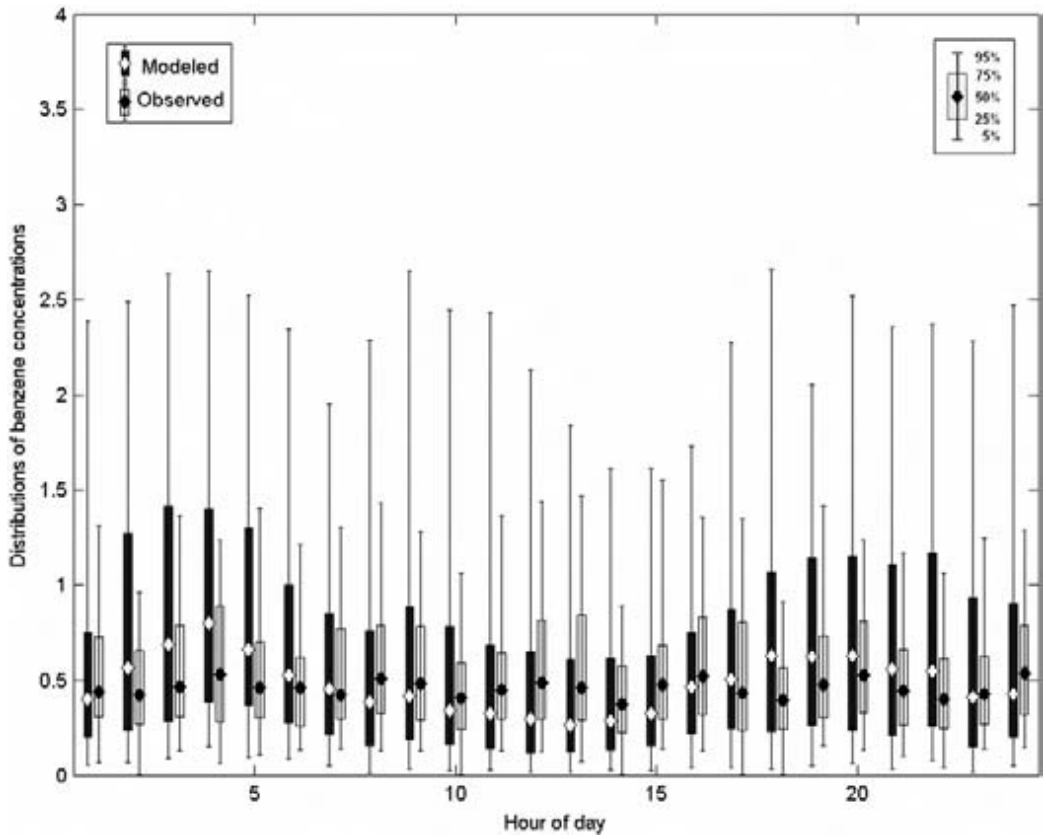

Figure 9. Comparison of modeled and observed distributions of benzene concentrations ($\mu g/m^3$) in New Haven, CT, at monitor no. 9005 (residential, suburban), by hour of day. Dots represent median values of the distribution; boxes represent 25–75% range; and whiskers represent 5–95% range.

averaged over the entire domain. The range of concentrations across the domain is less than in panel a, but is also high nevertheless. When the hourly concentrations are averaged at each Census block group over the entire year (c), the range in concentrations is much smaller, thus indicating that overall variability in ambient benzene is dominated by temporal variability. This is not unexpected because these pollutants are primarily emitted by mobile sources, which have a strong diurnal emission pattern. A similar pattern is observed for CO (Figure 8).

To evaluate model results, we compared hourly benzene and CO model predictions with existing monitor data in the New Haven area. Figure 9 shows a comparison of modeled and observed distribution of benzene concentrations by hour of day at monitor 9005 (latitude 41.34111 N, longitude 72.921389 W) in the New Haven area. This monitor is at a residential, suburban location. Generally, modeled results agree with observed values, and are within a factor of two. However, the modeled concentrations show a wider range of variability than the monitored values. Both modeled and observed concentrations vary according to time of day. This is expected because benzene emissions from automobiles are higher in the morning and afternoon rush-hour periods. In addition, meteorological conditions are more favorable to low dispersion during the morning.

Figure 10 shows a comparison of modeled and observed distribution of CO concentrations by hour of day at monitor 0025 (latitude 41.309167 N, longitude 72.923333 W). This monitor is located at the commercial center of the urban area, and does not show significantly higher concentrations during rush-hour periods. Here also, modeled results agree with observed values and are within a factor of two.

Although the approach presented in this paper represents a substantial advance over more traditional modeling approaches, there are still a significant number of limitations and uncertainties. Among these limitations and uncertainties are:

- Speeds obtained from travel demand models can be inaccurate.[36] In addition, the study used daily average speed and did not account for differences in speed during peak and offpeak hours.
- Roads can be inaccurately located in TIGER.
- Distributions of total VMT among vehicle types for road links can be mischaracterized.
- Differences in diurnal temporal distributions of activity for weekdays versus weekends were not accounted for in modeling.
- MOBILE6.2 does not account for speed or temperature effects on PM emissions, or temperature effects on diesel vehicle emissions.

SUMMARY

With more accurate geographic representation of spatial gradients associated with roadways and point sources, the results presented here appear to be better suited for developing mitigation strategies to address elevated pollutant concentrations near roads and resultant adverse health

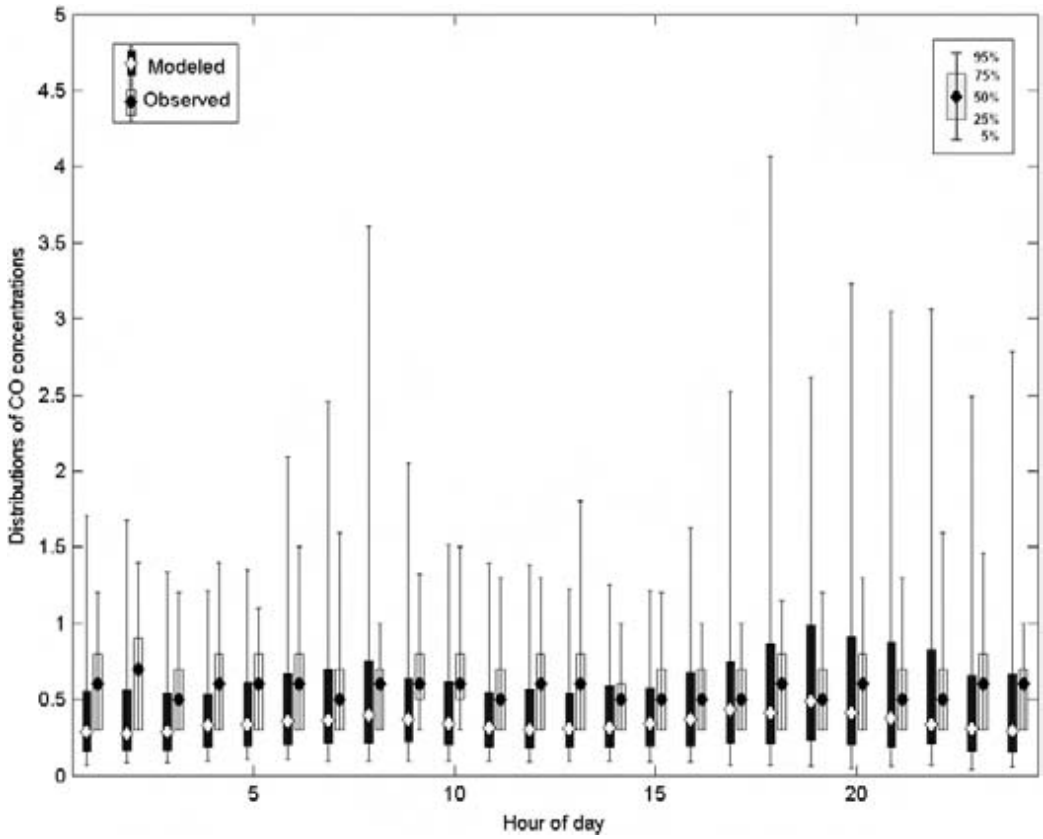

Figure 10. Comparison of modeled and observed distributions of CO concentrations (ppm) in New Haven, CT, at monitor no. 0025 (urban and center city, commercial), by hour of day. Dots represent median values of the distribution, boxes represent 25–75% range, and whiskers represent 5–95% range.

effects than more traditional air quality modeling approaches. In addition, the hybrid modeling approach combines the advantages of both models to provide better spatial resolution than either model alone. More refined approaches are especially important given the growing body of literature on near-road health effects. Furthermore, these data can be aligned with socioeconomic indicators and other population data in environmental justice analyses. Although the approach presented in this paper is more resource intensive than traditional top-down approaches in which emissions are allocated to grid cells for air quality modeling, it is practical and readily adaptable. Such approaches are likely to become more widespread as more tools, such as CONCEPT, are developed to link activity data from travel demand models with emission rates from emission factor models, and as hybrid air quality modeling tools are refined. In addition, EPA's new emissions model currently under development, the Motor Vehicle Emission Simulator (MOVES), will use a modal emission-rate approach that includes acceleration, rather than estimating emission rates based on average speeds.[37] This will improve capabilities to do more refined modeling of emissions at the local scale.

In this illustrative study, many assumptions were made that should be re-examined in real-world applications. For example, emission inventory must be consistent when the results from the AERMOD model are added to the CMAQ model. Also, meteorological data periods must be consistent between AERMOD, CMAQ, and the monitoring data.

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AERMOD: A Dispersion Model for Industrial Source Applications. Part I: General Model Formulation and Boundary Layer Characterization

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ABSTRACT

The formulation of the American Meteorological Society (AMS) and U.S. Environmental Protection Agency (EPA) Regulatory Model (AERMOD) Improvement Committee's applied air dispersion model is described. This is the first of two articles describing the model and its performance. Part I includes AERMOD's characterization of the boundary layer with computation of the Monin–Obukhov length, surface friction velocity, surface roughness length, sensible heat flux, convective scaling velocity, and both the shear- and convection-driven mixing heights. These parameters are used in conjunction with meteorological measurements to characterize the vertical structure of the wind, temperature, and turbulence. AERMOD's method for considering both the vertical inhomogeneity of the meteorological characteristics and the influence of terrain are explained. The model's concentration estimates are based on a steady-state plume approach with significant improvements over commonly applied regulatory dispersion models. Complex terrain influences are provided by combining a horizontal plume state and a terrain-following state. Dispersion algorithms are specified for convective and stable conditions, urban and rural areas, and in the influence of buildings and other structures. Part II goes on to describe the performance of AERMOD against 17 field study databases.

1. Introduction

Major developments in an improved understanding of the planetary boundary layer (PBL) began in the 1970s (Wyngaard 1988). One milestone involved numerical simulations by Deardorff (1972), revealing the convective boundary layer's (CBL's) vertical structure and important turbulence scales. Insights into dispersion followed from laboratory experiments, numerical simulations, and field observations (Briggs 1988; Lamb 1982; Weil 1988a). For the stable boundary layer (SBL), advancements occurred more slowly. However, a sound theoretical/experimental framework for surface layer dispersion and approaches for elevated sources existed by the mid-1980s (Briggs 1988; Venkatram 1988).

During the 1980s, researchers began to apply this information to applied dispersion models. These included eddy-diffusion techniques for surface releases, statistical theory and PBL scaling for dispersion parameter estimation, and a new probability density function (PDF) approach for the CBL. Much of this work was reviewed and promoted in workshops (Weil 1985), revised texts (Pasquill and Smith 1983), and in short courses and monographs (Nieuwstadt and van Dop 1982; Venkatram and Wyngaard 1988). By the mid- to late 1980s, new applied dispersion models had been developed, including the Power Plant Siting Program (PPSP) model (Weil and Brower 1984), Second-Order Closure Integrated Puff (SCIPUFF) (Sykes et al. 1996), Operationelle Meteorologiske Luftkvalitetsmodeller

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(OML) (Berkowicz et al. 1986), Hybrid Plume Dispersion Model (HPDM) (Hanna and Paine 1989), Multiple Source Dispersion Algorithm Using On-Site Turbulence Data (TUPOS) (Turner et al. 1986), and the Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS) (Perry et al. 1989); later, the Advanced Dispersion Modeling System (ADMS), developed in the United Kingdom (Carruthers et al. 1994), was added as well.

In February 1991, the U.S. Environmental Protection Agency (EPA) in conjunction with the American Meteorological Society (AMS) formed the AMS and EPA Regulatory Model (AERMOD) Improvement Committee (AERMIC), with the purpose of incorporating scientific advances from the 1970s and 1980s into a state-of-the-art dispersion model for regulatory applications. AERMIC's early efforts are described by Weil (1992). To improved PBL parameterizations, other concerns such as plume interaction with terrain, surface releases, building downwash, and urban dispersion were addressed. These efforts resulted in AERMOD. AERMOD is aimed at the same scenarios currently handled by EPA's Industrial Source Complex Short-Term model (ISCST3) (U.S. Environmental Protection Agency 1995). The early formulations of AERMOD are summarized in Perry et al. (1994) and Cimorelli et al. (1996). An extensive discussion of the current models' formulations appears in Cimorelli et al. (2003).

AERMOD, a steady-state dispersion model, includes the effects on dispersion from vertical variations in the PBL. In the SBL the concentration distribution is Gaussian, both vertically and horizontally, as is the horizontal distribution in the CBL. However, the CBL's vertical concentration distribution is described with a bi-Gaussian PDF, as demonstrated by Willis and Deardorff (1981). Buoyant plume mass that penetrates the elevated stable layer is tracked by AERMOD and allowed to reenter the mixed layer at some distance downwind.

For flow in complex terrain, AERMOD incorporates the concept of a dividing streamline (Snyder et al. 1985), and the plume is modeled as a combination of terrain-following and terrain-impacting states. The model considers the influence of building wakes and it enhances vertical turbulence to account for the "convective like" boundary layer found in nighttime urban areas.

This paper describes 1) algorithms for estimating PBL parameters, 2) algorithms for developing vertical meteorological profiles, 3) an approach for handling PBL inhomogeneity, 4) the approach used to establish the influence of terrain, 5) the general structure of the dispersion model, 6) the dispersion algorithms, 7) the building downwash algorithms, and 8) treatment of the urban boundary layer. Perry et al. (2005, hereinafter Part II) discusses the performance evaluation of AERMOD against 17 experimental databases.

2. Meteorological preprocessor (AERMET)

The growth and structure of the PBL is driven by the fluxes of heat and momentum, which, in turn, depend upon surface effects. The depth of this layer and the dispersion of pollutants within it are influenced on a local scale by surface characteristics such as surface roughness, albedo, and available surface moisture. As with models like HPDM (Hanna and Paine 1989; Hanna and Chang 1993) and CTDMPLUS (Perry 1992), AERMOD utilizes surface and mixed-layer scaling to characterize the structure of the PBL. AERMOD's meteorological preprocessor (AERMET) requires, as input, surface characteristics, cloud cover, a morning upper-air temperature sounding, and one near-surface measurement of wind speed, wind direction, and temperature. With this, the model computes the friction velocity, Monin–Obukhov length, convective velocity scale, temperature scale, mixing height, and surface heat flux. In a manner similar to models like CTDMPLUS and HPDM these scaling parameters are used to construct vertical profiles of wind speed, lateral and vertical turbulence, potential temperature gradient, and potential temperature. Extensive independent evaluations of these scaling parameters and vertical profiles have not been performed for urban and complex terrain situations other than those accomplished in the many references sited. However, evaluations of the overall model have shown that these parameterizations lead to estimates of plume concentration that compare well with a wide variety of field observations (Part II).

a. Derived parameters in the CBL

During convective conditions, AERMET characterizes the state of the PBL by first estimating the sensible heat flux (H) with a simple energy balance approach (Oke 1978), then the friction velocity (u_*) and the Monin–Obukhov length (L). With these parameters AERMET can estimate the mixing height (z_i) and the convective velocity scale (w_*).

The expression used for u_* (Panofsky and Dutton 1984) is

$$u_* = \frac{k u_{\mathrm{ref}}}{\ln(z_{\mathrm{ref}}/z_0) - \Psi_m\{z_{\mathrm{ref}}/L\} + \Psi_m\{z_0/L\}}, \qquad (1)$$

where k is the von Kármán constant, u_{ref} is the wind speed at reference height, z_{ref} is the lowest surface layer measurement height for wind, z_0 is the roughness length, and Ψ_m is defined by Panofsky and Dutton (1984) for the CBL and by van Ulden and Holtslag (1985) for the SBL. Note that braces are used throughout this paper to denote the functional form of variables. Assuming neutral conditions, u_* and L are initialized using Eq. (1) and L is defined as follows (Wyngaard 1988):

$$L = -\frac{\rho c_p T_{\mathrm{ref}} u_*^3}{kgH}, \tag{2}$$

where g is the acceleration of gravity, c_p is the specific heat at constant pressure, ρ is the density, and T_{ref} is the ambient temperature (K) that is representative of the surface layer. Final values for u_* and L are found by iterating Eqs. (1) and (2) until convergence. The convective velocity scale (w_*) is estimated from (Deardorff 1970)

$$w_* = \left(\frac{gHz_{ic}}{\rho c_p T_{\mathrm{ref}}}\right)^{1/3}, \tag{3}$$

where z_{ic} is the convective mixing height.

Assuming no measurements, z_{ic} is calculated with a simple one-dimensional energy balance model (Carson 1973), as modified by Weil and Brower (1983). In addition, a mechanical mixing height (z_{im}) is estimated from an empirically based expression (Venkatram 1980) as

$$z_{im} = 2300 u_*^{3/2}, \tag{4}$$

where the constant 2300 has units of ($\mathrm{s}^{3/2}\ \mathrm{m}^{-1/2}$).

For CBL dispersion calculations, the mixing height (z_i) is defined as the larger of z_{im} and z_{ic}.

b. Derived parameters in the SBL

Because estimates of the sensible heat flux using Oke's (1978) approach are unreliable in the SBL, Eqs. (1) and (2) are not used. Rather, using Venkatram's (1980) observation that the temperature scale (θ_*), which sets the "level" of the temperature fluctuations in the surface layer, varies little during the night, u_* can be determined from

$$\theta_* = -H/\rho c_p u_*; \tag{5}$$

$\theta_* = 0.09(1 - 0.5n^2)$ is taken from van Ulden and Holtslag (1985), where n is the fractional cloud cover and the constant 0.09 has units of kelvins.

By combining Eq. (2) with Eq. (5), L can be written as

$$L = \frac{T_{\mathrm{ref}}}{kg\theta_*} u_*^2. \tag{6}$$

Using Panofsky and Dutton's (1984) expression for the wind speed profile, that is,

$$u = \frac{u_*}{k}\left[\ln\left(\frac{z}{z_0}\right) + \frac{\beta_m z_{\mathrm{ref}}}{L}\right], \tag{7}$$

where $\beta_m = 5$, the solution for u_* is found by substituting Eq. (6) into Eq. (7) (Hanna and Chang 1993; Perry 1992).

Having computed u_* and θ_*, AERMET calculates the surface heat flux from Eq. (5). Last, because there is, by definition, no convective component in the SBL, the total mixing depth z_i is computed as the time-smoothed (Cimorelli et al. 2003) mechanical mixing depth z_{im} [Eq. (4)].

3. Vertical structure of the PBL

AERMOD estimates meteorological profiles using both measurements and similarity parameterizations [i.e., AERMOD uses the shape of the similarity profiles to interpolate between adjacent vertical measurements (Cimorelli et al. 2003)]. AERMOD's concentration formulations consider the effects from vertical variations in wind, temperature, and turbulence. These profiles are represented by equivalent (effective) values constructed by averaging over the layer through which plume material travels directly from the source to receptor (Cimorelli et al. 2003). The effective parameters are denoted by a tilde throughout the document (e.g., effective wind speed is denoted by $\tilde{u}$).

a. Wind speed and direction

The profile equation for wind speed has the familiar logarithmic form:

$$u\{z\} = u\{z = 7z_0\}\left(\frac{z}{7z_0}\right) \qquad \text{for} \qquad z < 7z_0,$$

$$u\{z\} = \frac{u_*}{k}\left[\ln\left(\frac{z}{z_0}\right) - \Psi_m\left\{\frac{z}{L}\right\} + \Psi_m\left\{\frac{z_0}{L}\right\}\right] \qquad \text{for} \quad 7z_0 \le z \le z_i,$$

and

$$u\{z\} = u\{z = z_i\} \qquad \text{for} \qquad z > z_i, \tag{8}$$

where $7z_0$ represents an approximate height of roughness elements below which the profile is assumed to be linear.

Wind direction is assumed to be constant with height both above the highest and below the lowest measurement and to vary linearly between measurements.

b. Potential temperature gradient

In the CBL $\partial\theta/\partial z$ is taken to be zero, in the stable interfacial layer it is estimated from the morning temperature sounding, and it is assumed to equal 0.005 K m^{-1} above, as suggested by Hanna and Chang (1991). Measurements (e.g., Clarke et al. 1971) of profiles throughout the day lend support to this approach.

In the SBL's first 100 m, $\partial\theta/\partial z$ is estimated from Dyer (1974) and Panofsky and Dutton (1984) as

$$\frac{\partial\theta}{\partial z} = \frac{\theta_*}{k(2)}\left[1 + 5\frac{(z = 2)}{L}\right] \qquad \text{for} \qquad z \le 2\ \mathrm{m}$$

and

$$\frac{\partial\theta}{\partial z} = \frac{\theta_*}{kz}\left(1 + 5\frac{z}{L}\right) \qquad \text{for} \quad 2\ \text{m} < z \le 100\ \text{m}. \tag{9}$$

Above 100 m the potential temperature gradient is taken from Stull (1983) and van Ulden and Holtslag (1985) as

$$\frac{\partial\theta}{\partial z} = \frac{\partial\theta\{z_{\text{mx}}\}}{\partial z}\exp\left[-\frac{(z - z_{\text{mx}})}{0.44 z_{i\theta}}\right], \tag{10}$$

where z_{mx} = 100 m, $z_{i\theta} = \max(z_{im}, 100\ \text{m})$, and the constant 0.44 is taken from measurements (Andre and Mahrt 1982). Last, AERMOD limits $\partial\theta/\partial z$ to a minimum of 0.002 K m^{-1} (Paine and Kendall 1993).

c. Vertical turbulence

In the CBL, vertical turbulence contains both a mechanical ($\sigma_{wm} \propto u_*$) and a convective ($\sigma_{wc} \propto w_*$) component, with the total vertical turbulence (σ_{wT}^2) given by

$$\sigma_{wT}^2 = \sigma_{wc}^2 + \sigma_{wm}^2, \tag{11}$$

while in the SBL $\sigma_{wT} = \sigma_{wm}$. These forms are similar to one introduced by Panofsky et al. (1977) and are included in other dispersion models (e.g., Berkowicz et al. 1986; Hanna and Paine 1989; and Weil 1988a).

The convective portion (σ_{wc}^2) of the total variance is calculated as

$$\sigma_{wc}^2 = 1.6\left(\frac{z}{z_{ic}}\right)^{2/3} w_*^2 \qquad \text{for} \quad z \le 0.1 z_{ic},$$

$$\sigma_{wc}^2 = 0.35 w_*^2 \qquad \text{for} \quad 0.1 z_{ic} < z \le z_{ic},$$

and

$$\sigma_{wc}^2 = 0.35 w_*^2 \exp\left[-\frac{6(z - z_{ic})}{z_{ic}}\right] \qquad \text{for} \quad z > z_{ic}, \tag{12}$$

where the first expression is taken from Panofsky et al. (1977) and the second from Hicks (1985). The third expression permits σ_{wc}^2 to smoothly decay to zero well above z_{ic}.

The mechanical turbulence (σ_{wm}) is assumed to consist of contributions from the current boundary layer (σ_{wml}) and residual turbulence from the previous day's boundary layer (σ_{wmr}), such that

$$\sigma_{wm}^2 = \sigma_{wml}^2 + \sigma_{wmr}^2. \tag{13}$$

The expression for σ_{wml}, following Brost et al. (1982), is

$$\sigma_{wml} = 1.3 u_*\left(1 - \frac{z}{z_i}\right)^{1/2} \qquad \text{for} \quad z < z_i$$

and

$$\sigma_{wml} = 0.0 \qquad \text{for} \quad z \ge z_i, \tag{14}$$

where $\sigma_{wml} = 1.3u_*$ at $z = 0$ is consistent with Panofsky et al. (1977). In the absence of measurements above z_i, σ_{wmr} is taken from (Briggs 1973) to be $0.02u\{z_i\}$.

d. Lateral turbulence

In the CBL the total lateral turbulence is also assumed to be a combination of a mechanical (σ_{vm}) and a convective (σ_{vc}) portion, such that

$$\sigma_{vT}^2 = \sigma_{vc}^2 + \sigma_{vm}^2. \tag{15}$$

In the mixed layer,

$$\sigma_{vc}^2 = 0.35 w_*^2, \tag{16}$$

which is supported by the Minnesota (Readings et al. 1974; Kaimal et al. 1976) and Ashchurch, United Kingdom (Caughey and Palmer 1979), datasets. Consistent with measurements reported by Hanna (1983), a minimum value of 0.5 m s^{-1} is assumed for σ_{vc} above z_i.

AERMOD assumes that σ_{vm}^2 varies linearly with height between its value at the surface and an assumed residual value at z_{im} as is suggested by field observations (e.g., Brost et al. 1982). The value of σ_{vm}^2 at z_{im} is assumed to persist at higher levels. The profile for lateral mechanical turbulence is calculated as

$$\sigma_{vm}^2 = \left(\frac{\sigma_{vm}^2\{z_{im}\} - \sigma_{vo}^2}{z_{im}}\right) z + \sigma_{vo}^2 \quad \text{for} \quad z \le z_{im}$$

and

$$\sigma_{vm}^2 = \sigma_{vm}^2\{z_{im}\} \qquad \text{for} \quad z > z_{im}, \tag{17}$$

where $\sigma_{vm}^2\{z_{im}\} = \min(\sigma_{vo}^2, 0.25\ \text{m}^2\ \text{s}^{-2})$ and σ_{vo}^2 is equal to $3.6u_*^2$ (Panofsky and Dutton 1984; Izumi 1971; Hicks 1985). In the SBL the turbulence is exclusively mechanical (σ_{vm}).

4. General form of the AERMOD dispersion model with terrain

AERMOD simulates a plume, in elevated terrain, as a weighted sum of concentrations from two limiting states: a horizontal plume (terrain impacting) and a terrain-following plume. Each plume state is weighted using the concepts of the critical dividing streamline and a receptor-specific terrain height scale (h_c) (Venkatram et al. 2001; Cimorelli et al. 2003).

The general concentration equation is

$$C_T\{x_r, y_r, z_r\} = fC_{c,s}\{x_r, y_r, z_r\} + (1 - f)C_{c,s}\{x_r, y_r, z_p\}, \tag{18}$$

where $C_T\{x_r, y_r, z_r\}$ is the total concentration, $C_{c,s}\{x_r, y_r, z_r\}$ is the contribution from the horizontal plume (subscripts c and s refer to convective and stable conditions, respectively), $C_{c,s}\{x_r, y_r, z_p\}$ is the contribution from the terrain-following plume, f is the weighting factor, $\{x_r, y_r, z_r\}$ is the receptor coordinate, z_p ($= z_r - z_t$) is the re-

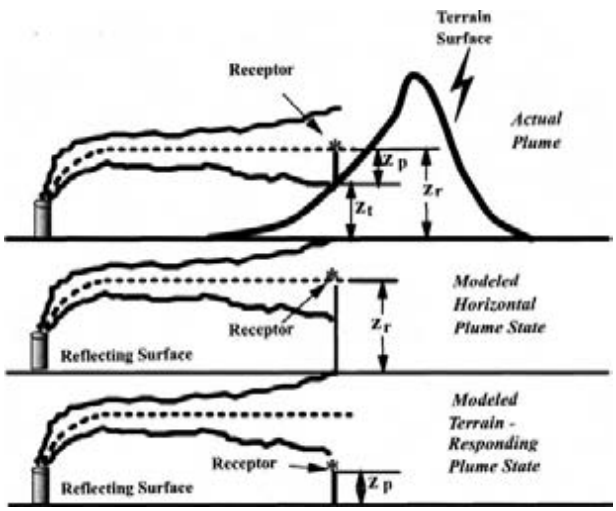

FIG. 1. AERMOD two-state approach. The total concentration predicted by AERMOD is the weighted sum of the two extreme possible plume states: the horizontal plume state and the terrain-following state.

ceptor height above local ground, and z_t is the local terrain height. Figure 1 illustrates the relationship between the actual plume and AERMOD's characterization of it.

The weighting of the two plume states depends on the amount of mass residing in each state. This mass partitioning is based on the relationship between the critical dividing streamline height (H_c) (Sheppard 1956; Snyder et al. 1985) and the vertical concentration distribution at a receptor. Complex terrain in often characterized by a number of irregularly shaped hills. Venkatram et al. (2001) first proposed the idea that H_c could be calculated using a receptor-specific height scale (h_c) that represents the height of a single isolated hill, which would act to affect the flow at the receptor in a manner similar to the real terrain. In this way, the participating of the plume mass into the two states is receptor specific. For a receptor at elevation z_t and an effective plume height of h_e, the height of the terrain-following state, at that receptor, is $z_t + h_e$. For streamlines to reach the terrain-following height the actual terrain that influences the flow at the receptor must extend up to or above this height; in this case, $h_c = z_t + h_e$. If the actual terrain is less than $z_t + h_e$ then h_c is set to the actual terrain height that causes the maximum vertical displacement of the plume above the receptor. Therefore, for any receptor, h_c is defined as the minimum of the highest actual terrain and the terrain-following height at that receptor. The dividing streamline height is computed using the same integral formula found in CTDMPLUS (Perry 1992), with h_c substituted for hill height.

The fraction of the plume mass below H_c (i.e., φ_p) is computed as

$$\varphi_p = \frac{\int_0^{H_c} C_s\{x_r, y_r, z_r\}\, dz}{\int_0^{\infty} C_s\{x_r, y_r, z_r\}\, dz}. \tag{19}$$

In convective conditions, $H_c = 0$ and $\varphi_p = 0$.

As described by Venkatram et al. (2001), the plume-state weighting factor f is given by $f = 0.5(1 + \varphi_p)$. When the plume is entirely below H_c ($\varphi_p = 1.0$ and $f = 1.0$) the concentration is determined by the horizontal plume only. When the plume is entirely above the critical dividing streamline height or when the atmosphere is convective, $\varphi_p = 0$ and $f = 0.5$. That is, during convective conditions the concentration at an elevated receptor is the average of the contributions from the two states. As plumes above H_c encounter terrain and are deflected vertically, there is also a tendency for plume material to approach the terrain surface and to spread out around the sides of the terrain. To simulate this, concentration estimates always contain a component from the horizontal state. Evaluation of the model against field observations supports this assumption (Part II). Therefore, under no conditions is the plume allowed to completely approach the terrain-following state. For flat terrain, the contributions from the two states are equal in value and are equally weighted.

5. AERMOD concentration predictions in the SBL

During stable conditions (i.e., stable and neutral stratifications when $L > 0$), AERMOD estimates concentrations from

$$C_s\{z_r, y_r, z\} = \frac{Q}{\sqrt{2\pi}\tilde{u}\sigma_{zs}} F_y \times \sum_{m=-\infty}^{\infty} \left\langle \exp\left[-\frac{(z - h_{es} - 2mz_{ieff})^2}{2\sigma_{zs}^2}\right] + \exp\left[-\frac{(z + h_{es} + 2mz_{ieff})^2}{2\sigma_{zs}^2}\right]\right\rangle, \tag{20}$$

where z_{ieff} is the effective mechanical mixing height, σ_{zs} is the total vertical dispersion, h_{es} is the plume height (Weil 1988b; Cimorelli et al. 2003), and F_y is the lateral distribution functions.

Above the mechanical mixing layer turbulence is expected to be small. AERMOD is designed with an effective mixing lid z_{ieff} that retards but does not prevent plume material from spreading into this region of low turbulence. When the plume is below z_{im} but its "upper edge" (plume height plus $2.15\sigma_{zs}$) reaches z_{im}, z_{ieff} is allowed to increase, maintaining its position relative to the plume.

The lateral dispersion function is defined as

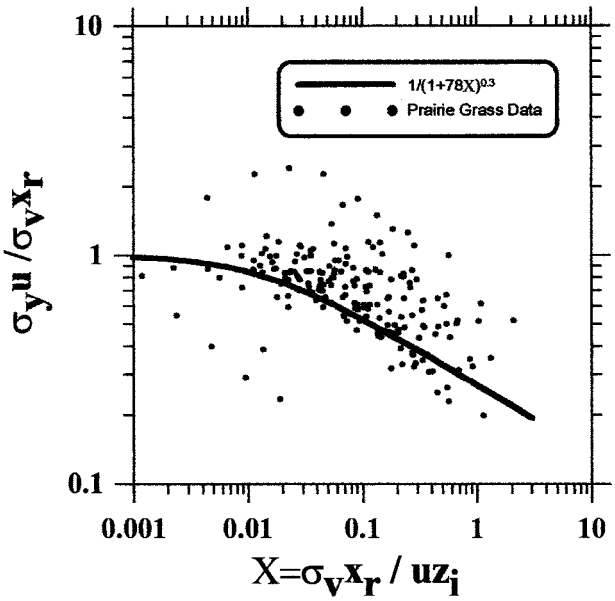

FIG. 2. Lateral spread (σ_y) as a function of nondimensional distance (X). The data are taken from the Prairie Grass Experiment (Barad 1958).

$$F_y = \frac{1}{\sqrt{2\pi}\sigma_y} \exp\left(\frac{-y^2}{2\sigma_y^2}\right). \tag{21}$$

Lateral dispersion is estimated from Taylor (1921), such that

$$\sigma_y = (\tilde{\sigma}_v x/\tilde{u}) \Big/ \left(1 + \frac{x/\tilde{u}}{2T_{\mathrm{Ly}}}\right)^p, \tag{22}$$

where $p = 0.5$, $\tilde{u}$ is the wind speed, $\tilde{\sigma}_v$ is lateral turbulence velocity [Eq. (15)], and T_{Ly} is the Lagrangian integral time scale. Application of Eq. (22) in a preliminary version of AERMOD yielded poor comparisons with data from the Prairie Grass Experiment (Barad 1958); the lateral spread was not well matched. In response, the lateral dispersion expression was reformulated to better fit the data.

From Venkatram et al. (1984) T_{Ly} is written as $l/\tilde{\sigma}_v$, where l is a lateral turbulent length scale. This allows Eq. (22) to be written in terms of the nondimensional downwind distance X and a nondimensional height scale δ:

$$\sigma_y = \frac{\tilde{\sigma}_v x}{\tilde{u}(1 + \delta X)^p}, \tag{23}$$

where $X = \tilde{\sigma}_v x/\tilde{u} z_i$, and $\delta = z_i/l$.

