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AERMOD Source Types RLINE and RLINEXT Testing

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Executive Summary

This report is one of a group of research reports sponsored by the Federal Highway Administration (FHWA) through State Departments of Transportation (DOTs) in a partnership to test two new source types within the AERMOD modeling regime (Version 21112): RLINE and RLINEXT. The Environmental Protection Agency (EPA) published a final rule revising the agency's Guideline on Air Quality Models (Appendix W to 40 CFR Part 51) which made AERMOD the preferred model for refined transportation project analyses beginning in January 2020. New algorithms within AERMOD are intended for this purpose. These include RLINE (Research Line) and RLINEXT (Research Line Extended) and were developed through efforts of the EPA's Office of Research and Development (ORD). RLINEXT includes the ability to model noise barriers along the roadway as well as depressed sections.

This report describes detailed model evaluations, analyzed results, model recommendations, and assisting tool recommendations. The final product is a stand-a-lone report which was part of a peer exchange. It must be noted that this is not a validation of the model since there is no "golden standard" database of measurements with which to compare at this time. Partial verification studies have and are being conducted but resources are not available for full validation. This is however a verification of the model operation and a detailed analysis of possible problem areas based on a review of model outputs. *This will serve the purpose of allowing a review of possible problem areas and help to guide future development. Accordingly, this partnership between FHWA and DOTs provides a goal of further evaluation of the model options that will provide insight to the RLINE and RLINEXT implementation and is needed to help determine future guidance and policy*.

This paper concentrates on review of trends of the concentration predictions for various configurations and varying inputs. The analyses are tied back to the methodology used in the model for insight. Analyses include the following geometric designs and inputs:

- Simple scenarios
  - straight roadway, no barrier
  - with barrier
  - curve
  - curve with barrier
  - depressed
  - elevated
- Source height
- Initial vertical dimension
- Wind direction
- Intersection scenarios
- Hypothetical freeway in Virginia with and without barriers (included as an appendix)

Large receptor grids beginning very near the roadway and extending away were primarily used to determine trends although strategically placed receivers were used for some specific scenarios. The use of large grids permitted both near field and far field evaluations. In specific scenarios, the number of receptors is reduced but kept to a very small area to determine abrupt changes in modeled such as at the ends of barriers. Near field evaluations are important because as described in the RLINE formulation document, vertical spread does not include the initial impact of vehicle turbulence. Evaluations at greater distances are needed representing neighborhood locations.

The intersection scenario is different in that it compares the results to the predecessor model, CAL3QHC. Intersections are often the most crucial analysis areas and the most modeled scenarios during hot spot analysis. This comparison was to evaluate differences in trends that would occur if RLINE were used and provides insights into the differences that might be expected in project analysis.

The remaining evaluations conducted are evaluations of different geometries and results evaluated to help indicate where further development may be needed. RLINEXT is still in alpha form and under development for not only modeling barrier effects, but other extreme conditions such as depressed roadway sections. RLINE, while beta, and still under evaluation, was also reviewed for situations listed previously.

As mentioned, a very thorough study was conducted by the Virginia Department of Transportation (VDOT) in support of the requisite match for this study. This expansive study was an evaluation of impacts for a hypothetical ten-lane freeway build scenario in northern Virginia opening to traffic in 2025 and is included as an appendix to separate the two types of analyses and testing. All modeling was conducted following EPA and FHWA guidance for projects subject to conformity requirements. Virginia-specific inputs were applied for MOVES (v.3.0.1) and AERMOD (v.21112,) including five years of meteorological data from Dulles International Airport (IAD). Typical traffic volumes, speeds, and fleet mix for a highway in northern Virginia were applied. Sensitivity testing was conducted for inputs of particular interest from the perspective of a state DOT practitioner, including source comparisons, initial vertical dimension (Szinit), urban setting, and receptor spacing. Many of these parameters such as receptor spacing affect the run times which were also evaluated. Included in the evaluations are a comparison of RLINEXT for a range of noise wall heights and distances typical for Virginia. Freeway orientations both east-west and north-south were tested to assess the effect of the wind field direction, which had a substantial component from the south. Testing also included freeway segments, both at-grade and depressed, with and without noise walls. Results for run time in addition to modeled maximum 24-hour (eighth highest) and annual concentrations of $PM_{2.5}$ were assessed.

Key Findings

Complete findings are summarized in the report. Major findings are briefly discussed here. Findings are discussed in the general order that they appear in the report without ranking of importance.

End effects (at the terminus of roadways) and discontinuities in concentration predictions at evenly spaced intervals for constant wind patterns were substantial and prevalent in all evaluations and could easily affect results in any roadway air quality evaluation. For a 500-meter roadway with 2 lanes, only the center 200 meters appear to be valid for use in modeling due to the end effects. This is problematic in that concentrations near the end of a modeled roadway could be reported incorrectly. Without solid data we do not know the true impact at the end of the line sources but intuitively, with a steady crosswind, the impacts should not extend along the roadway to the degree that is now occurring. These end effects become amplified with increased source height and during parallel winds.

Effects away from the roadway were also noted. End effects caused distorted patterns that extended far from the roadway and discontinuities in predictions occurred. Guidance on the distance a receiver is valid from the roadway as well as suggested receiver spacing may be required. Guidance for receiver locations may also be needed to address placement near barriers and depressed sections.

The width of the roadway affects the horizontal plume spread. Width also affected the cyclic concentration along the roadway. A review of inputs and processing algorithms related to width seem warranted. This is especially true due to the turbulent nature of mixing along a heavily travelled roadway. This has been considered in the past and would seem to be important to consider once again.

Upwind concentrations appear intuitively to be greater than should be predicted and this effect is exacerbated when including barriers. Since the contribution of each point source at the receptor is a function of horizontal and vertical meandering contributions, it could be beneficial to revisit the meander and perhaps the surface friction velocity algorithms implementation in the source code.

The initial plume vertical dimension is related to the meander but also to the mean plume height and can have significant effects on the overall prediction of concentrations. This is especially true for near receivers and for elevated sources. The initial vertical dimension also affects the variation of the horizontal plume spread with distance. As such, a review of the use and algorithms for release height, the initial vertical dimension, may be needed concurrently with meander to permit better approximations. The authors of this document would like to discourage the use of an optional value of zero for the initial vertical height in regulatory applications for transportation. Flexibility could be retained for research purposes.

Release height, somewhat of a misnomer, should be defined for the plume coming off the roadway and is really a factor in the plume mean effective height. Vehicle turbulence, the width of the roadway, vehicle speeds, vehicle mix, and volumes all effect this important variable. More work is needed to provide better guidance.

Barrier algorithms would appear to be problematic, especially for parallel winds. End effects are increased, and concentration profiles seem to be influenced far beyond what would be expected for perpendicular winds. For parallel winds it would seem a major software "bug" occurs resulting in very unrealistic predictions. Unless the barrier is on one defined side, winds are ignored and even then, are ignored for parallel winds from the opposite direction. These problems require both a review of the algorithms and again, data for comparison.

Barriers on curves present another consideration. The length of the barrier may need to be adjusted for inside and/or outside radius of the curve. This will depend on the degree of curvature, distance from roadway, and length of segments (links).

While the results from depressions seem better than for barriers, the parallel wind problem persists. Again, a review of the algorithms and data for comparison are needed.

Recommendations

Based on the analysis of the model trends and outputs, the following recommendations are thought to be important for further model development and guidance for good modeling practice.

