A Study of Air Flow Surrounding a Proposed Airport Terminal Expansion

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ABSTRACT

A southwest regional airport has proposed a terminal expansion project that will involve increasing the overhang on the north and south sides of the terminal by approximately 72 feet, directly above the passenger pickup and drop-off areas and above the access roadway. A concern has been raised that the additional enclosure of these heavily trafficked areas might restrict local airflow and the dispersion of vehicle exhaust emissions and lead to an increased buildup of air pollutant levels during adverse meteorological conditions.

This paper will focus on the flow phenomena, and subsequent concentration distributions, below the structural canopies from line sources positioned within and adjacent to the canopies. The flow phenomena and concentration distributions are investigated with the existing overhangs and with the proposed extension to examine the potential impact of the extension. Each configuration is evaluated for a windward approach flow, a leeward approach flow, and for an approach flow parallel to the canopies.

The use of physical modeling in a wind tunnel was considered the best approach for obtaining useful information on the potential air quality effects of the planned terminal expansion. This approach was selected in preference to the use of mathematical air quality dispersion models, due to the numerical models' simplistic characterization of air flow in the vicinity of complex structures and their probable inability to distinguish the air quality implications of the proposed structural modifications.

INTRODUCTION

This paper describes the results of a study conducted jointly by Dames & Moore and Cermak Peterka Petersen, Inc. (CPP) to examine potential air quality effects at the regional airport due to the planned terminal expansion project. The proposed expansion project will involve increasing the area of the 4th through 7th floors of the terminal (parking garage) to provide increased parking capacity. The expansion will increase the overhang on the north and south sides of the terminal by approximately 72 ft directly above the passenger pickup and drop-off areas and the access roadway, as shown in Figure 1.

The distinctive configuration of the existing and proposed terminal configurations provides a unique opportunity to evaluate line source dispersion within canopied areas with various exposures to approach flow. The Level 1, Passenger Pickup area, is isolated from the approach flow for both the existing configuration and the proposed expansion. The Level 1 area is not only protected from approach flow from above by the Level 2 canopy, but is also protected from the north by a large retaining wall running parallel to the terminal on the far side of the access roadway, as shown in Figure 2. The combination of the roof deck and the retaining wall creates an isolated area, which becomes even more protected from ambient flow with the proposed expansion.

The passenger drop-off area on Level 2 is also protected from the approach flow from above by the parking structure deck, but, unlike Level 1, is exposed to the approach flow from the north. The proposed extension further protects Level 2 from above and begins to reduce the exposure from a northerly approach flow.

Because of the complex structure of the terminal building and the approach flow, the use of physical modeling in the wind tunnel was judged to be the best means available for obtaining useful information of the potential air quality effects of the planned terminal expansion. This approach was selected in preference to the use of mathematical air quality dispersion models, due to the available models' simplistic characterization of air flow in the vicinity of complex structures and their probable inability to properly distinguish the air quality implication of the proposed structural modifications.

DATA COLLECTION METHODOLOGY

A 1:240 scale model of the terminal building and surroundings were constructed of Masonite, balsa wood, and polystyrene foam and placed on a 12 ft (3.7 m) diameter turntable. The area modeled is depicted in Figure 1. Figure 2 shows a side view of the terminal with and without the proposed extension.

Exhausts from idling vehicles at Levels 1 and 2 and moving vehicles on the access roadway were modeled using line sources along the three roadways, as shown in Figure 3. Each line source was supplied with a tracer gas (methane, ethane, or propane) and nitrogen-helium or nitrogen-argon neutral density mixture. Precision mass flow controllers were used to monitor and regulate the discharge flow volumes.

The exit momentum of exhaust from individual vehicles is minimal, thus, an accurate model-scale simulation can be achieved by assuring that a fully mixed plume exists along each line source. A fully mixed plume can be achieved by limiting the exit velocity of source gas through each exhaust port to a value less than 1.5 times the approach wind speed at the source location. The simulated full-scale exit velocities for the two idling sources were designed as 1.0 m/s. A 0.25 m/s exit velocity was used for the mobile (the access roadway) source. These values should result in a fully mixed plume for approach wind speeds as low as 0.7 m/s (1.5 mph).

Concentration sampling points (receptors) were installed at twenty equally spaced locations along the north side of the terminal at both Levels 1 and 2, as shown in Figure 4. Additional receptors were placed at the air intakes on the east and west sides of the terminal (Receptors 41 and 44), and at air intakes within the 4^{th} level of the parking garage (Receptors 42 and 43).