Using a subset of stable and convective cases from the Prairie Grass Experiment, Eq. (23) (based on Taylor 1921) produced the best σ_y comparisons with δ and p set equal to 78, and 0.3, respectively. In an independent comparison with the full dataset (Fig. 2), Eq. (23) was found to fall within this widely scattered data, yet it tended toward the lower end of the distribution of measured dispersion. More important, good agreement between AERMOD concentration predictions and Prairie Grass observations was found (Part II).

In the SBL, the vertical dispersion (σ_{zs}) is assumed to be composed of contributions from an elevated (σ_{zes}) and near-surface (σ_{zgs}) component. Lacking a strong physical justification otherwise, for $h_{\mathrm{es}} < z_i$, a simple linear interpolation between the two components is assumed. That is,

$$\sigma_{\mathrm{zs}} = \left(1 - \frac{h_{\mathrm{es}}}{z_i}\right)\sigma_{\mathrm{zgs}} + \left(\frac{h_{\mathrm{es}}}{z_i}\right)\sigma_{\mathrm{zes}}, \tag{24}$$

where h_{es} is the plume height, and for $h_{\mathrm{es}} \geq z_i$, σ_{zs} is set equal to σ_{zes}.

The elevated component follows Taylor, such that

$$\sigma_{\mathrm{zes}} = \tilde{\sigma}_{wT}(x/\tilde{u}) \Big/ \left(1 + \frac{x/\tilde{u}}{2T_{\mathrm{Lzs}}}\right)^{1/2}, \tag{25}$$

where $\tilde{\sigma}_{wT}$ is the vertical turbulence due to mechanical mixing [Eq. (11)].

Writing the Lagrangian time scale as $T_{\mathrm{Lzs}} = l/\tilde{\sigma}_{wT}$ (Venkatram et al. 1984) and interpolating l ($1/l = 1/l_n + 1/l_s$) between its neutral ($l_n = 0.36h_{\mathrm{es}}$) and stable ($l_s = 0.27\tilde{\sigma}_{wT}/N$) limits allows Eq. (25) to be rewritten as

$$\sigma_{\mathrm{zes}} = \frac{\tilde{\sigma}_{\mathrm{wT}} t}{\left[1 + \frac{\tilde{\sigma}_{wT} t}{2}\left(\frac{1}{0.36h_{\mathrm{es}}} + \frac{N}{0.27\tilde{\sigma}_{wT}}\right)\right]^{1/2}}, \tag{26}$$

where N is the Brunt–Väisälä frequency, that is, the frequency of the particle oscillation about its equilibrium position.

The surface component (σ_{zgs}) is calculated as (Venkatram 1992)

$$\sigma_{\mathrm{zgs}} = \sqrt{\frac{2}{\pi}}\left(\frac{u_* x}{\tilde{u}}\right)\left(1 + 0.7\frac{x}{L}\right)^{-1/3}. \tag{27}$$

In addition to ambient turbulence, plume buoyancy contributes to the total dispersion. Buoyancy-induced dispersion is calculated following Pasquill (1976) and Weil (1988b) as

$$\sigma_b = \frac{0.4\Delta h}{\sqrt{2}}, \tag{28}$$

where Δh is the stable plume rise above stack top (Cimorelli et al. 2003). Total dispersion is calculated by adding σ_b, in quadrature, to σ_y and also to σ_{zs} (Pasquill and Smith 1983).

6. AERMOD concentration predictions in the CBL

Unlike the SBL, in the CBL (i.e., convective and neutral stratifications when $L < 0$), the vertical velocity (w) distribution is positively skewed and results in a

non-Gaussian vertical concentration distribution (Weil et al. 1997; Lamb 1982) and a general descent of the plume centerline for an elevated nonbuoyant source (Lamb 1982; Weil 1988a). The vertical spread in concentration is modeled using a bi-Gaussian distribution, a good approximation to laboratory convection tank data (Baerentsen and Berkowicz 1984). In contrast, the lateral concentration distribution assumes a Gaussian shape, consistent with the lateral velocity distribution (Lamb 1982).

For buoyant releases AERMOD addresses distance-dependent plume rise. A "direct" source is defined to treat that portion of the plume's mass that is transported directly to the ground, plus all subsequent reflections of this direct mass. For plume segments initially rising in updrafts, an "indirect" or modified-image source is included to address the initial reflection at z_i and all subsequent reflections at $z = 0$ and z_i of this indirect mass. A plume-rise component is added to delay the downward dispersion of the indirect source material from the CBL top; this mimics the tendency of buoyant plumes to remain temporarily near z_i and resist downward mixing. Additionally, a "penetrated" source (above the CBL top) is included to account for material that initially penetrates the elevated inversion while allowing for it to subsequently reentrain into the growing CBL. The fraction f_p of the source material that does not penetrate is

$$f_p = 0 \quad \text{if} \quad \Delta h_h < 0.5\Delta h_{\text{eq}},$$
$$f_p = 1 \quad \text{if} \quad \Delta h_h > 1.5\Delta h_{\text{eq}},$$

and

$$f_p = \frac{\Delta h_h}{\Delta h_{\text{eq}}} - 0.5 \quad \text{if} \quad 0.5\Delta h_{\text{eq}} \le \Delta h_h \le 1.5\Delta h_{\text{eq}}, \tag{29}$$

where $\Delta h_h = z_i - h_s$, and h_{eq} is the equilibrium plume rise in a stable environment (Weil et al. 1997).

The total concentration (C_c) in the CBL is found by summing the contribution from the three sources. For the horizontal plume state,

$$C_c\{x_r, y_r, z_r\} = C_d\{x_r, y_r, z_r\} + C_r\{x_r, y_r, z_r\} + C_p\{x_r, y_r, z_r\}, \tag{30}$$

where C_d, C_r, and C_p are the contributions from the direct, indirect, and penetrated sources, respectively. This three-plume concept is shown schematically in Fig. 3. Similarly, the concentration for the terrain-following state has the form of Eq. (30), but with z_r replaced by z_p.

a. Direct source contribution to concentrations in the CBL

Following Weil et al. (1997), the concentration due to the direct plume is given by

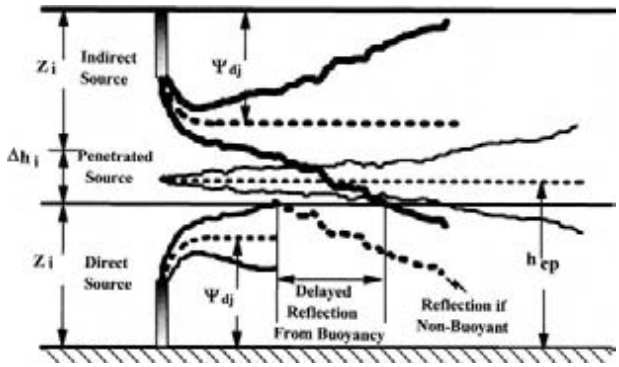

FIG. 3. AERMOD's three-plume treatment of the CBL.

$$C_d\{x_r, y_r, z\} = \frac{Qf_p}{\sqrt{2\pi}\tilde{u}} F_y \sum_{j=1}^{2} \sum_{m=0}^{\infty} \frac{\lambda_j}{\sigma_{zj}} \times \left\langle \exp\left[-\frac{(z - \Psi_{dj} - 2mz_i)^2}{2\sigma_{zj}^2}\right] + \exp\left[-\frac{(z + \Psi_{dj} + 2mz_i)^2}{2\sigma_{zj}^2}\right]\right\rangle, \tag{31}$$

where $\Psi_{dj} = h_s + \Delta h_d + \overline{w}_j x/\tilde{u}$ is the plume height, $\tilde{u}$ is the effective wind speed, F_y [Eq. (21)] is the lateral distribution function, and Δh_d is the plume rise (Briggs 1984). With $z = z_r$ and z_p, Eq. (31) estimates concentrations for the horizontal or terrain-following plume, respectively. The subscript j is equal to 1 for updrafts and 2 for downdrafts with λ_j defined as the weighting coefficient for each distribution. Equation (31) uses an image plume to handle ground reflections by assuming a source at $z = -h_s$. All subsequent reflections are handled by sources at $z = 2z_i + h_s$, $-2z_i - h_s$, $4z_i + h_s$, $-4z_i - h_s$, and so on.

The lateral dispersion coefficient (σ_y), in the equation for F_y, is estimated using the same approach that is used for the SBL [Eqs. (22) and (23)].

The vertical dispersion coefficient (σ_{zj}) is composed of an elevated (σ_{zej}) and surface (σ_{zg}) portion, such that

$$\sigma_{zj}^2 + \sigma_{zej}^2 + \sigma_{zg}^2. \tag{32}$$

The elevated component is obtained from Weil et al. (1997) as

$$\sigma_{zej} = \alpha_b \frac{\sigma_{wj} x}{\tilde{u}}, \tag{33}$$

where σ_{wj} is the standard deviation of the updraft ($j = 1$) and downdraft ($j = 2$) distributions of vertical wind speed. The coefficient $\alpha_b = \min(0.6 + 4\Psi_{dj}/z_i, 1.0)$ is designed to be 1.0 above the surface layer ($\psi_{dj} \ge 0.1z_i$) and match Venkatram's (1992) result for a surface source in neutral conditions. For the surface component,

$$\sigma_{zg} = b_c[1 - 10(\Psi_{dj}/z_i)](u_*/\tilde{u})^2(x^2/|L|), \quad (34)$$

where $b_c = 0.5$. Above the surface layer, σ_{zg} is set to zero, while for a surface release, Eq. (34) reduces to the form suggested by Venkatram (1992) for vertical dispersion in the unstable surface layer, that is, $\sigma_{zg} \propto (u_*/\tilde{u})^2 x^2/|L|$. The constant b_c was chosen to provide good agreement between the modeled and observed concentrations for the Prairie Grass Experiment data.

Total lateral and vertical dispersion, for all CBL plumes, are enhanced by plume buoyancy effects in the same manner as described for the SBL [Eq. (28)].

b. *Indirect source contribution to concentrations in the CBL*

The concentration due to the indirect source is calculated from

$$C_r\{x_r, y_r, z\} = \frac{Qf_p}{\sqrt{2\pi}\tilde{u}} F_y \sum_{j=1}^{2} \sum_{m=1}^{\infty} \frac{\lambda_j}{\sigma_{zj}} \times \left\langle \exp\left[-\frac{(z + \Psi_{rj} - 2mz_i)^2}{2\sigma_{zj}^2}\right] + \exp\left[-\frac{(z - \Psi_{rj} + 2mz_i)^2}{2\sigma_{zj}^2}\right]\right\rangle, \quad (35)$$

where σ_{zj} and F_y are the same as defined for the direct source, the plume height $\psi_{rj} = \psi_{dj} - \Delta h_i$, and Δh_i, which delays vertical mixing to account for residual buoyancy in the plume at the top of the boundary layer, is given by

$$\Delta h_i = \left(\frac{2F_b z_i}{\alpha_h u_p r_y r_z}\right)^{1/2} \frac{x}{u_p}, \quad (36)$$

where r_y and r_z are the plume half-widths in the lateral and vertical directions, u_p is the wind speed used for plume rise, and $\alpha_h = 1.4$ (see Weil et al. 1997).

c. *Penetrated source contribution to concentration in the CBL*

For the penetrated source, the vertical and lateral concentration distributions have a Gaussian form, such that

$$C_p\{x_r, y_r, z\} = \frac{Q(1 - f_p)}{\sqrt{2\pi}\tilde{u}\sigma_{zp}} F_y \times \sum_{m=-\infty}^{\infty} \left\langle \exp\left[-\frac{(z - h_{ep} - 2mz_{ieff})^2}{2\sigma_{zp}^2}\right] + \exp\left[-\frac{(z + h_{ep} + 2mz_{ieff})^2}{2\sigma_{zp}^2}\right]\right\rangle, \quad (37)$$

where F_y is the same as defined for the SBL and z_{ieff} is the height of the upper reflecting surface in a stable layer (see section 6). The penetrated plume height $h_{ep} = h_s + \Delta h_{eq}$ for ($f_p = 0$), while for partial penetration $h_{ep} = (h_s + z_i/2) + 0.75\Delta h_{eq}$. The vertical dispersion coefficient (σ_{zp}) contains only a stable elevated component, Eq. (26), because this source is decoupled from the surface. However, for the penetrated source, Eq. (26) is applied with N set to zero because it must pass into or through the well-mixed CBL prior to reaching ground-level receptors.

7. Treatment of lateral plume meander

Plume meander is the slow lateral back-and-forth shifting of the plume in response to nondispersing lateral eddies that are larger than the plume. For time-averaged concentrations, meander has the effect of increasing the lateral spread of the actual plume's distribution. Meander is treated by interpolating the concentrations that result from two limits of the horizontal distribution function (F_y)—the coherent plume limit F_{yC} (which assumes that the wind direction is distributed about a well-defined mean direction) and the random plume limit F_{yR} (which assumes that the plume has equal probability of moving in any direction). The estimated concentration is a weighted sum of the concentrations from these two limits, where the weighting is proportional to the horizontal energy in each of these state.

For the coherent plume, F_{yC} has the familiar Gaussian form

$$F_{yC} = \frac{1}{\sqrt{2\pi}\sigma_y} \exp\left(\frac{-y^2}{2\sigma_y^2}\right), \quad (38)$$

while for the random limit F_{yR} is written as

$$F_{yR} = \frac{1}{2\pi x_r}, \quad (39)$$

where x_r is the straight line distance from the source to the receptor.

To consider meander, the total concentration, on the order of 1 h, for stable or convective conditions ($C_{c,s}$) is determined as a weighted sum of the coherent (C_{Ch}) and random (C_R) plume concentrations as

$$C_{c,s} = C_{Ch}(1 - \sigma_r^2/\sigma_h^2) + C_R(\sigma_r^2/\sigma_h^2); \quad (40)$$

C_{Ch} is computed from Eq. (20) in the SBL and from Eq. (30) in the CBL, with the lateral terms replaced by Eq. (38). Similarly, C_R is computed with the lateral terms replaced by Eq. (39). The weighting factor is the ratio of the random component of the horizontal wind energy (σ_r^2) to the total horizontal wind energy (σ_h^2).

The horizontal wind is composed of a mean component $\bar{u}$, and random components σ_u and σ_v. Thus, a measure of the total horizontal wind "energy" can be represented as

$$\sigma_h^2 = 2\tilde{\sigma}_v^2 + \bar{u}^2, \quad (41)$$

where the mean wind $\bar{u} = (\tilde{u}^2 - 2\tilde{\sigma}_v^2)^{1/2}$. The random component is initially $2\tilde{\sigma}_v^2$ and becomes equal to σ_h^2 at large travel times when the mean wind is uncorrelated, as is seen in the following expression for σ_r^2:

$$\sigma_r^2 = 2\tilde{\sigma}_v^2 + \bar{u}^2[1 - \exp(-x_r/\tilde{u}T_r)], \tag{42}$$

where T_r is an autocorrelation time scale that is set to 24 h for uncorrelated winds (Brett and Tuller 1991).

8. Building downwash

AERMOD incorporates the Plume Rise Model Enhancements (PRIME) algorithms to handle plumes that are affected by building wakes. A detailed description of PRIME's formulation is found in Schulman et al. (2000). Conceptually, PRIME partitions plume mass between a cavity and wake region according to boundaries that are specified by the lateral and vertical separation streamlines. Dispersion of the mass that is initially captured within the cavity is based on building geometry and is assumed to be uniformly mixed. Beyond the cavity region, this mass is emitted into the wake where it is combined with uncaptured plume mass and dispersed at an enhanced rate (beyond ambient dispersion). In the wake, turbulence smoothly decays with distance, achieving ambient levels in the far field. Plume rise is estimated using a numerical model that includes effects from streamline deflection near the building, vertical wind speed shear, enhanced dilution from the turbulent wake, and velocity deficit.

A basic design tenet for incorporating PRIME into AERMOD was to be as faithful as possible to the PRIME formulation while ensuring that 1) AERMOD's new dispersion regime is applied with PRIME, and 2) far beyond the wake region, concentrations approach AERMOD's estimate. To ensure a smooth transition beyond the wake, the total concentration (C_{total}) is calculated as follows:

$$C_{\text{total}} = \gamma C_{\text{prime}} + (1 - \gamma)C_{\text{AERMOD}}, \tag{43}$$

where C_{prime} is the concentration that is estimated using the PRIME algorithms with AERMOD-derived meteorological inputs and C_{AERMOD} is the concentration that is estimated using AERMOD without building effects. The weighting parameter γ is designed such that the contribution from the PRIME calculation decreases exponentially with vertical, lateral, and downwind distance from the wake boundaries. That is,

$$\gamma = \exp\left[\frac{-(x - \sigma_{\text{xg}})^2}{2\sigma_{\text{xg}}^2}\right] \exp\left[\frac{-(y - \sigma_{\text{yg}})^2}{2\sigma_{\text{yg}}^2}\right] \times \exp\left[\frac{-(z - \sigma_{\text{zg}})^2}{2\sigma_{\text{zg}}^2}\right], \tag{44}$$

where x is the distance from the upwind edge of the building to the receptor, y is the crosswind distance from the building centerline to the receptor, z is the receptor height above ground, σ_{xg} is the longitudinal dimension of the wake, σ_{yg} is the distance from the building centerline to lateral edge of the wake, and σ_{zg} is the height of the wake at the receptor location, as specified in Schulman et al. (2000).

9. Dispersion characterization in the urban boundary layer

Although urban surface characteristics influence the boundary layer parameters at all times, the thermal effects of the urban area on the structure of the boundary layer is largest at night and relatively absent during the day (Oke 1998). In built-up areas a weak "convective like" boundary layer forms during nighttime hours when stable rural air flows onto a warmer urban surface. AERMOD accounts for this by enhancing the vertical turbulence beyond that found in the nighttime rural boundary layer. A representative convective velocity scale is defined from the urban heat flux (H_u) and urban mixed-layer height (z_{iu}).

Flux H_u is calculated from

$$H_u = \alpha\rho c_p \Delta T_{u-r} u_*, \tag{45}$$

which is analogous to the bulk transfer parameterization of heat flux over a homogeneous surface (e.g., Businger 1973), with α as the "bulk" transfer coefficient. Because the urban–rural temperature difference ΔT_{u-r} has a maximum value on the order of 10°C, and with light winds u_* on the order of 0.1 m s^{-1}, α should have a maximum value on the order of 0.1 in the city center. Assuming a linear variation of α from 0 at the edge of the urban area to about 0.1 at the center of the urban area results in an areal average of approximately 0.03. This value of α yields very good concentration comparisons between AERMOD and the Indianapolis, Indiana, data (Part II). Here, ΔT_{u-r}, used to estimate H_u, is empirically based on data from Oke (1973, 1982) for a number of Canadian cities with populations from 1000 to 2 000 000. These data were collected during conditions of clear skies, low winds, and low humidities, and represent periods of expected maximum urban effect. An empirical fit to these data yields

$$\Delta T_{u-r} = \Delta T_{\max}[0.1 \ln(P/P_o) + 1.0], \tag{46}$$

where $\Delta T_{\max} = 12°\text{C}$, $P_o = 2\ 000\ 000$, and P is the population of the modeling domain.

Empirical evidence presented in Oke (1973, 1982) and Venkatram (1978) suggests that $z_{iu} \propto P^{1/4}$, such that

$$z_{iu} = z_{iuo}(P/P_o)^{1/4}, \tag{47}$$

where z_{iuo} is the boundary layer height corresponding to P_o.

Hanna and Chang (1991) report lidar measurements from the Indianapolis tracer study for nocturnal conditions. While the mixing heights at night range from 100 to 500 m, they were generally around 400 m during

clear, calm conditions. Using 400 m for z_{iu} in Eq. (47), and the Indianapolis population of 700 000, the value of z_{iuo} is computed to be 500 m. This is not inconsistent with measurements by Bornstein (1968) in New York, New York.

The (nighttime urban) convective velocity scale is computed by substituting z_{iu} and H_u into the definitional equation for w_* (Deardorff 1970), such that

$$w_{*u} = \left(\frac{gH_u z_{iuc}}{\rho c_p T_{\mathrm{ref}}}\right)^{1/3}. \tag{48}$$

Enhanced vertical turbulence in the urban boundary layer is computed using Eq. (11) with Eq. (48) used for the convective velocity scale. With enhanced turbulence, vertical dispersion is calculated from Eq. (26).

10. Summary

This paper presents a comprehensive description of the AERMOD dispersion model formulations, including AERMOD's characterization of the boundary layer, the representative terrain used to influence flow, and the specification of model dispersion algorithms for both convective and stable conditions in urban and rural areas. A notable strength of AREMOD's formulations, particularly in the characterization of the boundary layer, lies in its reliance on previously successful modeling approaches that have been established in the literature, coupled with the developers' efforts to avoid major discontinuities that are often found in atmospheric dispersion models. The performance of this model has been evaluated, with results documented in Part II.

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AERMOD: A Dispersion Model for Industrial Source Applications. Part II: Model Performance against 17 Field Study Databases

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ABSTRACT

The performance of the American Meteorological Society (AMS) and U.S. Environmental Protection Agency (EPA) Regulatory Model (AERMOD) Improvement Committee's applied air dispersion model against 17 field study databases is described. AERMOD is a steady-state plume model with significant improvements over commonly applied regulatory models. The databases are characterized, and the performance measures are described. Emphasis is placed on statistics that demonstrate the model's abilities to reproduce the upper end of the concentration distribution. This is most important for applied regulatory modeling. The field measurements are characterized by flat and complex terrain, urban and rural conditions, and elevated and surface releases with and without building wake effects. As is indicated by comparisons of modeled and observed concentration distributions, with few exceptions AERMOD's performance is superior to that of the other applied models tested. This is the second of two articles, with the first describing the model formulations.

1. Introduction

In 1991, the U.S. Environmental Protection Agency (EPA) in conjunction with the American Meteorological Society (AMS) formed the AMS and EPA Regulatory Model (AERMOD) Improvement Committee (AERMIC) with the expressed purpose of incorporating the current understanding of the planetary boundary layer (PBL) into a state-of-the-art applied dispersion model, AERMOD.

AERMIC's work clearly has benefited from the model development activities worldwide over the past few decades, especially in the parameterization of mean winds and PBL turbulence, dispersion in the CBL, the treatment of plume/terrain interactions, plume–building interactions, and urban dispersion.

AERMOD (Cimorelli et al. 2003) is a steady-state plume model aimed at short-range (up to 50 km) dispersion from stationary industrial-type sources—the same scenarios that are currently handled by the EPA's Industrial Source Complex Short-Term model (ISCST3) (U.S. Environmental Protection Agency 1995). The meteorological conditions are assumed to be steady during the modeling period (typically 1 h) and horizontally homogeneous. Vertical variations in the PBL, however, are incorporated into the model's predictions. For flow in complex terrain AERMOD incorporates the concept of a dividing streamline (Snyder et al. 1985). The model considers the influence of building wakes on plume rise and dispersion using the algorithms of the Plume Rise Model Enhancements (PRIME) model (Schulman et al. 2000). In urban areas, AERMOD accounts for the dispersive nature of the "convective like" boundary layer that forms during nighttime conditions by enhancing the turbulence resulting from urban heat flux (Oke 1978, 1982).

This paper is the second of two describing the newly developed AERMOD modeling system. Cimorelli et al. (2005, hereinafter Part I) describe the model formula-

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TABLE 1. Description of field studies (without building wake effects).

Database	Description of field study
Prairie Grass (SO_2)	Very flat, rural (Nebraska); nonbuoyant single-point source; 0.46-m release; 44 data hours; SO_2 samplers in arcs out to 800 m; 16-m meteorological tower (wind, turbulence, and temperature data); Barad (1958) and Haugen (1959).
Kincaid (SF_6)	Flat, rural (Illinois), highly buoyant single source; tall stack release (187 m); 375 data hours; SF_6 samplers in arcs out to 50 km; 100-m tower (wind, turbulence, and temperature); Liu and Moore (1984) and Bowne et al. (1983).
Indianapolis (SF_6)	Flat, urban (Indiana), highly buoyant release (84 m); 170 data hours; SF_6 samplers in arcs out to 12 km; Urban tower (94 m); 10-m suburban and rural towers (wind, turbulence, and temperature); Murray and Bowne (1988).
Kincaid (SO_2)	Flat, rural (Illinois), highly buoyant single source; tall stack release (187 m); 4614 data hours; 30 samplers out to 20 km; 100-m tower (wind, turbulence, and temperature); Liu and Moore (1984) and Bowne et al. (1983).
Lovett (SO_2)	Hilly, rural (New York), highly buoyant release (145 m); 12 monitors out to 3 km; 1 yr of data; 100-m (wind, turbulence, and temperature); Paumier et al. (1992).
Baldwin (SO_2)	Flat, rural (Illinois); three highly buoyant stacks (184 m); 10 fixed samplers out to 10 km; 1 yr of data; 100-m (wind and temperature data); Hanna and Chang (1993).
Clifty Creek (SO_2)	Moderately hilly, rural (Indiana); three highly buoyant stacks (each 208 m); six fixed samplers out to 15 km; 1 yr of data; 60-m tower on nearby plateau, 115 m above stack base (wind and temperature data).
Martins Creek (SO_2)	Hilly, rural (Pennsylvania); multiple highly buoyant releases (122–183 m); 1 yr of data; seven fixed samplers out to 8 km; 10-m tower plus sodar (wind, turbulence, and temperature data).
Westvaco (SO_2)	Hilly, rural (Maryland); highly buoyant stack (183 m); 11 fixed samplers out to 3 km; 1 yr of data; two 30-m towers; 100-m tower (wind, turbulence, and temperature data); Strimaitis et al. (1987).
Tracy (SF_6)	Mountainous, rural (Nevada); moderately buoyant stack (91 m); 128 h of data; SF_6 samplers out to 8 km; 150-m tower (wind, turbulence and temperature data); tethersonde temperatures; acoustic sounder; DiCristofaro et al. (1985).

tion, while this paper provides an overview of the model's performance against the concentration observations at 17 field study databases. The studies include sites with flat and complex terrain, urban and rural conditions, and elevated and surface releases with and without building wake effects. The evaluation measures are focused on those that are relevant to regulatory applications, that is, emphasis on ability of the model to simulate the upper end of the concentration distributions. AERMOD estimates have been compared with those of other applied models, including ISCST3 (U.S. Environmental Protection Agency 1995), the Hybrid Plume Dispersion Model (HPDM) (Hanna and Paine 1989), the Rough Terrain Diffusion Model (RTDM) (Paine and Egan 1987), and the Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS) (Perry 1992).

2. Model evaluation field studies

Of the 17 databases that were considered, 10 were designed to collect data for overall model performance where building wakes were not an issue, while the remaining 7 were specifically focused on building influences. The studies are summarized in Tables 1 and 2. Maps of the various sites can be found in Paine et al. (1998, 2003). The first five databases listed in Table 1 were used during the AERMOD development process to identify major problems with the model algorithms but generally were not used to set empirical parameters to improve the model results. An exception is found with the use of the Prairie Grass Experiment data to specifically develop the formulation for the lateral dispersion parameter. The remaining five databases were independently applied to the developed model code. The first four building wake databases in Table 2 were each subdivided to provide data for both model development and evaluation of the PRIME building downwash algorithms. However, all of the data from the seven building wake databases were used in the performance results described in this paper.

3. Performance measures

Although the model evaluation examined the quality of the predictions relative to the model physics, the results reported here are focused primarily on answering the questions: how well does AERMOD predict the high-end, ground-level concentrations that are generally used to assess compliance with air quality regulations; and is AERMOD's performance distinguishably better than that of other applied models for this purpose? To answer these questions the analyses of the model's performance utilized all of the relevant input data that are available with each dataset. The performances of earlier versions of AERMOD were examined with reductions in the number of height levels in the measured profiles of PBL variables (e.g., wind, temperature). Paine (2003) found that the performance of the model tended to degrade as more and more levels of data were removed from the analysis. In general, the model predictions tended toward higher concentrations and, thus, provided more conservative results when compared to the observed concentrations.

In the absence of model formulation errors and stochastic variations, the major reasons for deviations between model estimates and observations are errors in the model inputs, and the concentration observations

TABLE 2. Description of field studies (with building wake emphasis).

Database	Description of field study
Bowline Power Plant (SO_2)	Rural, locally flat (New York); buoyant twin stacks; 87-m release; dominant building height = 65 m; SO_2 samplers at 250 and 850 m; 100-m meteorological tower (wind, temperature); full year of data; Schulman and Hanna (1986).
Millstone Nuclear Plant (SF_6, CF_3Br)	Rural (coastal Connecticut) with terrain variation < 10 m; nonbuoyant releases at 48 and 29 m; building height = 45 m; sampling on arcs from 350 to 1500 m; 43-m meteorological tower (wind and temperature; mostly high winds and onshore flow); Bowers and Anderson (1981).
Duane Arnold Energy Center (SF_6)	Rural (Iowa); with terrain variations up to 30 m; rooftop (nonbuoyant) releases at 46 and 24 m plus ground-level releases; samplers on arcs at 300 and 1000 m; 50-m meteorological tower (mostly light wind, convective conditions); Thullier and Mancuso (1980).
Alaska North Slope (SF_6)	Isolated, very flat (Prudhoe Bay area, Alaska); buoyant release at 39 m; building height of 34 m; samplers in seven arcs from 50 to 3000 m; 33-m meteorological tower (wind, temperature, and velocity variance; primarily stable to very stable conditions); Guenther et al. (1989) and Guenther and Lamb (1990).
American Gas Association Study (SF_6)	Rural, flat (Texas and Kansas); highly buoyant releases varied from about 1 to 2.5 times building heights; sampler arrays from 50 to 200 m; 10-m meteorological tower; Engineering Science (1980).
EOCR Study (SF_6)	Rural (Idaho); terrain variations < 10 m; nonbuoyant releases at 30 m, 25 m, and near ground level; building height = 25 m; sampling arcs at seven distances from 50 to 1600 m; wide range of stabilities and wind speeds; many stable; Start et al. (1981).
Lee Power Plant (wind tunnel study)	Rural simulation, flat (wind tunnel); buoyant release at 1.5H (H is model building height); sampling at arcs of 150–900 m (full scale); neutral and stable conditions; stack Froude numbers varied; wind directions varied; Melbourne and Taylor (1994).

themselves. An individual model prediction will most likely differ from the corresponding observation because the model cannot include all of the variables that affect the observation at a particular time and location. It is the experience of model developers (e.g., Weil 1992 and Liu and Moore 1984) that wind direction uncertainties alone can, and do, cause disappointing results from what otherwise may be well-performing dispersion models. However, a model that is based on appropriate characterizations of the important physical processes should be able to reproduce the distribution of observations as long as the range of model inputs is similar to that of the observations (Venkatram et al. 2001). A model with the ability to adequately predict the distribution of concentrations provides information for regulatory questions, such as what is the probability that a certain concentration is exceeded?

Concentration distributions can be readily assessed with quantile–quantile (Q–Q) plots (Chambers et al. 1983) that are created by ranking the predicted and observed concentrations and then pairing by rank. Specifically, a good model will have a slope in this plot similar to that of the 1:1 line and, specifically for regulatory applications, will have values in the important upper end of the distribution near to those of the measurements. Paumier et al. (1992) demonstrated the usefulness of Q–Q plots in characterizing the performance of CTDMPLUS. Venkatram et al. (2001) argue for the use of Q–Q plots for evaluating regulatory models.

Furthermore, the ability of AERMOD to assess the high end of the concentration distribution is examined with the robust highest concentration (RHC) statistic (Cox and Tikvart 1990). The RHC represents a smoothed estimate of the highest concentrations based on an exponential fit to the upper end of the concentration distribution:

$$\mathrm{RHC} = \chi\{n\} + (\chi - \chi\{n\}) \ln\left(\frac{3n - 1}{2}\right), \qquad (1)$$

where n is the number of values used to characterize the upper end of the concentration distribution, χ is the average of the $n - 1$ largest values, and $\chi\{n\}$ is the nth largest value; $n = 26$ (suggested by Cox and Tikvart 1990) for most comparisons reported here. RHC is a preferred statistic because it yields a representative high-end estimate while mitigating the undue influence of individual unusual events. In summary, for regulatory applications, a good model would produce a concentration distribution parallel to the slope of the measured distribution and produce high-end concentrations (RHCs) that are similar to that of the observations.

Other methods for comparing model performance could have been applied in this analysis [e.g., the recently approved American Society for Testing and Materials (ASTM) methodology for comparing the performance of dispersion models (Irwin et al. 2003)], but the focus here is on the estimates of the high end of the concentration distributions.

4. Model performance results

Of the 17 databases considered, seven emphasized near-field concentrations resulting from building wake effects. Four of the no-wake studies involve short-term, intensive measurements with extensive sampler arrays, while six include long-term, continuous sampling at more limited locations. In the intensive studies, where experimental periods are rarely continuous, only 1-h averages are considered. With the long-term studies, results are also reported for 3-h, 24-h, and annual averages.

a. Model comparisons with data from intensive studies (no building wakes)

These studies involve a nonbuoyant, surface release in very flat terrain (Prairie Grass, Nebraska), an elevated buoyant release in flat terrain (Kincaid, Illinois; SF_6), an elevated buoyant release in a midsized urban area (Indianapolis, Indiana), and an elevated, weakly buoyant release in mountainous terrain (Tracy, Illinois). For these data, observations and predictions correspond to maximum concentrations on each arc of samplers to minimize the effect of wind direction uncertainties. The RHC and Q–Q plots for each model and field study are developed from the ranked and paired distributions of observations and predictions. Table 3 summarizes the ratio of modeled to observed RHC values for AERMOD, ISCST3, and CTDMPLUS. CTDMPLUS was designed for applications in complex terrain and is, therefore, compared with AERMOD for Tracy, which is a mountainous location.

The RHC ratios reveal generally good performance for AERMOD at all four sites. The model shows a tendency to underpredict the higher concentrations for the flat-terrain, rural sites (Prairie Grass and Kincaid) and a tendency to overpredict at the urban and mountainous sites. In all cases, AERMOD shows improvement over ISCST3, which, except for Kincaid, tends to overpredict (particularly in complex terrain). For Tracy, AERMOD is found to be unbiased, while CTDMPLUS shows underprediction. This is particularly interesting because Tracy was one of the primary databases used in the original development of CTDMPLUS.

Figure 1 shows the Q–Q plots that are relevant to these models and the intensive databases. The slope of the ISCST3 concentration distribution compares well to that of the Prairie Grass data (Fig. 1a) to a great degree because ISCST3 dispersion is based on the Pasquill–Gifford–Turner (PGT) curves (Pasquill 1961; Gifford 1961). However, the modeled values tend to remain consistently above the observations (RHC ratio of 1.5). AERMOD (with an RHC ratio of 0.87) also shows a concentration distribution that matches observations well, suggesting that both models are capable of simulating near-field dispersion for a near-surface release. In contrast, for an elevated plume in flat terrain (Fig. 1b; Kincaid SF_6 data), both models have distributions that drop below the observations for the lower concentrations. Because short-term maximum concentrations from elevated plumes are generally associated with convective conditions, this dropoff is related primarily to stable conditions. This is borne out upon comparing the Kincaid convective and stable residual plots (not shown here), a pairing of modeled and predicted concentrations in time and downwind distance (Paine et al. 1998). Figure 1b also displays a distinction between the two models' performance in the upper end of the distribution with AERMOD tracking the observations noticeably better. This stems from the fact that AERMOD's plume formulation is non-Gaussian in convective conditions, in keeping with field and laboratory observations (Willis and Deardorff 1981; Baerentsen and Berkowicz 1984; Weil et al. 1997).