Model Development and Evaluation

- The limit now employed for the convergence routine for the Romberg integration scheme should be reviewed and a possible increase in precision or additional ways to set precision for nearby receivers may be required.
- The release height was shown to be a critical factor. More work is needed to define the release height considering traffic mix, speed, volume, local wind speed, and width of roadway.
- While modeled maximum $PM_{2.5}$ concentrations vary substantially by source, URBAN setting and initial vertical dimension, the effect appears greater for URBAN setting and initial vertical dimension than source. More detail on these findings and related recommendations are presented in Section 4.3 of the Appendix.
- The initial vertical dimension was also shown to be a key parameter affecting predicted concentrations. This is especially true due to the turbulent nature of mixing along a heavily travelled roadway. It is recommended that the initial vertical dimension not be described as optional for regulatory applications for transportation since this leads to a value of zero which has significant effects on predicted concentrations, especially in the near field. Use of a zero value may still be useful in model testing and research so does not need to be excluded. Additionally, more work is needed for the initial vertical dimension as it is directly related to

release height and affected by traffic mix, speed, volume, local wind speed, and width of roadway. This input (Sigma-z) also affects the variation of Sigma-y with distance. As such, a review of the use and algorithms for release height, the initial vertical dimension (Sigma-z), as well as meander may need to be conducted concurrently.

- Effects of the initial vertical dimension change based on time of predictions (24-hour standard vs. annual standard) and should be reviewed.
- Parallel winds to the roadway and walls are not being handled well within the model. More work is needed considering the concentration build along the roadway with possible limits included and in the scenario of barriers troubleshooting a major software problem that causes large problems with predictions.
- RLINEXT with noise walls or barriers needs to be validated against field data, as it generates very high maximum concentrations for both the 24-hour and annual standards for $PM_{2.5}$ near the wall. This effect was observed for walls for both at-grade and depressed sections. In contrast, vertical-cut depressed sections (which effectively present a vertical barrier adjacent to the travelled roadway) without a noise wall did not exhibit this effect. RLINEXT should not be made applicable for regulatory analyses until it has been validated against field data. More detailed recommendations on this point are provided in Sections 4.1 and 4.2 of the Appendix.
- Prediction results from depressions seem better than for barriers, but the parallel wind problem persists. A review of the barrier algorithms in addition to the previous recommendations are needed as results appear to be affected beyond what would be expected. End effects are increased, and concentration profiles seem to be influenced at far distances from the roadway, especially upwind. Upwind concentrations appear intuitively to be greater than should be predicted and this effect is exacerbated when including barriers. Since the contribution of each point source at the receptor is a function of horizontal and vertical meandering contributions it could be beneficial to revisit this implementation in the source code.
- A review of end effects and possible ways to avoid the substantial changes in concentrations including but not limited to precision in the Romberg integration scheme.
- A review of elevated source propagation is needed.
- True validation of the model against field data for all typical transportation applications is strongly recommended. Measurements conducted away from other sources and complications are needed for many different scenarios (see Appendix Sections 4.1.2 and 4.1.3) to permit an *enhanced* model validation or evaluation process, involving not only tracer studies but also validation of the models in regulatory applications against near-road monitoring data. Care should especially be taken to evaluate the models as applied in regulatory air quality analyses of transportation projects conducted to meet federal transportation conformity requirements and for purposes of NEPA to ensure that the intended regulatory purpose of showing compliance with statistical confidence in NAAQS and build/no-build tests is met. Estimates of accuracy and uncertainty are needed as a product of validation studies for the entire traffic, emission and dispersion modeling chain including

the determination of background concentrations. The enhanced process must involve transportation stakeholders including state DOTs and commit more resources, which may be accomplished with a pooled fund approach.

- Run times are a product of many variables (see Appendix Section 3.4.2). It may be possible to optimize some algorithms to improve performance.
- Model output should be enhanced to better facilitate model testing. Suggestions for this are provided in Section 4.4 of the Appendix.

Guidance

Specification of good modeling procedures or in some scenarios modeling requirements may be needed to reduce possible modeling inconsistencies. Suggested changes are listed below.

- Until further validation is completed, it is recommended that all modeling regimes (LINE, AREA, RLINE, RLINEXT, and VOLUME) be retained as options for transportation sources.
- It is recommended that the urban setting be used wherever applicable.
- Guidance is needed for the inputs of release height and the initial vertical dimension. It is highly recommended that the optional value of zero for the initial vertical dimension is not used in regulatory applications for transportation as currently defined in guidance.
- Limits to the placement of receivers for both near the ends of roadways and distance from the roadway are needed. This may include the specification of receptor exclusion zones for areas near noise walls, at least until the model has been validated for typical transportation facilities with noise walls.
- Definition of good modeling practices of elevated sections including use of walls along the roadway are needed.
- Good modeling practice for the placement of receivers for barriers and depressed sections are needed. Incorrect placement can lead to misleading results and should be avoided.
- Guidance on use of barriers should be expanded especially for connecting barriers (connecting roadways) and barriers on curves.

Priority Considerations

While the previous findings and recommendations have not been ranked in terms of priority but follow the report order, the authors considered four areas to be a priority for future work. These are:

- Enhanced quality data collection for a true validation including multiple roadway configurations.
- Software updates for parallel winds.
- Further review of using increased precision for integration in the Romberg integration scheme or other methods to set precision in scenarios such as when near receivers.
- Issuance of guidance to allow consistency among users.

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1. Introduction

1.1 Purpose

This report is one of a group of research reports sponsored by The Federal Highway Administration (FHWA) through State Departments of Transportation (DOTs) in a partnership to test two new source types within the AERMOD modeling regime: RLINE and RLINEXT. RLINE (Research Line) and RLINEXT (Research Line Extended) were developed through efforts of the EPA's Office of Research and Development (ORD).[1] R-LINE uses Gaussian dispersion algorithms, is imbedded in AERMOD, and approximates a line source based on Romberg integration of point sources.[2] Designed for roadway applications, plume meander is considered under low wind conditions, an advancement over using extended area sources. RLINE also has an advantage over using volume sources due to being computationally less intensive. Additionally, RLINEXT now includes the ability to model noise barriers along the roadway.

At the beginning of the project, Version 19191 was to be tested. However, a new release, Version 21112, was released after testing began. This resulted in a rerun of multiple tests to ensure the latest results would be available.

AERMOD Version 21112 includes the latest dispersion algorithms for RLINE in a beta option and RLINEXT for specific scenarios such as depressed roadway sections and highway barriers as an alpha option. These model options, intended to model highways as simulated line sources, are continuing to be developed and information gathered now can help guide this development.

This report describes detailed model evaluations, analyzed results, model recommendations, and assisting tool recommendations. The final product is a stand-a-lone report which is part of a peer exchange. It must be noted that this is not a model validation since there is no "golden standard" database of measurements for which to compare. Partial verification studies have and are being conducted but resources are not available for full validation. This is however a verification of the model operation and a detailed analysis of possible problem areas based on a review of model outputs. Of note is that in the case of graphics some small artifacts may occur due to software characteristics. Efforts have been taken to minimize this possibility by using dense receptor grids, running the same scenario with slightly different inputs, and careful review of results.

This document is intended to serve the purpose of allowing a review of possible problem areas and help guide future development.

1.2 Goal

The Environmental Protection Agency (EPA) published a final rule revising the agency's Guideline on Air Quality Models (Appendix W to 40 CFR Part 51) which made AERMOD the preferred model for refined transportation project analyses beginning in January 2020. The new source types (RLINE and RLINEXT) were included in the AERMOD model to assist in this change. As noted in

[1] EPA, Mobile Source Dispersion Modeling, White Papers on Planned Updates to AERMOD Modeling System, WP5-1, 2017.