The wake created by vehicles on the access roadway was simulated using a conveyer belt with equally spaced 0.25inch (0.64 mm) cubes. The spacing of the cubes was designed such that the total drag created by the cubes was equivalent to the total drag created by vehicles on the roadway. The total drag created by vehicles on the access roadway was calculated using the dynamic pressure and drag characteristics of the vehicles as defined with the following relationship:

Equation 1. Total drag of vehicles along the access roadway.

$$Total\ Drag = \frac{1}{2}\rho V^2 \sum n_i A_i C_{d_i}$$

where:

$\frac{1}{2}\rho v^2$ = dynamic pressure of vehicles traveling on the access roadway;
n_i = number of vehicles of type i on roadway;

A_i = average frontal area of vehicle type i; and

C_{di} = drag coefficient for vehicle type *i*.

The vehicle mix, for this purpose, was divided into three classifications, sedans, minivan/sports utility vehicles, and light duty trucks. The percentage for each vehicle type was estimated based on national averages of vehicle sales. The values used were 70% sedans, 20% minivan/sports utility vehicles, and 10% light duty trucks. Vehicle drag coefficients and frontal areas were defined as average values obtained from manufacturer's published data for a variety of makes and models. The total number of vehicles present on the roadway was obtained from a traffic count data report presented by ADT Counts (Cullen/Burr, 1998).

The vehicle dynamic pressure was calculated assuming standard atmospheric conditions and an average vehicle speed of 35 mph, the posted speed limit on the access roadway. Discussions with airport personnel indicated that the average speed maybe greater than 35 mph under typical driving condition. However, since the wake provides a potential benefit to reducing concentrations at the terminal building, the conservative (i.e., lower) value was used for this analysis.

The cube spacing on the conveyor belt was subsequently calculated by rearranging Equation 1 to solve for the number of cubes, *n*, using the total drag value calculated for the moving vehicles and a drag coefficient of 1.05 for a cube.

RESULTS

A qualitative visualization of flow surrounding the north side of the terminal building revealed that three distinct flow phenomena occur depending upon the approach wind direction. These three distinct conditions occur for a windward approach flow (northerly winds), a leeward approach flow (southerly winds), and for an approach flow parallel to the terminal building (easterly or westerly winds). Therefore, the focus of this paper is to evaluate each of these three approach wind conditions and their impact on the concentration distributions along the north face of the terminal.

Windward Approach Flow

For a windward approach flow the highest concentrations were recorded along the most protected area of the terminal canopy, i.e., the Level 1 receptors. With this wind condition, the approach flow results in a high-pressure region along the north face of the terminal, causing much of the exhaust from the access roadway and some of the exhaust from Level 2 to be deflected up and over the top of the terminal building. At Level 1, which is highly protected from the approach flow, the approach flow does not penetrate the canopy. Thus, much of the exhaust from the access roadway and the Level 1 traffic is maintained within the canopy.

Extending the parking garage structure lowered concentrations associated with Level 1 emissions along the Level 1 canopy. Since the Level 1 canopy area was already well protected from the windward approach flow, the extension results in an increase in the volume of the recirculation area, without a corresponding increase in emissions. Thus, normalized concentrations at the Level 1 receptors decrease with the addition of the parking garage extension. The extent of the decrease, is proportional to the increase in the recirculation area, which is greatest near the center of the terminal building, as shown in Figure 5.

The measured concentrations at Level 2 from the Level 2 emissions decreased slightly with the extension in place. It is surmised that this decrease is a resultant of two competing factors. First, with the extension in place, a greater portion of the vehicle emissions are captured within the canopy, potentially increasing concentrations along the north wall of the terminal. Second, the extension also increases the volume of the recirculation area, subsequently lowering concentration within the recirculation area, assuming a fully mixed air flow. Since, the normalized concentrations slightly decreased, this is an indication that the increase in the area of recirculation was more than sufficient to compensate for the additional emissions captured with the extension.

Unlike emissions from Levels 1 and 2, normalized concentrations from vehicles traveling along the access roadway, increased at the Level 2 receptors with the terminal extension in place. With the existing terminal configuration, the access roadway is uncovered and the emissions are deflected up and over the top of the terminal building. The northerly wind creates a high-pressure region within the Level 1 and Level 2 canopy areas, providing a buffer from the access roadway emissions. With the extension in place, the access roadway is now located within the canopied area. As a result, the emissions are physically blocked from traversing over the roof of the terminal and are therefore, caught within the high pressure recirculation areas under the two canopies. This phenomenon increases the level of concentrations present along the north wall of the terminal building. Figure 5 shows that measured concentrations at the Level 2 receptors from vehicles traveling along the access roadway increased by approximately a factor of four with the terminal extension in place. (Level 2 receptors were used for this analysis because the normalized concentrations measured at Level 2 were consistently higher than those measured at the Level 1 receptors.)