TABLE 3. Ratio of modeled to observed robust highest concentrations—intensive studies.

Database	AERMOD (1 h)	ISCST3 (1 h)	CTDMPLUS (1 h)
Prairie Grass	0.87	1.50	—
Kincaid SF6	0.77	0.68	—
Indianapolis	1.18	1.30	—
Tracy	1.07	2.81	0.77

The Indianapolis database provides a test of model performance in a moderately sized urban area with a population of approximately 700 000. Based on the RHC ratios in Table 3, both ISCST3 and AERMOD perform well. For this single stack situated near the downtown business district, the Q–Q plot (Fig. 1c) shows AERMOD's superiority in tracking the full distribution of observed concentrations; suggesting an added ability to predict longer averaging times. Although not shown here, an examination of the residuals (Paine et al. 1998) found that for convective conditions, during which most of the highest measured concentrations were observed, AERMOD performed well at all downwind distances. For stable conditions, the residuals show that the model underpredicted the very small concentrations occurring within a kilometer of the stack but performed better for the more distant, higher concentrations.

Of the intensive tracer studies, the most notable difference in the performance of AERMOD and ISCST3 appears with the Tracy data. Tracy, a tall buoyant stack in mountainous terrain, is equipped with a very high quality meteorological and tracer sampling network (Fig. 1d). The Tracy data were collected during predominately stable conditions. The concept that the plume in stable conditions is influenced by the flow in the layers separated by the dividing streamline has been shown to be integral to plume modeling in complex terrain. This concept is central to the formulations in both AERMOD and CTDMPLUS but is not considered by ISCST3. The distributions of AERMOD and CTDMPLUS are well matched throughout the range of the Tracy data. ISCST3 estimates exhibit an approximate factor-of-3 overprediction.

b. Model comparisons with data from long-term, continuous studies (no building wake)

The six long-term field studies provide data for both individual and multiple elevated, buoyant stack releases. The study sites are located in predominantly rural areas of flat to complex terrain (with topography in some cases extending above stack height). Receptor fields were more limited for these studies, such that

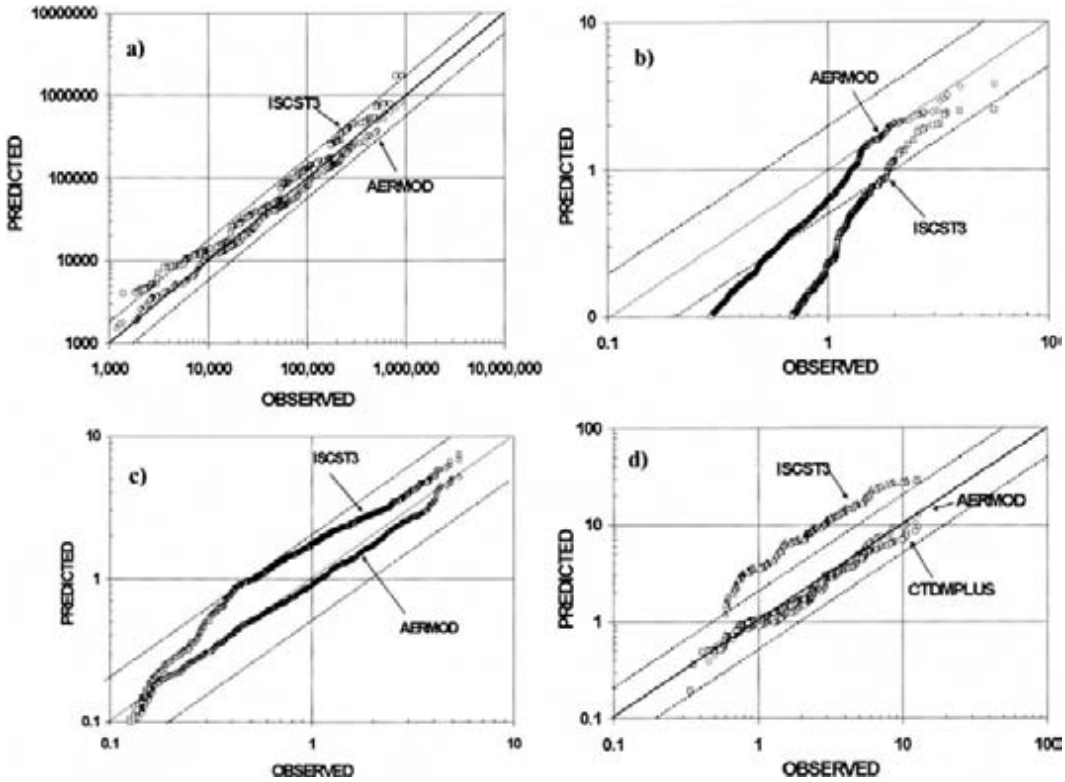

FIG. 1. Quantile–quantile plot of model-predicted vs observed 1-h-averaged concentrations (μg m^{-3}) for (a) Prairie Grass data, (b) Kincaid SF_6 data, (c) Indianapolis data, and (d) the complex terrain case of Tracy Power Plant. Solid line indicates a one-to-one correspondence in the concentration distributions; the dashed lines indicate factor-of-2 over- and underestimates.

well-defined arcs as a function of downwind distance did not exist. Therefore, the distributions of modeled and observed concentrations are based on the 1-h maximum concentrations throughout the network.

Table 4 shows RHC ratios for the two studies in relatively flat terrain (Kincaid SO_2 and Baldwin, Illinois). AERMOD does very well in capturing the upper end of the distribution for both the 3- and 24-h averaging period. This is confirmed by the Q–Q plots of Figs. 2 and 3. ISCST3 displays a considerable underprediction at Kincaid and an overprediction at Baldwin for the upper end of the 3-h-averaged concentrations. Although the two studies share similar stack heights and parameters, Kincaid involves a single stack, while Baldwin has three that are separated over a distance of 100 m. Baldwin also has many fewer sampler locations than Kincaid. The better performance shown by AERMOD is not unexpected in these comparisons because the shorter averaging times are dominated by near-field impacts that are controlled by convective conditions for which AERMOD's formulation is superior. Additionally, the HPDM model (with a convective formulation not unlike that of AERMOD) predictions matched the Baldwin observations exceptionally well for all of the averaging periods (Table 4 and Fig. 3).

Clifty Creek, Indiana, is an interesting database because this highly buoyant source, with nearly collocated stacks, has near-field monitors at elevations of about 0.5 times the stack height in elevation. Both AERMOD and ISCST3 perform well for 3- and 24-h averages (Table 4 and Fig. 4). HPDM shows a tendency to overpredict the RHC ratios particularly for the 24-h average but has a distribution that otherwise "parallels" the observations well. The hilly terrain setting at Clifty Creek provided the only full-year database for which ISCST3 showed a very good performance.

The three complex terrain databases (Lovett, New York; Martin's Creek, Pennsylvania; and Westvaco, Maryland) all contain samplers at elevations above the stack top and at locations generally between 2 and 8 km from the stacks. Lovett and Westvaco each involve a single stack while Martin's Creek has emissions from three identical stacks with horizontal separations on the order of 100–200 m. All stacks in these studies are tall (145–189 m), and emissions are highly buoyant.

AERMOD performed well for all three complex terrain studies with RCH ratios of 1.0–1.65 for the 3-h and 24-h averages (Table 4 and Figs. 5, 6, and 7). This is a very satisfying result given the complexity of the terrain, the source configurations, and the relatively few sampling locations in these studies. When examined in

TABLE 4. Ratio of modeled to observed robust highest concentrations—continuous studies.

Database	Time avg	AERMOD	ISCST3	CTDMPLUS	HPDM	RTDM
Kincaid SO_2	3 h	1.02	0.56	—	—	—
	24 h	0.97	0.45	—	—	—
	Annual	0.31	0.14	—	—	—
Baldwin	3 h	1.35	1.48	—	1.06	—
	24 h	1.04	1.13	—	1.02	—
	Annual	1.00	0.63	—	1.15	—
Clifty Creek	3 h	1.26	0.98	—	1.33	—
	24 h	0.73	0.67	—	1.46	—
	Annual	0.55	0.31	—	0.96	—
Lovett	3 h	1.00	8.20	2.37	—	—
	24 h	1.00	9.11	2.01	—	—
	Annual	0.79	7.49	1.34	—	—
Martins Creek	3 h	1.06	7.25	4.80	—	3.33
	24 h	1.65	8.88	5.56	—	3.56
	Annual	0.76	3.37	2.19	—	1.32
Westvaco	3 h	1.08	11.00	2.14	—	—
	24 h	1.14	8.74	1.54	—	—
	Annual	1.65	10.33	0.93	—	—

conjunction with the Tracy results, it is clear that AERMOD is very capable of estimating the important regulatory concentrations for situations in which the plume is either impinging directly on the terrain or significantly interacting with the distorted flow near and above the terrain. This reflects well on the robust nature of the model.

The remaining three models tested in complex terrain were all consistently high in their estimates. For short-term averages, CTDMPLUS's and RTDM's RHC ratios ranged over a factor of 2–5 too high, and modeled estimates remained overpredictive over much of the distributions. Despite the fact that CTDMPLUS accounts for much of the flow details, AERMOD was found to be superior in determining the distribution of concentrations (particularly the important high end). ISCST3 demonstrates consistently poor performance for all three studies, overpredicting the high concentrations by on the order of a factor of 10!

All of the Q–Q plots reflect a dropoff in the modeled distributions for the low concentrations. This has obvious implications for the annual average estimates. As Table 4 suggests, both ISCST3 and AERMOD have some problems with the annual average estimates. For flat and simple terrain, the models underpredict the observed annual averages. For complex terrain, ISCST3 overpredicts observations by a factor of 3–10. The use of SO_2 as a tracer and the detection limits of the samplers contribute to these poor comparisons. When determining background, residual concentrations from previous periods interfere with its true estimate. Also, SO_2 monitors typically have a detection limit on the order of 16 μg m^{-3}. Concentrations below this are set to one-half of the limit even though actual concentrations may be much less or even zero. These uncertainties, in combination with a great many small sampled concentrations throughout extended periods, reflect on the reliability of the long-term averages. Peak short-term concentrations are much less impacted because background estimates and instrument limitations are a much smaller percentage of the total concentration. In contrast, CTDMPLUS and RTDM do not underestimate the annual averages, perhaps due somewhat to their overestimates for the short-term averages. HPDM does very well for the annual averages for the two databases with which it was compared. For the applications for which HPDM was designed (particularly, tall-stack, simple-terrain databases) it performs like a state-of-the-science model. Additional evaluations of HPDM can be found in Hanna and Chang (1993).

c. *Model comparisons with databases where building wakes are important*

Of the seven building wake studies (Table 2), Millstone Nuclear Plant in Waterford, Connecticut, Duane Arnold Energy Center (DAEC) in Cedar Rapids, Iowa, Alaska North Slope, Alaska, and (one-half of) the Bowline Power Plant in Haverstraw, New York, databases were used to some degree in the development of the PRIME algorithms that have been most recently implemented within the AERMOD framework. A summary of the AERMOD and ISCST3 performances against these building wake studies with RHC as the indicator is shown in Table 5. A more detailed discussion, including comparisons using Q–Q plots, can be found in Paine et al. (2003).

Looking first at the Bowline Power Plant study (the only full-year, continuous building wake database), there is little difference in the two models. Both show a modest overprediction for the upper end of the concentration distribution. However, the short-term estimates (3 h), which are most dominated by downwash conditions, are nearly unbiased. The increased overprediction of RHCs for the longer averaging times suggests that the models may be finding a higher incidence of

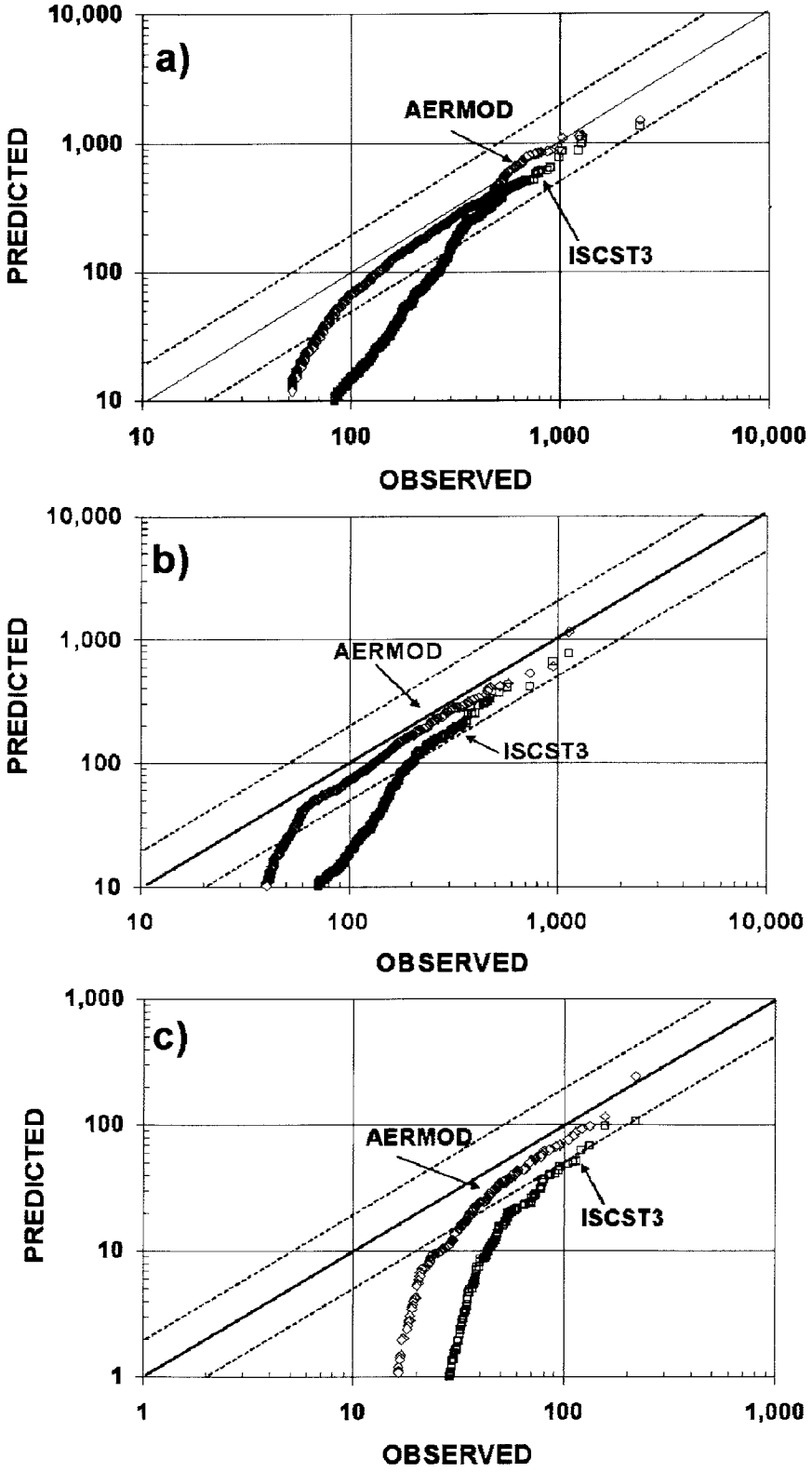

FIG. 2. Quantile–quantile plot of model-predicted vs observed concentrations (μg m^{-3}) for the Kincaid SO_2 database for (a) 1-, (b) 3-, and (c) 24-h averages. Dashed and solid lines mean the same as in Fig. 1.

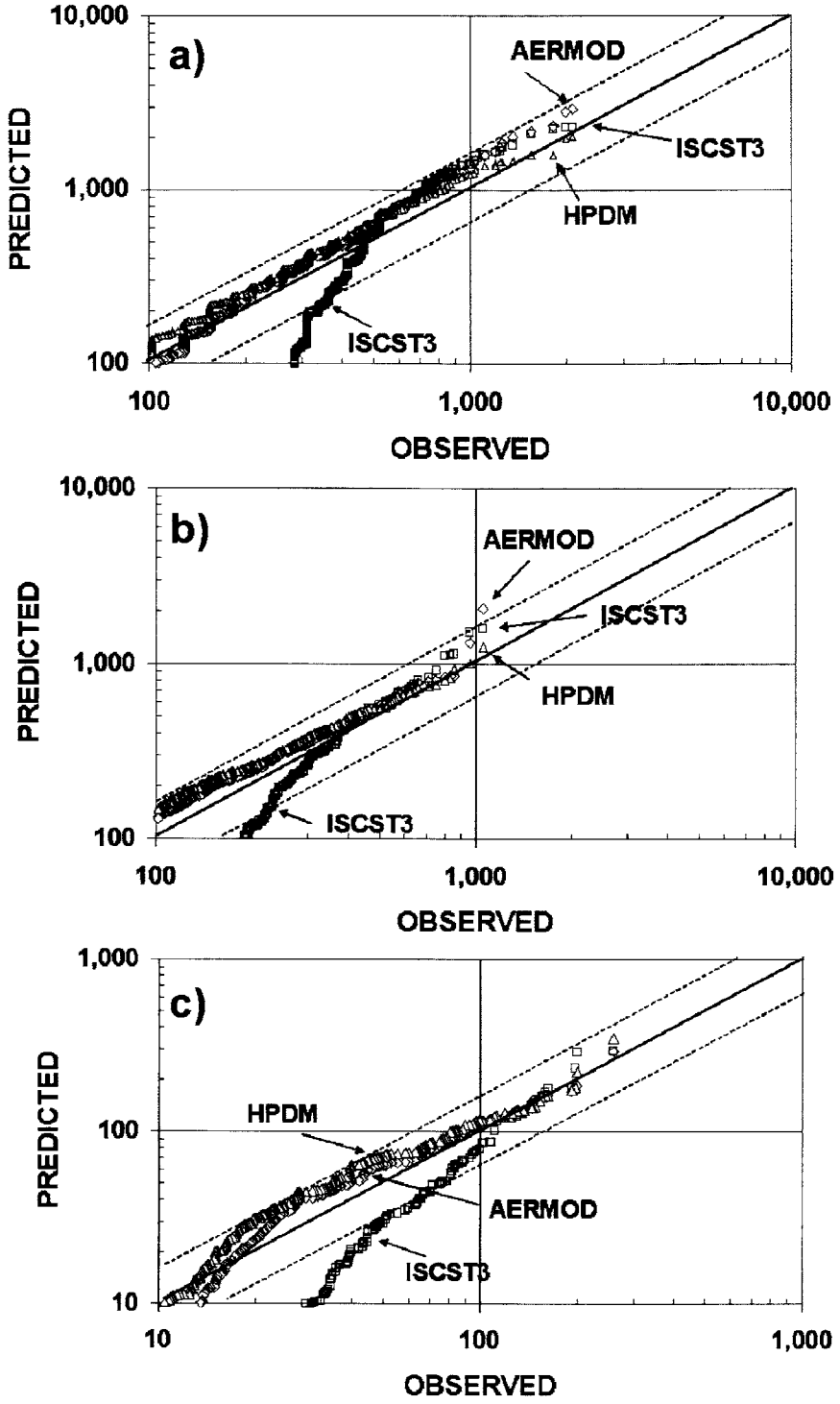

FIG. 3. Quantile–quantile plot of model-predicted vs observed concentrations (μg m^{-3}) for the Baldwin SO_2 database for (a) 1-, (b) 3-, and (c) 24-h averages. Dashed and solid lines mean the same as in Fig. 1.

downwashed plumes that are represented in the measurements.

The Millstone Nuclear Plant facility provides an opportunity to examine the sensitivity of the model estimates to plume/cavity geometry, because its nonbuoyant plumes are released at the height of the building and at one-half of that height. With release of material in the cavity (29-m release), AERMOD is overpredict-

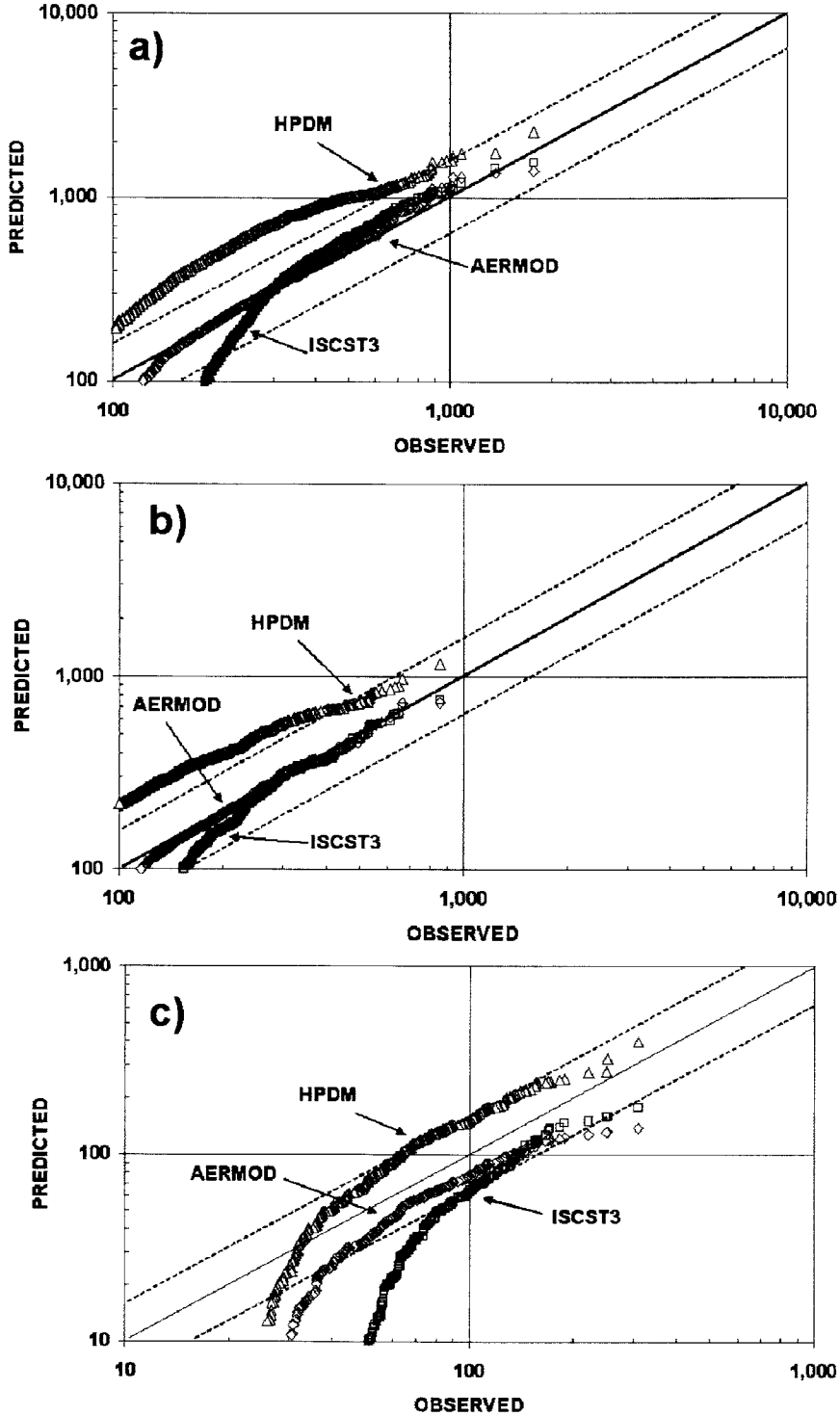

FIG. 4. Quantile–quantile plot of model-predicted vs observed concentrations (μg m^{-3}) for the Clifty Creek SO_2 database for (a) 1-, (b) 3-, and (c) 24-h averages. Dashed and solid lines mean the same as in Fig. 1.

ing the RHC. The plume is assumed to be well mixed in the cavity. However, when the plume is released near the boundary of the cavity or wake (near or slightly above the building top), the specification of those boundaries apparently becomes critical to the determination of peak ground-level concentrations. With an underprediction of over a factor of 2 for the near-building-height release, it appears that the models may

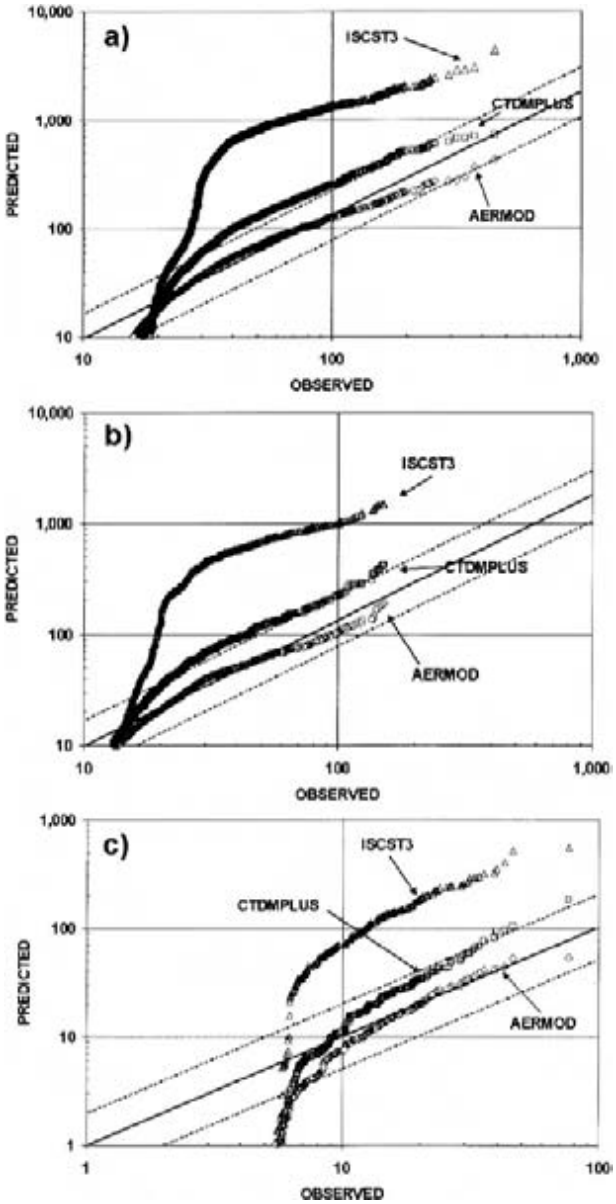

FIG. 5. Quantile–quantile plot of model-predicted vs observed concentrations (μg m^{-3}) for the Lovett SO_2 database for (a) 1-, (b) 3-, and (c) 24-h averages. This is a complex terrain site. Dashed and solid lines mean the same as in Fig. 1.

not be specifying the plume/cavity relationship particularly well.

The remainder of the databases yields comparisons with the model estimates that considerably emphasize the sensitivity of the models to the geometry and meteorological characteristics of a particular site. For example, the Duane Arnold and Experimental Organic Cooled Reactor (EOCR), Idaho Falls, Idaho, studies both involve nonbuoyant, near-building-height (or below) releases, yet the Duane Arnold study was dominated by convective conditions and EOCR by stable conditions. As Table 5 shows, the models consistently underpredict at Duane Arnold and equally overpredict for EOCR.

A more compounded contrast can be found with the Duane Arnold and the Alaska North Slope studies. For the nonbuoyant plumes at Duane Arnold, the conditions were mostly convective, while in Alaska the plume was buoyant and conditions were very stable. Again, at Duane Arnold AERMOD underpredicts (particularly for the lower releases), and yet the model shows little bias for the Alaska cases. The sensitivity of the model estimates to the specification of the plume/cavity/wake geometry is suggested.

The Alaska North Slope results (with very stable conditions) also contrast with the stable wind-tunnel results for the Lee Power Plant (Pelzer, South Carolina) case. These studies are similar in plume/wake geometry with the difference being that, in some cases, the wind-tunnel study had releases much higher than the building. Despite the fact that the meteorological conditions and geometry were comparable in these two studies, the model is unbiased in its estimates for Alaska and yet overpredicts by more than a factor of 2 for the stable wind-tunnel comparisons.

In general, it is not surprising that these results are complex for modeling regimes that are themselves complex. It seems that a combination of meteorological conditions (obviously affecting plume rise) and the building geometry and, thus, specification of wake and cavity dimensions highly influences these high-end concentration predictions represented by the RHC ratios in Table 5. One summary observation after reviewing all the results (Table 5) is that AERMOD is generally capable of capturing the important regulatory concentrations within a factor of 2 or better. Further comparisons (particularly with the wind-tunnel data) may help to articulate the specific algorithms in the model for which sensitivity is greatest.

d. AERMOD performance for area and volume sources

Because all 17 studies previously discussed in this paper involved point source releases, one particular study in the literature that examines the model's performance for area and volume source types is worth discussing here. A report commissioned by the American Petroleum Institute (Hanna et al. 1999) was summarized in a paper by Hanna et al. (2000) in which they examined the performance of AERMOD against the Kincaid, Indianapolis, and Lovett databases, already discussed here, and two additional studies—a nonbuoyant release within a refinery complex (OPTEX data) and a nonbuoyant release from area and volume source configurations in an open grassy area (Duke Forest, North Carolina, data). Both of these studies, described in some detail by Hanna et al. (1999), involved multiple release points that are generally near the surface. The OPTEX data were intended to simulate point, area,

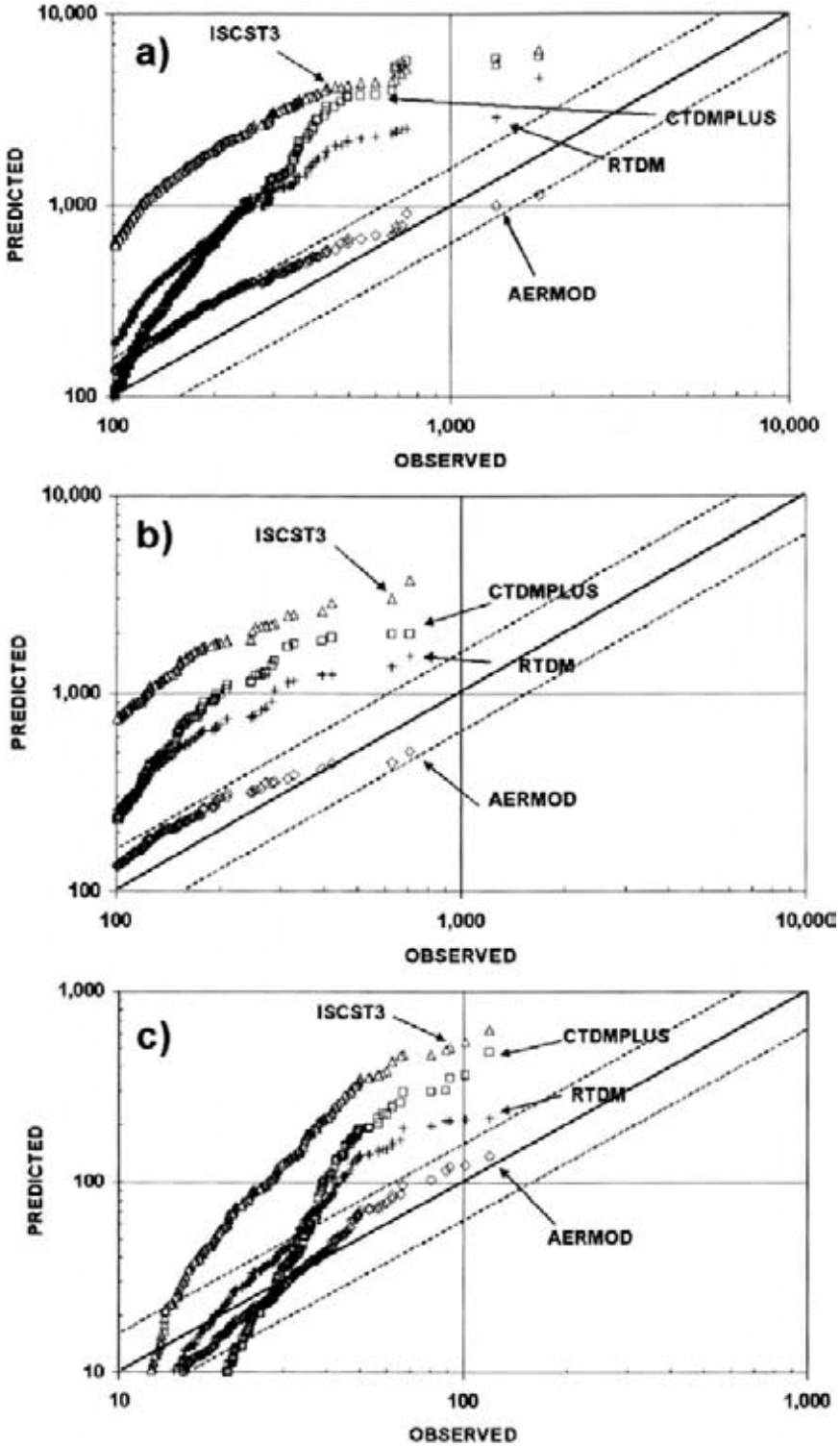

FIG. 6. Quantile–quantile plot of model-predicted vs observed concentrations (μg m^{-3}) for the Martin's Creek SO_2 database for (a) 1-, (b) 3-, and (c) 24-h averages. This is a complex terrain site. Dashed and solid lines mean the same as in Fig. 1.