[2] Snyder, M.G., Venkatram, A., Heist, D.K., Perry, S.G., Petersen, W.B. and Isakov, V. (2013a). RLINE: A line source dispersion model for near-surface releases. Atmospheric environment, 77, pp.748-756.

the Transportation Conformity Hot Spot Guidance[3], area or volume sources are to be used for roadways but in practice, the use of extended, connected area sources were found to be more realistic during modeling due to the resources expended. The transition to AERMOD was problematic and some results were questioned when compared to older modeling practices using the CALINE series of models. The RLINE/RLINEXT option in AERMOD now offers a Romberg numerical integration of the contributions of point sources along a line (a link) which computes the final concentration as the sum of the contribution from each point source. This is an approximation, similar in nature to CALINE methodology, for highway source definition. *Accordingly, this partnership between FHWA and DOTs provides a goal of further evaluation of the model options that will provide insight to the RLINE and RLINEXT implementation and is needed to help determine future guidance and policy*.

1.3 Methodology

A detailed review of AERMOD modeling results using the RLINE/RLINEXT source types was conducted. The three teams conducting the review have divided the work to make better use of resources. The team from New Mexico University are developing software to make application more efficient. The team from the Georgia Institute of Technology (GaTech) are doing comparisons of concentration results from specific roadways in the Atlanta area and includes a comparison of volume and area sources results. As such, results in this report do not evaluate these other sources types except during a project level analysis review. This paper concentrates on review of trends of the concentration predictions for various configurations and varying inputs. The analyses are tied back to the methodology used in the model for insight. Comparisons have been made in the past[4,5,6,7] but more is needed, especially for varying geometries. Analyses include the following geometric designs and inputs:

- Simple
  - straight roadway, no barrier
  - with barrier
  - curve
  - curve with barrier
  - depressed
  - elevated
- Source height
- Initial vertical dimension

[3] EPA, Transportation Conformity Guidance for Quantitative Hot-spot Analyses in $PM_{2.5}$ and PM_{10} Nonattainment and Maintenance Areas, EPA-420-B-15-084, Office of Transportation and Air Quality, November, 2015.

[4] Heist, et.al, Estimating near-road pollutant dispersion: a model inter-comparison, EPA https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&TIMSType=&count=10000&dirEntryId=262340&searchAll=&showCriteria=2&simpleSearch=0&startIndex=10001, last accessed on June 28, 2020.

[5] USEPA, Technical Support Document (TSD) for Replacement of CALINE3 with AERMOD for Transportation Related Air Quality Analysis, EPA-454/B-15-002, July, 2015.

[6] Finn, D., Clawson, K.L., Carter, R.G., Rich, J.D., Eckman, R.M., Perry, S.G., Isakov, V. and Heist, D.K., Tracer studies to characterize the effects of roadside noise barriers on near-road pollutant dispersion under varying atmospheric stability conditions. Atmospheric Environment, 44(2), pp.204-214, 2010.

[7] Baldauf, R., Thoma, E., Hays, M., Shores, R., Kinsey, J., Gullett, B., Kimbrough, S., Isakov, V., Long, T., Snow, R. and Khlystov, A., Traffic and meteorological impacts on near-road air quality: Summary of methods and trends from the Raleigh near-road study. Journal of the Air & Waste Management Association, 58(7), pp.865-878, 2008.

- Wind direction
- Intersection
- Hypothetical freeway in Virginia with and without barriers (See Appendix)

More work, such as in street canyons or in extreme terrain, is needed but thought to be beyond the scope of this initial evaluation. Large receptor grids very near the roadway and extending away were primarily used to determine trends although strategically placed receivers were used for some specific scenarios. In specific scenarios, the number of receptors is reduced and kept to a very small area to determine abrupt changes in modeled concentrations such as at the ends of barriers. The use of large grids permitted both near field and far field evaluations. Near field evaluations are important because as described in the RLINE formulation document[8], vertical spread does not include the initial impact of vehicle turbulence. Evaluations at greater distances are needed representing neighborhood locations.

The intersection scenario is different in that it compares the results to the CAL3QHC model results. Intersections are often the most crucial analysis areas and the most modeled scenarios during hot spot analysis and this comparison was to evaluate differences in trends that occur if RLINE were used, providing insights into the differences expected in project analysis.

The remaining evaluations conducted are for different geometries and results evaluated to help indicate where further development may be needed. RLINEXT is still in alpha form and under development and includes modeling barrier effects, and depressed roadway sections. RLINE, while beta, needs more evaluation for situations listed previously.

While absolute modeling uncertainties cannot be established and evaluations cannot be completely definitive because we are not comparing to actual concentration values, the reported concentration trends will provide an indicator of overall applicability and possible problem areas that can help guide possible changes to the model and immediate guidance. In addition, overall predicted concentrations of actual roadways were reviewed for reasonableness.

Once modeling of the different scenarios was completed, unusual responses to key variables were noted during analyses preformed. Where a specific input was identified to have inconsistent or unintuitive results, other variables were held constant, and the key variable changed over prescribed range to evaluate corresponding trends. This helps to determine possible abnormalities in the programming and equation implementation. Examples of the sensitivity performed included testing wind directions, very low winds, and for different curvature of roadways. This is meant to isolate key areas for development. For example, previous key comparisons[9] to measured data were limited to within 60-degrees to the perpendicular angle of

[8] Snyder, M.G., Venkatram, A., Heist, D.K., Perry, S.G., Petersen, W.B. and Isakov, V., RLINE: A line source dispersion model for near-surface releases. Atmospheric environment, 77, pp.748-756, 2013.

[9] Snyder, et.al, RLINE: A Line Source Dispersion Model for near-Surface Releases, EPA https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&TIMSType=&count=10000&dirEntryId=280769&searchAll=&showCriteria=2&simpleSearch=0&startIndex=10001, last accessed May, 2020.

the roadway. Experience has shown that curves and near parallel winds become important considerations. Inconsistencies in RLINE were reviewed for these conditions.

Errors ("bugs") have previously been found in the software as expected during any new implementation. While the RLINE model has been moved to beta status, problems may still exist. The evaluation of the outputs from varying input, after plotting and review, should help to define abnormalities. Limited by available resources, it has been possible to extend the analysis due to the cooperation and coordination of the three teams with resources being used more efficiently.

2. Evaluations

The following sections describe the evaluations that were performed during testing of the RLINE/RLINEXT options in the AERMOD model, Version 21112.

2.1 Simple Roadway

This section describes analysis using simple, straight roadways to evaluated RLINE. Because of the requirement of flat terrain, all roadways were at grade with varying number of lanes beginning with Eastbound (EB) and Westbound (WB) directions. Varying the number of lanes for different analyses permitted effects of roadway width to be reviewed.

Because of the nature of the analyses in this document, to review the model trends but not absolute values, meteorology input for all analyses were based on the program MakeMet[10] so that key meteorological variables such as the wind direction could be carefully controlled. This testing used a 1 m/s wind speed defined at 10 meters above the ground plane. U* was unadjusted, temperature held to 298° Kelvin, albedo as well as surface roughness and Bowen ratios were defined to be very low. Table 1 shows information for the typical meteorological input used in analyses. It should be noted that this is only a partial listing to show key details. During MakeMet analysis, a total of 574 hours was included in the meteorological input.

Due to the use of MakeMet, AERMOD was run in the screening mode. This resulted in only maximum hourly values being reported in the output. Since absolute values were not the goal of the project, this was acceptable. Additionally, very high emission values were used to allow results to be more easily shown during analysis. Some of the results noted would have been difficult to discern at lower concentration values. While the pollutant is not of concern, except for the project level analysis, the non-reactive pollutant of carbon monoxide was selected to review modeling trends.

The terrain used the FLAT option as required by the RLINE and RLINEXT. Unless otherwise noted, an initial source height of 2.3 meters (based on a typical traffic mix), and receptor heights of 1.8 meters for both receptor grids and discrete receptors were used.