Parallel Approach Flow

With a wind direction from the east, the exhaust from all three line sources traveled along the roadways and exited at the west end of the terminal building. It was anticipated that concentrations at the west end might be high due to this build-up of exhaust. However, Figure 6 indicates that concentrations at the west end were quite often lower than at the east end.

Concentrations from Level 1 emissions at Level 1 receptors were generally lower for the parallel approach flow than for the windward approach flow. With a parallel approach flow, the ambient wind can somewhat penetrate the canopy area and disperse a portion of the emissions. Whereas, with the windward approach flow, nearly all emissions were held within the canopy area. As a result, concentrations with the parallel approach flow were slightly slower than for the windward approach flow.

The extension of the terminal building has little, or no impact on concentrations from Level 1 emissions at Level 1 receptors for a parallel approach flow. Concentrations at the east end decreased slightly with the extension in place. At the west end, the extension had no impact on measured concentrations.

The most significant increase in concentrations attributed to a parallel approach flow were measured at the Level 2 receptors from Level 2 emissions. A comparison between results presented in Figures 5 and 6 indicates that maximum measured concentrations were approximately six times greater with the parallel approach flow than with a windward approach flow.

Figure 6 indicates the highest concentrations with the existing canopy configuration were measured at the eastern half of the terminal. With this configuration, the approach wind is able to penetrate the canopy at the east end, creating high concentrations along the north wall of the terminal. While the approach flow is capable of penetrating the canopy, concentrations continue to build up as they move towards the west. However, as the flow travels farther west, it becomes less capable of penetrating the canopy, and concentrations begin to taper off.

With the existing terminal configuration in place, the emissions from vehicles traveling along the access roadway move along the corridor between the terminal on the south and the retaining wall on the north. The plume spreads as it moves along the corridor and eventually becomes wide enough to impact the terminal building. With the extension in place, the emissions continue to traverse along the corridor. However, because of the additional shelter provided by the extension, the plume never disperses enough to significantly impact the terminal building.

Leeward Approach Flow

Based on the initial flow visualization, it was anticipated that the highest concentrations at the terminal building may be attributed to a leeward approach flow. With a leeward (southerly) approach flow, a recirculation region develops downwind of the terminal building. The recirculation region is defined by a low pressure region along the downwind face of the building. This low-pressure region will tend to cause emissions from the three line sources to be drawn upwind into the face of the terminal building, resulting in high concentrations at the receptor locations.

Concentrations at the Level 1 receptors from the Level 1 emissions with a leeward approach wind were similar to, or slightly less than those measured with either a windward or parallel approach wind. This area remains relatively protected from the approach flow. Placement of the terminal extension had no impact on receptor concentrations.

The highest concentrations measured throughout the study were attributed to Level 2 emissions at the Level 2 receptors for a leeward approach wind. With the existing terminal configuration in place, the recirculation region trapped the emissions at Level 2 and brought them inward towards the terminal building. With the modified terminal configuration in place, the recirculation region moved outward, trapping an even greater percentage of the flow and increased measured concentrations. Figure 7 shows that maximum measured normalized concentrations from the Level 2 emissions were approximately 50 percent higher with the terminal extension in place.

Similar results were witnessed for impact of the access roadway emissions on the Level 2 receptors. With the existing configuration, the leeward approach wind creates a downwind recirculation cavity which captures a portion of the vehicle emissions and forces them inward toward the terminal building. With the terminal extension in place, a greater percentage of emissions are captured by the low pressure recirculation region, increasing concentrations at Level 2.

CONCLUSIONS

This paper describes results of a study conducted jointly by Dames & Moore and Cermak Peterka Petersen, Inc. (CPP) to examine potential air quality effects at the southwest regional airport due to the planned terminal expansion project. The distinctive configuration of the existing and proposed terminal configurations provides a unique opportunity to evaluate line source emissions below structural canopies with different exposures to the approach flow.

The results of the study can be summarized by the following bullet items:

- The flow visualization and subsequent concentration measurements provided insight into the dispersion of a line source exhaust located within and adjacent to a canopy. The results indicate that at the isolated Level 1 canopy, concentrations along the back wall are relatively unaffected by the direction of the approach flow.

- For the exposed Level 2 canopy, the highest concentrations occur from a leeward approach flow. This flow creates a low-pressure recirculation region that captures the emissions and forces them inward. Extension to the canopy may increase the portion of the plume which is captured and increase the intensity of the recirculation region, ultimately increasing concentrations within the canopy.

- The highest concentrations within a canopy from the access roadway line-source located adjacent to the canopy also occur for a leeward approach flow. Extending the canopy over the line-source increases concentrations of the vehicle emissions within the canopy for both a leeward and a windward approach wind condition.