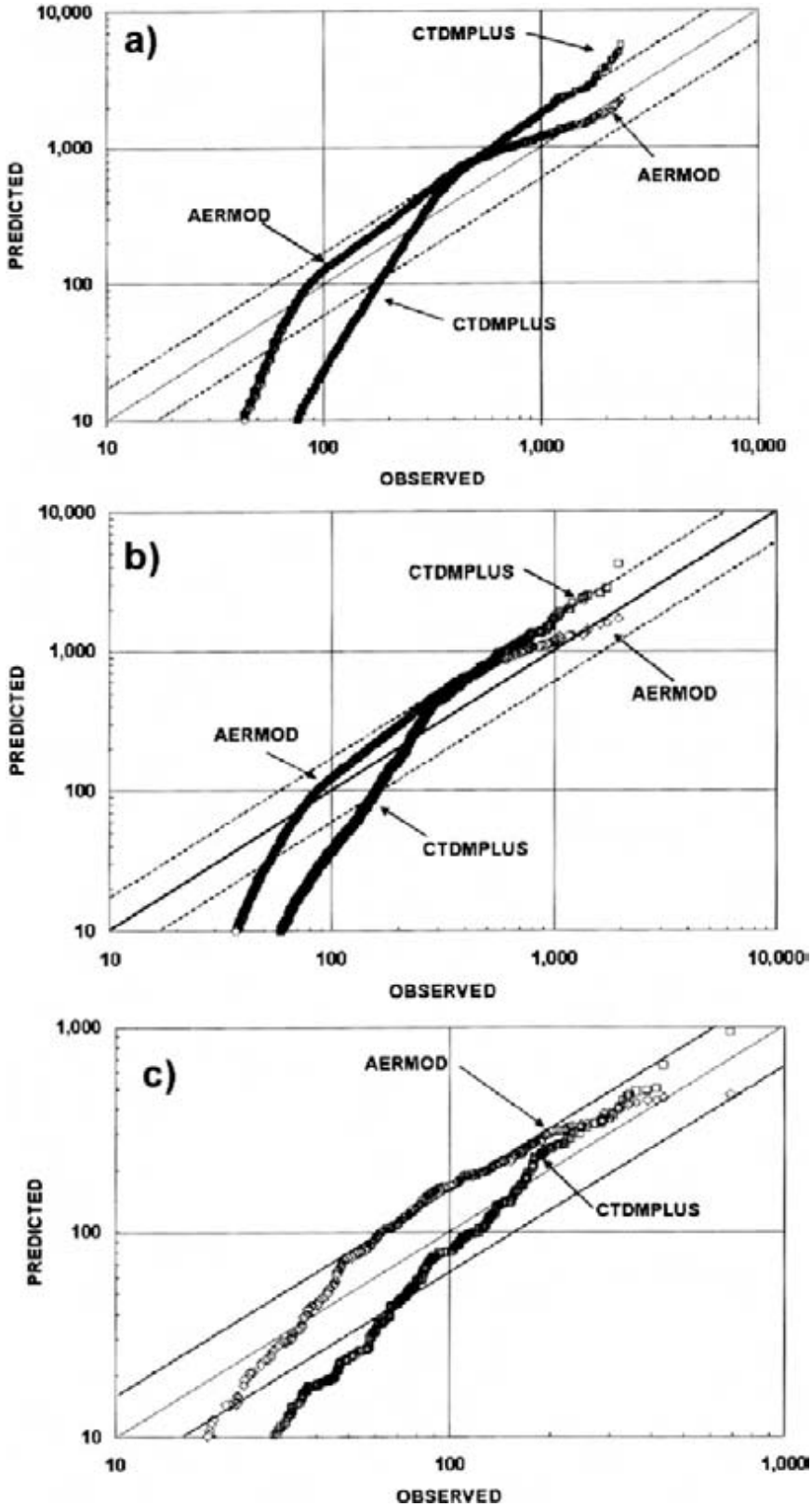

FIG. 7. Quantile–quantile plot of model-predicted vs observed concentrations (μg m^{-3}) for the Westvaco SO_2 database for (a) 1-, (b) 3-, and (c) 24-h averages. This is a complex terrain site. Dashed and solid lines mean the same as in Fig. 1.

TABLE 5. Ratio of modeled to observe robust highest concentrations—downwash studies.

Database	Time avg	AERMOD	ISCST3-PRIME
Bowline Point	3 h	1.14	1.23
	24 h	1.43	1.42
	Annual	1.50	1.35
Alaska North Slope	1 h	1.06	1.49
Duane Arnold	1 h (1-m release)	0.51	0.38
	1 h (24-m release)	0.25	0.29
	1 h (46-m release)	0.69	0.76
Millstone Nuclear Power Plant	1 h (29-m release)	1.32	1.42
	1 h (46-m release)	0.44	0.41
American Gas Association	1 h	0.92	0.76
EOCR	1 h	1.72	1.69
Lee Power Plant	1 h (stable)	2.50	2.11

line, and volume source types within a refinery complex. The experiments were separated into what was called a "matrix source" configuration and a "tank-farm source" configuration. The matrix source involved up to nine point sources (with heights of 2, 15, and 40 m) that were placed among the refinery piping. The tank source involved releases from 1.5 m above the surface in the vicinity of storage tanks. At the Duke Forest site, arrays of point sources were arranged to simulate area and volume sources with release heights from about 3 to 8 m. Unlike the previously discussed databases for which the sources were generally elevated point releases, these databases challenge the model's ability to simulate the dispersion of area and volume sources near the surface.

AERMOD had difficulty simulating the dispersion from the OPTEX tank source, perhaps because the model was applied using old building downwash algorithms. The geometric mean ratio of AERMOD to monitored concentration was 2.47. The model has been modified, since these comparisons, to include the downwash algorithms of the PRIME model as discussed earlier. For the OPTEX matrix source and the Duke Forest comparisons, AERMOD was found to perform very well with geometric means of 1.02 and 1.42 respectively. It should be noted that the Hanna et al. (2000) geometric means are computed for concentrations paired in time (a much more demanding comparison) and give no special emphasis for the higher concentrations, as was discussed earlier with the RHC calculations. Additionally, AERMOD was found to provide predictions for all three datasets that were within a factor of 2 of the observations over 70% of the time.

5. Summary and discussion

The formulations of the newly developed AERMOD steady-state plume dispersion model are described in the companion to this paper (Part I). The model was designed to fill the niche of applications currently filled by ISCST3 where comparisons with air quality standards are important. Because of the inherent uncertainties in individual model simulations, plume models, such as AERMOD, find their greatest potential for success in simulating the overall distributions of concentrations related to a wide variety of modeling conditions. The new modeling system's concentration distributions have been compared with those of 16 separate tracer (field) studies and one laboratory wind tunnel study. The primary purpose of this evaluation study is to identify the scenarios for which AERMOD shows good performance and those for which it may be lacking. Additionally, there is a desire to examine the value obtained in these improved formulations by comparing AERMOD with some currently used regulatory models with these varied databases.

Ten databases avoided the complications of building wakes to challenge the remainder of the model algorithms. The other seven studies provided a focused look at cases in which building downwash was dominant. Of the 10 nonwake studies, AERMOD found its greatest overall success in reproducing the concentration distributions for buoyant, tall-stack releases in moderate to complex topography (Lovett, Martin's Creek, Westvaco, and Tracy). This is believed to be due to AERMOD's characterization and utilization of the vertical structure of the boundary layer in combination with its implementation of the dividing streamline concept for flow in complex terrain.

Similarly, for tall, buoyant stacks in flat terrain (Kincaid, Baldwin), AERMOD performs well in reproducing the upper end of the concentration distribution. This success is most likely related to the improved algorithms for convective conditions. The bi-Gaussian vertical concentration distribution in AERMOD is based upon years of model development following the observations and calculations of laboratory, field, and numerical studies over the past 30 yr. These formulations result in a much more appropriate treatment of elevated plume material in convective conditions. In contrast, the model is still somewhat challenged in reproducing some of the lower concentration values, particularly in stable conditions, as suggested by the annual average comparisons.

The model also performed well in the only urban database in the study. The Indianapolis data were utilized to some extent in the model development (specifically, in the formulation of the urban mixing height). The authors believe that it is not unreasonable to expect AERMOD's formulation to translate well to other urban areas because the urban formulation (Part I) is based on meteorological observations in a variety of urban areas. Obviously, evaluation in other urban areas is desirable.

The comparison of AERMOD with the measurements of seven building wake studies provided a very interesting variety of sometimes contrasting results.

This served to highlight the sensitivity of dispersion to local meteorological behavior and the geometry of the building wakes and cavities. Overall, the model found the representative high-end concentrations (i.e., RHC) within a factor of 2 or better. Although it seems rather obvious, the results here strongly suggest that specification of the cavity extent and plume material height and spread (near the building) is critical to appropriately simulating the downwash effect.

AERMOD (Part I) represents many formulation improvements over commonly applied regulatory models such as ISCST3. In model-to-model comparisons, AERMOD's performance is clearly superior to that of ISCST3. Models such as HPDM and CTDMPLUS perform similarly to AERMOD in the selected circumstances for which these models were designed. This is not surprising because many of the formulations of AERMOD are based, to some extent, on earlier work by others in developing these and other models.

Acknowledgments. We thank the many scientists who provided evaluation databases and conducted peer reviews and beta testing throughout the period of the AERMOD development. This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer review and administrative review policies for approval for presentation and publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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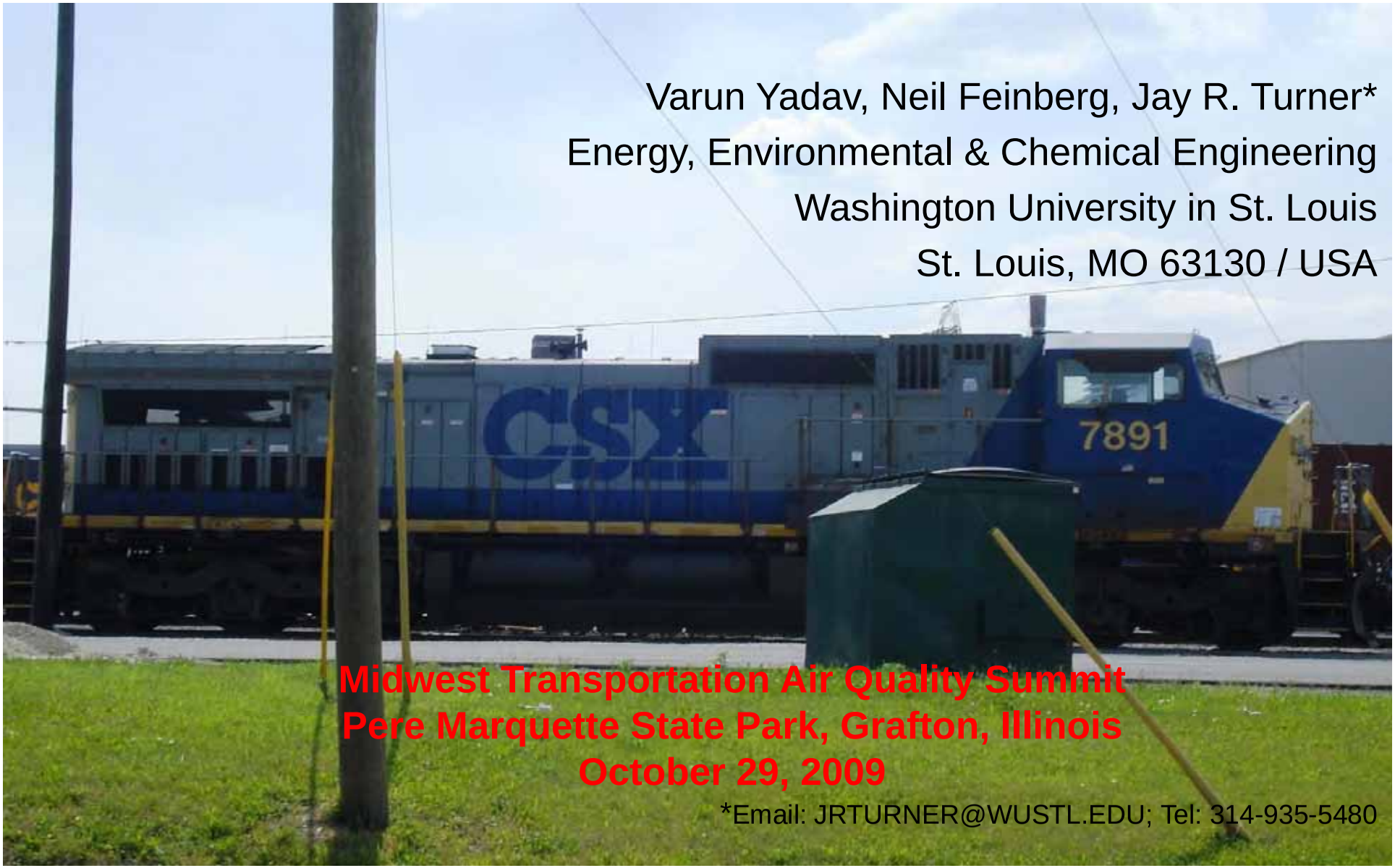
The Midwest Rail Study (Phase I)



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Project Motivation and Objectives

- Large rail yards often located in vicinity of monitors violating particulate matter NAAQS
  - Characterize and quantify PM emissions from rail yard activities
- Funded as a USEPA Region V RARE project
  - LADCO — project management
  - Michigan DEQ — air quality monitoring (special study)
  - Sierra Research — emission inventory development
  - Wash. Univ. — data analysis and dispersion modeling

Project Overview and Timeline

- Focus on **CSX Rougemere Yard**, Dearborn, MI
- Field measurement campaign
  - September 2008 to January 2009
  - Semicontinuous measurement of PM carbon at three sites, September to December
  - Instrument collocation study, December to January
- Emission inventory – delivered by Sierra Research, June 2009
- Data analysis and dispersion modeling completed
  - **Draft final report submitted to LADCO, October 2009**

Emissions Inventory

- Developed by Sierra Research, Inc.
- CSX Rougemere Yard, Dearborn
- Period January 2007 to December 2008
- Emission estimates for THC, CO, NO_x, $PM_{2.5}$, SO_x
- Date-specific emission rates (lb/day)
  - Further temporal allocation by hour-of-day profiles
  - Spatial allocation by rail yard activities maps

Emission Categories

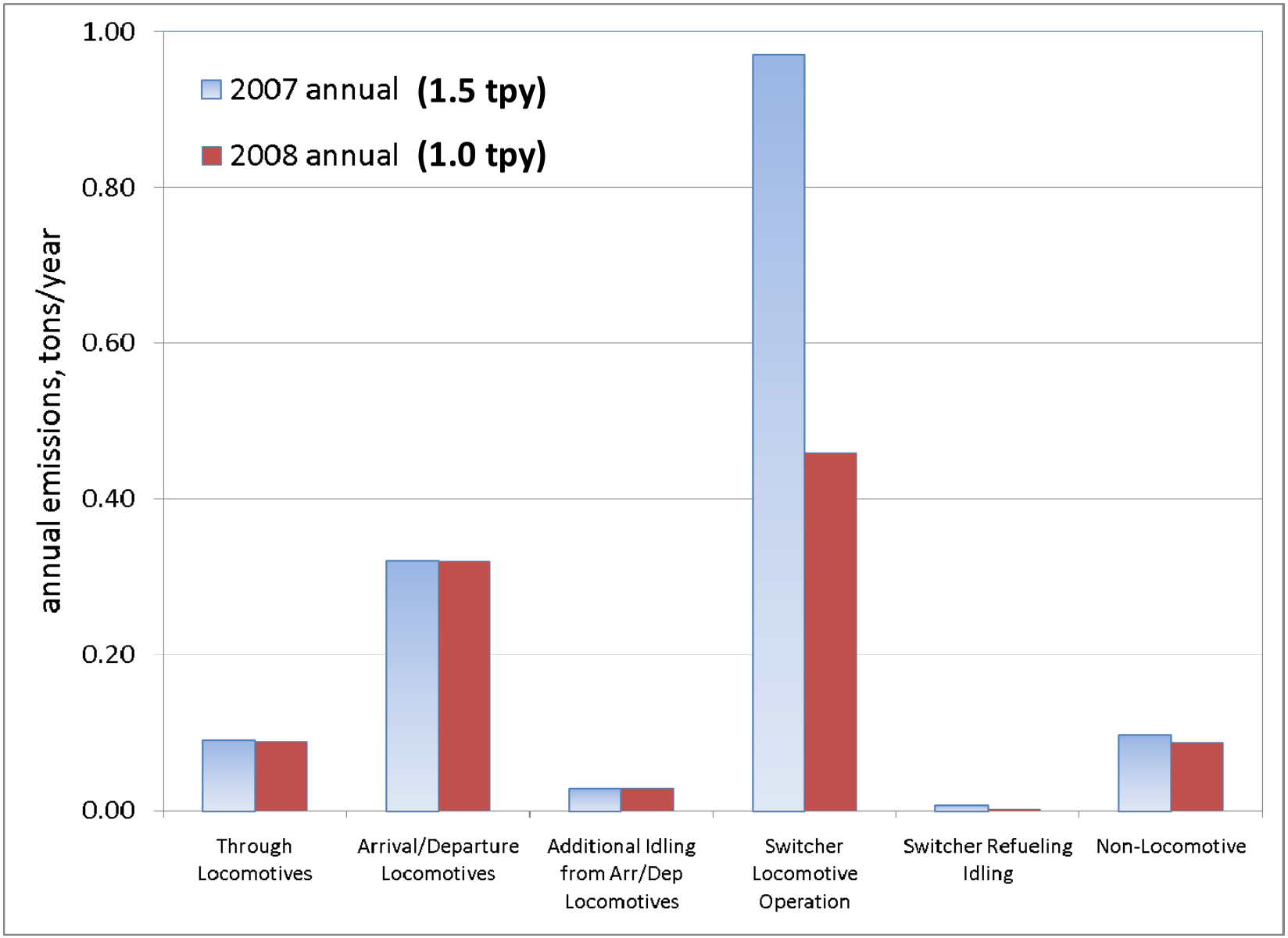
Locomotives

- Through Locomotives
- Arrival/Departure Locomotives
- Additional Idling from Arrival/Departure Locomotives
- Switcher Locomotive Operation
- Switcher Refueling Idling

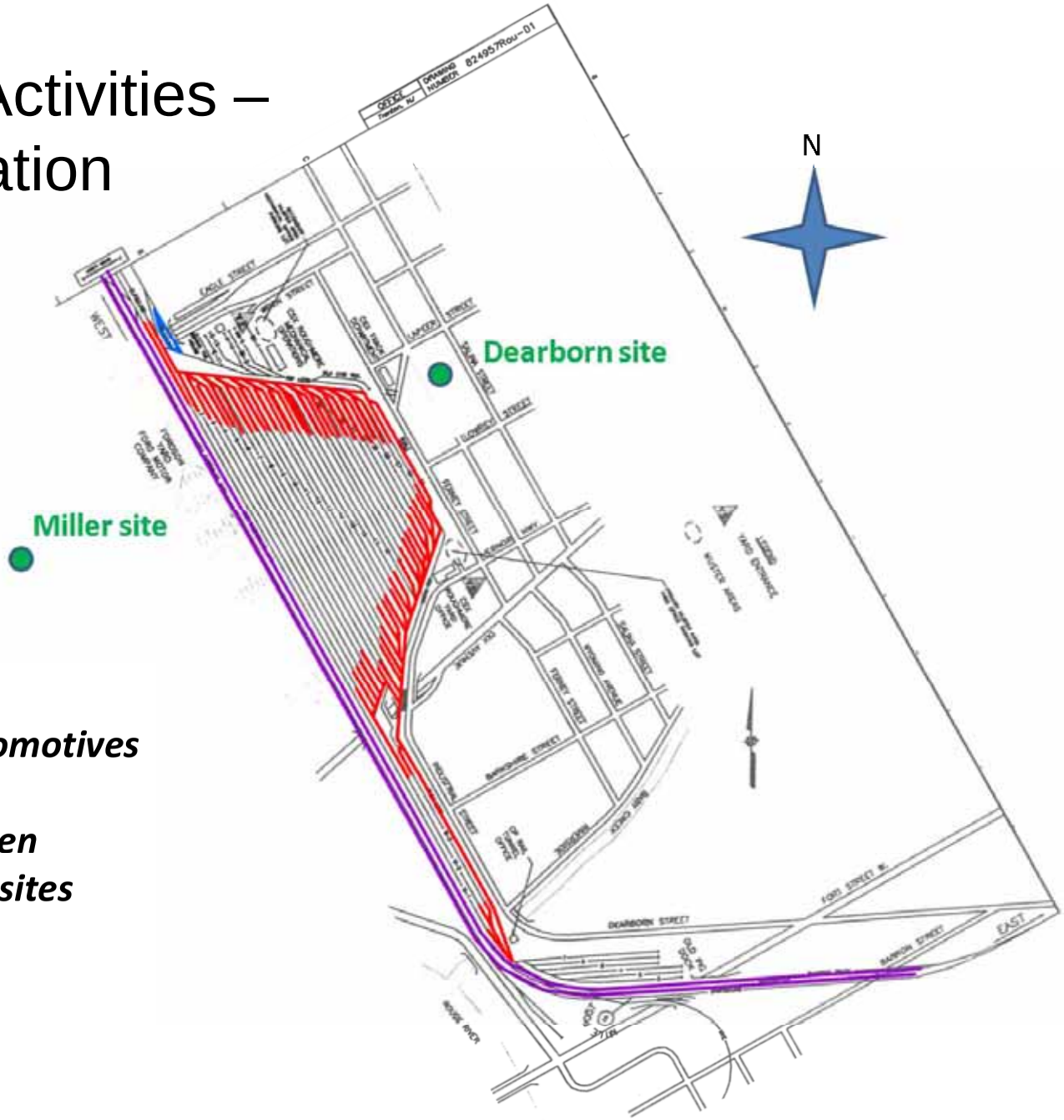
Non-Locomotives

- Worker Vehicle Exhaust
- Worker Vehicle Evaporative
- HDDT Delivery
- HDDT Delivery Idle
- Facility Truck Facility Truck Idle
- Space Heating
- Water Heating
- LPG - Welders/Cutters
- Diesel - Specialty Vehicle Carts
- Diesel - Rubber Tire Loaders
- Diesel - Forklifts
- Diesel - Other General Industrial Equipment
- Diesel - Snowblowers
- Aerosol Paints

$PM_{2.5}$ Annual Emissions



Locomotive Activities – Spatial Allocation



Red = switchers
Purple = through locomotives

Approx. 400m between Dearborn and Miller sites

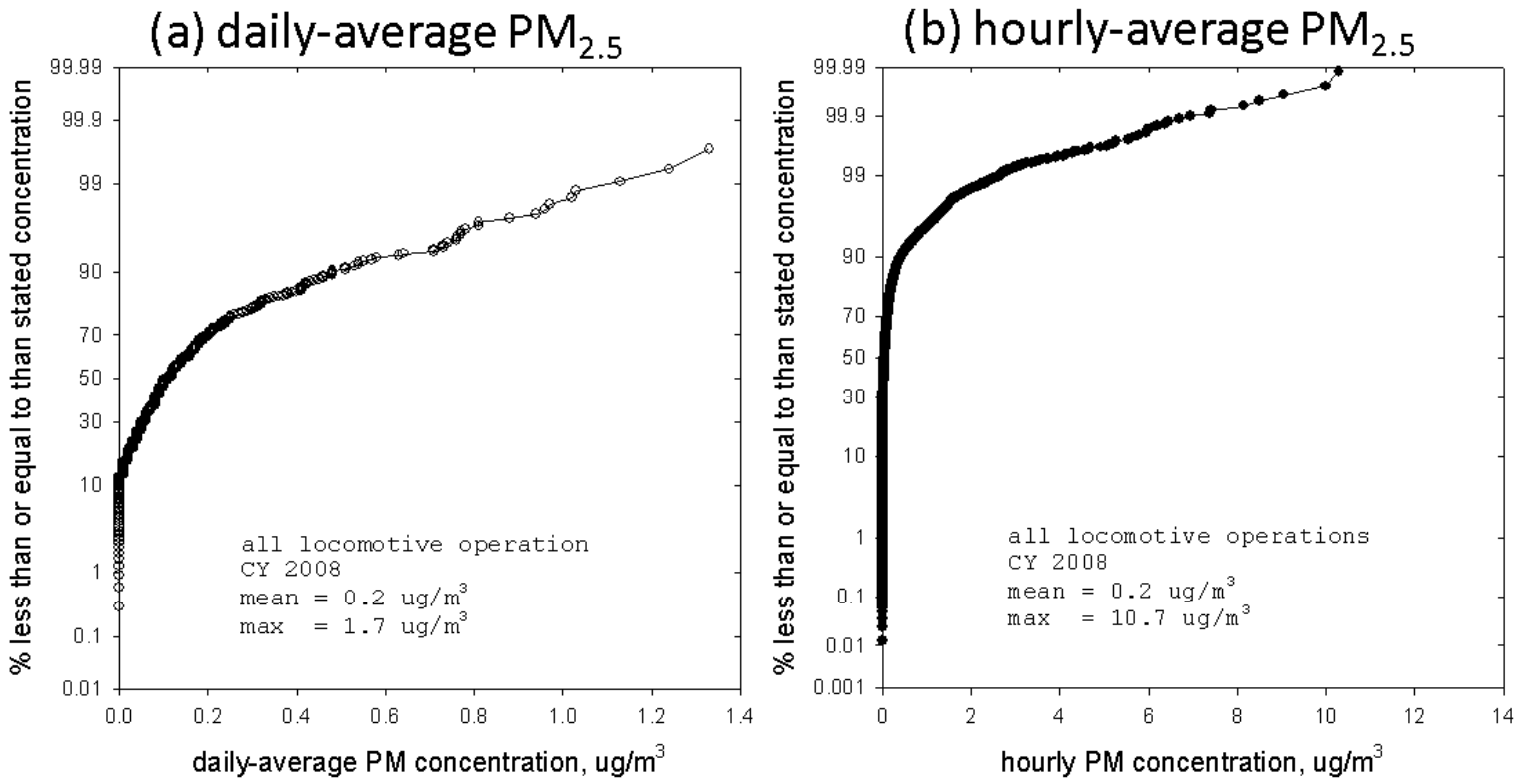
Dispersion Modeling

- AERMOD
- Model locomotive activities only
- Model each track segment as an area source
- Surface winds for DTW airport (Jim Haywood/MDEQ)
- Model each hour of the day from 1/1/2007 to 12/31/2008
- **BASE CASE**
  - Locomotive activity emissions homogeneously distributed over the activity zones defined by Sierra (previous map)
- Additional Scenarios…
  - Weight *Switcher Locomotives* to tracks where they tend to park between tasks
  - Weight *Arrival/Departure* Locomotives to area near Yard Office

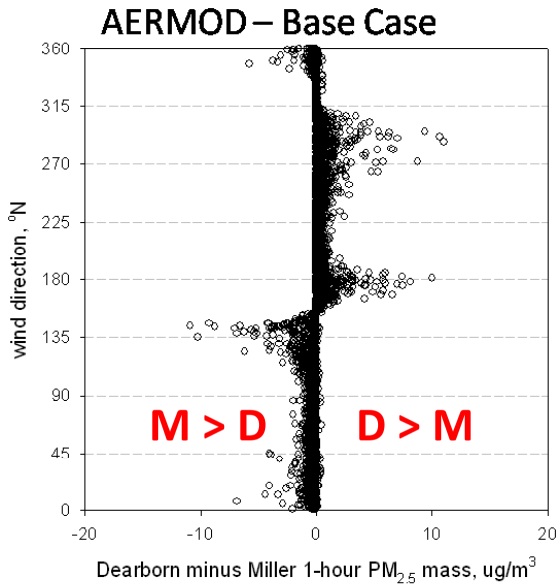
Dispersion Modeling Results

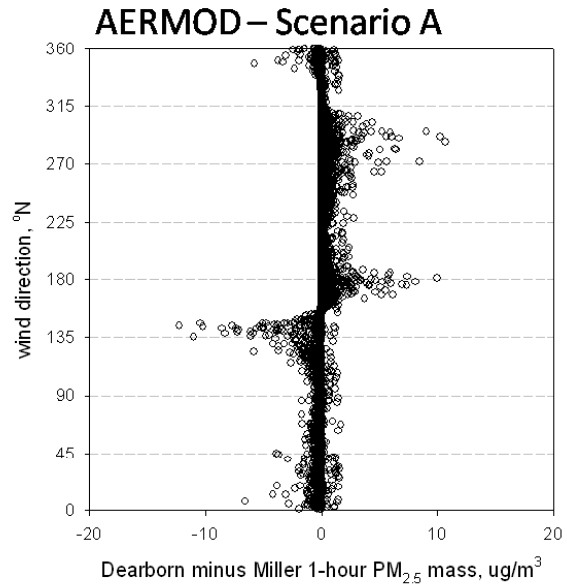
- Annual average $PM_{2.5}$ mass @ Dearborn station:
  - 2007: 0.45 $\mu g/m^3$
  - 2008: 0.21 $\mu g/m^3$
  - Excludes calm hours (11% in 2007, 9% in 2008)
  - Overwhelmingly from switcher locomotive operation

Year 2008



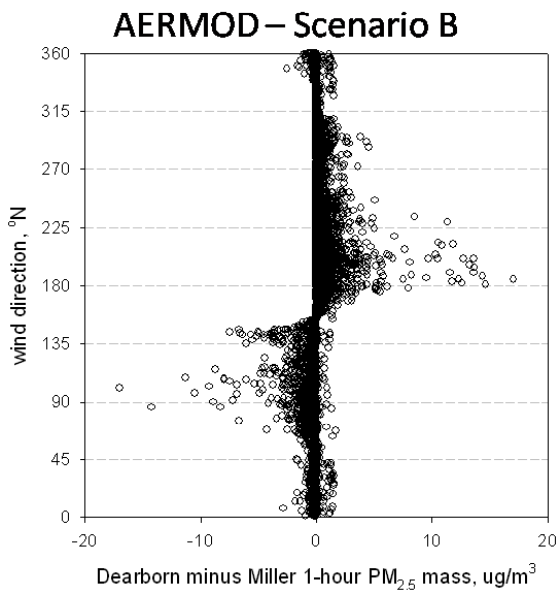
Year 2008 Hourly Impacts at Dearborn and Miller Stations

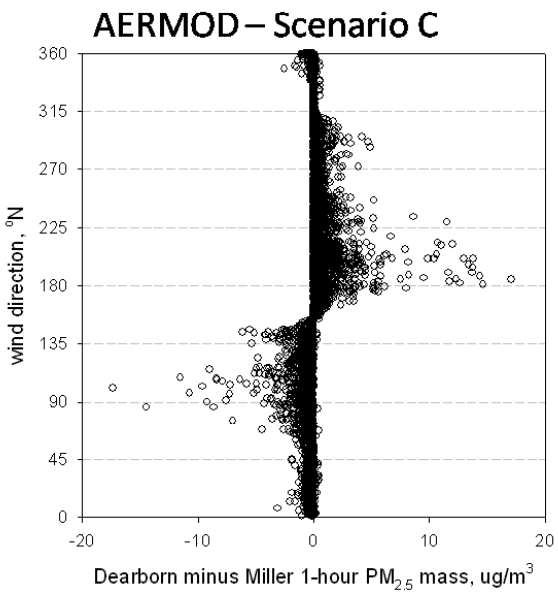




Arrival/departure locomotives weighted towards Yard Office

Switcher locomotives weighted towards outside (eastern) edge of track ladder



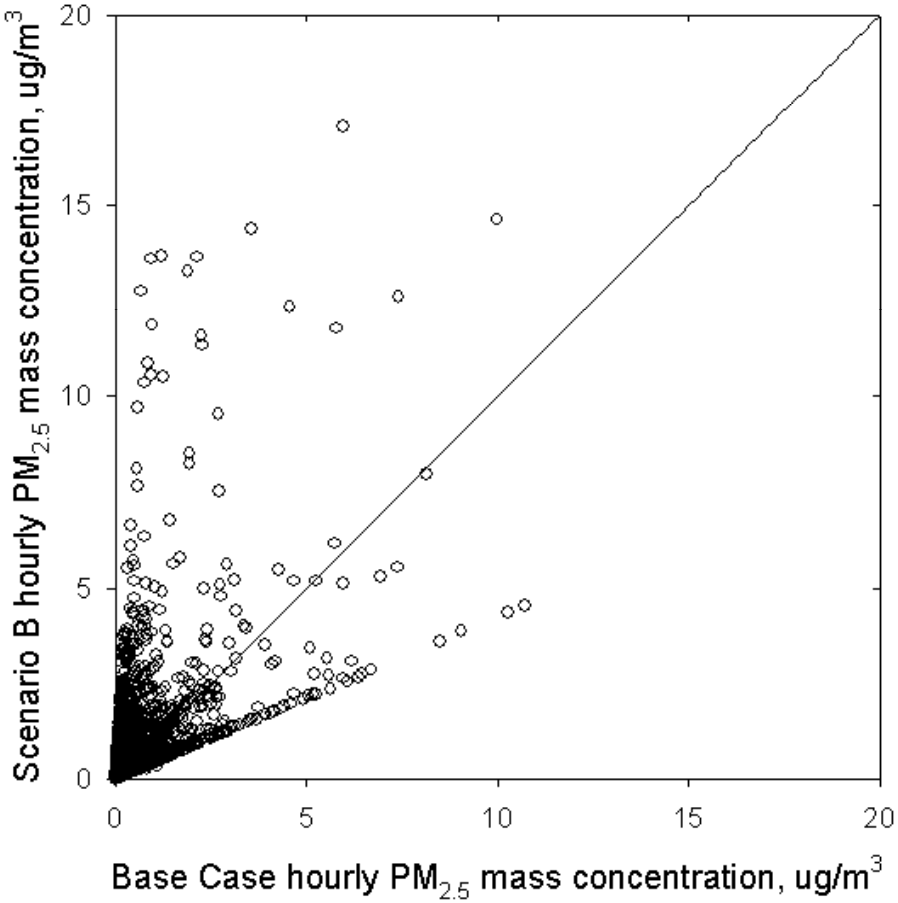


Arrival/departure locomotives weighted towards Yard Office

Switcher locomotives weighted towards outside (eastern) edge of track ladder

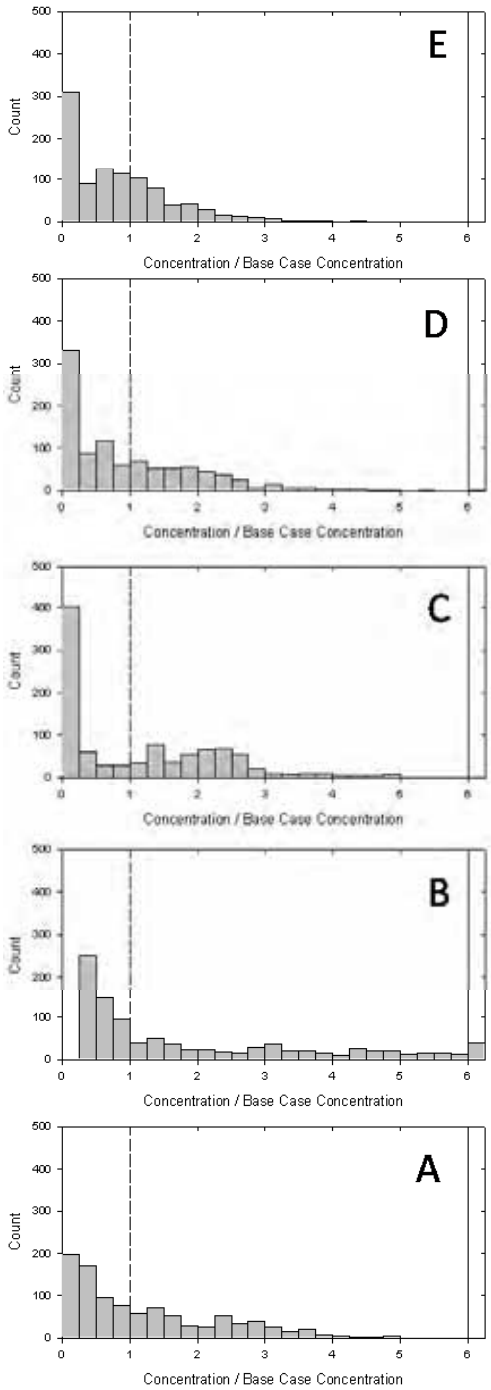
Year 2008 Modeled Hourly Impacts at Dearborn Station: Sensitivity to Spatial Allocation of Switcher Activities