[10] U.S. EPA, AERSCREEN User's Guide. EPA-454/B-21-005. U.S. Environmental Protection Agency, Research Triangle Park, NC, 2021.

2.1.1 No Barrier, Single Lane, Cross Wind

This is a very simple scenario with a single 3-meter-wide lane extending from east to west for 1000 meters with a cross wind only from 180 degrees (°) or from the south. Wind rose details are shown in Figure 1 while results are shown in Figure 2.

Analysis. Since the wind is only from the south (upwards in figure) it would not be expected that end effects would be so prominent and extend to about 250 meters from each end of the roadway. This would tend to show that receptor concentrations near the ends of roadways should not be used and practical limits may need to be established. Additionally, again since winds are only from the south, upwind concentrations appear to be elevated.

2.1.2 No Barrier, Two Lanes, Cross Wind

In this scenario, again the wind direction input is again perpendicular to the roadway direction, but the number of lanes has been increased to two (2). The roadway is east to west with a length of 1,000 meters. Wind is only permitted from the south (180 °). Results shown in Figure 3a are a macro view of the entire area while 3b is zoomed in to provide additional detail. Emission factors were reduced to avoid AERMOD errors in output.

Analysis. Of note is that in the macro-view, end effects are once again very prominent are very similar to the single lane scenario. Initial high concentrations extend further from the roadway on the downwind side. The greater downwind concentrations seem to extend too far from the roadway. Additionally, greater upwind concentrations also seem to be predicted farther from the roadway than would be expected for a wind direction only from 180°.

Also apparent along the roadway is an increase in the discontinuities of the concentration pattern. To show greater detail, a zoomed in view was created as shown in Figure 3b. Of note, is that near the roadway (out to approximately 90 meters), the discontinuities result in slight areas of varying concentrations. These areas are approximately 60 meters apart on the south (upwind) side of the roadway. At a slightly greater distance, approximately 200 meters south of the roadway. Since emissions should be evenly distributed along the roadway and that the wind direction is only from 180 °, these variations in concentrations should not occur. This would seem to be an artifact of the point source integration process and is discussed in more detail later in this report.

Also, of note is the difference in concentration gradients both upwind and downwind that occur from varying widths. Increased emissions due to additional lanes would be expected to cause some difference but not to the degree shown.

Of note is that testing was also accomplished for cross winds coming from 0° (North) and results were very similar to those with a south wind. As such, these tests were not shown in this document as no new findings occurred.

Table 1. Typical Meteorological Input (Wind from 180° Shown)

a. Surface (SFC) Sample

	Year	Month	Day	Julian Day	Hour	Sensible Heat Flux [W/m^2])	Surface Friction Velocity [m/s]	Convective Velocity Scale [m/s]	Vertical Potential Temperature Gradient above PBL	Height of Convectively-Generated Boundary Layer - PBL [m]	Height of Mechanically-Generated Boundary Layer - SBL [m]	Monin-Obukhov Length [m]	Surface Roughness Length [m]	Bowen Ratio	Albedo	Wind Speed - Ws [m/s]	Wind Direction - Wd [degrees]	Reference Height for Ws and Wd [m]	Temperature - temp [K]	Reference Height for temp [m]	Precipitation Code	Precipitation Rate [mm/hr]	Relative Humidity [%]	Surface Pressure [mb]	Cloud Cover [tenths]
Min.	2010	Jan	1	1	1	-64.0	0.043	-9.000	0.020	-999.0	21.0	-8888.0	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	1.0	1.0	1
Max.	2010	Dec	31	365	13	119.3	1.563	1.800	0.020	2620.0	4000.0	8888.0	0.100	0.20	0.00	18.00	180.0	10.0	298.0	2.0	10	3.00	3.0	4.0	5
Graph						☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐
1	2010	Jan	1	1	1	-1.8	0.043	-9.000	0.020	-999.0	21.0	4.2	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	1.0	1.0	1
2	2010	Jan	2	2	1	-1.8	0.043	-9.000	0.020	-999.0	104.0	4.2	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	1.0	1.0	2
3	2010	Jan	3	3	1	-1.8	0.043	-9.000	0.020	-999.0	208.0	4.2	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	1.0	1.0	3
4	2010	Jan	4	4	1	-1.7	0.043	-9.000	0.020	-999.0	21.0	4.5	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	1.0	2.0	1
5	2010	Jan	5	5	1	-1.7	0.043	-9.000	0.020	-999.0	104.0	4.5	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	1.0	2.0	2
6	2010	Jan	6	6	1	-1.7	0.043	-9.000	0.020	-999.0	208.0	4.5	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	1.0	2.0	3
7	2010	Jan	7	7	1	-0.7	0.069	-9.000	0.020	-999.0	41.0	41.1	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	1.0	3.0	1
8	2010	Jan	8	8	1	-0.7	0.069	-9.000	0.020	-999.0	207.0	41.1	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	1.0	3.0	2
9	2010	Jan	9	9	1	-1.8	0.043	-9.000	0.020	-999.0	21.0	4.2	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	3.0	1.0	1
10	2010	Jan	10	10	1	-1.8	0.043	-9.000	0.020	-999.0	104.0	4.2	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	3.0	1.0	2
11	2010	Jan	11	11	1	-1.8	0.043	-9.000	0.020	-999.0	208.0	4.2	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	3.0	1.0	3
12	2010	Jan	12	12	1	-1.7	0.043	-9.000	0.020	-999.0	21.0	4.5	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	3.0	2.0	1
13	2010	Jan	13	13	1	-1.7	0.043	-9.000	0.020	-999.0	104.0	4.5	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	3.0	2.0	2
14	2010	Jan	14	14	1	-1.7	0.043	-9.000	0.020	-999.0	208.0	4.5	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	3.0	2.0	3
15	2010	Jan	15	15	1	-0.7	0.069	-9.000	0.020	-999.0	41.0	41.1	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	3.0	3.0	1
16	2010	Jan	16	16	1	-0.7	0.069	-9.000	0.020	-999.0	207.0	41.1	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	1.00	3.0	3.0	2
17	2010	Jan	17	17	1	-1.3	0.043	-9.000	0.020	-999.0	21.0	5.9	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	3.00	1.0	1.0	1
18	2010	Jan	18	18	1	-1.3	0.043	-9.000	0.020	-999.0	104.0	5.9	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	3.00	1.0	1.0	2
19	2010	Jan	19	19	1	-1.3	0.043	-9.000	0.020	-999.0	208.0	5.9	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	3.00	1.0	1.0	3
20	2010	Jan	20	20	1	-1.2	0.043	-9.000	0.020	-999.0	21.0	6.4	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	3.00	1.0	2.0	1
21	2010	Jan	21	21	1	-1.2	0.043	-9.000	0.020	-999.0	104.0	6.4	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	3.00	1.0	2.0	2
22	2010	Jan	22	22	1	-1.2	0.043	-9.000	0.020	-999.0	208.0	6.4	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	3.00	1.0	2.0	3
23	2010	Jan	23	23	1	-0.4	0.079	-9.000	0.020	-999.0	51.0	107.8	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	3.00	1.0	3.0	1
24	2010	Jan	24	24	1	-0.4	0.079	-9.000	0.020	-999.0	255.0	107.8	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	3.00	1.0	3.0	2
25	2010	Jan	25	25	1	-1.3	0.043	-9.000	0.020	-999.0	21.0	5.9	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	3.00	3.0	1.0	1
26	2010	Jan	26	26	1	-1.3	0.043	-9.000	0.020	-999.0	104.0	5.9	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	3.00	3.0	1.0	2
27	2010	Jan	27	27	1	-1.3	0.043	-9.000	0.020	-999.0	208.0	5.9	0.100	0.20	0.00	1.00	180.0	10.0	298.0	2.0	2	3.00	3.0	1.0	3