- This study shows that the wind-tunnel simulations can be an effective method to evaluate the air quality implication of alternate architectural design approaches. The wind tunnel can be used to simulate flow patterns around complex structures and to differentiate the flow patterns created by modifications to the structures.

REFERENCES

ASHRAE, “ASHRAE Handbook of Fundamental”, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA, 30329, 1997

Cermak, J.E., “Laboratory Simulation of the Atmospheric Boundary Layer,” *AIAA Jl.*, Vol. 9, September 1971.

Cermak, J.E., “Applications of Fluid Mechanics to Wind Engineering,” Journal Fluids Engineering, Vol. 97, P. 9, 1975.

Cermak, J.E., “Aerodynamics of Buildings,” *Annual Review of Fluid Mechanics*, Vol. 8, pp. 75-106, 1976.

Counihan, J., “Adiabatic Atmospheric Boundary Layers. A Review and Analysis of Data from the Period 1880-1972,” *Atmospheric Environment*, September 1975.

Cullen/Burr, Traffic Counting Data, Letter of Transmittal to Brad Cochran, Cermak Peterka Petersen, Inc, April 21, 1998.

EPA, *Guideline for Use of Fluid Modeling of Atmospheric Diffusion*. U.S. Environmental Protection Agency, Office of Air Quality, Planning and Standards, Research Triangle Park, North Carolina, EPA-600/8-81-009, April 1981.

Pasquill, F., *Atmospheric Diffusion*, 2nd Edition, John Wiley & Sons, New York, 1984.

Turner, D.B., “Workbook of Atmospheric Dispersion Estimates,” U.S. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, North Carolina, 1970.

Weiringa, J., “Representative Roughness Parameters for Homogeneous Terrain,” *Boundary Layer Meteorology*, Volume 63, pp 323-363, 1993.

Figure 1. Plan view of the southwest regional airport terminal showing area modeled