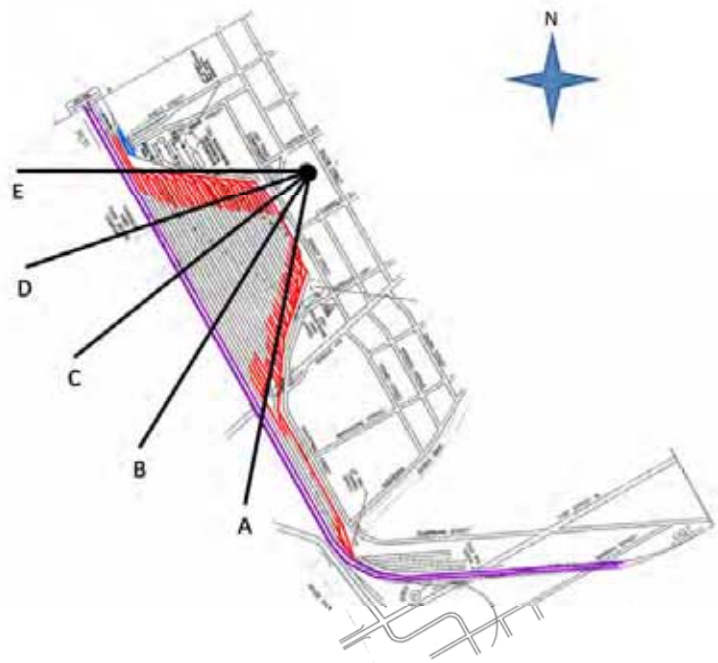
Switcher locomotives weighted towards outside (eastern) edge of track ladder



Switcher locomotives uniformly distributed across activity zones defined by Sierra

Monte Carlo Simulations: Spatial Allocation of Switcher Activities





- random allocation of switcher activities to four locations within red zones
- calculate modeled concentration at Dearborn, repeat 100 times to get distribution of impacts
- examples shown for five hours with noted wind directions from southwest through west (1000 simulations in these cases)
- ***x axis* is modeled concentration scaled to base case concentration; *y axis* is counts (# of hours)**

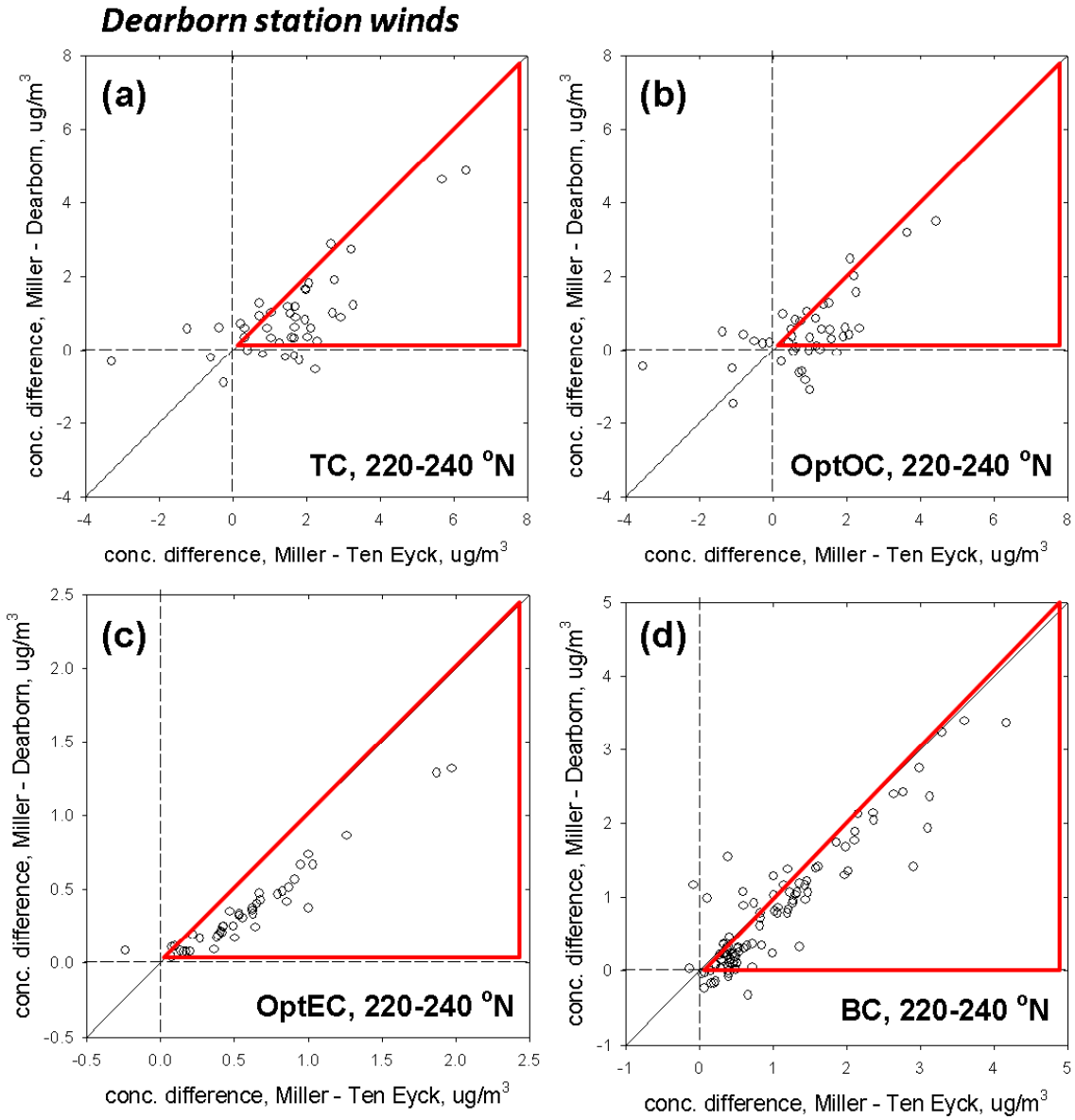
Field Campaign

Hourly OC, EC and BC at three sites for three months

Upwind/Downwind Measurements Across the Rail Yard

Winds rarely from the northeast during the study

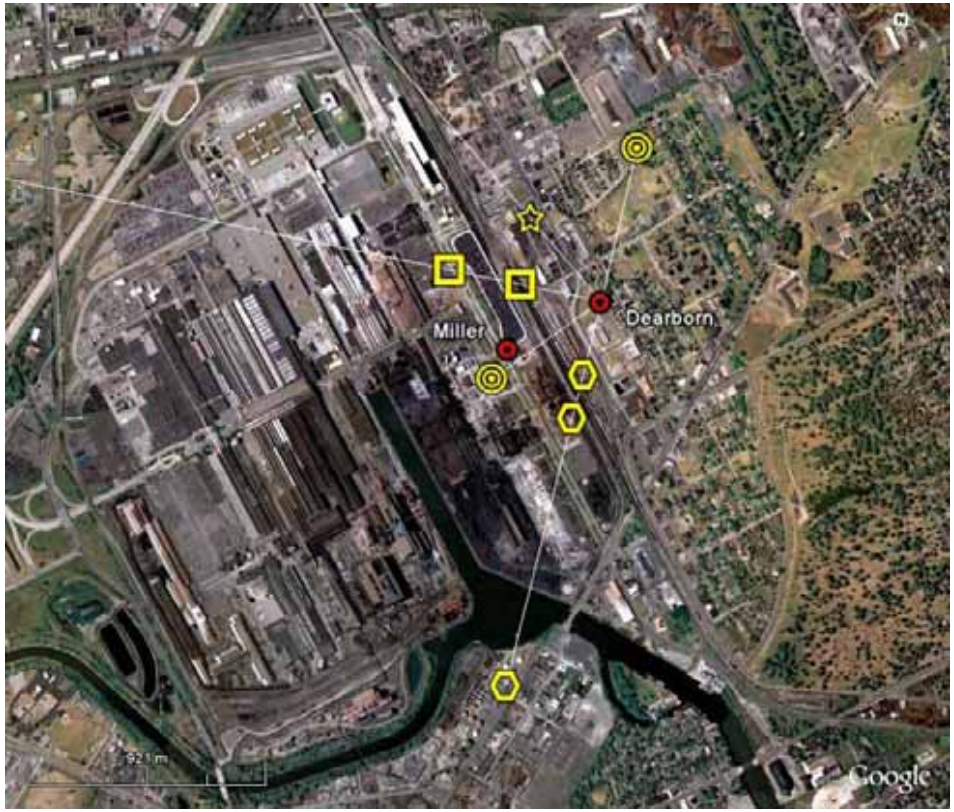
For winds from southwest, higher concentrations upwind of the rail yard than downwind of the rail yard



Triangulation of Pollution roses to Obtain Putative Emission Source Locations

(more sources located off the maps)

Organic Carbon (OC)



Elemental Carbon (EC)

Dispersion Modeling Summary and Status

CSX Rougemere rail yard $PM_{2.5}$ emissions study

- Year 2008 modeled impact at Dearborn station is 0.2 $\mu g/m^3$
- Annual-average results are resistant to spatial allocation of locomotive activities
- Hourly-average results very sensitive to spatial allocation of locomotive activities
  - Complicates comparisons to field observations
- Numerous other local carbonaceous PM emission sources confounds measuring rail yard impacts

Future Work (beyond the project deliverable)

- This analysis used DTW winds; repeat using winds measured at Dearborn station and Severstal (nearby steelworks)
- Generating annual-average concentration field around rail yard

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Sierra Research, Inc.

- Jeremy Heiken, Jim Lyons

FINAL REGULATION ORDER

REGULATION FOR MOBILE CARGO HANDLING EQUIPMENT AT PORTS AND INTERMODAL RAIL YARDS

Section 2479. Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards.

(Amended, effective December 3, 2009)

(a) Purpose

The purpose of this regulation is to reduce diesel particulate matter (PM) and criteria pollutant emissions from compression ignition (CI) mobile cargo handling equipment that operate at ports and intermodal rail yards in the state of California.

(b) Applicability

Except as provided in subsection (c), the regulation would apply to any person who conducts business in California who sells, offers for sale, leases, rents, purchases, owns or operates any CI mobile cargo handling equipment that operates at any California port or intermodal rail yard.

(c) Exemptions

(1) The requirements of this section do not apply to mobile cargo handling equipment that do not operate at a port or intermodal rail yard;

(2) The requirements of this section do not apply to portable CI engines;

(3) The requirements of subsections (e), (f), (g), (h), and (i) do not apply to mobile cargo handling equipment that are not used to handle cargo at any time but are used for transporting personnel or fuel delivery. Examples include, but are not limited to, fuel delivery trucks operating solely at the terminal to deliver fuel to terminal equipment and vans and buses used to transport personnel;

(4) The requirements of this section do not apply to military tactical support cargo handling equipment;

(5) The requirements of this section do not apply to mobile cranes as defined in subsection (d)(33); and

(6) The requirements of this section to not apply to sweepers as defined in subsection (d)(54).

(d) Definitions

For purposes of this section, the definitions of Health and Safety Code section 39010 through 39060 shall apply except to extent that such definitions may be modified by the following definitions that apply specifically to this regulation:

(1) "Alternative Diesel Fuel" means any fuel used in a CI engine that is not commonly or commercially known, sold, or represented by the supplier as diesel fuel No. 1-D or No. 2-D, pursuant to the specifications in ASTM D975-81, "Standard Specification for Diesel Fuel Oils," as modified in May 1982, which is incorporated herein by reference, or an alternative fuel, and does not require engine or fuel system modifications for the engine to operate, although minor modifications (e.g., recalibration of the engine fuel control) may enhance performance. Examples of alternative diesel fuels include, but are not limited to, biodiesel that does not meet the definition of CARB diesel fuel; Fischer-Tropsch fuels; emulsions of water in diesel fuel; and fuels with a fuel additive, unless:

(A) the additive is supplied to the engine fuel by an on-board dosing mechanism, or

(B) the additive is directly mixed into the base fuel inside the fuel tank of the engine, or

(C) the additive and base fuel are not mixed until engine fueling commences, and no more additive plus base fuel combination is mixed than required for a single fueling of a single engine.

(2) "Alternative Fuel" means natural gas, propane, ethanol, methanol, gasoline (when used in hybrid electric mobile cargo handling equipment only), hydrogen, electricity, fuel cells, or advanced technologies that do not rely on diesel fuel. "Alternative fuel" also means any of these fuels used in combination with each other or in combination with other non-diesel fuel.

(3) "Basic Container Handling Equipment" means mobile cargo handling equipment, other than yard trucks, bulk cargo handling equipment, and RTG cranes, used to handle cargo containers. Basic Container Handling Equipment includes but is not limited to top handlers, side handlers, reach stackers, straddle carriers, and forklifts.

(4) "Bulk Cargo Handling Equipment" means mobile cargo handling equipment, other than yard trucks, basic container handling equipment, and RTG cranes, generally used to move non-containerized cargo, including but not limited to dozers, excavators, loaders, tractors, and aerial lifts.

(5) "California Air Resources Board (CARB) Diesel Fuel" means any diesel fuel that meets the specifications of vehicular diesel fuel, as defined in title 13 CCR, sections 2281, 2282, and 2284.

(6) “Carbon Monoxide (CO)” is a colorless, odorless gas resulting from the incomplete combustion of hydrocarbon fuels.

(7) “Cargo Handling Equipment” means any off-road, self-propelled vehicle or equipment used at a port or intermodal rail yard to lift or move container, bulk, or liquid cargo carried by ship, train, or another vehicle, or used to perform maintenance and repair activities that are routinely scheduled or that are due to predictable process upsets. Equipment includes, but is not limited to, rubber-tired gantry cranes, yard trucks, top handlers, side handlers, reach stackers, forklifts, loaders, aerial lifts, excavators, and dozers.

(8) “Certified Off-road Diesel Engine” means an engine certified to California off-road engine emission standards under title 13 CCR, section 2423.

(9) “Certified On-road Diesel Engine” means an engine certified to California on-road diesel engine emission standards under title 13 CCR, section 1956.8.

(10) “Compression Ignition (CI) Engine” means an internal combustion engine with operating characteristics significantly similar to the theoretical diesel combustion cycle. The regulation of power by controlling fuel supply in lieu of a throttle is indicative of a compression ignition engine.

(11) “Contiguous Properties” means two or more parcels of land with a common boundary or separated solely by a public roadway or other public right-of-way.

(12) “Diesel Fuel” means any fuel that is commonly or commercially known, sold, or represented by the supplier as diesel fuel, including any mixture of primarily liquid hydrocarbons (HC) - organic compounds consisting exclusively of the elements carbon and hydrogen - that is sold or represented by the supplier as suitable for use in an internal combustion, compression-ignition engine.

(13) “Diesel-Fueled” means a CI engine fueled by diesel fuel, CARB diesel fuel, or jet fuel, in whole or part.

(14) “Diesel Oxidation Catalyst (DOC)” means a catalyst promoting oxidation processes in diesel exhaust, and usually designed to reduce emissions of the organic fraction of diesel particulates, gas-phase HC, and CO.

(15) “Diesel Particulate Filter (DPF)” means an emission control technology that reduces PM emissions by trapping the particles in a flow filter substrate and periodically removes the collected particles by either physical action or by oxidizing (burning off) the particles in a process called regeneration.

(16) “Diesel Particulate Matter (Diesel PM)” means the particles found in the exhaust of diesel-fueled CI engines. Diesel PM may agglomerate and adsorb other species to form structures of complex physical and chemical properties.

(17) “Dozer” means an off-road tractor, either tracked or wheeled, equipped with a blade.

(18) “Emission Control Strategy” means any device, system, or strategy employed with a diesel engine that is intended to reduce emissions, including, but not limited to, diesel oxidation catalysts, selective catalytic reduction systems, fuel additives, diesel particulate filters, alternative diesel fuels, water emulsified fuels, and any combination of the above.

(19) “Excavator” means an off-road vehicle consisting of a backhoe and cab mounted on a pivot atop an undercarriage with tracks or wheels.

(20) “Executive Officer” means the Executive Officer of the California Air Resources Board or his/her designee.

(21) “Fleet” means the total number of mobile cargo handling equipment vehicles owned, rented, or leased by an owner or operator at a specific terminal or intermodal yard location.

(22) “Forklift” means an off-road industrial truck used to hoist and transport materials by means of steel fork(s) under the load.

(23) “Fuel Additive” means any substance designed to be added to fuel or fuel systems or other engine-related engine systems such that it is present in-cylinder during combustion and has any of the following effects: decreased emissions, improved fuel economy, increased performance of the engine; or assists diesel emission control strategies in decreasing emissions, or improving fuel economy or increasing performance of the engine.

(24) “Heavy-duty Pilot Ignition Engine” means an engine designed to operate using an alternative fuel, except that diesel fuel is used for pilot ignition at an average ratio of no more than one part diesel fuel to ten parts total fuel on any energy equivalent basis. An engine that can operate or idle solely on diesel fuel at any time does not meet this definition.

(25) “Hydrocarbon (HC)” means the sum of all hydrocarbon air pollutants.

(26) “In-Use” means a CI engine that is not a “new” CI engine.

(27) “Intermodal Rail Yard” means any transportation facility primarily dedicated to the business of rail and/or intermodal rail operations where cargo is transferred to or from a train and any other form of conveyance, such as train to ship, ship to train, train to truck, or truck to train.

(28) “Lease” means a contract by which one conveys cargo handling equipment for a specified term and for a specified rent.

(29) “Level” means one of three categories of Air Resources Board-verified diesel emission control strategies as set forth in title 13, CCR, section 2701 et seq: Level 1 means the strategy reduces engine diesel particulate matter emissions by between 25 and 49 percent, Level 2 means the strategy reduces engine diesel particulate matter emissions by between 50 and 84 percent, and Level 3 means the strategy reduces engine diesel particulate matter emissions by 85 percent or greater, or reduces engine emissions to less than or equal to 0.01 grams diesel PM per brake horsepower-hour.

(30) “Loader” means any type of off-road tractor with either tracks or rubber tires that uses a bucket on the end of movable arms to lift and move material; can be also referred to as a front-end loader, front loader, skid steer loader, backhoe, rubber-tired loader, or wheeled loader.

(31) “Military Tactical Support Cargo Handling Equipment” means cargo handling equipment that meets military specifications, owned by the U.S. Department of Defense and/or the U.S. military services, and used in combat, combat support, combat service support, tactical or relief operations, or training for such operations.

(32) “Minimum Use Requirement” means an agreement, as part of state or local incentive funding programs or written agreement between mobile cargo handling equipment owners or operators and the Ports of Long Beach, Los Angeles, or Oakland, to use an emission control device on mobile cargo handling equipment for a specified minimum number of years and/or hours.

(33) “Mobile Crane” means a mobile machine, other than a rubber-tired gantry crane, with a hoisting mechanism mounted on a specially constructed truck chassis or carrier; a mobile crane can either be a single-engine crane or a two-engine crane.

(34) “Model Year” means the CI engine manufacturer’s annual production period, which includes January 1st of a calendar year, or if the manufacturer has no annual production period, the calendar year.

(35) “Newly Purchased, Leased, or Rented Cargo Handling Equipment” means mobile cargo handling equipment, or a diesel-fueled CI engine installed in mobile cargo handling equipment, that is newly purchased, rented, or leased by an owner or operator on or after January 1, 2007, and is operated at a port or intermodal rail yard in the state of California after January 1, 2007.

(36) “Nitrogen Oxides (NOx)” means compounds of nitric oxide (NO), nitrogen dioxide (NO_2), and other oxides of nitrogen, which are typically created during combustion processes and are major contributors to smog formation and acid deposition.

(37) “Non-Methane Hydrocarbons (NMHC)” means the sum of all HC air pollutants except methane.

(38) “Non-Yard Truck Mobile Cargo Handling Equipment” means all mobile cargo handling equipment other than yard trucks.

(39) “Ocean-going Vessel” means a commercial, government, or military vessel meeting any one of the following criteria:

(A) a vessel with a “registry” (foreign trade) endorsement on its United States Coast Guard certificate of documentation, or a vessel that is registered under the flag of a country other than the United States;
(B) a vessel greater than or equal to 400 feet in length overall (LOA) as defined in 50 CFR § 679.2, as adopted June 19, 1996;
(C) a vessel greater than or equal to 10,000 gross tons (GT ITC) per the convention measurement (international system) as defined in 46 CFR 69.51-.61, as adopted September 12, 1989; or
(D) a vessel propelled by a marine compression ignition engine with a per-cylinder displacement of greater than or equal to 30 liters.

(40) “Off-Road Engine” means an engine used in an off-road vehicle, or piece of equipment, including a certified on-road diesel engine.

(41) “Off-Road Vehicle or Equipment” means any non-stationary device, including registered motor vehicles, powered by an internal combustion engine or motor, used primarily off the highways to propel, move, or transport persons or property.

(42) “Owner or Operator” means any person subject to the requirements of this section, including but not limited to:

(A) an individual, trust, firm, joint stock company, business concern, partnership, limited liability company, association, or corporation including but not limited to, a government corporation; and

(B) any city, county, district, commission, the state or any department, agency, or political subdivision thereof, any interstate body, and the federal government or any department or agency thereof to the extent permitted by law.

(43) “Particulate Matter (PM)” means the particles found in the exhaust of CI engines, which may agglomerate and adsorb other species to form structures of complex physical and chemical properties.

(44) “Port” means a place, which typically consists of different terminals, where cargo is loaded onto and unloaded from ocean-going vessels primarily. A port includes military terminals that operate cargo handling equipment when located as part of, or on contiguous properties with, non-military terminals.

(45) “Portable CI Engine” means a compression ignition (CI) engine designed and capable of being carried or moved from one location to another. Indicators of

portability include, but are not limited to, wheels, skids, carrying handles, dolly, trailer, or platform. Portable engines are not self-propelled.

(46) “Purchased” means the date shown on the front of the cashed check, the date of the financial transaction, or the date on the engine purchasing agreement, whichever is earliest.

(47) “Railcar Mover” means an off-road vehicle fitted with rail couplers and capable of traveling on both roads and rail tracks.

(48) “Reach Stacker” means an off-road truck-like cargo container handler that uses an overhead telescopic boom that can reach across two or more stacks of cargo containers and lift the containers from the top.

(49) “Registered Motor Vehicle” means a yard truck or other cargo handling vehicle that is registered as a motor vehicle under Vehicle Code section 4000, et seq.

(50) “Rent” means payment for the use of mobile cargo handling equipment for a specified term.

(51) “Retirement” or “Retire” means an engine or vehicle that will be taken out of service by an owner or operator and will not be operated at a port or intermodal rail yard in the State of California. The engine may be sold outside of California or scrapped.

(52) “Rubber-tired Gantry Crane or RTG Crane” means an off-road overhead cargo container crane with the lifting mechanism mounted on a cross-beam supported on vertical legs which run on rubber tires.

(53) “Side Handler or Side Pick” means an off-road truck-like cargo container handler that uses an overhead telescopic boom to lift empty or loaded cargo containers by grabbing either two top corners on the longest side of a container, both arms of one side of a container, or both top and bottom sides of a container.

(54) “Sweeper” means a vehicle with attached brushes underneath that sweep the ground and pick up dirt and debris.

(55) “Terminal” means a facility, including one owned or operated by the Department of Defense or the U.S. military services, that operates cargo handling equipment at a port or intermodal rail yard.

(56) “Tier 4 Off-road Emission Standards” means the emission standards promulgated by the United States Environmental Protection Agency in "Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel; Final Rule" (Vol. 69, No. 124 Fed. Reg. pp. 38957-39273, June 29, 2004) which harmonize with the final amended emission standards for newly manufactured off-road engines approved by the Air Resources Board on December 12, 2004.

(57) “Top Handler or Top Pick” means an off-road truck-like cargo container handler that uses an overhead telescopic boom to lift empty or loaded cargo containers by grabbing the top of the containers.

(58) “Verification Procedure, Warranty and In-Use Compliance Requirements for In-Use Strategies to Control Emissions from Diesel Engines (Verification Procedure)” means the Air Resources Board (ARB) regulatory procedure codified in title 13, CCR, sections 2700-2710*,* which is incorporated herein by reference, that engine manufacturers, sellers, owners, or operators may use to verify the reductions of diesel PM and/or NOx from in-use diesel engines using a particular emission control strategy.

(59) “Verified Diesel Emission Control Strategy (VDECS)” means an emission control strategy, designed primarily for the reduction of diesel PM emissions, which has been verified pursuant to the “Verification Procedure for In-Use Strategies to Control Emissions from Diesel Engines” in title 13, California Code of Regulations, commencing with section 2700.

(60) “Yard truck” means an off-road mobile utility vehicle used to carry cargo containers with or without chassis; also known as utility tractor rig (UTR), yard tractor, yard goat, yard hostler, yard hustler, or prime mover.

(e) Requirements

(1) Newly Purchased, Leased, or Rented Equipment Performance Standards:

(A) Yard Trucks:

1. Except as provided in subsection (c), on or after January 1, 2007, no owner or operator shall operate any newly purchased, leased, or rented yard trucks unless they are equipped with the following types of engines:

   a. Yard trucks that are registered as motor vehicles shall be equipped with engines that meet the on-road emission standards as specified in title 13, California Code of Regulations, section 1956.8, for the model year in which the yard trucks and engines were newly purchased, leased, or rented.

   b. Yard trucks that are *not* registered as motor vehicles shall be equipped with engines:

      i. that are certified to the on-road emission standards set forth in title 13, CCR, section 1956.8; for the model year in which the yard trucks and engines were newly purchased, leased, or rented; or
      ii. that have been certified to meet the final Tier 4 off-road emission standards for the rated horsepower.

(B) Non-Yard Truck Cargo Handling Equipment:

1. Except as provided in subsection (c), on or after January 1, 2007, no owner or operator shall operate any newly purchased, leased, or rented non-yard truck vehicles or equipment unless they meet the following:

   a. Non-yard truck mobile cargo handling equipment that are registered as motor vehicles shall be equipped with engines that meet the on-road emission standards as specified in title 13, California Code of Regulations, section 1956.8, for the model year in which the non-yard truck mobile cargo handling equipment and engines were newly purchased, leased, or rented.

   b. Non-yard truck mobile cargo handling equipment that are *not* registered as motor vehicles shall be equipped with engines:

      i. that have been certified to meet the on-road emission standards as specified in title 13, California Code of Regulations, section 1956.8 for the model year in which the non-yard truck mobile cargo handling equipment and engines were newly purchased, leased, or rented; or
      ii. that have been certified to meet the Tier 4 off-road emission standards for the model year and rated horsepower of the newly purchased, leased, or rented non-yard truck mobile cargo handling equipment engines; or

   c. if (b) above is not available for the specific application and equipment type, the non-yard truck mobile cargo handling equipment shall be equipped with engines that have been certified to meet the highest available level off-road diesel engine emission standards as specified in title 13, California Code of Regulations, section 2423 for the rated horsepower and model year in which the equipment were newly purchased, leased, or rented, provided the owner or operator must install the highest level VDECS available within one year after the purchase, lease, or rental of the equipment, or within 6 months of when a VDECS becomes available, if that occurs after one year after the purchase, lease, or rental.

(2) In-Use Performance Standards for Yard Trucks

(A) In accordance with the schedule set forth below in paragraph (e)(2)(B), no owner or operator shall operate an in-use yard truck at a port or intermodal rail yard unless the engine meets the performance standards set forth below:

1. is certified to 2007 or later on-road emission standards for the model year of the year purchased as specified in title 13, California Code of Regulations, section 1956.8; or

2. is certified to final Tier 4 off-road emission standards for the rated horsepower; or
3. is equipped with a VDECS that results in emissions less than or equal to the diesel PM and NOx emission standards for a certified final Tier 4 off-road diesel engine of the same horsepower rating.

(B) Compliance Schedules for In-Use Yard Trucks

1. All owners or operators of three or fewer yard trucks shall comply with subsection (e)(2) according to the schedule in Table 1:

Table 1: Compliance Schedule for In-Use Yard Truck Fleets of Three or Less

Off-road without VDECS Installed by December 31, 2006

Model Year	Compliance Deadline
Pre-2003	Dec. 31, 2007
2003	Dec. 31, 2010
2004	Dec. 31, 2011
2005	Dec. 31, 2012
2006	Dec. 31, 2013

Off-road with VDECS Installed by December 31, 2006

Model Year	Compliance Deadline
Pre-2003	Dec. 31, 2008
2003	Dec. 31, 2011
2004	Dec. 31, 2012
2005	Dec. 31, 2013
2006	Dec. 31, 2014

On-road without VDECS Installed by December 31, 2006

Model Year	Compliance Deadline
Pre-2000	Dec. 31, 2007
2000	Dec. 31, 2008
2001	Dec. 31, 2009
2002	Dec. 31, 2010
2003	Dec. 31, 2011
2004	Dec. 31, 2012
2005	Dec. 31, 2013
2006	Dec. 31, 2014

On-road with VDECS Installed by December 31, 2006

Model Year	Compliance Deadline
Pre-2000	Dec. 31, 2008
2000	Dec. 31, 2009
2001	Dec. 31, 2010
2002	Dec. 31, 2011
2003	Dec. 31, 2012
2004	Dec. 31, 2013
2005	Dec. 31, 2014
2006	Dec. 31, 2015

2. All owners or operators of four or more yard trucks shall comply with subsection (e)(2) according to the schedule in Table 2:

Table 2: Compliance Schedule for In-Use Yard Truck Fleets of Four or More

Off-road without VDECS Installed by December 31, 2006

Model Year	% of Model Year	Compliance Deadline
Pre-2003	Greater of 3 or 50%	Dec. 31, 2007
	100%	Dec. 31, 2008
2003	Greater of 3 or 25%	Dec. 31, 2010
	50%	Dec. 31, 2011
	100%	Dec. 31, 2012
2004	Greater of 3 or 25%	Dec. 31, 2011
	50%	Dec. 31, 2012
	100%	Dec. 31, 2013
2005	Greater of 3 or 25%	Dec. 31, 2012
	50%	Dec. 31, 2013
	100%	Dec. 31, 2014
2006	Greater of 3 or 25%	Dec. 31, 2013
	50%	Dec. 31, 2014
	100%	Dec. 31, 2015

Off-road with VDECS Installed by December 31, 2006

Model Year	% of Model Year	Compliance Deadline
Pre-2003	Greater of 3 or 50%	Dec. 31, 2008
	100%	Dec. 31, 2009
2003	Greater of 3 or 25%	Dec. 31, 2011
	50%	Dec. 31, 2012
	100%	Dec. 31, 2013
2004	Greater of 3 or 25%	Dec. 31, 2012
	50%	Dec. 31, 2013
	100%	Dec. 31, 2014
2005	Greater of 3 or 25%	Dec. 31, 2013
	50%	Dec. 31, 2014
	100%	Dec. 31, 2015
2006	Greater of 3 or 25%	Dec. 31, 2014
	50%	Dec. 31, 2015
	100%	Dec. 31, 2016

On-road without VDECS Installed by December 31, 2006

Model Year	% of Model Year	Compliance Deadline
Pre-2000	Greater of 3 or 25%	Dec. 31, 2007
	50%	Dec. 31, 2008
	100%	Dec. 31, 2009
2000	Greater of 3 or 25%	Dec. 31, 2008
	50%	Dec. 31, 2009
	100%	Dec. 31, 2010
2001	Greater of 3 or 25%	Dec. 31, 2009
	50%	Dec. 31, 2010
	100%	Dec. 31, 2011
2002	Greater of 3 or 25%	Dec. 31, 2010
	50%	Dec. 31, 2011
	100%	Dec. 31, 2012
2003	Greater of 3 or 25%	Dec. 31, 2011
	50%	Dec. 31, 2012
	100%	Dec. 31, 2013
2004	Greater of 3 or 25%	Dec. 31, 2012
	50%	Dec. 31, 2013
	100%	Dec. 31, 2014
2005	Greater of 3 or 25%	Dec. 31, 2013
	50%	Dec. 31, 2014
	100%	Dec. 31, 2015
2006	Greater of 3 or 25%	Dec. 31, 2014
	50%	Dec. 31, 2015
	100%	Dec. 31, 2016

On-road with VDECS Installed by December 31, 2006

Model Year	% of Model Year	Compliance Deadline
Pre-2000	Greater of 3 or 25%	Dec. 31, 2008
	50%	Dec. 31, 2009
	100%	Dec. 31, 2010
2000	Greater of 3 or 25%	Dec. 31, 2009
	50%	Dec. 31, 2010
	100%	Dec. 31, 2011
2001	Greater of 3 or 25%	Dec. 31, 2010
	50%	Dec. 31, 2011
	100%	Dec. 31, 2012
2002	Greater of 3 or 25%	Dec. 31, 2011
	50%	Dec. 31, 2012
	100%	Dec. 31, 2013
2003	Greater of 3 or 25%	Dec. 31, 2012
	50%	Dec. 31, 2013
	100%	Dec. 31, 2014
2004	Greater of 3 or 25%	Dec. 31, 2013
	50%	Dec. 31, 2014
	100%	Dec. 31, 2015
2005	Greater of 3 or 25%	Dec. 31, 2014
	50%	Dec. 31, 2015
	100%	Dec. 31, 2016
2006	Greater of 3 or 25%	Dec. 31, 2015
	50%	Dec. 31, 2016
	100%	Dec. 31, 2017

a. for each compliance deadline, the percentage of yard trucks (25 percent, 50 percent, or 100 percent) that must meet the requirements of subsection (e)(2) is determined based on the total population of yard trucks for a specific model year or model year group (i.e., pre-2000 or pre-2003, depending upon whether the equipment is characterized as on- or off-road) that exist in the owner's or operator's yard truck fleet as of January 1 of the first compliance deadline year for that model year or model year group; and
b. if the number of yard trucks is not a whole number, conventional rounding practices apply (i.e., if less 0.5, round down; if 0.5 or greater, round up).

(3) In-Use Performance Standards for Non-Yard Truck Mobile Cargo Handling Equipment

(A) In accordance with the schedule set forth in subsection (e)(3)(C), no owner or operator shall operate non-yard truck mobile cargo handling equipment unless they meet all of the following:

1. Use one of the Compliance Options for each vehicle or equipment in the active fleet as specified in paragraph (e)(3)(B) per the compliance schedule listed in Table 3 in subsection (e)(3)(C); and

2. Adherence to any special circumstances that may apply when a diesel emission control strategy is used as a Compliance Option as specified in subsection (g); and

3. Maintenance of all records as specified in subsection (i); and

4. Continuous Compliance. An owner or operator is required to keep all mobile cargo handling equipment operating in California in compliance with the requirements of this regulation at all times.

(B) Compliance Option. Each owner or operator shall use one of the following Compliance Options on each engine or vehicle in his fleet as required by the implementation schedule listed in Table 3 in subsection (e)(3)(C):

1. Basic Container Handling Equipment:

a. An engine or power system, including a diesel, alternative fuel, or heavy-duty pilot ignition engine, certified to either the 2007 or later model year on-road emission standards for the year manufactured as specified in title 13, CCR, section 1956.8, or the Tier 4 off-road emission standards for the rated horsepower and model year of the year manufactured; or

b. An engine or power system certified to the on-road emission standards for the year manufactured as specified in title 13, CCR, section 1956.8, or certified to the Tier 2 or Tier 3 off-road diesel engine standard for the rated horsepower and model year of the year manufactured, and used in conjunction with the highest level VDECS that is verified for a specific engine family and model year. If the highest level VDECS used is Level 1, the engine or power system must meet the certified Tier 4 off-road emission standards, or be equipped with a Level 3 VDECS by December 31, 2015; or

c. An engine or power system either certified to the Tier 1 off-road diesel engine standard, as specified in title 13, CCR, section 2423, or manufactured prior to implementation of the Tier 1 off-road diesel engine standard, both of which must be used in conjunction with the highest level VDECS that is verified for the specific engine family and model year. If the highest level VDECS used is Level 1 or Level 2, the engine or power system must meet the certified Tier 4 off-road emission standards or be equipped with a Level 3 VDECS by December 31, 2015.