Is meant as an example, does not include the entire file of 574 hours

Table 1. Continued

b. Profile (PFL) Sample

	Year	Month	Day	Hour	Measurement Height [m]	1, if this is the last (highest) level for this hour, or 0 otherwise	Direction the wind is blowing from for the current level [degrees]	Wind Speed for the current level [m/s]	Temperature at the current level [C]	Standard deviation of the wind direction fluctuations [degrees]	Standard deviation of the vertical wind speed fluctuations [m/s]
Min.	2010	Jan	1	1	10.0	1	180.0	1.00	24.8	99.0	99.00
Max.	2010	Dec	31	13	10.0	1	180.0	18.00	24.8	99.0	99.00
Graph					☐	☐	☐	☐	☑	☐	☐
9	2010	Jan	9	1	10.0	1	180.0	1.00	24.8	99.0	99.00
10	2010	Jan	10	1	10.0	1	180.0	1.00	24.8	99.0	99.00
11	2010	Jan	11	1	10.0	1	180.0	1.00	24.8	99.0	99.00
12	2010	Jan	12	1	10.0	1	180.0	1.00	24.8	99.0	99.00
13	2010	Jan	13	1	10.0	1	180.0	1.00	24.8	99.0	99.00
14	2010	Jan	14	1	10.0	1	180.0	1.00	24.8	99.0	99.00
15	2010	Jan	15	1	10.0	1	180.0	1.00	24.8	99.0	99.00
16	2010	Jan	16	1	10.0	1	180.0	1.00	24.8	99.0	99.00
17	2010	Jan	17	1	10.0	1	180.0	1.00	24.8	99.0	99.00
18	2010	Jan	18	1	10.0	1	180.0	1.00	24.8	99.0	99.00
19	2010	Jan	19	1	10.0	1	180.0	1.00	24.8	99.0	99.00
20	2010	Jan	20	1	10.0	1	180.0	1.00	24.8	99.0	99.00
21	2010	Jan	21	1	10.0	1	180.0	1.00	24.8	99.0	99.00
22	2010	Jan	22	1	10.0	1	180.0	1.00	24.8	99.0	99.00
23	2010	Jan	23	1	10.0	1	180.0	1.00	24.8	99.0	99.00
24	2010	Jan	24	1	10.0	1	180.0	1.00	24.8	99.0	99.00
25	2010	Jan	25	1	10.0	1	180.0	1.00	24.8	99.0	99.00
26	2010	Jan	26	1	10.0	1	180.0	1.00	24.8	99.0	99.00
27	2010	Jan	27	1	10.0	1	180.0	1.00	24.8	99.0	99.00
28	2010	Jan	28	1	10.0	1	180.0	1.00	24.8	99.0	99.00
29	2010	Jan	29	1	10.0	1	180.0	1.00	24.8	99.0	99.00
30	2010	Jan	30	1	10.0	1	180.0	1.00	24.8	99.0	99.00
31	2010	Jan	31	1	10.0	1	180.0	1.00	24.8	99.0	99.00
32	2010	Feb	1	1	10.0	1	180.0	1.00	24.8	99.0	99.00
33	2010	Feb	2	1	10.0	1	180.0	1.50	24.8	99.0	99.00
34	2010	Feb	3	1	10.0	1	180.0	1.50	24.8	99.0	99.00
35	2010	Feb	4	1	10.0	1	180.0	1.50	24.8	99.0	99.00
36	2010	Feb	5	1	10.0	1	180.0	1.50	24.8	99.0	99.00
37	2010	Feb	6	1	10.0	1	180.0	1.50	24.8	99.0	99.00
38	2010	Feb	7	1	10.0	1	180.0	1.50	24.8	99.0	99.00
39	2010	Feb	8	1	10.0	1	180.0	1.50	24.8	99.0	99.00

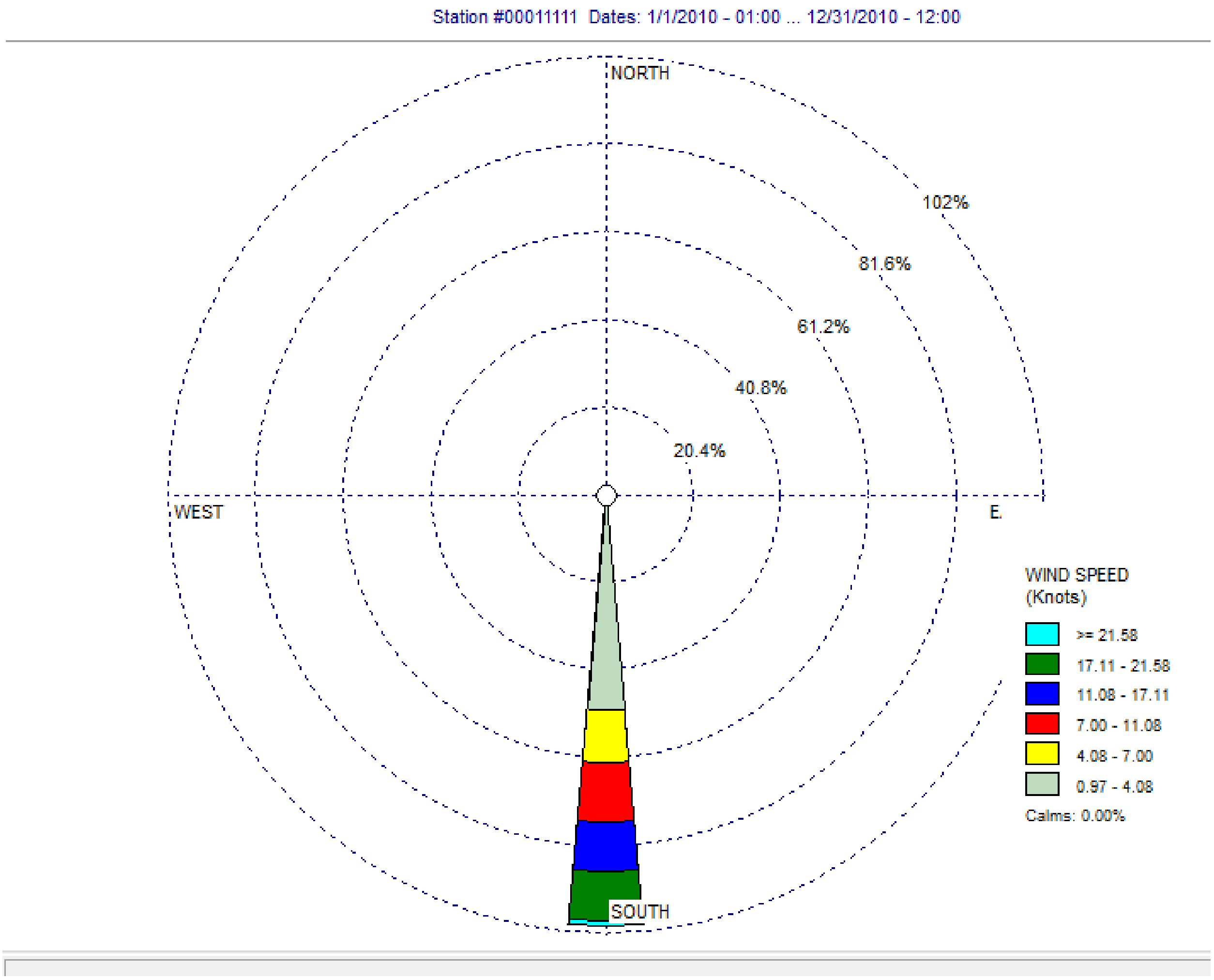


Figure 1. Example Wind Rose with Wind Only From the South (180°)