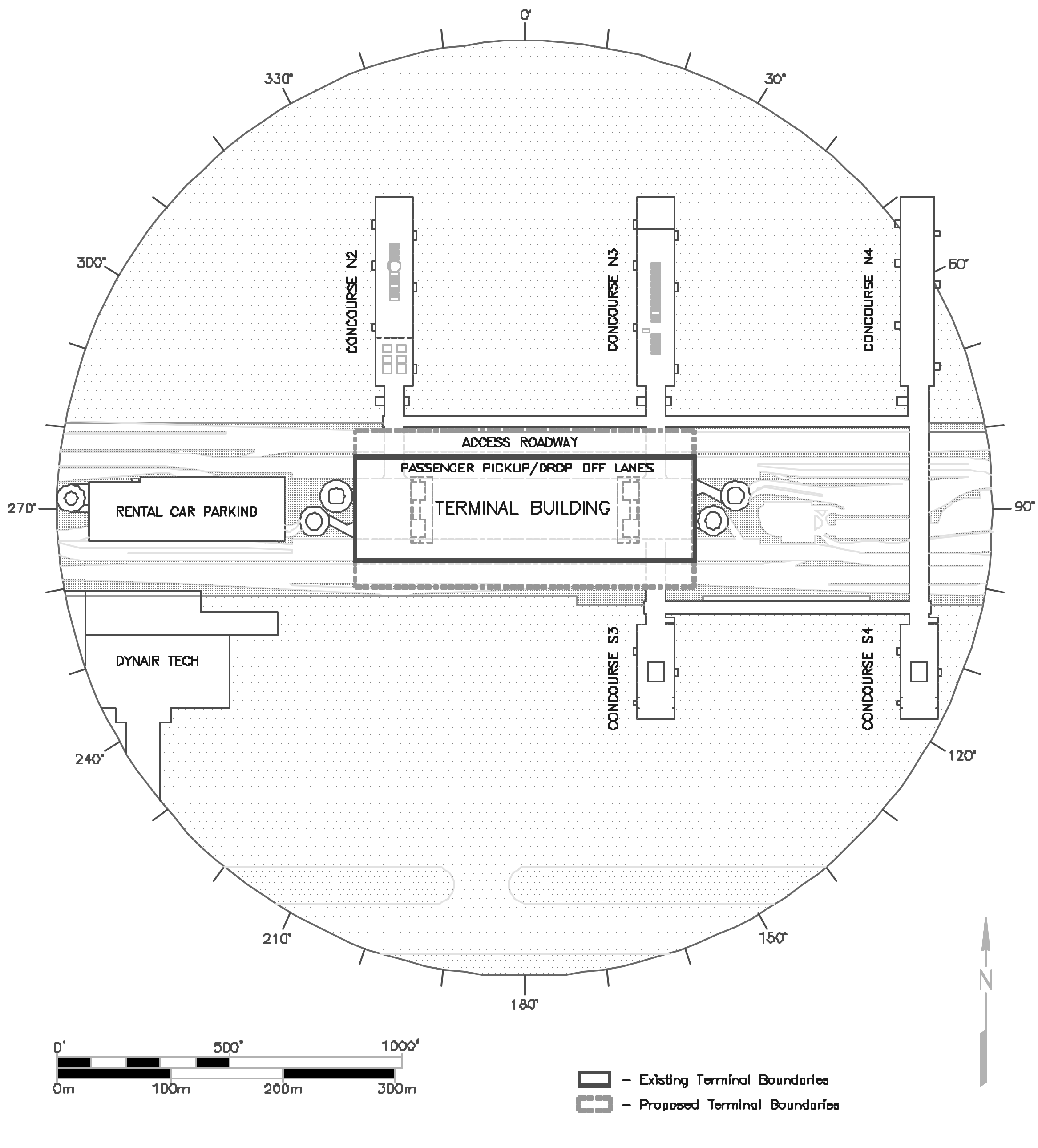


Figure 2. Side view of the terminal showing parking area extensions

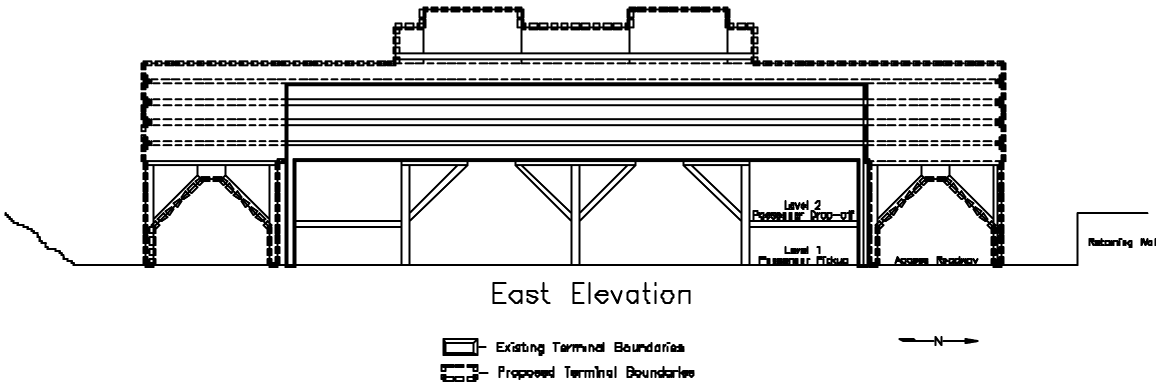


Figure 3. Emission sources modeled