2. Bulk Cargo Handling Equipment:

a. An engine or power system, including a diesel, alternative fuel, or heavy-duty pilot ignition engine, certified to either the 2007 or later model year on-road emission standards for the year manufactured as specified in title 13, CCR, section 1956.8, or the Tier 4 off-road emission standards for the rated horsepower and model year of the year manufactured; or

b. An engine or power system certified to the on-road emission standards for the year manufactured as specified in title 13, CCR, section 1956.8, or certified to the Tier 2 or Tier 3 off-road diesel engine standard for the rated horsepower and model year of the year manufactured, and used in conjunction with the highest level VDECS that is verified for a specific engine family and model year. If the highest level VDECS used is Level 1, the engine or power system must meet the certified Tier 4 off-road emission standards, or be equipped with a Level 3 VDECS by December 31, 2015; or

c. An engine or power system either certified to the Tier 1 off-road diesel engine standard, as specified in title 13, CCR, section 2423, or manufactured prior to implementation of the Tier 1 off-road diesel engine standard, both of which must be used in conjunction with the highest level VDECS that is verified for the specific engine family and model year. If the highest level VDECS used is Level 1, the engine or power system must meet the certified Tier 4 off-road emission

standards or be equipped with a Level 3 VDECS by December 31, 2015.

3. Rubber-Tired Gantry Cranes:

   a. An engine or power system, including a diesel, alternative fuel, or heavy-duty pilot ignition engine, certified to either the 2007 or later model year on-road emission standards for the year manufactured as specified in title 13, CCR, section 1956.8, or the Tier 4 off-road emission standards for the rated horsepower and model year of the year manufactured; or

   b. An engine or power system certified to the on-road emission standards for the year manufactured as specified in title 13, CCR, section 1956.8, or certified to the Tier 2 or Tier 3 off-road diesel engine standard for the rated horsepower and model year of the year manufactured, and used in conjunction with the highest level VDECS that is verified for a specific engine family and model year; or

   c. An engine or power system either certified to the Tier 1 off-road diesel engine standard, as specified in title 13, CCR, section 2423, or manufactured prior to implementation of the Tier 1 off-road diesel engine standard, both of which must be used in conjunction with the highest level VDECS that is verified for the specific engine family and model year. If the highest level VDECS used is Level 1 or Level 2, the engine or power system must meet the certified Tier 4 off-road emission standards or be equipped with a Level 3 VDECS by the latter of model year plus 12 years or December 31, 2015.

(C) Compliance Schedule for Non-Yard Truck Mobile Cargo Handling Equipment

1. All owners or operators of non-yard truck mobile cargo handling equipment shall comply with subsection (e)(3) according to the schedule in Table 3:

Table 3: Compliance Option Compliance Schedule for Non-Yard Truck In-Use Mobile Cargo Handling Equipment

Engine Model Years	Compliance Date[1]				
	Non-Yard Truck Fleets of 3 or Fewer	Non-Yard Truck Fleets of 4 or More			
		First 3 or 25% (whichever is greater)	50%	75%	100%
pre-1988	2007	2007	2008	2009	2010
1988-1995	2008	2008	2009	2010	2011
1996-2002	2009	2009	2010	2011	2012
2003-2006	2010	2010	2011	2012	2013

a. for each compliance deadline, the percentage of non-yard truck equipment (25 percent, 50 percent, or 100 percent) that must meet the requirements of subsection (e)(3) is determined based on the total population of non-yard truck equipment for a specific model year group (i.e., pre-1988) that exist in the owner's or operator's non-yard truck fleet as of January 1 of the first compliance deadline year for that model year group; and
b. if the number of non-yard truck equipment is not a whole number, conventional rounding practices apply (i.e., if less 0.5, round down; if 0.5 or greater, round up).

(4) Fuel Requirements

(A) Except as provided for in subsection (c), on or after January 1, 2007, no owner or operator of cargo handling equipment shall fuel the equipment with any fuel unless the fuel is one of the following:

1. CARB Diesel Fuel; or
2. An alternative diesel fuel that meets the requirements of the Verification Procedure; or
3. An alternative fuel; or
4. CARB Diesel Fuel used with fuel additives that meets the requirements of the Verification Procedure; or
5. Any combination of (e)(4)(A)1. through (e)(4)(A)4. above.

(B) Owners or operators choosing to use alternative diesel fuels in mobile cargo handling equipment to meet the requirements of subsections (e)(2) and (e)(3) shall:

[1] Compliance date refers to December 31st of the year indicated.

1. Maintain records in accordance with subsection (i); and
2. Use only fuel that is a VDECS alternative diesel fuel in mobile cargo handling equipment at ports or intermodal rail yards in California; and
3. Permanently affix a label in clear view near the fill spout that identifies the proper fuel that is required to be in compliance; and
4. In the event that the owner or operator decides to revert to using CARB diesel fuel, the operator shall comply with the requirements of subsections (e)(2) and (e)(3) within 10 days of discontinuation of alternative diesel fuel use. Within 10 days of discontinuation, the owner or operator shall notify the Executive Officer in writing of this change in fuel use and shall include an update to any annual report submitted to comply with subsections (j).

(C) Owners or operators that retrofit mobile cargo handling equipment with a VDECS that requires certain fuel properties to be met in order to achieve the required PM reduction or PM emissions shall only fuel the subject mobile cargo handling equipment with fuel that meets these specifications. In addition, owners or operators that choose a VDECS that requires certain fuel properties to be met in order to prevent damage to the VDECS or an increase in toxic air contaminants, other harmful compounds, or in the nature of the emitted PM, shall only fuel the subject mobile cargo handling equipment with fuel that meets these specifications.

(f) Compliance Extensions

An owner or operator may be granted an extension to a compliance deadline specified in subsection (e) for one of the following reasons. If a compliance extension is granted by the Executive Officer, the owner or operator shall be deemed to be in compliance as specified by the Executive Officer's authorization. Unless specifically stated, compliance extensions may not be combined or used consecutively, and only one compliance extension type may be granted per engine or vehicle.

(1) *Compliance Extension for an Engine Near Retirement*. If an owner or operator has applied a Compliance Option to its fleet pursuant to the schedule set forth in Table 3 of subsection (e), and the next engine subject to the Compliance Options is scheduled to be retired from the active fleet within one year of the applicable compliance deadline, the owner or operator does not need to apply a Compliance Option to that engine for up to one year, provided the owner or operator maintains appropriate records and documentation, as specified in subparagraph (i)(1)(F), regarding the assigned retirement date and the engine is retired on or before the assigned date. If upon inspection, ARB finds the aforementioned conditions to have not been met, the engine would be in noncompliance from the date that compliance would otherwise have been required under the schedule set forth in Table 3 of subsection (e).

(2) *Compliance Extension Based on No Verified Diesel Emission Control Strategy for Non-Yard Truck Mobile Cargo Handling Equipment*. If the Executive Officer has not verified a diesel emission control strategy or one is not commercially available for a particular engine and equipment combination, an annual extension in compliance, up to a maximum of two years, may be granted by the Executive Officer. The Executive Officer shall grant the extension upon determining that the following circumstances have been met:

(A) The owner or operator has applied to the Executive Officer for a compliance extension for an engine six months prior to each compliance deadline specified in subsection (e)(3)(C) and provided sufficient documentation to meet the conditions set forth below. The owner or operator may, six-months prior to the expiration of the extension, apply for an additional one-year extension. In such a case, the owner or operator shall once again be required to show to the Executive Officer's satisfaction that the conditions set forth below have been met:

1. Establish that it has applied a Compliance Option specified in subsection (e)(3) to all applicable engines in its fleet for which a Compliance Option is feasible pursuant to the schedule set forth in Table 3 of subsection (e),
2. Identify each engine for which an extension is requested by engine serial number; engine manufacturer, model year, family, and series; and type of mobile cargo handling equipment, for which a specific diesel emission control strategy would jeopardize the original engine warranty and a statement from the engine manufacturer or authorized dealer stating the original engine warranty would be jeopardized; or
3. Identify each engine and equipment or vehicle combination for which an extension is requested by engine serial number; engine manufacturer, model year, family, and series; and type of mobile cargo handling equipment, for which no diesel emission control strategy is commercially available and a list of manufacturers that have been contacted with their responses to a request to purchase, and
4. Describe the reason(s) for the request for a compliance extension for each engine or engine and equipment or vehicle combination.

(3) *Use of Experimental Diesel Particulate Matter Emission Control Strategies for Non-Yard Truck Mobile Cargo Handling Equipment*. An annual compliance extension may be granted by the Executive Officer for the use of an experimental, or non-verified, diesel PM emission control strategy if a VDECS is not available or if the owner or operator can demonstrate that an existing VDECS is not feasible for their equipment or application. The owner or operator shall keep documentation of this use in records as specified in paragraph (i)(1)(G). Each mobile cargo handling equipment engine will be considered to be in compliance for the duration of the experiment, until the extension expires. The owner or operator must bring the mobile cargo handling equipment into compliance prior to the end of the annual compliance extension. The Executive

Officer may grant the extension upon determining that the owner or operator has met the conditions specified below:

(A) The engine owner or operator has applied to the Executive Officer for a compliance extension six months prior to each compliance deadline, including annually if the owner or operator wishes to continue with the experimental controls. The application must include emissions data demonstrating the experimental control achieves at least a Level 1 diesel PM emission reduction through:
   1. off-road engine certification test data for the cargo handling equipment engine;
   2. engine manufacturer test data;
   3. emissions test data from a similar engine;
   4. emissions test data used in meeting the requirements of the Verification Procedure for the emission control strategy implemented; or
   5. emissions testing conducted under the following conditions:
      a. baseline testing may be conducted with the emission control strategy in place, provided the test sample is taken upstream of the emission control strategy;
      b. control strategy testing shall be performed on the cargo handling equipment engine with full implementation of the emission control strategy;
      c. the percent change from baseline shall be calculated as the baseline emissions minus control strategy emissions, with the difference being divided by the baseline emissions and the result expressed as a percentage;
      d. the same test method shall be used for determining both baseline emissions and control strategy emissions; and
      e. diesel PM, NOx, CO, HC, NMHC, and CO_2 testing shall be done in accordance with one of the following methods:
         i. International Organization for Standardization (ISO) 8178 Test procedures: ISO 8178-1: 1996(E) (“ISO 8178 Part 1”); ISO 8178-2: 1996(E) (“ISO 8178 Part 2”); and ISO 8178-4: 1996(E) (“ISO 8178 Part 4”), which are incorporated herein by reference; or
         ii. Title 13, California Code of Regulations, section 2423, “Exhaust Emission Standards and Test Procedures – Off-Road Compression Ignition Engines,” which is incorporated herein by reference.

(B) The application for extension must include the following: explanation demonstrating that the highest level VDECS are not feasible for the specific equipment or application (if applicable), identification of each engine (serial number, engine manufacturer, model year, family, and series), description of the emission control system to be demonstrated, emissions data required in (A) above, the contact information for the emission control system supplier,

and a letter of intent from the supplier that they intend to apply for verification of the experimental system;

(C) The owner or operator must bring the mobile cargo handling equipment into compliance prior to the end of the compliance extension period;

(D) If VDECS are available, or become available during the extension period, and are determined to be feasible for the specific engine and equipment type, the owner or operator must demonstrate that the experimental control achieves equivalent to or better than a Level 1 VDECS; and

(E) No experimental diesel particulate matter emission control strategy may be used on mobile cargo handling equipment after December 31, 2015.

(4) *Compliance Extension for Equipment Manufacturer Delays*. An owner or operator who has purchased new equipment in order to comply with subsection (e), including an owner or operator who has been granted a compliance extension per subsections (f)(2), (f)(3), or (f)(5), will be considered to be in compliance if the new equipment has not been received due to manufacturing delays, as long as the following conditions are met:

(A) The equipment was purchased, or the owner or operator and seller had entered into contractual agreement for the purchase, at least six months prior to the required compliance date as specified in subsection (e); and

(B) Proof of purchase, such as a purchase order or signed contract for the sale, including engine specifications for each applicable equipment, must be maintained by the owner or operator and provided to an agent or employee of ARB upon request.

(5) *Compliance Extension for Yard Trucks Having VDECS with Minimum Use Requirements*. If VDECS were installed on a yard truck prior to December 31, 2005, and the minimum use requirements of the VDECS, as established under a public funding program, is later than the compliance date as specified in subsection (e)(2)(B), an exemption from compliance may be extended to three years beyond the installation date of the VDECS if the following conditions are demonstrated by the owner or operator:

(A) The VDECS was installed using funding from a public agency; and

(B) The funding program stipulated minimum use requirements that would expire after the required compliance date as specified in subsection (e)(2)(B).

(g) Diesel Emission Control Strategy Special Circumstances

An owner or operator shall maintain the original level of the elected Compliance Option for each engine once that engine is required to be in compliance, and is not required to upgrade to a higher level of Compliance Option, except under specified special circumstances, as follows:

(1) In the event of a failure or damage of a diesel emission control strategy, the following conditions apply:

(A) Failure or Damage during the Warranty Period. If a diesel emission control strategy fails or is damaged within its warranty period and the diesel emission control strategy manufacturer or authorized dealer determines it cannot be repaired, the owner or operator shall replace the diesel emission control strategy with either the same level diesel emission control strategy or another approved Compliance Option as defined in subsection (e)(3) within 90 days of diesel emission control strategy failure.

(B) Failure or Damage Outside of Warranty Period. If a diesel emission control strategy fails or is damaged outside of its warranty period, and it cannot be repaired, the owner or operator shall apply a Compliance Option within 90 days, as defined in subsection (e)(3).

(h) Alternative Compliance Plan for Non-Yard Truck Cargo Handling Equipment

(1) Requirements

(A) The purpose of this subsection is to allow any person ("person" or "applicant") subject to this regulation the option of complying with the requirements of this subsection (h) in lieu of the requirements of subsection (e)(3). Under this subsection (h), alternative emission control strategies (AECS) can be implemented as an alternative compliance plan (ACP), provided they result in no greater emissions, expressed in pounds, of diesel PM and NOx from the non-yard truck cargo handling equipment, over the applicable calendar year, relative to the emissions that would have occurred under subsection (e)(3).

(B) An applicant wishing to participate in an ACP may include one or more non-yard truck cargo handling equipment in the ACP, but the applicant shall only include equipment that the person owns or operates under their direct control at the same port or intermodal rail yard.

(C) No cargo handling equipment shall be included in more than one ACP.

(D) AECS may include, but are not limited to:

1. equipment engine modifications,
2. exhaust treatment control,
3. engine repower,
4. equipment replacement, and
5. use of alternative fuels or fuel additives.

(E) The ACP application demonstrating compliance with this subsection shall contain, at a minimum, the following information:

1. the company name, address, and contact information;
2. the equipment subject to the ACP, including equipment and engine make, model, and serial numbers, and other information that uniquely identify the equipment;
3. documentation, calculations, emissions test data, or other information that establishes the diesel PM and NOx reductions, expressed in pounds, from non-yard truck cargo handling equipment will be equivalent to or greater than the emission reductions that would have been achieved upon compliance with subsection (e)(3);
4. the proposed recordkeeping, reporting, monitoring, and testing procedures that the applicant plans to use to demonstrate continued compliance with the ACP.

(F) Emission reduction calculations demonstrating equivalence with the requirements of subsection (e)(3) shall only include diesel PM and NOx emissions from non-yard truck cargo handling equipment that operate at the California port or intermodal rail yard to which the ACP applies.

(G) Any owner or operator subject to an approved ACP shall maintain operating records in a manner and form as specified by the Executive Officer in the approved ACP. Required records may include, but are not limited to, information on hours of operation, fuel usage, maintenance procedures, and emissions test results. Such records and reports shall be retained for a period of not less than three (3) years and shall be submitted to the Executive Officer in the manner specified in the approved ACP and upon request by the Executive Officer.

(H) Emission reductions included in an ACP shall not include reductions that are otherwise required by any local, State, or federal rule, regulation, or statute, or that are achieved or estimated from equipment not located at the specific port or intermodal rail yard to which the ACP applies.

(I) No person may operate any non-yard truck cargo handling equipment under an ACP unless the applicant has first been notified in writing by the Executive Officer that the ACP application has been approved. Prior to such

approval, applicants shall comply with the provisions of this section, including the requirements in subsection (e)(3).

(2) Application Process

(A) Applications for an ACP shall be submitted in writing to the Executive Officer for evaluation.

(B) The Executive Officer shall establish an Internet site ("ACP Internet site") in which all documents pertaining to an ACP application will be made available for public review. The Executive Officer shall also provide a copy of all such documents to any person upon request ("interested party(ies)"). The Executive Officer shall provide two separate public comment periods during the ACP application process, as specified in this subsection (h)(2).

(C) Completeness Determination

Within 15 days after receiving an ACP application(s), the Executive Officer shall notify the applicant whether the application is deemed sufficiently complete to proceed with further evaluation. If the application is deemed incomplete, the notification shall identify the application's deficiencies. The Executive Officer shall have an additional 15-day period for reviewing each set of documents or information submitted in response to an incompleteness determination. Nothing in this subsection prohibits the Executive Officer from requesting additional information from the applicant, during any part of the ACP application process, which the Executive Officer determines is necessary to evaluate the application.

(D) Notice of Completeness and 30-Day First Public Comment Period

After an ACP application has been deemed complete, the Executive Officer shall provide a 30-day public comment period to receive comments on any element of the ACP application and whether the Executive Officer should approve or disapprove the ACP application based on the contents and merits of the application. The Executive Officer shall notify all interested parties of the following:

1. the applicant(s);
2. the start and end dates for the 30-day first comment period; and
3. the address of the ACP Internet site where the application is posted.

The Executive Officer shall also make this notification available for public review on the ACP Internet site.

(E) Proposed Action and 15-Day Second Public Comment Period

Within 30 days after the first public comment period ends, the Executive Officer shall notify the applicant and all interested parties of ARB's proposed approval or disapproval. This notification shall propose to approve the application as submitted, disapprove the application, or approve the ACP application with modifications as deemed necessary by the Executive Officer. The notification shall identify the start and end dates for the 15-day second public comment period. During the second public comment period, any person may comment on the Executive Officer's proposed approval or disapproval of the ACP application and any element of the application. The Executive Officer shall also make this notification available for public review on the ACP Internet site.

(F) Final Action

Within 15 days after the second public comment period ends, the Executive Officer shall take final action to either approve or deny an ACP application and shall notify the applicant accordingly. If the application is denied or modified, the Executive Officer shall state the reasons for the denial or modification in the notification. The notification to the applicant and approved ACP, if applicable, shall be made available to the public on the ACP Internet site. In addition, the Executive Officer shall consider and address all comments received during the first and second public comment periods, and provide responses to each comment on the ACP Internet site.

(G) Notification to the Executive Officer of Changes to an Approved ACP

The applicant shall notify the Executive Officer in writing within 30 days upon learning of any information that would alter the emissions estimates submitted during any part of the ACP application process. If the Executive Officer has reason to believe that an approved ACP has been granted to a person that no longer meets the criteria for an ACP, the Executive Officer may, pursuant to subsection (h)(3) below, modify or revoke the ACP as necessary to assure that the applicant and subject non-yard truck cargo handling equipment will meet the emission reduction requirements in this section.

(3) Revocation or Modification of Approved ACPs

With 30-days notice to the ACP holder, the Executive Officer may revoke or modify, as needed, an approved ACP if there have been multiple violations of the ACP provisions or the requirements of the approved ACP; or if the Executive Officer has reason to believe that an approved ACP has been granted that no longer meets the criteria or requirements for an ACP or the applicant can no longer comply with the requirements of the approved ACP in its current form.

Public notification of a revocation or modification of an approved ACP shall be made available on the ACP Internet site.

(i) Recordkeeping Requirements

Beginning December 31, 2006, an owner or operator of mobile cargo handling equipment shall maintain the following records or copies of records at port and intermodal rail yard facilities where applicable. The owner or operator shall provide the following records for inspection to an agent or employee of ARB upon request, including copies of these records at the department's expense, for all mobile cargo handling equipment subject to compliance with the regulation:

(1) Records Kept at Terminal. The owner or operator shall keep the following records accessible either in hard copy format or computer records at the terminal where the mobile cargo handling equipment normally resides:

(A) Owner or Operator Contact Information
1. Company name
2. Contact name, phone number, address, e-mail address
3. Address of equipment

(B) Equipment and Engine Information
1. Make of equipment and engine
2. Model of equipment and engine
3. Engine family (if applicable)
4. Engine serial number
5. Year of manufacture of equipment and engine (if unable to determine, approximate age)
6. Rated brake horsepower
7. Control equipment (if applicable)
   a. Type of diesel emission control strategy
   b. Serial number of installed diesel emission control strategy
   c. Manufacturer of installed diesel emission control strategy
   d. Model of installed diesel emission control strategy
   e. Installation date of installed diesel emission control strategy
   f. Level of control (1, 2, or 3); if using a Level 1 or 2, include the reason for the choice
   g. Documentation for Minimum Use Requirement Compliance Extension pursuant to paragraph (f)(5)

(C) Records of maintenance for each installed diesel emission control strategy

(D) Fuel(s) Used
1. CARB Diesel
2. Alternative diesel fuel (specify)
3. Alternative fuel (specify)

4. Combination (dual fuel) (specify)
5. Other (specify)

(E) Operation Information
1. Describe general use of engine
2. Typical load (percent of maximum bhp rating)
3. Typical annual hours of operation
4. If seasonal, months of year operated and typical hours per month operated

(F) For each engine for which an owner or operator is claiming an exemption pursuant to paragraph (f)(1), the retirement date correlated to the information in paragraph (i)(1) above

(G) For each engine for which an owner or operator is claiming an extension pursuant to paragraph (f)(3), the records of the test plan, including start and end dates of the experiment; diesel particulate matter emission control strategy manufacturer name and contact information (representative, address, and phone number); name and type of experimental diesel particulate matter emission control strategy; and targeted data to be generated by experiment, correlated to the information in paragraph (i)(1) above

(H) For each engine for which an owner or operator is claiming an extension pursuant to paragraph (f)(4), the purchase order or signed contract between the owner or operator and seller of the new equipment that has been purchased in order to comply with subsection (e)

(I) A statement of compliance, prepared beginning January 1, 2007, and renewed each January 1 thereafter until January 1, 2016, certifying that the owner's or operator's engines are in compliance as required, including the following:

1. "The mobile cargo handling equipment at terminal (insert terminal name and name of port or intermodal rail yard) are in compliance with title 13, California Code of Regulations, section 2479;" and
2. The owner's or operator's name, business address, business telephone; and
3. The signature of the owner or operator or its agent and date signed.

(2) Records Kept in Mobile Cargo Handling Equipment. For each mobile cargo handling equipment, the owner or operator shall keep the following information affixed to the driver's side door jamb, or another readily accessible location known by the owner or operator of each mobile cargo handling equipment, in the form of a legible and durable label or in an alternative form approved by the

Executive Officer or designee that is immediately accessible at the time of inspection by the enforcement agency:

(A) For each installed diesel emission control strategy, label information as specified in title 13, CCR, section 2706(g), and the installation date; or

(B) For each mobile cargo handling equipment that has installed a certified on-road or off-road engine in order to comply with subsection (e), the engine make, model, and installation date; or

(C) Engine model year and planned compliance date; or

(D) Engine model year and retirement date for an engine for which an owner or operator is claiming an extension pursuant to paragraph (f)(1); or

(E) Engine model year and beginning and end date for which an owner or operator is claiming an extension pursuant to paragraph (f)(2): or

(F) Engine model year and beginning and ending date of the test plan for an engine for which an owner or operator is claiming an extension pursuant to paragraph (f)(3); or

(G) Engine model year and date of purchase of replacement engine or equipment for which an owner or operator is claiming an extension pursuant to paragraph (f)(4); or

(H) Engine model year, date of installation of VDECS, and supporting documentation for public funding program, for the engine and equipment for which an owner or operator is claiming an extension pursuant to paragraph (f)(5).

(3) Each owner or operator shall maintain these records for each mobile cargo handling equipment until it is sold outside of the State of California or is no longer used at a port or intermodal rail yard in the State of California. If ownership is transferred, the seller shall convey the records to the buyer.

(j) Reporting Requirements

(1) Compliance Plan. By January 31, 2007, each owner or operator of in-use mobile cargo handling equipment subject to the requirements of subsection (e) shall provide the following information to the Executive Officer:

(A) Information listed in paragraph (i)(1), and

(B) An identification of the planned control strategy (Compliance Plan) for each mobile cargo handling equipment listed in paragraph (i)(1) that, when

implemented, will result in compliance with subsection (e). If applicable, the information should include the Executive Order number issued by the Executive Officer for a VDECS that has been approved by the Executive Officer through the Verification Procedure. The Compliance Plan is not binding and can be changed by the owner or operator prior to the required compliance date(s).

(2) Demonstration of Compliance. By no later than the earliest applicable compliance date specified in subsections (e)(2)(B) or (e)(3)(C), for each in-use cargo handling equipment subject to the requirements of subsection (e), the owner or operator shall provide the following information to the Executive Officer:

(A) Information listed in (i)(1), and

(B) An identification of the control strategy implemented for each mobile cargo handling equipment in accordance with the requirements of subsection (e) for purposes of demonstrating compliance.

(3) Annual Reporting. Each terminal owner or operator shall submit an annual report to the Executive Officer by January 31, 2007, and by each January 31 annually, through 2016 as described below:

(A) Company name;

(B) Contact name, phone number, address, e-mail address;

(C) Address of equipment, including name of port or intermodal rail yard where equipment is operated;

(D) The population, as of January 1 of that year, of equipment in each yard truck model year group and each non-yard truck model year group; and

(E) A signed affidavit stating the completeness and accuracy of the annual report.

(4) Reporting for Off-Road Equipment that Does Not Handle Cargo at any Time. Each terminal owner or operator to whom subsection (c)(3) applies, shall submit a report to the Executive Officer by January 31, 2007, as described below:

(A) Owner or Operator Contact Information
1. Company name
2. Contact name, phone number, address, e-mail address
3. Address of equipment

(B) Equipment and Engine Information
1. Make of equipment and engine
2. Model of equipment and engine
3. Engine family (if applicable)
4. Engine serial number
5. Year of manufacture of equipment and engine (if unable to determine, approximate age)
6. Rated brake horsepower
7. Control equipment (if applicable)
   a. Type of diesel emission control strategy
   b. Serial number of installed diesel emission control strategy
   c. Manufacturer of installed diesel emission control strategy
   d. Model of installed diesel emission control strategy
   e. Installation date of installed diesel emission control strategy
   f. Level of control (1, 2, or 3)

(C) Fuel(s) Used
1. CARB Diesel
2. Alternative diesel fuel (specify)
3. Alternative fuel (specify)
4. Combination (dual fuel) (specify)
5. Other (specify)

(D) Operation Information
1. Describe general use of engine
2. Typical load (percent of maximum bhp rating)
3. Typical annual hours of operation
4. If seasonal, months of year operated and typical hours per month operated

(k) Right of Entry

An agent or employee of the Air Resources Board has the right of entry to port and intermodal rail yard cargo handling facilities for the purpose of inspecting on-road and off-road cargo handling equipment and their records to determine compliance to these regulations.

(l) Prohibitions

No person who is engaged in this State in the business of selling to an ultimate purchaser, or renting or leasing new or used mobile cargo handling equipment, including, but not limited to, manufacturers, distributors, and dealers, shall sell, offer for sell, import, deliver, purchase, receive, or otherwise acquire a new or used mobile cargo handling equipment for the purpose of selling, renting, or leasing in California, that does not meet the performance requirements of this regulation.

(m) Severability

If any subsection, paragraph, subparagraph, sentence, clause, phrase, or portion of this regulation is, for any reason, held invalid, unconstitutional, or unenforceable by any court of competent jurisdiction, such portion shall be deemed as a separate, distinct, and independent provision, and such holding shall not affect the validity of the remaining portions of the regulation.

(n) Submittal of Documents

(A) All documents required under this regulation to be submitted to the Executive Officer shall be submitted as follows:

California Air Resources Board
Stationary Source Division, Cargo Handling Equipment
P.O. Box 2815
Sacramento, California 95812-2815

(B) An alternative method, including electronic submittals, may be approved by the Executive Officer.

NOTE: Authority cited: sections 39600, 39601, 39618, 39658, 39659, 39667, 39674, 39675, 42400, 42400.1, 42400.2, 42400.3, 42400.3.5, 42400.6, 42402, 42402.1, 42402.2, 42402.3, 42402.4, 42410, 43013, 43018, California Health and Safety Code. Reference: sections 39618, 39650, 39658, 39659, 39667, 39674, 39675, 42400, 42400.1, 42400.2, 42400.3, 42400.3.5, 42400.6, 42402, 42402.1, 42402.2, 42402.3, 42402.4, 42410, 43013, and 43018. Health and Safety Code.

BARACK OBAMA AND JOE BIDEN: PROMOTING A HEALTHY ENVIRONMENT

"We cannot afford more of the same timid politics when the future of our planet is at stake. Global warming is not a someday problem, it is now. We are already breaking records with the intensity of our storms, the number of forest fires, the periods of drought. By 2050 famine could force more than 250 million from their homes . . . . The polar ice caps are now melting faster than science had ever predicted. . . . This is not the future I want for my daughters. It's not the future any of us want for our children. And if we act now and we act boldly, it doesn't have to be."

[Barack Obama, Portsmouth, NH, 10/8/07]

BARACK OBAMA AND JOE BIDEN ON THE ENVIRONMENT

Barack Obama has worked to ensure that our nation's environmental laws and policies balance America's need for a healthy, sustainable environment with economic growth. He has reached across the aisle to sponsor ambitious legislation to drastically reduce greenhouse gas emissions and turn this crisis of global warming into a moment of opportunity for innovation and job creation. *The League of Conservation Voters has given Barack Obama the highest lifetime rating of anyone currently running for president.*

As president, Barack Obama will make combating global warming a top priority. He will reinvigorate the Environmental Protection Agency (EPA), respecting its professionalism and scientific integrity. And he will protect our children from toxins like lead, be a responsible steward of our natural treasures and reverse the Bush administration's attempts to chip away at our nation's clean air and water standards.

CLIMATE CHANGE

Global warming is real, is happening now and is the result of human activities. Barack Obama and Joe Biden believe we have a moral, environmental, economic and security imperative to tackle climate change in a serious, sustainable manner.

Reduce Carbon Emissions 80 Percent by 2050: Barack Obama and Joe Biden support implementation of a market-based cap-and-trade system to reduce carbon emissions by the amount scientists say is necessary: 80 percent below 1990 levels by 2050. They will start reducing emissions immediately in his administration by establishing strong annual reduction targets, and they will also implement a mandate of reducing emissions to 1990 levels by 2020.

A cap-and-trade program draws on the power of the marketplace to reduce emissions in a cost-effective and flexible manner. Under the program, an overall national cap on carbon emissions is established. The emissions allowed under the cap are divided up into individual allowances that represent the permission to emit that amount. Because the emissions cap restricts the amount of pollution allowed, allowances that give a company the ability to pollute take on financial value. Companies are free to buy and sell allowances in order to continue operating in the most profitable manner available to them. Those that are able to reduce pollution at a low cost can sell their extra allowances to companies facing high costs. Each year the number of allowances will decline to match the required annual reduction targets.

- 100 Percent Allowance Auction: Barack Obama and Joe Biden's cap-and-trade system will require all pollution credits to be auctioned. A 100 percent auction ensures that all large corporate polluters pay for every ton of emissions they release, rather than giving these emission rights away for free to coal and oil companies.

- Invest Revenue for a Clean Energy Future: Some of the revenue generated by auctioning allowances will be used to support the development and deployment of clean energy, invest in energy efficiency improvements to help families reduce their energy prices, and to address transition costs, including helping American workers affected by this economic transition and helping lower-income Americans with their energy costs.

I. Invest in a Clean Energy Economy and Create American Jobs

Barack Obama and Joe Biden will invest $150 billion over 10 years in advanced energy technologies.

(1) Increase Investment in Basic Research and Human Capital.

- Invest in Basic Research: Barack Obama and Joe Biden will double federal science and research funding for clean energy projects.
- Invest in a Skilled Clean Technologies Workforce: Barack Obama and Joe Biden will invest in job training and transition programs to help workers and industries adapt to clean technology development and production.

(2) Invest in Key Technology Deployment.

- Clean Technologies Deployment Venture Capital Fund: Barack Obama and Joe Biden will create a Clean Technologies Venture Capital Fund to fill a critical gap in U.S. technology development. This fund will partner with existing investment funds and our National Laboratories to ensure that promising technologies move beyond the lab and are commercialized in the U.S.
- Production Tax Credit: Barack Obama and Joe Biden will also extend the federal Production Tax Credit (PTC) for 5 years to encourage the deployment of renewable technologies.

(3) Set Standards to Allow the Market to Invest and Innovate.

Barack Obama and Joe Biden will also establish new national standards to ensure less carbon intensive energy is used in our energy supply.

- Establish a National Low Carbon Fuel Standard: Barack Obama and Joe Biden will establish a National Low Carbon Fuel Standard (LCFS) to speed the introduction of low-carbon, non-petroleum fuels. The standard requires fuels suppliers to reduce the carbon their fuel emits by ten percent by 2020.
- Require 25 Percent of Electricity to Come from Renewable Sources by 2025: Barack Obama and Joe Biden will establish a 25 percent federal Renewable Portfolio Standard (RPS) to require that 25 percent of electricity consumed in the U.S. is derived from clean, sustainable energy sources, like solar, wind and geothermal by 2025.
- Ensure the Federal Government Uses Renewable Sources of Electricity: Barack Obama and Joe Biden will ensure that at least 30 percent of the federal government's electricity comes from renewable sources by 2020.

II. Invest in the Fastest, Cleanest Way to Reduce Emissions: Energy Efficiency

Barack Obama and Joe Biden will make energy conservation a top priority and use their offices to communicate directly with the American people about the importance of reducing our energy consumption. Their agenda will provide the American people the tools they need to begin reducing their energy consumption and energy bills.

Make the Federal Government the Leader in Saving Electricity:

- Make Federal Buildings More Efficient: Barack Obama and Joe Biden will ensure that all new federal buildings are zero-emissions by 2025, and they will ensure that all new federal buildings are 40 percent more efficient within the next five years. They will also make retrofitting existing federal buildings a top priority and seek to improve their efficiency by 25 percent within five years.
- Overhaul Federal Efficiency Codes: Barack Obama and Joe Biden will ensure his Department of Energy will regularly update efficiency standards.