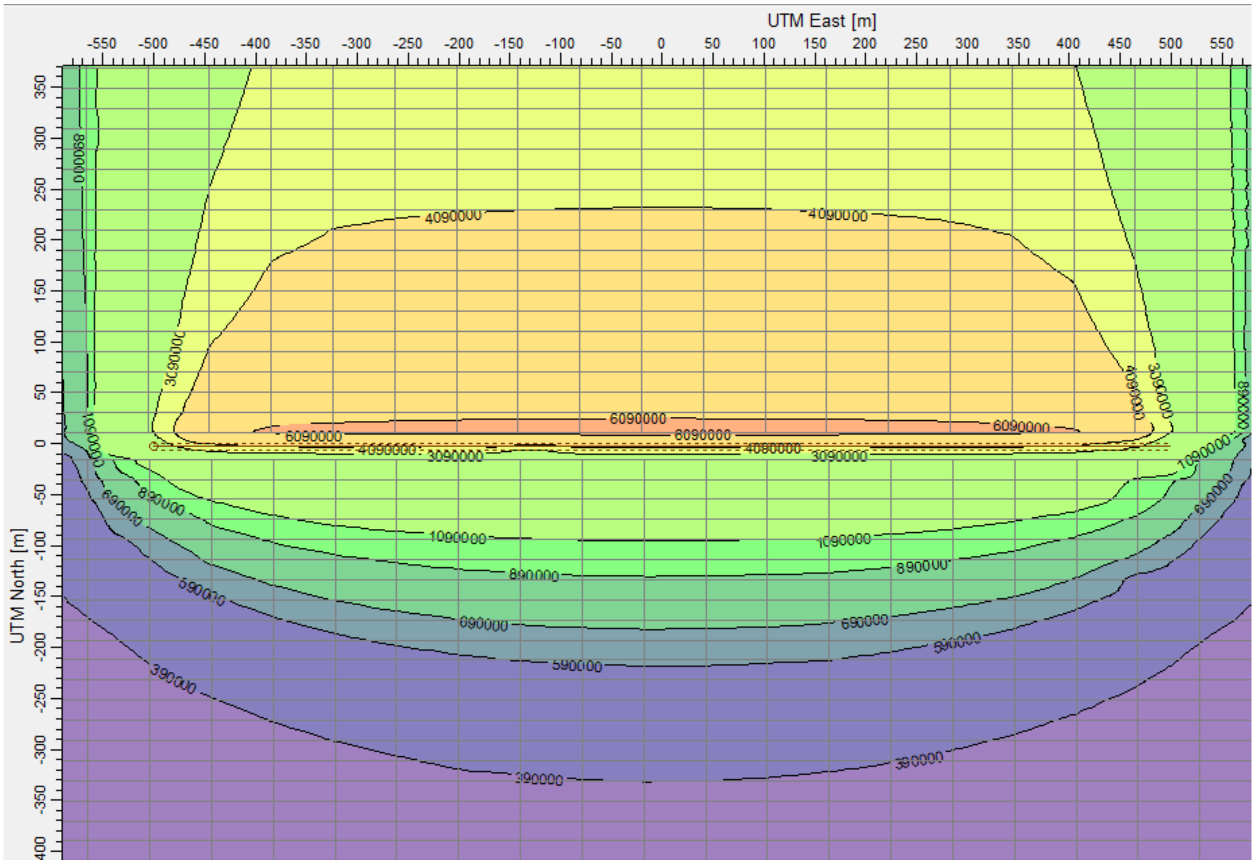
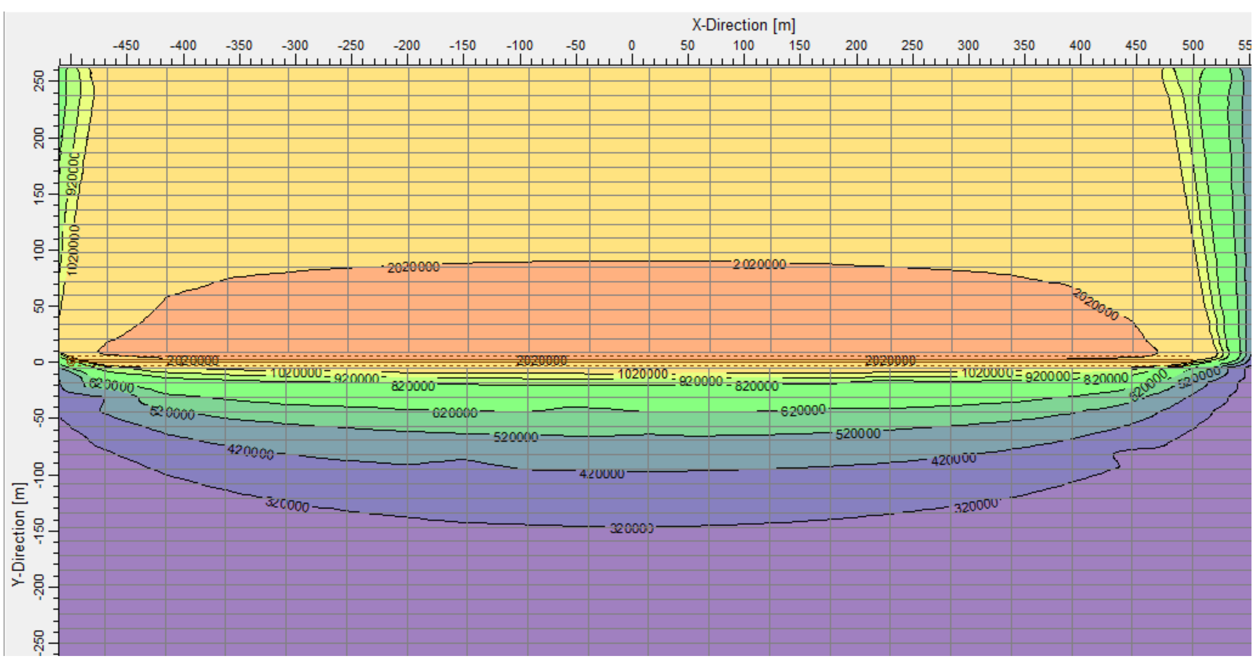
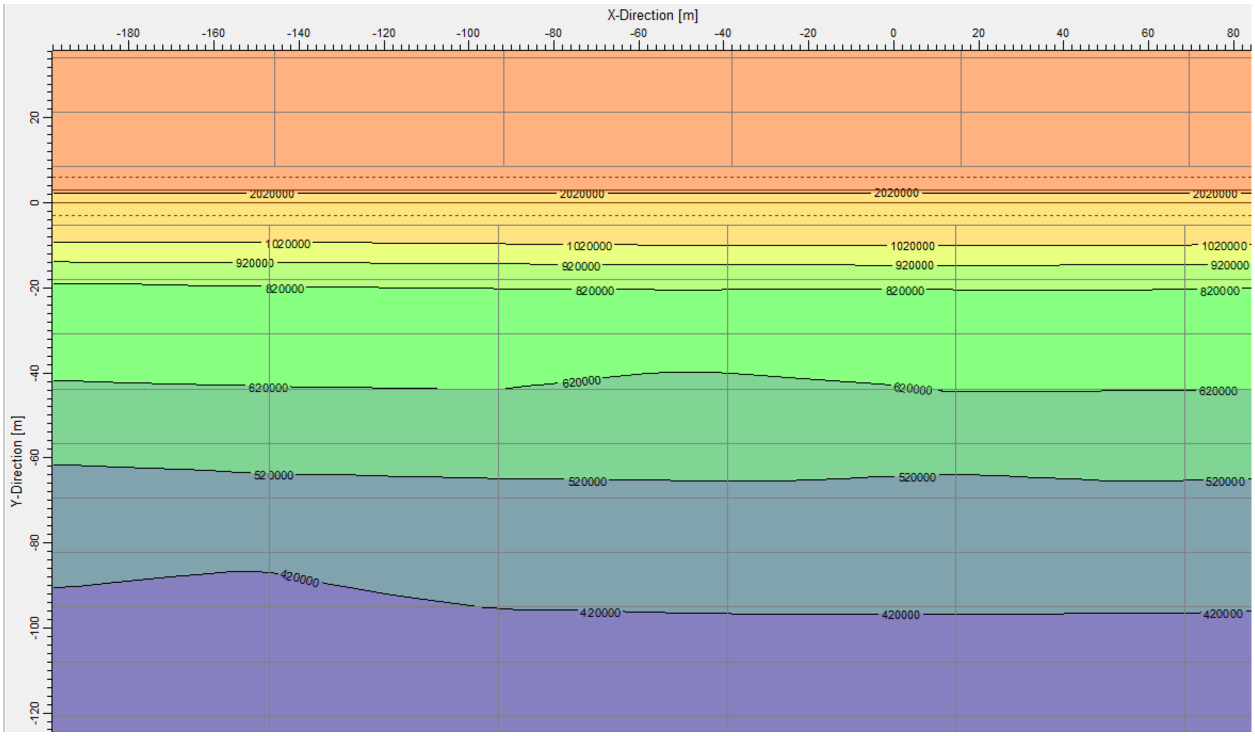