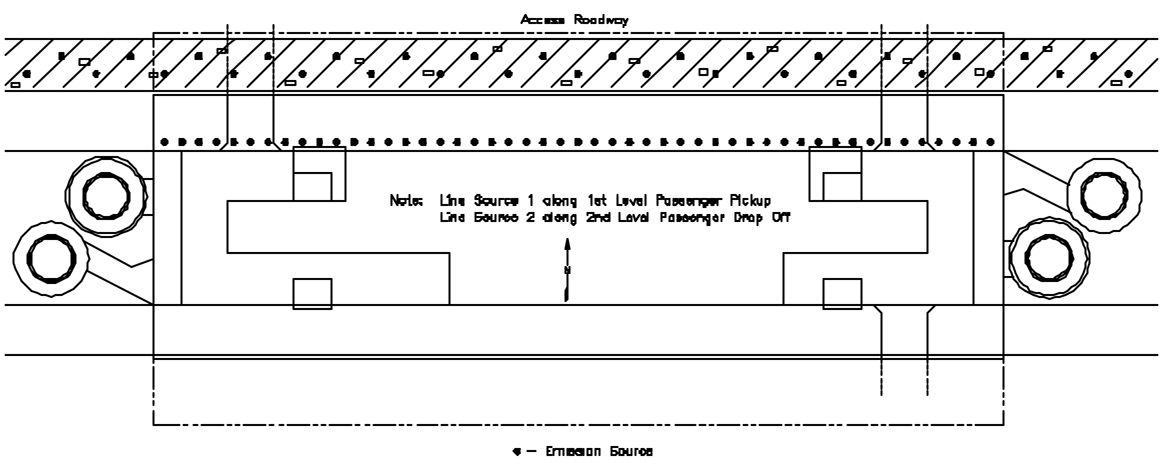


Figure 4. Concentration receptor sampling points

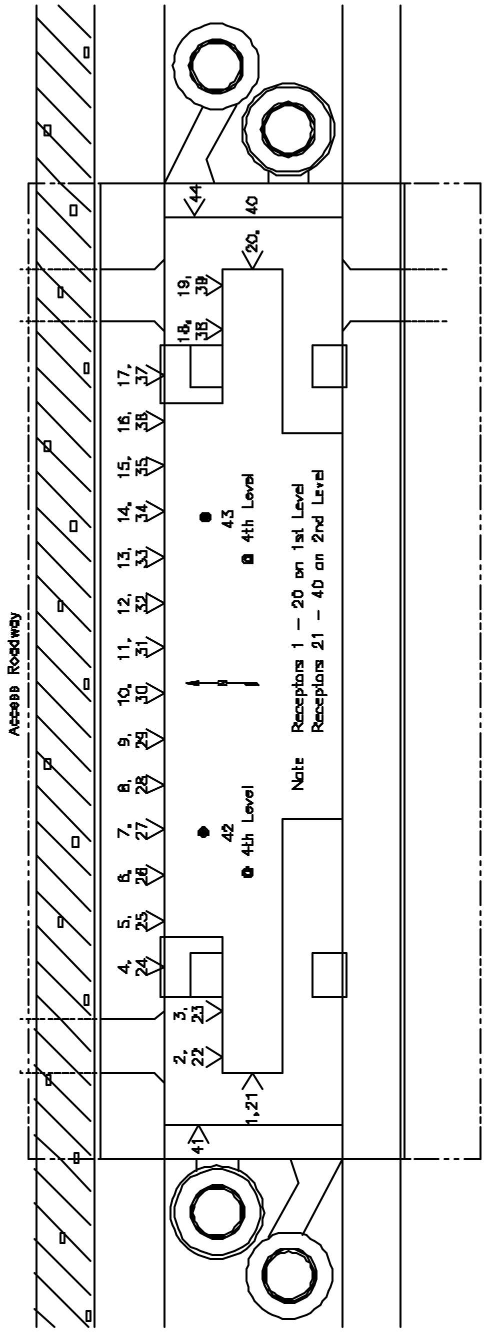
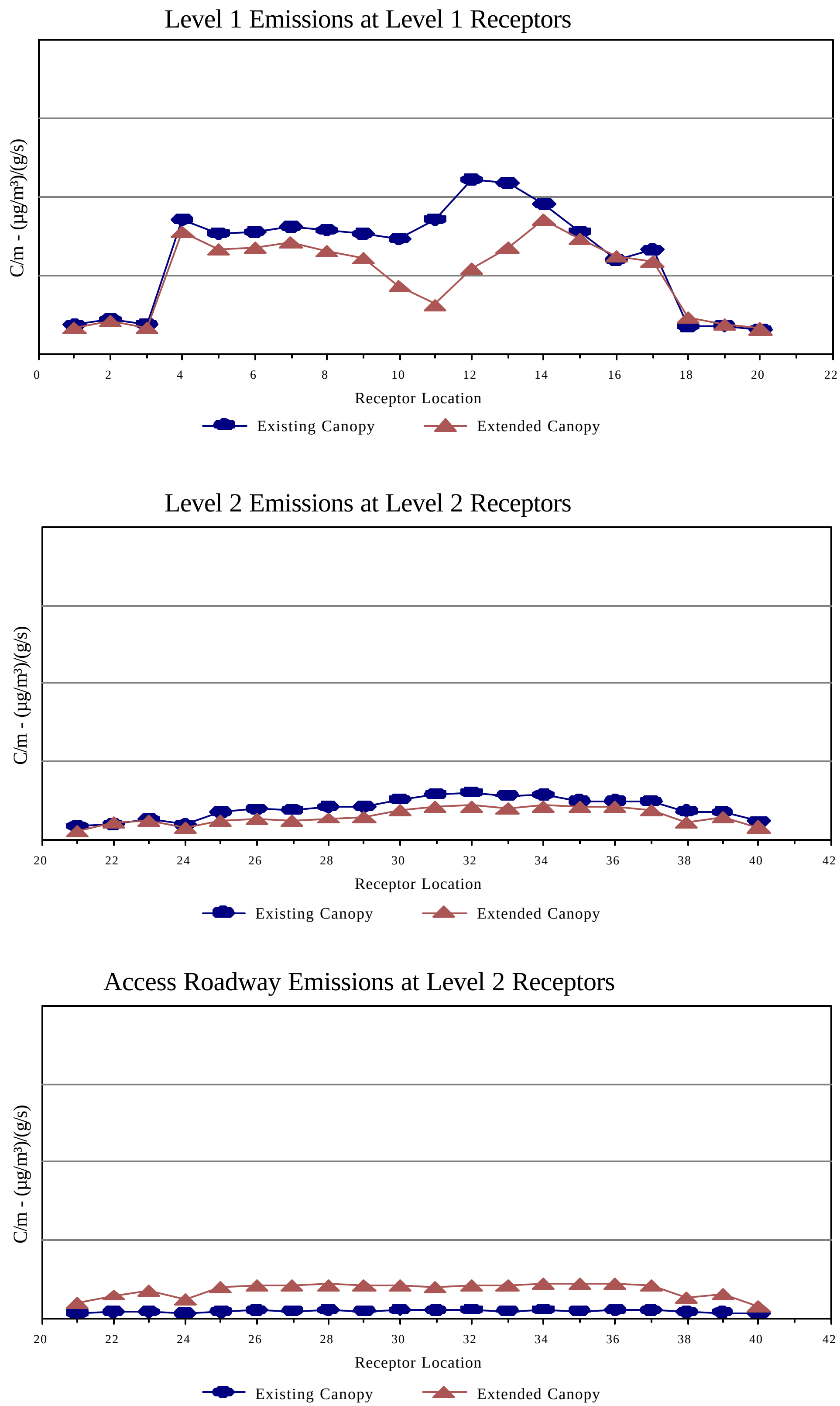