Use Innovative Measures to Dramatically Improve Efficiency of Buildings:

- Set National Building Efficiency Goals: Barack Obama and Joe Biden will establish a goal of making all new buildings carbon neutral, or produce zero emissions, by 2030. They will also establish a national goal of improving new building efficiency by 50 percent and existing building efficiency by 25 percent over the next decade to help us meet the 2030 goal.
- Establish a Grant Program for Early Adopters: Barack Obama and Joe Biden will create a competitive grant program to award those states and localities that take the first steps in implementing new building codes that prioritize energy efficiency. They will also provide a federal match for those states with public benefits funds that support energy efficiency retrofits for existing buildings.
- Flip Incentives to Energy Utilities: Barack Obama and Joe Biden will work to provide incentives for energy conservation by ensuring utilities get increased profits for improving energy efficiency, rather than higher energy consumption. This decoupling of profits from increased energy usage will incentivize utilities to partner with consumers and the federal government to reduce monthly energy bills for families and businesses. Barack Obama and Joe Biden will provide early adopter grants and other financial assistance from the federal government to states that implement this energy efficient policy.
- Expand Federal Efficiency Grants: Barack Obama and Joe Biden will expand federal grant programs to help states and localities build more efficient public buildings that adopt aggressive green building provisions like those provided by Green Globes and the Leadership in Energy and Environmental Design program of the U.S. Green Buildings Council.

Create a Green Job Corps: Barack Obama and Joe Biden will create an energy-focused youth jobs program for disconnected and disadvantaged youth. This program will provide participants with service opportunities to improve energy conservation and efficiency of homes and buildings in their communities, while also providing practical experience in important career fields of expected high-growth employment. It will also engage private sector employers and unions to provide apprenticeship opportunities. The program will also work closely with Barack Obama and Joe Biden's proposed Clean Energy Corps to help participants find additional service opportunities after they complete the Green Job Corps.

Invest in a Digital Smart Grid: Barack Obama and Joe Biden will pursue a major investment in our national utility grid to enable a tremendous increase in renewable generation and accommodate 21st century energy requirements, such as reliability, smart metering and distributed storage. Barack Obama and Joe Biden will direct federal resources to the most vulnerable and congested urban and rural areas where significant renewable energy sources are located. They will work toward national transformation of our energy grid in partnership with states and utilities.

Increase Fuel Economy Standards: Barack Obama and Joe Biden will double fuel economy standards within 18 years while protecting the financial future of domestic automakers. Their plan will provide retooling tax credits and loan guarantees for domestic auto plants and parts manufacturers, so that the new fuel-efficient cars can be built in the U.S. rather than overseas.

Invest in Developing Advanced Vehicles: Barack Obama and Joe Biden will invest in advanced vehicle technology that utilizes advanced lightweight materials and new engines. They will also expand consumer tax incentives by lifting the 60,000-per-manufacturer cap on buyer tax credits to allow more Americans to buy ultra-efficient vehicles.

Build More Livable and Sustainable Communities:

- Reform Federal Transportation Funding: Barack Obama and Joe Biden will re-evaluate the transportation funding process to ensure that smart growth considerations are taken into account and he will also re-commit federal resources to public mass transportation projects across the country.
- Require States to Plan for Energy Conservation: Barack Obama and Joe Biden will require governors and local leaders in our metropolitan areas to make "energy conservation" a required part of their planning for the expenditure of federal transportation funds.

III. Make the U.S. a Leader in Combating Climate Change around the World

Re-Engage with the U.N. Framework Convention on Climate Change (UNFCCC): The UNFCCC process is the main international forum dedicated to addressing the climate change problem and an Obama administration will work constructively within it.

Create New Forum of Largest Greenhouse Gas Emitters: Barack Obama and Joe Biden will create a Global Energy Forum – based on the G8+5, which includes all G-8 members plus Brazil, China, India, Mexico and South Africa – comprised of the largest energy consuming nations from both the developed and developing world, which would focus exclusively on global energy and environmental issues. This Global Energy Forum will complement – and ultimately merge with – the much larger negotiation process underway at the UN to develop a post-Kyoto framework.

Transfer American Technology to the Developing World to Fight Climate Change: Barack Obama and Joe Biden will create a Technology Transfer Program within the Department of Energy dedicated to exporting climate-friendly technologies, including green buildings, clean coal and advanced automobiles, to developing countries to help them combat climate change.

Confront Deforestation and Promote Carbon Sequestration: A comprehensive strategy to combat global warming must address tropical deforestation which accounts for approximately 20 percent of global greenhouse gas emissions. Reducing rates of tropical deforestation will not only slow greenhouse gas emissions but will also protect the livelihoods of local people and the abundance of biodiversity inextricably linked to those forests. By offering incentives to maintain forests and manage them sustainably, the United States can play a leadership role in dealing with climate change. In addition, Barack Obama and Joe Biden will develop domestic incentives that reward forest owners, farmers, and ranchers when they plant trees, restore grasslands, or undertake farming practices that capture carbon dioxide from the atmosphere.

CLEAN AIR

Air pollution causes thousands of deaths each year. Barack Obama and Joe Biden have a record of successfully fighting for cleaner air. In an Obama administration, they will continue that fight.

Fight for Clean Air: During his time on the Senate Environment and Public Works Committee, Barack Obama helped stop President Bush's attempt to undermine the Clean Air Act, which would have increased industrial emissions of mercury and sulfur. He also helped block attempts to roll back environmental regulations on oil refineries. And he has been an outspoken proponent of funding for the Diesel Emissions Reduction Act of 2005, a bipartisan initiative that could achieve major reductions in harmful emissions by helping states clean up diesel vehicles.

As president, Barack Obama will restore the force of the Clean Air Act. He and Joe Biden will fight for continued reductions in smog and soot, and continue his leadership in combating toxins that contribute to air pollution. Unlike President Bush, they will listen to his scientific advisers on air quality standards. And they will reverse the Bush administration's attempts to chip away at our nation's clean air standards.

Reduce Health Risks Caused by Mercury Pollution: More than five million women of childbearing age have high levels of toxic mercury in their blood and approximately 630,000 newborns are born every year at risk. The EPA estimates that every year, more than one in six children could be at risk for developmental disorders because of mercury exposure in the mother's womb. Barack Obama fought a Bush administration rule that would have imposed very weak emissions reductions on utilities, delaying meaningful reductions in power plant mercury emissions for another two decades. Recognizing that one major cause of mercury also comes through the air from across the oceans, particularly from China, Obama introduced legislation to ban the export of elemental mercury, and he successfully pressured the U.S. Department of Energy to stop its proposed sale of large quantities of mercury to companies overseas. Obama also introduced legislation to phase out the use of mercury in the manufacture of chlorine.

CLEAN WATER

As a senator, Barack Obama has been a strong leader on clean water issues. He fought against offshore drilling in the U.S. Senate, and he supports maintaining current moratoriums on new offshore oil and natural gas drilling. He supports full funding for the Clean Water State Revolving Fund, which funds water quality protection projects for wastewater treatment, nonpoint source pollution control, and watershed and estuary management. He also supported a new stormwater cleanup program to manage polluted runoff from roads and highways, which is the largest source of water pollution in coastal areas today. In Illinois, Obama cosponsored legislation that stopped the use of MTBE, a fuel additive which has been found to contaminate ground water. As president, he will improve the quality of our nation's lakes, rivers, and drinking water.

Clean up our Water: Barack Obama and Joe Biden will reinvigorate the drinking water standards that have been weakened under the Bush administration and update them to address new threats. They will help communities by restoring better federal financing for water and wastewater treatment infrastructure, and they will continue his leadership in protecting national treasures like the Great Lakes from threats such as industrial pollution, water diversion, and invasive species. Barack Obama and Joe Biden will establish policies to help high-growth regions with the challenges of managing their water supplies.

Regulate CAFOs: Concentrated Animal Feeding Operations (CAFOs), which raise more than 40 percent of U.S. livestock, comprise a larger share of the livestock industry every year. Barack Obama has worked for tougher environmental regulations on CAFOs. He has supported legislation to set tough air and water pollution limits for livestock operations, including limits on nitrogen, phosphorus, hydrogen sulfide, ammonia, and other pollutants. In the Obama Administration, the Environmental Protection Agency will strictly monitor and regulate pollution from large CAFOs, with fines for those who violate tough air and water quality standards. Obama also strongly supports efforts to ensure meaningful local control.

Restore the Wetlands: Barack Obama is an advocate for preserving our wetlands and supports a broad range of traditional conservation programs, including the North American Wetlands Conservation Act and the Wetland Reserve Program in the Farm Bill. He and Joe Biden will work with local governments to develop the best strategies for protecting and expanding wetlands. Obama's record on protecting wetlands dates back to his days as a state senator, when he was a cosponsor of the Wetlands Protection Act, which provided for the conservation of wetlands in Illinois.

Barack Obama will help the Gulf Coast restore the wetlands, marshes and barrier islands that are critical to tamping down the force of hurricanes and serve as critical fish and wildlife habitat. As president, he will immediately close the Mississippi River Gulf Outlet, which experts say funneled floodwater into New Orleans.

Restore the Great Lakes: Having lived near Lake Michigan for 20 years, Barack Obama has a deep appreciation for the Great Lakes – for their beauty as well as their centrality to the region's economy, recreation, transportation, and drinking water. He has worked tirelessly in the Illinois State Senate and U.S. Senate to protect the Great Lakes from sludge, mercury, and invasive species. As president, Barack Obama will push for the passage of the Great Lakes Collaboration Implementation Act, which will move us past playing defense against environmental problems and toward a comprehensive restoration of the Great Lakes. He is a cosponsor of the Great Lakes Environmental Restoration Act, which would provide grants for projects including wetland restoration, coastal wildlife and fisheries habitat improvement, water quality improvement and nonpoint source pollution reduction. Recently, when the Indiana Department of Environmental Management agreed to allow a BP refinery to release significantly more ammonia, treated solids and mercury into Lake Michigan, Barack Obama fought back, calling for congressional hearings into the permit and its relation to Clean Water Act provisions intended to prevent any decline in water quality.

Water in the West: Barack Obama and Joe Biden understand that the American West is facing a serious water crisis. In the long run, we do not have enough water to meet the West's fast-growing needs. Barack Obama and Joe Biden believe the federal government has an important role to play in helping local communities conserve water. They support federal policies to encourage voluntary water banks, wastewater treatment, and other market-based conservation measures. We also need to improve technology for water conservation and efficiency, and remove institutional barriers to increase cooperation and collaboration among federal, state, tribal, and private organizations. Nevada's "cash for grass" program, in which people are paid to remove grass and put in desert landscaping, is an excellent model of conservation, and Barack Obama and Joe Biden intend to help local communities develop similar projects that work for them.

HEALTHIER COMMUNITIES

As president, Barack Obama will continue his fight, begun as a community organizer, to protect our children from health hazards and developmental disabilities caused by environmental toxins, such as lead, mercury, particulate matter, and industrial land waste. Barack Obama and Joe Biden will fight to clean brownfields, restore abandoned industrial riverfront sites, and give communities the tools they need to eat healthy foods and expand livable, walkable neighborhoods.

Protect Children and Families from Lead Poisoning: Lead is a neurotoxin that is especially harmful to the developing nervous systems of fetuses and young children. There are currently 400,000 children suffering from lead poisoning in the U.S. In 2005, Barack Obama introduced the Lead-Free Toys Act, which would require the Consumer Product Safety Commission to ban children's products containing more than a trace amount of lead. Following news reports that millions of Chinese-made toys were being recalled because of lead paint, he has pressured toy manufacturers and Bush administration officials to do a better job of protecting American children.

In 2006, Barack Obama introduced the Lead Poisoning Reduction Act, which would help protect children from lead poisoning by requiring all non-home-based child care facilities, including Head Start programs and kindergartens, to be lead-safe within five years. The legislation would also establish a $42.6 million grant program to help local communities pay to make these facilities safe. The Environmental Protection Agency recently announced support for Obama's proposal to remove toxic lead from child care, pre-school, and kindergarten facilities.

Barack Obama has fought to get the Environmental Protection Agency to publish long-overdue rules for how contractors involved in the renovation and remodeling of homes should deal with lead paint hazards. When the rules are eventually finalized, they will prevent 28,000 lead-related illnesses each year, resulting in an annual net economic benefit of more than $4 billion.

Protect the Public from Nuclear Material: After a series of reports that Illinois nuclear power plants failed to disclose that radioactive substances had leaked into the groundwater, Barack Obama worked with Senator Dick Durbin (D-IL) to introduce legislation that would require nuclear companies to inform state and local officials if there is an accidental or unintentional leak of a radioactive substance. In 2005, Obama introduced legislation requiring the Nuclear Regulatory Commission to track unaccounted spent nuclear fuel rods used at power plants in the United States.

Control Superfund Sites and Data: Barack Obama demanded that the Environmental Protection Agency report on what it is doing to reduce and control human exposure to hazardous contaminants at more than 100 Superfund sites nationwide. As a state senator, he voted to create the Brownfields Rehabilitation and Redevelopment Program, which encourages private sector voluntary remediation of environmentally-distressed and underutilized sites. As president, Obama will restore the strength of the Superfund program by requiring polluters to pay for the cleanup of contaminated sites they created.

Strengthen Federal Environmental Justice Programs: Barack Obama and Joe Biden will make environmental justice policies a priority within the Environmental Protection Agency (EPA). As a U.S. Senator, Obama has worked to ensure that low-income communities are represented in the EPA's long-term planning. As president, he and Joe Biden will work to strengthen the EPA Office of Environmental Justice and expand the Environmental Justice Small Grants Program, which provides non-profit organizations across the nation with valuable resources to address local environmental problems. They will also work to ensure that environmental health issues in the wake of man-made or terrorist disasters are promptly addressed by federal, state and local officials. They will work to provide low-income communities the legal ability to challenge policies and processes that adversely affect the environmental health of low-income and minority communities.

Build Healthy Communities: How a community is designed – including the layout of its roads, buildings and parks – has a huge impact on the health of its residents. For instance, nearly one-third of Americans live in neighborhoods without sidewalks and less than half of our country's children have a playground within walking distance of their homes. This lack of a safe place to walk and play is a major contributor to the growing numbers of overweight children. Barack Obama introduced the Healthy Places Act to help local governments assess the health impact of new policies and projects, like highways or shopping centers. Once the health impact is determined, the bill gives grant funding and technical assistance to help address potential health problems.

Minorities in America are significantly more likely to be affected by toxins and pollutants. To focus federal attention on this environmental health problem, Barack Obama introduced the Healthy Communities Act, which would expand research on toxins and provide the resources to clean up blighted communities.

Encourage Organic and Sustainable Agriculture: Organic food is the fastest growing sector of the American food marketplace. Demand for sustainable, locally-grown, grass-finished and heritage foods is also growing quickly. These niche markets present new opportunities for beginning farmers because specialty operations often require more management and labor than capital. To support the continued growth of sustainable alternative agriculture, Barack Obama and Joe Biden will increase funding for the National Organic Certification Cost-Share Program to help farmers afford the costs of compliance with national organic certification standards. They will also reform the U.S. Department of Agriculture (USDA) Risk Management Agency's crop insurance rates so that they do not penalize organic farmers.

Support Local Family Farmers with Local Foods and Promote Regional Food System Policies: Farming is a vanishing lifestyle. Less than one million Americans claim farming as their primary occupation. Those farmers who sell directly to their customers cut out all of the middlemen and get full retail price for their food - which means farm families can afford to stay on the farm, doing the important work they love. Barack Obama and Joe Biden recognize that local and regional food systems are better for our environment and support family-

scale producers. They will emphasize the need for Americans to Buy Fresh and Buy Local, and they will implement USDA policies that promote local and regional food systems.

PRESERVING OUR LAND

Barack Obama and Joe Biden believe that we have a responsibility to our children to leave this Earth better than we found it. All Americans have an interest in the protection and proper maintenance of our irreplaceable national treasures. Conservation is also vitally important to providing clean drinking water, cleaning our air and reducing greenhouse gas pollution. Barack Obama and Joe Biden believe we need a new vision for conservation that both protects our existing publicly-owned lands while dramatically expanding investments in protecting and restoring forests, grasslands, and wetlands across America for generations to come.

Protect National Parks and Forests: For too long, America's National Parks and Forests have been threatened by lax protection. Barack Obama fought efforts to drill in the Arctic National Wildlife Refuge. Obama supports the Roadless Area Conservation Rule to keep over 58 million acres of national forests pristine. As president, he and Joe Biden will repair the damage done to our national parks by inadequate funding and emphasize the protection and restoration of our National Forests.

Barack Obama is also an original cosponsor of the Combat Illegal Logging Act, which would prohibit the importation of illegally harvested wood products. This would make foreign companies much less likely to engage in massive, illegal deforestation in other countries. Saving these endangered forests preserves a major source of carbon sequestration.

Conserve New Lands: Barack Obama is a strong supporter of increased funding for the Land and Water Conservation Fund, which supports land acquisition and maintenance of parks. As a state senator, he supported the creation of the Illinois Open Land Trust Act, which allowed the state to buy property from willing sellers for conservation and recreation purposes and make grants and loans to local governments for acquiring land for open spaces.

While Americans can take great pride in our National Parks and other public lands, there are many landscapes and ecosystems which do not have adequate protection. As president, Barack Obama will lead efforts to acquire and conserve new parks and public lands, focusing on ecosystems such as the Great Plains and Eastern forests which do not yet have the protection they deserve.

Partner with Landowners to Conserve Private Lands: Because most land is privately-owned, private landowners are the principle stewards of America's land and water. As a U.S. Senator, Barack Obama has supported conservation programs that serve as a resource to landowners and assist them with sustainable environmental planning and best land management practices. As president, he and Joe Biden will put an unprecedented level of emphasis on the conservation of private lands. They will advance legislation that works with landowners and follows in the tradition of the Wilderness Act, the Clean Water Act, and the Clean Air Act to focus federal attention and increased resources for this key environmental issue. They will also increase funding for the Conservation Security Program and the Conservation Reserve Program and will create additional incentives for private landowners to protect and restore wetlands, grasslands, forests, and other wildlife habitat.

Encourage Farmers at the Cutting Edge of Renewable Energy and Energy Efficiency: Farmers realize that they can help their bottom line and the environment by using more wind and solar power production systems and sharing energy with other users. They are using new irrigation practices to conserve energy and water. Barack Obama and Joe Biden will encourage the use of methane digesters that are being used to produce power from animal waste.

“No till” and other agricultural practices are reducing energy input and keeping the health of our soil sustainable. Barack Obama and Joe Biden will expand USDA projects that focus on energy efficiency and conservation.

Paid for by Obama for America

Printed in House

STORMWATER AUTHORITY

http://www.stormwaterauthority.org/library/view_article.aspx?id=1311

Detroit Cancels Costly Combined Sewer Overflow Tunnel

DETROIT, Michigan, June 1, 2009 (ENS) - The giant Upper Rouge Tunnel combined sewer overflow control project was canceled Friday by Detroit city officials worried about residents' ability to pay increased sewer fees to build the $1.2 billion project.

A report in the "Detroit Free Press" Saturday quoted George Ellenwood, a spokesman for the Detroit Water and Sewerage Department, as saying sewer fees would have been 16 percent higher as of July 1 if the long-planned tunnel had gone ahead.

In view of the Motor City's current 22 percent unemployment rate, "It exceeds what is considered reasonable," said Ellenwood,

Detroit, like many Midwestern cities, has a combined sewer system that carries both sanitary sewage and stormwater. During heavy rain and snow melt, the flow capacity of a sewer system is exceeded and an overflow of this mixture runs into the Rouge River.

The seven mile long Upper Rouge CSO Tunnel was designed to capture up to 201 million gallons of wet weather flows conveyed through existing sewer infrastructure located in western Detroit from 17 designated outfalls that historically discharge to the upper tributary of the Rouge River.

It would also have captured overflows from three outfalls in Dearborn Heights and eight outfalls in Redford Township.

The tunnel would have stored the combined sewage and stormwater until it could be treated at the Detroit Wastewater Treatment Plant and discharged.

Construction of the tunnel is a requirement of the Detroit Water and Sewerage Department's 2008 NPDES Permit, and is a condition of a consent decree in litigation brought by the U.S. Environmental Protection Agency. It was supposed to be completed in the 2014-2015 timeframe.

Ellenwood said the department will seek an alternative during the next six months.

Plans for the tunnel have been stalled for months for lack of financing.

In late February, the Detroit Water and Sewerage Department canceled plans to bid the North Tunnel section, advising prospective bidders not to submit any bids. No official explanation for the cancelation was offered.

Still, continued work was planned for the South Tunnel. A contract for this section of the project was awarded to Kenny Construction and Japan's Obayashi Corporation in September 2008.

Friday's decision canceled work on both North and South tunnel sections.

The tunnel was designed to be 30 feet in diameter. It would have run parallel to the Rouge River, mostly under park space, 160 feet below ground from Pembroke Avenue and Berg to Warren Avenue and West Outer Drive.

The tunnel was intended to cut the frequency of overflow events from about 50 a year to fewer than one a year, reducing the overflow from an average of 1.3 billion gallons to 250 million gallons annually.

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CITY OF CARSON

PLANNING COMMISSION STAFF REPORT

WORKSHOP:	November 24, 2009
SUBJECT:	Alameda Street Sound-wall and Noise Mitigation Workshop
APPLICANT:	City of Carson
REQUEST:	Workshop to discuss sound-wall design and noise mitigation alternatives for train and diesel truck noise along Alameda Street between Dominguez Street and the Freeway 405
PROPERTY INVOLVED:	Light-industrial zoned properties and residences east of Alameda Street between Dominguez Street and the 405 Freeway to the Harbor View Avenue alignment

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COMMISSION ACTION

_____ Concurred with staff

_____ Did not concur with staff

_____ Other

COMMISSIONERS' VOTE

AYE	NO		AYE	NO	
		Chairman Faletogo			**Graber**
		Vice-Chair Saenz			**Park**
		Brimmer			**Schaefer**
		Brown			**Verrett**
		Gordon			

Item No. 12-A

I. Introduction

The purpose of this workshop is to discuss the staff identified preferred alternative design and noise attenuation alternative to mitigate diesel truck and train noise along Alameda Street (Alameda Corridor) between Dominguez Street and the San Diego 405 Freeway to the Harbor View Avenue alignment. This alternative has received varying levels of support and opposition from the community. In order to proceed, there should be a determination of the preferred alternative so that the project can proceed with CEQA review and identification of funding sources.

II. Background

On April 8, 2008, staff held a Planning Commission workshop to discuss the sound-wall design and noise attenuation alternatives for residents along the Alameda Corridor. The Planning Commission, after hearing staff's presentation and the public testimony, directed staff to: explore all funding options; determine cost of implementing a sound-wall and noise attenuation measures to mitigate diesel truck and train noise; consider traffic mitigation for Dominguez Street; evaluate the feasibility of placing a sound-wall west of Alameda Street; and to provide information as to the status of the $1 million that the city received from the Alameda Corridor Transportation Authority (ACTA) for noise mitigation to those residential properties east of Alameda Street impacted by diesel trucks and train noise.

On September 9, 2009, city engineering and planning staff met with affected residents and business owners that reside east of Alameda Street. Staff presented the attached preferred sound-wall design and noise attenuation alternative. Staff described the alternative, heard public input and addressed questions regarding the project's timing and feasibility. Concerns were raised including but not limited to the closure of the residential streets, potential traffic impacts on Harbor View Street and the acquisition of residential properties. Staff informed the public that there would be a follow-up workshop with the Planning Commission where they could provide input. Staff also met with the City Traffic Engineer and the Principal Engineer to discuss noise mitigation alternatives provided by the public.

The total cost for the staff identified preferred alternative is approximately $20 million. The preferred sound-wall design and noise attenuation alternative consists of the following:

1. A 14-foot-high sound-wall using acoustical absorption material on the west side of Alameda Street

2. The closing of the street openings east of Alameda Street between East Tyler and East Washington Streets with a 14-foot high sound-wall and an off-set cul-de-sac

3. A 14-foot-high sound-wall between existing industrial buildings on the west side of the alley

4. Installation of 5 fire hydrants east of Alameda Street on east/west streets

5. Insulating the closest three houses from Alameda Street with new energy efficient windows, doors, wall insulation and new heating/air-conditioning systems

The various components associated with the above preferred alternative can be viewed individual or in various groupings. Implementation will ultimately be determined based upon evaluating a final project design, completing the CEQA process and obtaining necessary funding for the partial, phased or complete build-out of the sound-wall design and noise attenuation project.

Regarding, the $1 million that the city previously received in 1999 from ACTA for noise mitigation along Alameda Street, planning staff confirmed that the complete funds are still in a city reserve account and available for use. Furthermore, the city retained Mr. John Young with C J Strategies LLC., based in Washington D.C. to explore funding opportunities for this project. Planning staff previously met with Mr. John Young, gave him a tour of the affected area and presented the -wall design noise attenuation alternative with projected costs.

III. Recommendation

That the Planning Commission:

- **REVIEW** and **PROVIDE** comments for implementing the subject "Preferred Alternative" for a sound-wall and noise attenuation project

IV. Exhibits

1. Planning Commission staff report for April 8, 2008 on the Alameda Street Sound-wall Noise Mitigation Workshop

2. Alameda Street cross-section

3. Preferred Alternative map

4. Preliminary Preferred Alternative Cost Estimate

5. Noise Consultant's Study

Prepared by: _____
Zak Gonzalez II, Associate Planner

Reviewed & Approved by: _____
Sheri Repp Loadsman, Planning Officer

ZG: srAlamedaPCWorkshop

CITY OF CARSON

PLANNING COMMISSION STAFF REPORT

Workshop:	April 8, 2008
SUBJECT:	Alameda Street Sound-wall and Noise Mitigation Workshop
APPLICANT:	City of Carson
REQUEST:	Workshop to discuss sound-wall design and noise mitigation alternatives for train and diesel truck noise along Alameda Street between Dominguez Street and Freeway 405
PROPERTY INVOLVED:	Light-industrial zoned properties and residences east of Alameda Street between Dominguez Street and 405 Freeway to the Harbor View Avenue alignment

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COMMISSION ACTION

_____ Concurred with staff

_____ Did not concur with staff

_____ Other

COMMISSIONERS' VOTE

AYE	NO		AYE	NO	
		Chairman Faletogo			**Graber**
		Vice-Chair Hudson			**Saenz**
		Cannon			**Verrett**

Exhibit 1

4

I. Introduction

The purpose of this workshop is to discuss sound-wall design and noise attenuation alternatives to mitigate diesel truck and train noise along Alameda Street (Alameda Corridor) between Dominguez Street and the San Diego 405 Freeway to the Harbor View Avenue alignment.

II. Background

The Alameda Corridor is the primary rail access and a significant truck route to and from the ports of Los Angeles and Long Beach. The Alameda Corridor is located in southern Los Angeles County, California, running from the ports of Long Beach and Los Angeles 20 miles north to downtown Los Angeles, primarily along and adjacent to Alameda Street. The project extends through or borders the cities of Vernon, Huntington Park, South Gate, Lynwood, Compton, Carson, Los Angeles, and the County of Los Angeles. In 1989, the Alameda Corridor Transportation Authority was created to have design and construction responsibility for the Alameda Corridor. The Alameda Corridor Transportation Authority (ACTA) and cities along the corridor have made significant improvements along the length of the route to reduce delays, increase safety and lessen the impact of traffic on the adjoining neighborhoods.

The 1993 Alameda Corridor EIR/EIS identified that train noise levels in the subject location met Cal-Trans "Noise Abatement Criteria" of 67 dBA decibels exterior noise levels near residences. This EIR/EIS further identified a sound-wall location in the subject area to mitigate identified excessive noise levels. The existing noise impact from the Alameda Corridor on the adjacent residents within the Dominguez neighborhood area is significant. Trains couple and idle at the Dominguez Yard and along the nearby rail lines creating loud noises. Noise levels are expected to increase as a result of increased volume of truck traffic associated with the completion of the proposed SR-47 Expressway and Schuyler Heim Bridge road and bridge improvements and other rail and transportation related projects near the ports.

Over the past 20 years, the residential community has expressed a desire for a sound wall to lessen the noise generated by the train and anticipated increased truck traffic. Both ACTA and the City of Carson acknowledged the need for a sound wall. Numerous discussions and community meetings have discussed alternatives but no final plans were developed due to difficulties in identifying an appropriate location, design and funding.

On May 2, 2006, the Carson City Council and Redevelopment Agency directed staff to retain a consultant through a Request for Proposal process to conduct the studies required to implement a sound barrier. Such studies would include alternative feasibilities analysis and preliminary designs to study and mitigate loud noise.

On June 5, 2007, staff retained Tetra Tech, an engineering/planning firm to prepare the Alameda "Sound-wall Feasibility Study". Tetra Tech completed the feasibility study in March of 2008, and identified four alternatives. The four alternatives are summarized as follows:

1. Alternative 1 is a 14 foot high masonry wall constructed at grade on the west side (business side) of the alley in properties currently occupied with industrial and commercial structures. Acquisition of private property is required between Dominguez and Carson Streets. The wall would be continuous with no breaks and would close access to side streets between Dominguez and Carson Streets.
2. Alternative 2 is a 6 foot high landscaped berm with an 8 foot high masonry wall erected atop of the berm. Acquisition of properties and street closure would also apply to this alternative.
3. Alternative 3 utilizes existing 2 story buildings as sound barriers and connects new sound-walls between the existing buildings. This alternative would require acquisition of land requiring sound-walls and does not propose side street closure.
4. Alternative 4a/b proposes a continuous 14 foot sound-wall on the east side of the alley. It would require widening the existing 15 foot alley to 26 feet and acquisition of residences east of the alley. Side street closure would also be required.

On April 3, 2008, staff in coordination with the Dominguez Area Property Owner's Association held a community meeting to discuss sound-wall design alternatives. The staff shared information regarding the potential need to acquire residential or industrial properties in order to obtain an appropriate location to place a sound wall. The community was also advised that all of the options would be subject to identifying and receiving adequate funding to complete the project.

The area south of Carson Street east of Alameda to the 405 Freeway while not addressed through the Tetra Tech study was evaluated under separate agreement. The noise study for this area found noise readings exceeding Cal-Trans "Noise Abatement Criteria". However, a sound-wall may not be the best approach to mitigate excessive noise levels in this area since constructing the wall may require closing 218th Place, the main point of vehicular access to this residential area. Staff will hold a separate community meeting with residents in this area and discuss alternative noise mitigation such as residential sound insulation programs.

III. Analysis

Staff has completed its evaluation of the sound-wall feasibility study and has also evaluated other noise mitigation alternatives. Other alternatives evaluated include: various street closure designs (cul de sac or hammer head turn-arounds); economic development opportunities for commercial/industrial properties by adding parking via alley widening; and a sound insulation program (similar to airport mitigation program used in the City of Inglewood) that retrofits residences with windows, walls, doors, and ceiling through increased insulation treatments. Additionally the residences air/heating systems may also require retrofit and or replacement to gain full benefit of structure insulation upgrade.

The 1993 Alameda Corridor EIR/EIS identified a sound-wall location in the Dominguez area to mitigate identified excessive noise levels. With the addition of new projects that increase rail and truck activities along the Alameda Corridor, the noise levels are expected to increase. The noise studies of the Tetra Tech sound-

wall feasibility study re-affirm previous noise studies in this area. Therefore, staff is presenting to the Planning Commission, Tetra Tech's Sound-wall Feasibility Study, and other potential noise mitigation alternatives to obtain comments that may assist in providing the best sound-wall/noise mitigation alternative to improve the subject area resident's health and quality of life.

Information obtained from this meeting will be utilized to refine the noise mitigation alternatives. There is a need to identify a preferred alternative so that projected costs can be determined. Additionally, if the preferred alternative requires acquisition of property, the City Council and Redevelopment Agency would need to determine a willingness to assist with the purchase and eminent domain proceedings. Staff is currently working with ACTA to identify potential funding sources and will continue to do outreach with ACTA, Cal-Trans and other key stakeholders.

IV. Recommendation

That the Planning Commission:

- **REVIEW** and **PROVIDE** comments and direction to determine a preferred noise mitigation alternative for the Dominguez area.

V. Exhibits

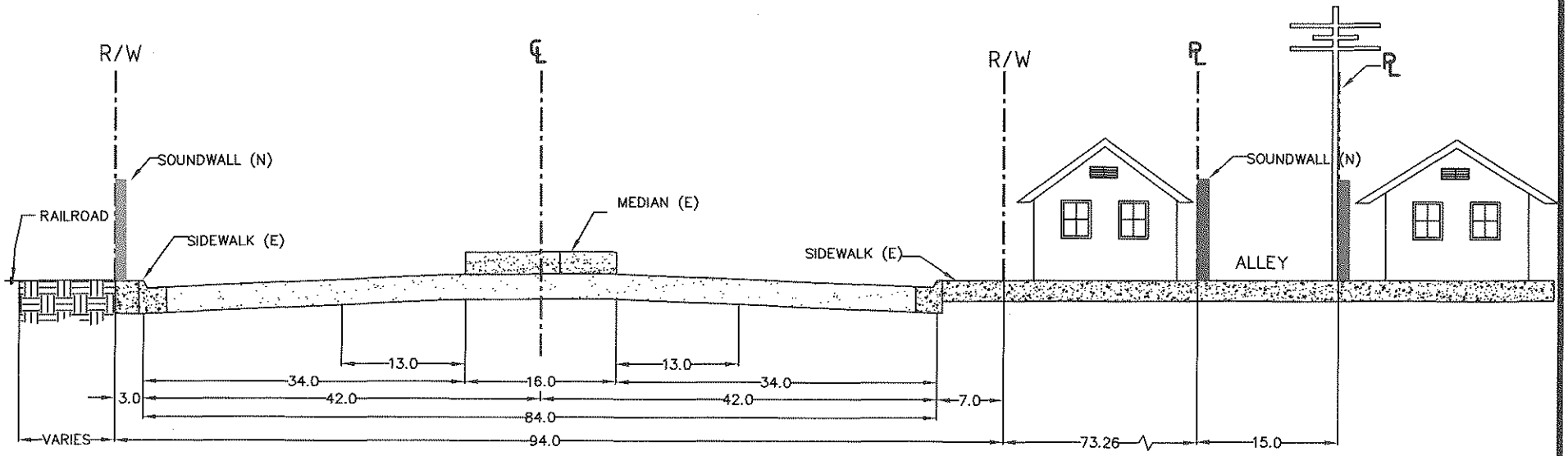
1. Tetra Tech's Sound-wall Feasibility Study

Prepared by: _____
Zak Gonzalez II, Associate Planner

Reviewed & Approved by: _____
Sheri Repp, Planning Manager

ZG: srAlamedaPCWorkshop

Exhibit 2



LEGEND

- PROPOSED WALL–EAST SIDE OF THE ALLEY ON STREET
- PROPOSED WALL–WEST SIDE OF THE ALLEY
- PROPOSED WALL–WEST SIDE OF ALAMEDA ST.