Figure 2. Single Lane, Winds from South (180°)



a. Macro-view



b. Zoomed In

Figure 3. Two Lanes, No Medium, Wind from 180 Degrees

2.1.3 No Barrier, 2 Lanes, Cross Wind, Optional Initial Vertical Dimension

In addition to the roadway width, differences related to the initial vertical dimension input was reviewed for this simple roadway. In this evaluation, 2 lanes in each direction were again modeled with crosswinds but the optional value of zero was used for the initial vertical dimension. The length of the roadway was reduced to 500 meters. Results of the modeled concentrations are shown in Figure 4.

Analysis. A comparison of Figure 3a and 4 show there are large difference in the results when the only change is optionally not including the initial vertical dimension. The concentration gradient falls off a greater rate. Concentrations tend to be less upwind that when the initial vertical dimension is used. End effects still occur resulting a significant decrease in concentrations near the ends of the roadway. Small perturbations still occur upwind and since the emissions are evenly distributed along the entire roadway and winds do not vary from 180°, it would be expected that these perturbations would not occur.

2.1.4 North South Simple Roadway, Wind from 90°

To evaluate if any differences occurred, a simple north to south roadway was also evaluated. To be similar, the same parameters were used for the roadway as in 2.2.2. Winds are from the east, 90°. Results are shown in Figure 5.

Analysis. When compared to Figure 3a, results are very similar. Noticeable are cyclic discontinuities upwind of the roadway.

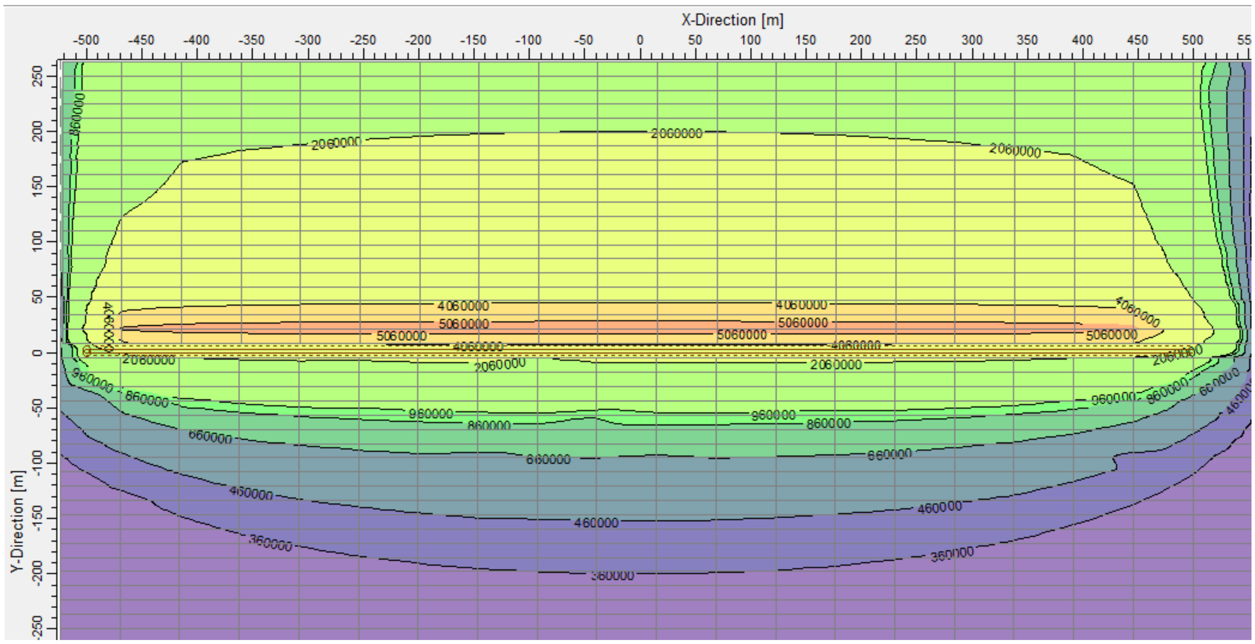


Figure 4. Simple Roadway; Wind from 180°, 2 Lanes Each Direction, Optional Initial Vertical Dimension