Figure 5. Normalized concentration distributions for northerly (windward) approach winds



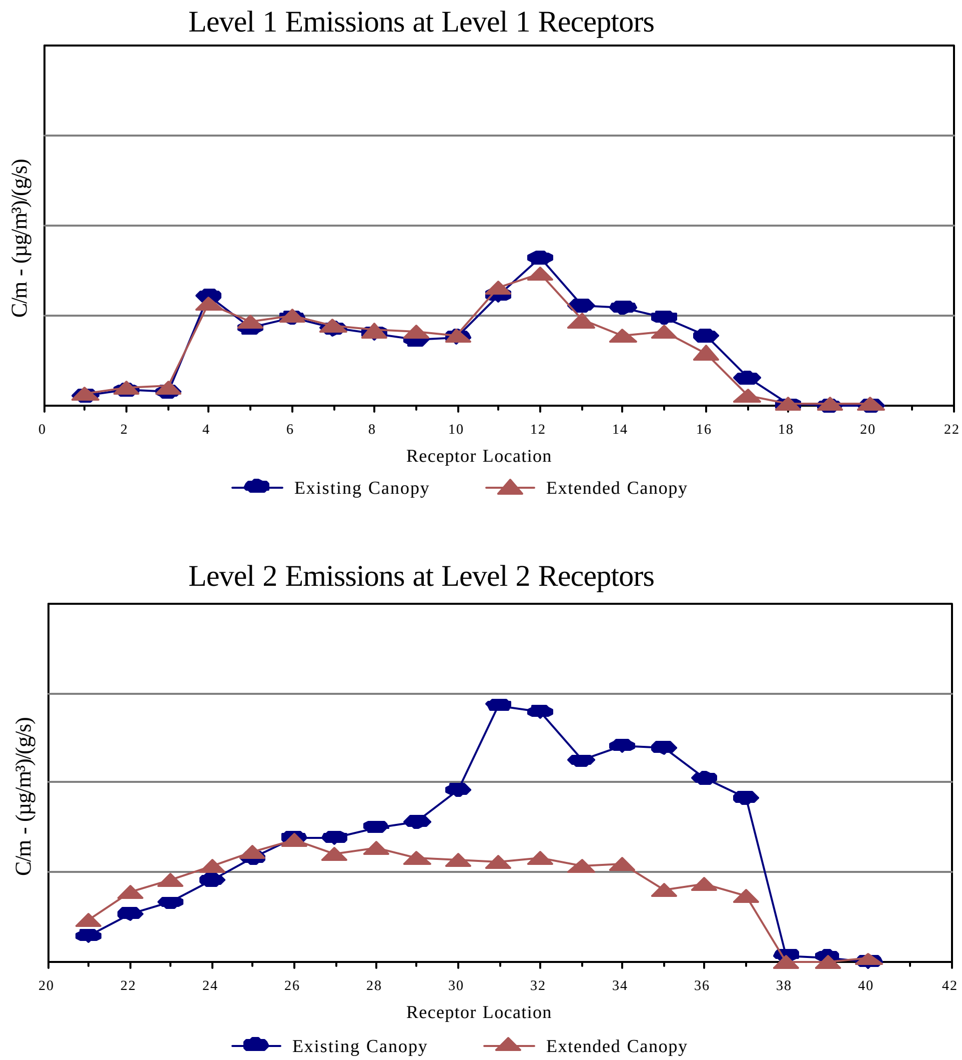


Figure 6. Normalized concentration distributions for easterly (parallel) approach winds