N

ALAMEDA STREET CROSS SECTION

SCALE: 1:16

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PREFERRED SOUND-WALL NOISE MITIGATION ALTERNATIVE

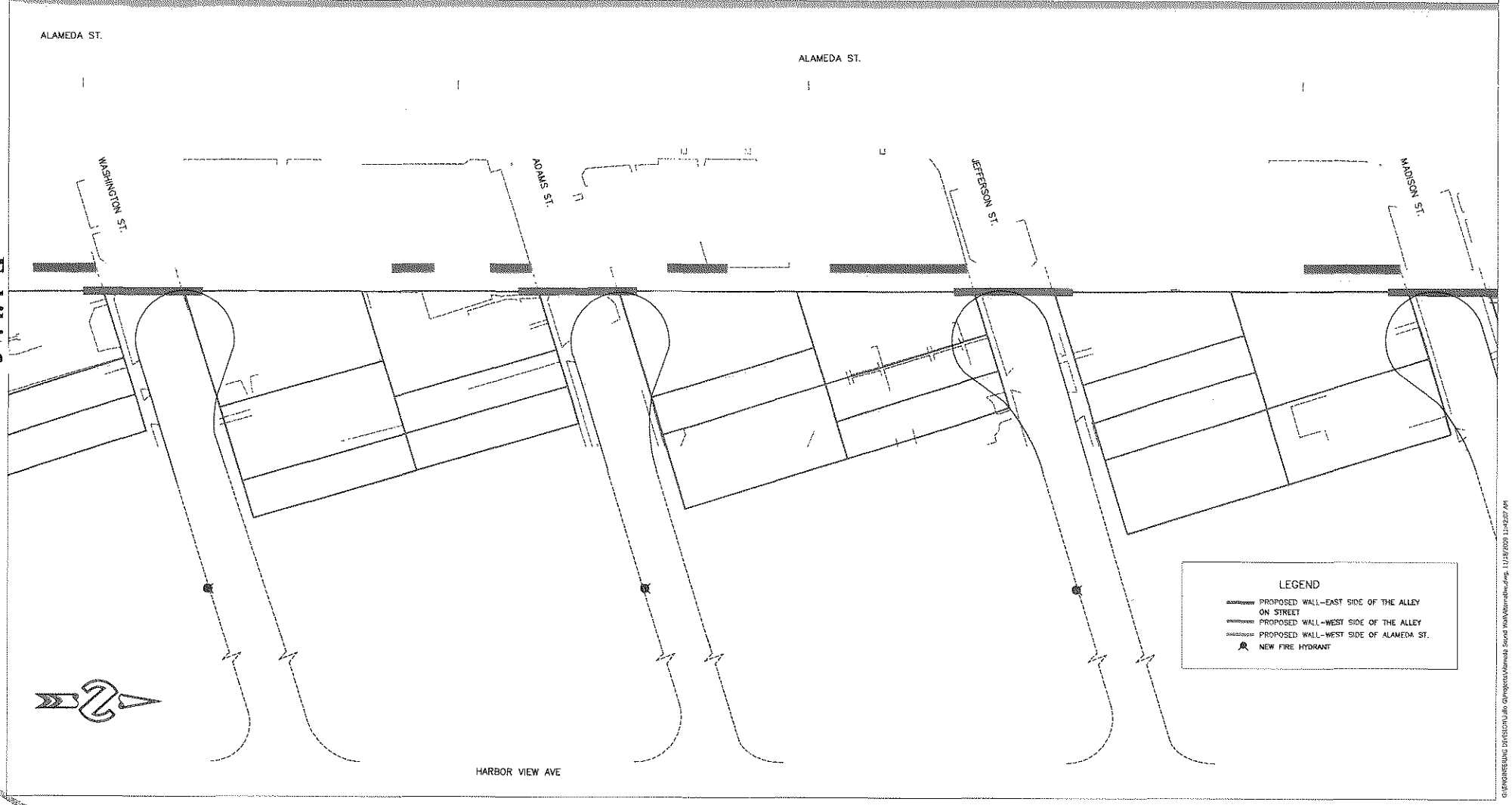

Exhibit 3

9

SOUNDWALL ON ALAMEDA STREET
PREFERRED ALTERNATIVE

SUMMARY:

1. **Cost of soundwall between exist. bldgs. - - - - - - - - - - - $1,100,000.00**
2. **Insulating first 3 rows of houses - - - - - - - - - - - - - - - - $ 2,520,000.00**
3. **Property acquisition (for cul-de-sac construction) - - - $11,000,000.00**
4. **Cul-de-sac and soundwall construction - - - - - - - - - - - $ 870,000.00**
5. **Installation of fire hydrants - - - - - - - - - - - - - - - - - - - $ 100,000.00**

SUB - TOTAL - - - - - - - - - - - - - - - - $ 15,590,000.00

6. **Cost of soundwall on the west side of Alameda St. (Using noise absorbent materials)- - - - - - - - - - - - - - - - $ 2,500,000.00**

GRAND TOTAL - - - - - - - - - - - - - - - $ 18,090,000.00

1.) Utilize existing 2 story bldgs. as sound barrier and construct new soundwall between existing buildings:

- Cost of soundwall between exist. bldgs. = **$ 1,100,000.00**

2.) Insulating existing first 3 rows of houses from Dominguez St. to 220th St.

- Insulating 1st 3 rows of houses = 63 houses @ $ 40,000.00/house
  = **$ 2,520,000.00**

3.) Property Acquisition for closing the side street by construction of soundwall and offset cul-de-sac.

- Property Acquisition = 22 parcels @ $500,000.00/parcel
  = **$11,000,000.00**

4.) Construction of soundwall & offset cul-de-sac.

- 8,400 S.F. of soundwall @ $50.00/S.F. = $ 420,000.00
- 9 cul de sac @ $50,000.00/cul de sac = $ 450,000.00

$ 870,000.00

5.) Installation of Fire Hydrant per FD requirements:

- 5 FH @ $20,000.00/FH = **$100,000.00**

6.) Construction of soundwall on the west side of Alameda St. = **$2,500,000.00**

Exhibit No. 4

ATSConsulting
acoustics, transportation + strategy

MEMORANDUM

To: Sherri Repp
Zak Gonzalez II
City of Carson
Economic Development/Planning Division

From: Hugh Saurenman
ATS Consulting

Date: July 22, 2008

Subject: Acoustical Benefits of Sound Wall on West Side of Alameda Street

INTRODUCTION

At the request of the City of Carson Planning Division, ATS Consulting has reviewed the potential locations and benefits of placing a sound wall along the west side of Alameda Street between Dominguez Street on the north and I-405 on the south. The general area and location for a sound wall on the west side of Alameda Street is shown in Figure 1.

The goal of the sound wall would be to reduce noise from freight rail activities in the residential areas east of Alameda Street. A wall west of Alameda Street would not reduce noise from traffic on Alameda Street and could result in a small increase in traffic noise because of reflections off the wall. The City of Carson has conceptual plans for a sound wall east of Alameda that would reduce noise from both traffic and rail operations. Options for the wall east of Alameda include a solid wall east of the commercial properties fronting on Alameda and redevelopment of the commercial area so that the buildings act a sound wall. The expectation is that a wall on the west side of Alameda would be an interim measure until the wall or redevelopment on the east side of Alameda has been completed.

The topics covered in this memorandum are:

1. Where the wall should be located to be effective.
2. The attenuation of different rail noise sources that could be achieved with different heights walls.
3. How much reflections off the wall would increase levels of traffic noise in the residential area east of Alameda.

Attached as an appendix is some information on suppliers of sound wall products. The list does not include all suppliers of suitable sound wall systems but is representative of the products that are available and would be suitable for the proposed sound wall along the west side of Alameda.

RAIL NOISE SOURCES

Noise sources associated with the Union Pacific rail yard and the Alameda Corridor mainline tracks include locomotives, intermittent train horns, wheel/rail noise from steel wheels rolling on steel rails, impact noise from assembling trains and from trains starting up and stopping, and activities within the UP yard. Although there are some curves in the yard for access to the storage tracks, we have not observed wheel squeal to be a major issue.

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Our understanding is that the community is most annoyed by the impact noise from coupling cars together, locomotive engine noise, and train horn noise. A key part of the design of any sound wall is to make sure that the wall blocks the direct path between the noise source and the receiver's ears. The equivalent heights of the principal noise sources are:

- Locomotive engines and fans: 8 ft.
- Locomotive horns: 12 to 15 ft.
- Steel wheels rolling on steel tracks: 2 ft. Our observation is that noise levels are relatively low when trains are moving on the Alameda Corridor tracks or on the yard tracks except when the locomotives are passing. The wheel/rail noise is source A in Figure 2.
- Impact noise: 4 ft to 14 ft.

The wide range in the source height indicated for impact noise is because the source height depends on which part of the rail car and containers the noise is radiated from. Figure 2 shows a typical container flatcar with two containers. The letters indicate locations on the vehicle and containers that impact noise could be radiated from. First is at the couplers (B). This is where the impact occurs but is a relatively inefficient noise radiator because of the small surface area. It is about 3 ft above the top of rail. The second is the car skirt (C). The top of the skirt is about 4 ft above the top of rail. The final source is the container sides. In essence, the containers could act as large sounding boards amplifying the radiated noise. For a double stack container car or a boxcar, the equivalent noise source height would be 10 to 12 ft above top of rail; for a single container the equivalent height would be 7 to 8 ft high. It is important to note that the heights are relative to top of rail. As shown in Figure 2, south of Carson Street the top of rail is approximately 4 ft higher than the sidewalk.

For this analysis we have used the following noise sources and source heights relative to top of rail:

Source	Height	
Locomotive Horn	12 ft	
Locomotive Noise	8 ft	
Coupler Impacts 1	3 ft	(at coupler)
Coupler Impacts 2	6 ft	(flat car skirt and bottom container)
Coupler Impacts 3	11 ft	(top container)

POTENTIAL LOCATIONS FOR BARRIERS

Area 1 (South of Carson Street)

There are limited options for locating sound walls on the west side of Alameda. For Area 1 south of Carson, there is an approximately 60-ft wide buffer of open land between the tracks and Alameda. As shown in Figure 3 and Figure 4, a sound wall could be placed either along the tracks or along Alameda. The preferred location for the wall is location 1 along the Union Pacific tracks with sufficient room between the tracks and the wall for vehicle access. Sound wall location 2 along the west side of the Alameda sidewalk is an alternative location for the wall south of Carson Street.

The advantage of location 1 is that the wall would be close to the noise sources, which would make it more effective at reducing train noise. The rule of thumb is that sound walls are most effective when they are placed close to the receiver or close to the noise source. The obvious disadvantage is that location 1

would require cooperation and approval of the railroad and could leave a "no-man's land" between the wall and Alameda Street.

Sound wall location 2 is along the sidewalk of Alameda. This is a less favorable location for the wall because the footing for the wall would be located approximately 4 ft below the top of rail and because there would be a greater distance between the wall and the noise source, which would make the wall less effective at reducing noise.

As shown in Figure 4, for both wall locations the wall would need to extend from just north of the I-405 off ramp to a point approximately 350 ft south of Carson Street.

Area 2

Because of the short distance between the tracks and Alameda north of Carson Street, the only feasible location for the sound wall is at the railroad property line. As seen in Figure 5, the track ballast extends to the sidewalk and it is only about 10 ft from the sidewalk to the side of the rail cars. The wall would need to extend from Carson Street to just south of Dominguez Street (see Figure 6). The top of rail north of Carson Street is approximately 1 ft higher than the sidewalk.

BARRIER EFFECTIVENESS

We have used standard formulas for sound wall attenuation to estimate the noise attenuation that would be provided by various height walls. The results for wall heights of 8 ft, 12 ft and 14 ft are summarized in Table 1. The heights are measured from the top of rail, which means that for location 2 south of Carson Street the wall heights relative to the existing grade are 12 ft, 16 ft, and 18 ft.

A common rule of thumb is that a noise mitigation measure should provide a minimum of 5 decibels of attenuation. This is sufficient for most people to notice that noise levels are lower. A reduction of 10 decibels is commonly perceived as making the noise source half as loud and is considered a substantial noise reduction. The attenuations in Table 1 that are 5 decibels or greater are in **bold**, and those 10 decibels or greater are in **bold and blue**.

An 8-ft wall is the minimum height that would have any noticeable effect on the impact noise. It would have no effect on the horn or locomotive engine noise. The 12-ft wall would provide substantial reduction of most potential sources of the impact noise and would have a marginal effect on locomotive noise. The 14-ft wall is the minimum height required to be effective at reducing horn noise. It would also be very effective at reducing noise from all the other sources. Whether a 14-ft wall would be practical is questionable, particularly at location 2 south of Carson Street where the grade is approximately 4 ft below the top of rail.

MATERIALS FOR BARRIERS

Effective sound walls have been constructed from a variety of materials. The primary requirements for a wall to be acoustically effective are that the wall material have a minimum surface density of 4 lb/ft^2 and that it be an impervious material. Most highway sound walls are constructed of concrete or masonry block. However, 1" thick plywood meets the density requirement and would be equally effective as a concrete sound wall at reducing noise levels. Plywood is often used for temporary barriers at construction sites, although it has obvious esthetic and maintenance problems for permanent installations.

Another option is to use composite sound walls that are proprietary products. There are a number of potential suppliers of suitable products. The material cost for the commercial products tends to be higher but the construction costs can be much lower. For barriers that will not be in place for an extended

period, mass-loaded vinyl curtain barriers are a viable option. These are often used on construction sites where they will be in place for several years. The curtains are held in place by a metal framework; often the framework is supported by standard "k-rail" guardrail. The advantages of the curtain walls are that they are relatively inexpensive, that they are straightforward to install and take down, and, after the project is complete, the materials are usually recycled by the supplier.

REFLECTED NOISE

The traffic noise reflected off a sound wall west of Alameda would tend to increase traffic noise in the residential area east of Alameda Street. Except for the residences closest to Alameda, the effect would be marginal and may not be noticed by residents. Even at the properties adjacent to the alley east of Alameda, the noise level increase caused by reflections would be less than 1 to 1.5 decibels. A 1-decibel change is normally considered an insignificant and unnoticeable noise level increase. However, people often say that they believe that the noise levels increased after a sound wall was installed on the opposite side of a noise source. Possible reasons for this include:

- annoyance that a sound wall was installed to protect people on the opposite side of the roadway and not for them,
- reflections off the wall causing a small change in the character of the traffic noise that is noticeable to those who have lived with the noise for a long period of time, and
- people who have lived with the traffic noise for a long time may be sensitized to the sound levels and be able to notice a 1 to 2 decibel change in noise levels.

The amount of acoustic energy reflected by a sound wall can be substantially reduced by acoustical absorption material placed on the traffic side of the wall. The acoustical absorption material can be as simple as fiberglass bats or semi-rigid fiberglass panels. In addition, there are a number of sound wall products that incorporate acoustical absorption on one or both sides. If the acoustical curtains are a feasible option, there are models that incorporate absorption material on one side.

Table 1: Sound Wall Effectiveness

Noise Source	Barrier Attenuation for Different Height Walls*		
	8 ft	**12 ft**	**14 ft**
South of Carson, Location 1(30 ft from tracks)			
Horn	0	1	**6**
Loco	0	**9**	**13**
Coupler	**10**	**15**	**15**
Skirt/Container	4	**12**	**15**
Top Container 2	0	3	**8**
South of Carson, Location 2 (next to Alameda sidewalk)			
Horn	0	2	**6**
Loco	1	**8**	**11**
Coupler	7	**12**	**14**
Skirt/Container	3	**10**	**12**
Top Container 2	0	4	**8**
North of Carson			
Horn	0	0	8
Loco	0	**13**	**15**
Coupler	**15**	**15**	**15**
Skirt/Container	7	**15**	**15**
Top Container 2	0	4	**11**

Note:
* The attenuations that are 5 decibels or greater are in **bold**, and those 10 decibels or greater are in **bold and blue**. An attenuation of 5 decibels is sufficient for most people to notice and an attenuation of 10 decibels or greater is usually considered a substantial noise reduction.

Figure 1: Aerial Photograph of Area

Figure 2: Noise Source Locations for Container Flatcar

Noise Sources:
A: Wheel/rail noise (steel wheels rolling on steel rails)
B: Couple impact noise (when coupling cars and when slack is taken up as trains start up
C: Impact noise radiated off of car skirt
D: Impact noise radiated off of containers

Figure 3: Open Area between Sidewalk and Tracks, Alameda, Area 1 (South of Carson)

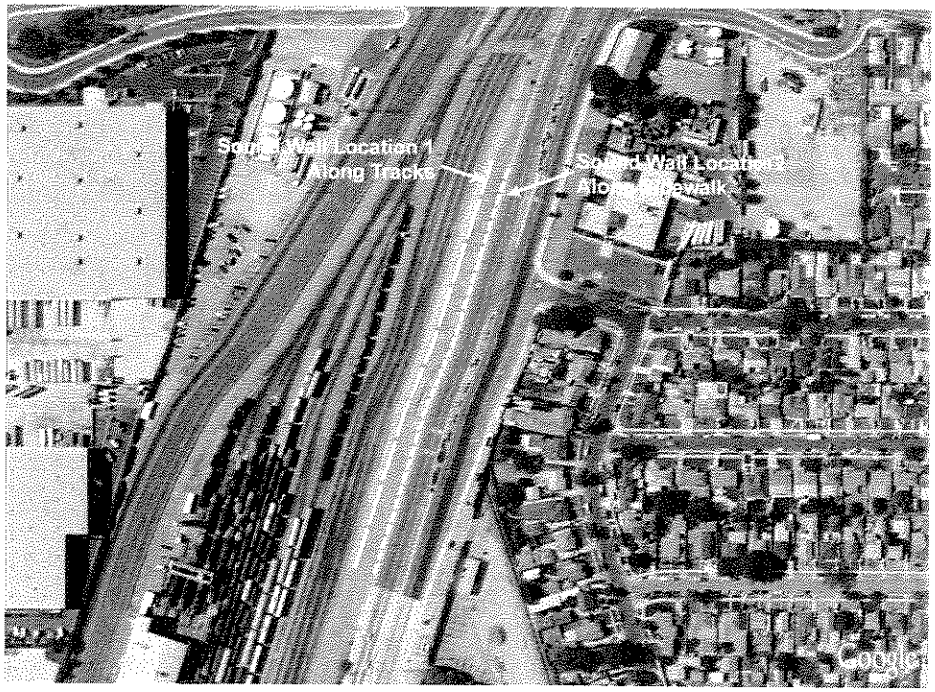

Figure 4: Locations for Barrier on West Side of Alameda, Area 1 (South of Carson)

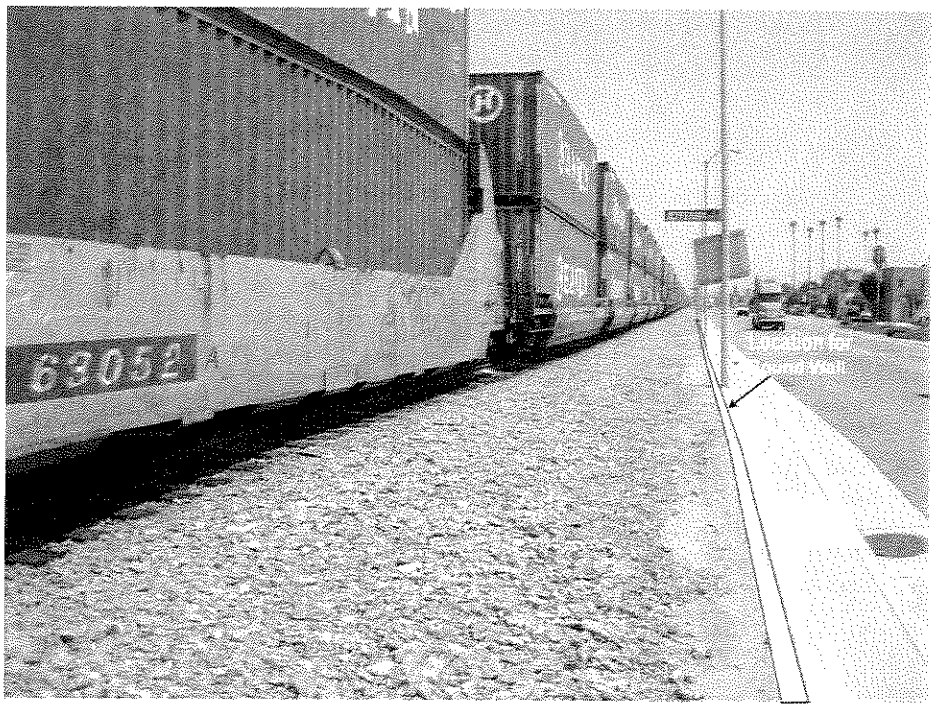

Figure 5: West Sidewalk of Alameda, Area 2, North of Carson

Figure 6: Location for Barrier on West Side of Alameda, Area 2 (North of Carson)

APPENDIX A. SOUND WALL SYSTEMS

The most common materials used for sound walls on roadways are concrete, either cast-in-place or precast panels, and masonry block. The primary requirement for a sound wall material is that the sound transmitted through the wall material be at least 10 decibels less than the sound transmitted over the top or around the sound wall. This means that a sound wall designed to reduce noise levels at the receiver by 15 decibels, which represents a very effective sound wall, should reduce sound transmitted through the wall by at least 25 decibels. Sound transmission of materials is generally characterized using the STC rating. STC, which stands for Sound Transmission Class, is approximately equal to the A-weighted reduction that would be achieved by the material. That is, a material with an STC of 25 will have a transmission loss of approximately 25. There are a wide variety of materials and commercially available sound wall systems that have an STC rating of 25 or greater.

Discussed below are several of the commercially available sound wall systems that could be used for the proposed sound wall along Alameda. Table 2 is a summary of the seven different systems. This list is not exhaustive. Rather these systems were selected as representative of the systems that are available. There are a number of other commercially available products designed specifically for sound wall systems that would be equally effective.

Carsonite®

Carsonite® is a composite system using fiberglass-reinforced composite for the shell and shredded tires for the filler. A 12-foot-high sound wall can use up to 250,000 lbs. of recycled tire rubber per mile of installation. This system was used for that sound wall along the Union Pacific tracks in Pomona, CA that is shown in Figure 7. The basic system is load bearing structural composite tongue and groove building planks that are placed between beams. The shell does not support combustion and the system can contain a fire retardant when requested. The shell wall can be painted.

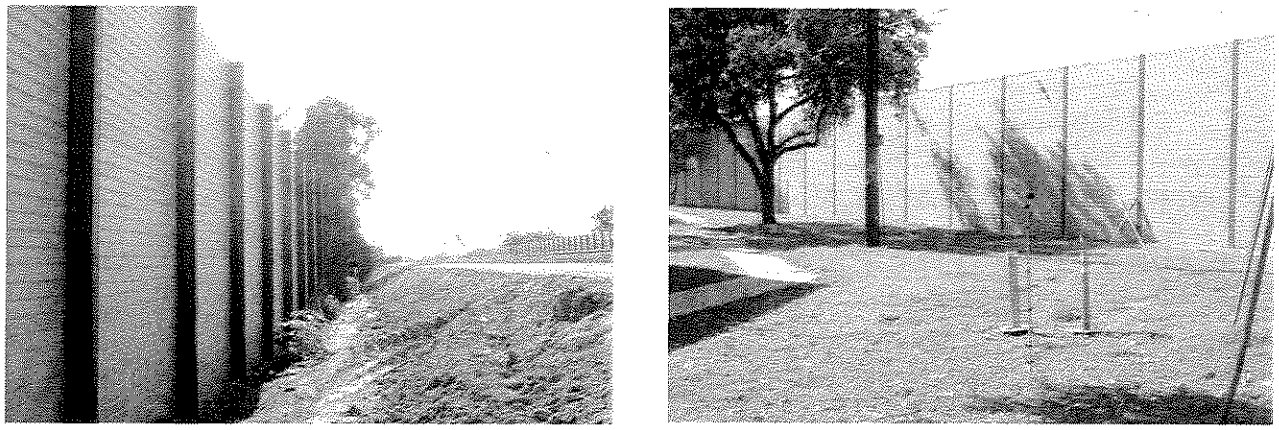

Figure 7. Carsonite Sound Wall at Lanterman Development, Pomona, CA

(Photograph on left is track side of wall and photograph on right is receiver side)

Plywall®

Plywall® by Hoover Treated Wood Products, Inc. is a pre-engineered treated wood noise barrier system. Hoover claims that the cost is 45% less than concrete walls of that have the same noise ratings. It has been used in a wide-variety of outdoor sound wall applications for residential neighborhoods near highways transit systems. According to the Hoover web site:

"PLYWALL® is adaptable to various heights, soils, climates, and terrains. Because of the warm natural appearance of wood and our specific design, our barrier system is aesthetically pleasing and well received by the public. Compared to other barriers, like concrete and steel, PLYWALL® has economical advantages, including material, repair, and installation costs."

Photographs of Plywall installations are shown in Figure 8.

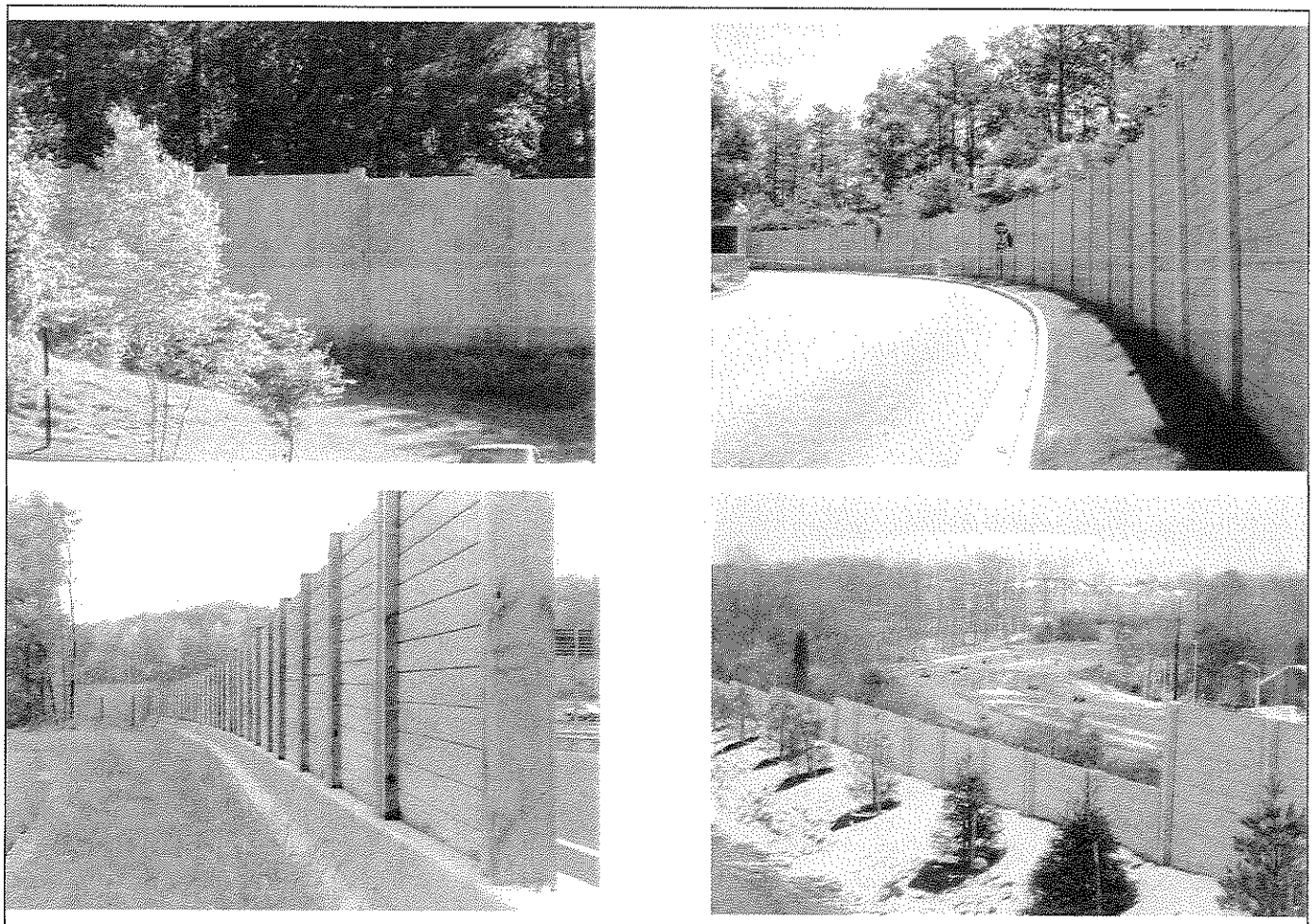

Figure 8. Examples of Plywall® Installations

Acoustax®

Acoustax sound walls are designed to be acoustically absorbent. That is, sound is not reflected off the barrier face, rather it is absorbed. Using absorptive barriers will generally improve the noise reduction, particularly when there are parallel barriers that the sound can reflect back and forth between the walls. The description on the Acoustax web site is:

"Acoustax is a stackable, lightweight noise barrier designed to remedy a broad range of community and industrial noise problems. Certified tests prove Acoustax absorbs a broad frequency spectrum and prevents noise transmission through the barrier, making it ideal for use as noise walls – absorbing twice as much noise as painted concrete block."

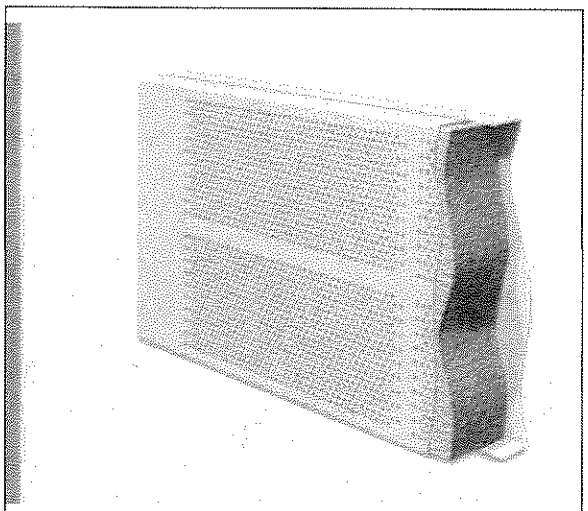

Figure 9. Acoustax® Sound Wall Panel

As seen in Figure 9, the basic design is perforated metal covering an acoustically absorbent material. The covering can be either perforated aluminum (3 lb/ft^2) or galvanized steel (7.5 lb/ft^2) with panels mounted horizontally or vertically. The lighter weight of Acoustax makes it easier and less expensive to install than concrete panels.

Sound Fighter®

This is a second example of an absorptive sound wall, in this case a composite made of polyethylene channels that are filled with mineral wool. The channels are installed in beams that are made of Aluminum or fiber-reinforced plastics (FRP). This is a very-lightweight system and is claimed to be graffiti-proof. According to the supplier: "The Sound Fighter® LSE Noise Barrier Wall System is the perfect solution to virtually any highway or industrial noise application. The noise absorptive panels are easy to install and maintenance free. … Sound Fighter has been manufacturing and shipping the LSE Noise Barrier Wall System throughout the world for over 30 years." An interesting feature of this system is that it is easy to both assemble and disassemble.

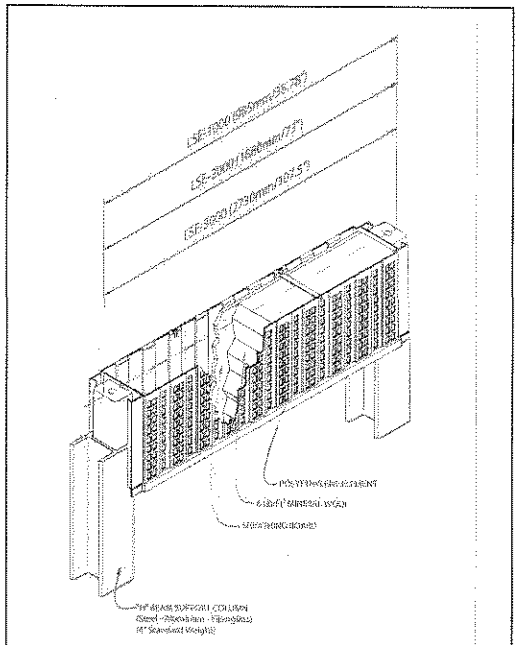

Figure 10. Sound Fighter Systems

Quietline®

QuietLine is a sound wall system similar to the SoundFigher and Acoustax absorptive barriers discussed above.

Noise Control Corporation

Noise control corporation provides a variety of sound wall systems ranging from blankets held in place with a metal framework to solid panels. The Noise Control Corp. blankets and similar products by other suppliers are often used for construction sites and are usually mass loaded vinyl. The curtain material is returned to the supplier once the construction project is complete. The installed cost of temporary barriers of this type is currently between $350 and $500 per foot. The installed price is sometimes lower when a third party contractor does the installation rather than the supplier.

The figure to the right shows a temporary barrier being installed at a construction site.

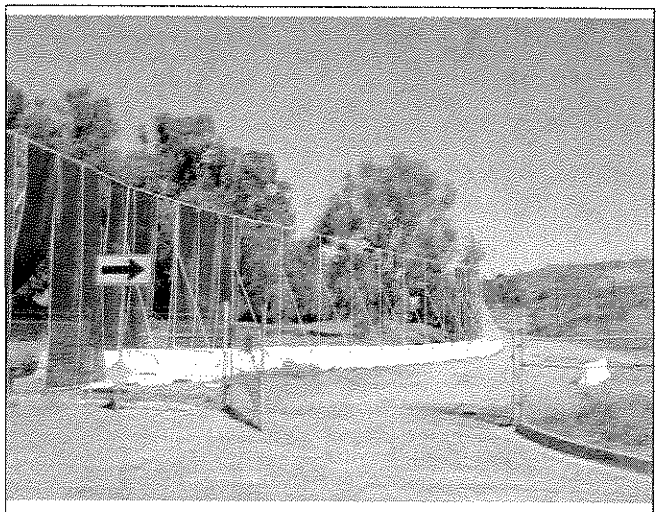

Figure 11. Temporary sound wall under construction along West Los Angeles College haul road (loaded-vinyl curtain)

Table 2. Examples of Alternative Barrier Systems

Product	Manufacturer	STC[1]	Material	Cost per square ft[2]	Example Projects
Carsonite®	Carsonite Composites www.carsonite.com 800-648-7916	36	Composite channels filled with rubber from recycled tires	Negotiable	City of Long Beach has recently used this for 33,000 feet of sound wall
Plywall®	Hoover Treated Wood Products, Inc. www.plywall.com 800-531-5558 Ext: 189	31/36	Pre-fabricated wood	Negotiable	Stocktown, GA Grovetown, GA
Acoustax®	Acoustax Noise Barriers www.acoustax.com 570-430-1058	34 (Al) 39 (Steel)	Perforated metal covering absorptive material	$20 - $30	
Sound Fighter Systems®	Sound Fighter Systems, LLC www.soundfighter.com 318-861-6640	33	Polyethylene elements filled with mineral wool and using Al/FRP beams	$30 - $35	Used for several highway projects by state agencies including Caltrans
QuietLine®	Noise Barriers, LLC www.noisebarriers.com 847-843-0500	37	Perforated metal covering with absorptive material	Negotiable	
Noise Barrier Blankets	Noise Control Corporation www.noisecontrol.com	Up to 31	Various types of blankets and panels	$18 to $25 (blankets)[3]	West Los Angeles College Construction Site

Notes:
(1) Cost varies with the choice of material for beams and type of installation.
(2) Includes installation cost. Installation cost may be higher for relatively small sound walls.
(3) Based on 20 ft high barrier that client received bids on of $350 to $500 per linear foot (installed cost).