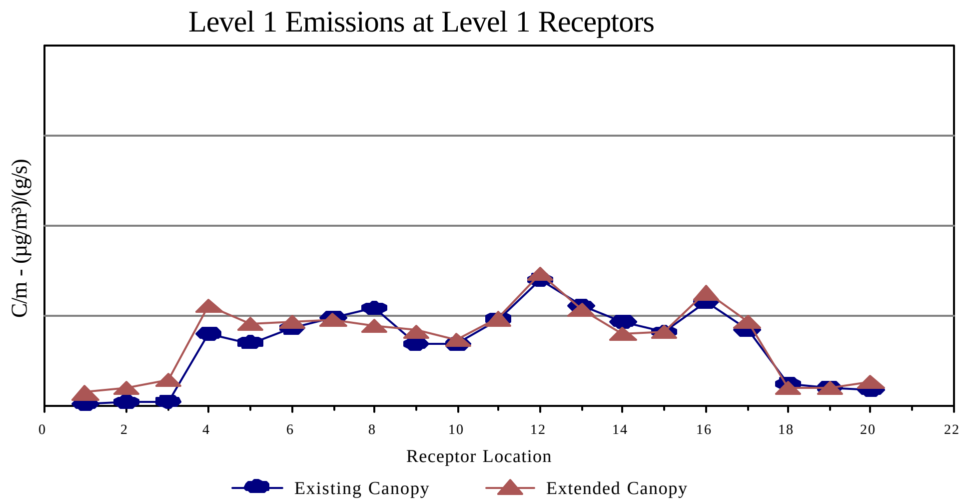
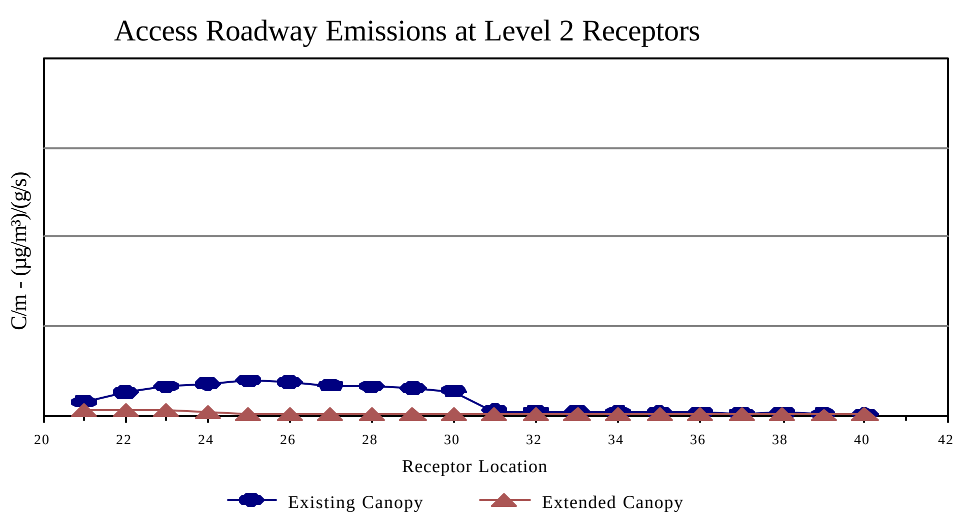
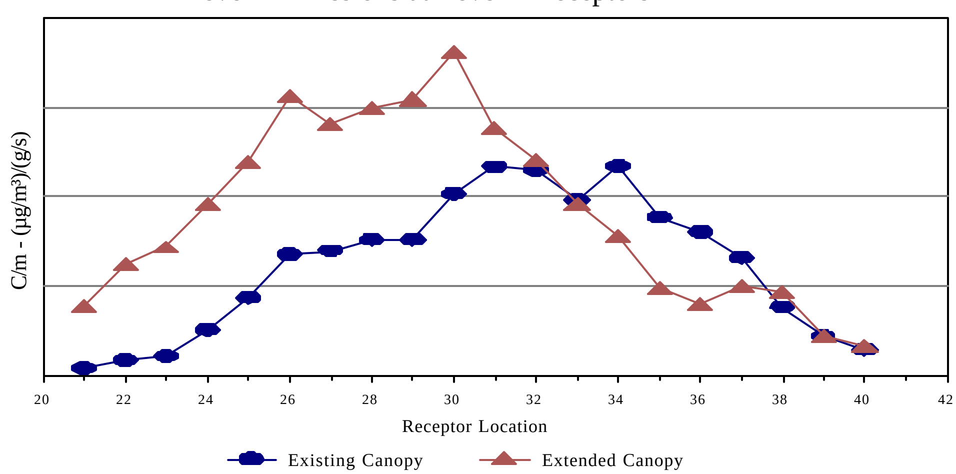


Figure 7. Normalized concentration distributions for southerly (leeward) approach winds



Level 2 Emissions at Level 2 Receptors



Access Roadway Emissions at Level 2 Receptors