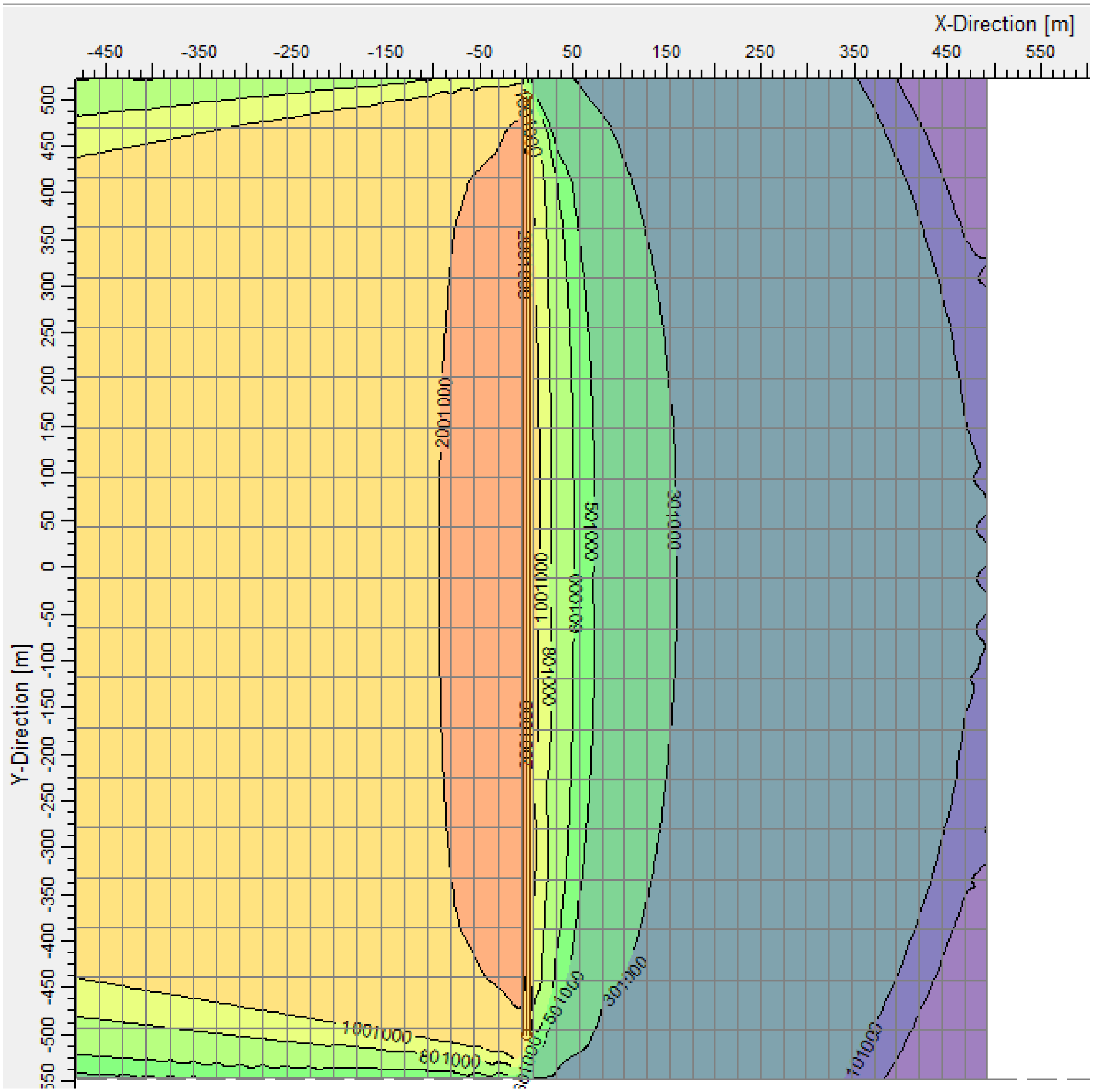


Figure 5. North South Roadway, 2 Lanes, Wind from 90°

2.1.5 No Barrier, Varying Width

Varying roadway widths can cause considerably variability in the prediction patterns as was shown in 2.1.1 and 2.1.2. This effect was further evaluated to allow a better understanding of how RLINE predicted values change. Figure 6 shows a comparison of multiple roadway widths and the effect of including a 3-meter median.

Analysis. End effects are apparent in all as before. Inclusion of a median results in an extended downwind concentration gradient and increased discontinuity in the upwind dispersion pattern. Increased width results in concentrations patterns extending farther downwind. Upwind concentrations again appear to be greater than would be expected. This may be part of the meander algorithm. Also, upwind variations in concentrations occur near the roadway in varying degrees depending on configuration.

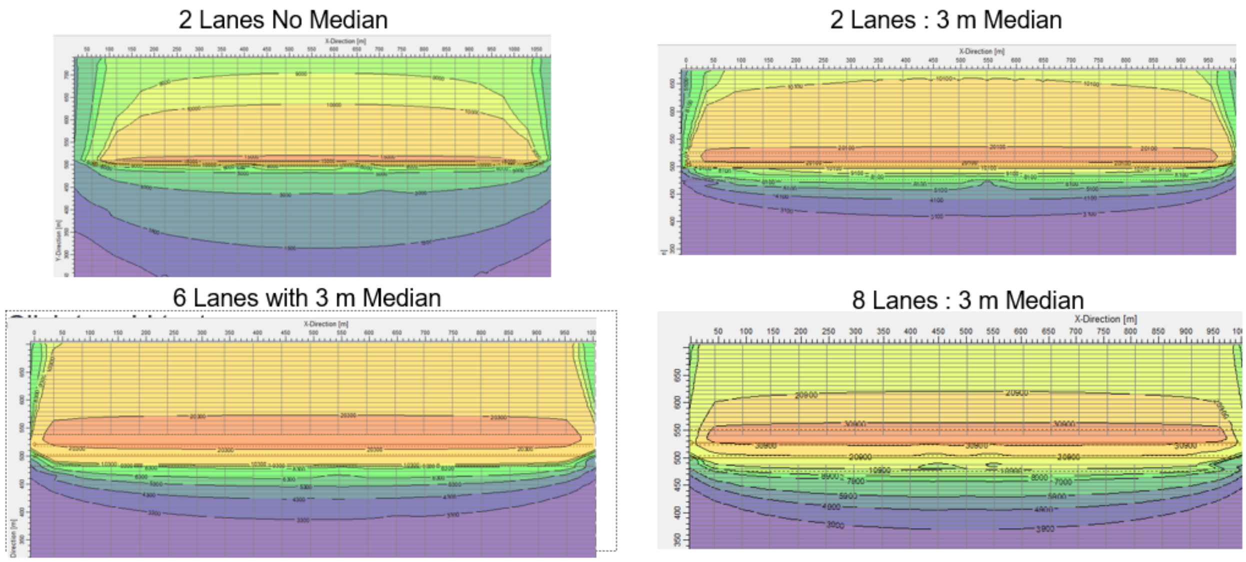


Figure 6. Comparison of Lanes and with Median with Wind from 180°

2.1.6 No Barrier, Single Lane, Segmented Roadway

Due to the roadway end effect problem noted for the concentration patterns, another test was run with a segmented roadway. In this case, the roadway was divided in the center and endpoints of both roadways exactly matched to form a continuous road, although in two links. Figure 7 shows the results of this evaluation.

Analysis. Figure 7 shows that extending roadways with additional links does not seem to cause end effects at the intersecting points if exact coordinates are used.

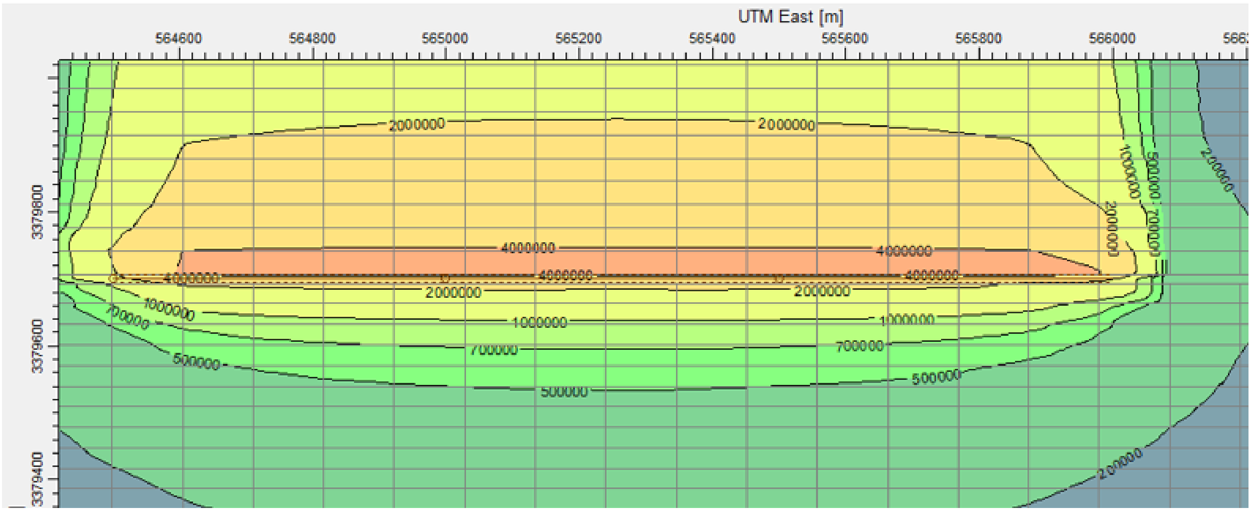


Figure 7. Roadway Modeled as Two Connected Links

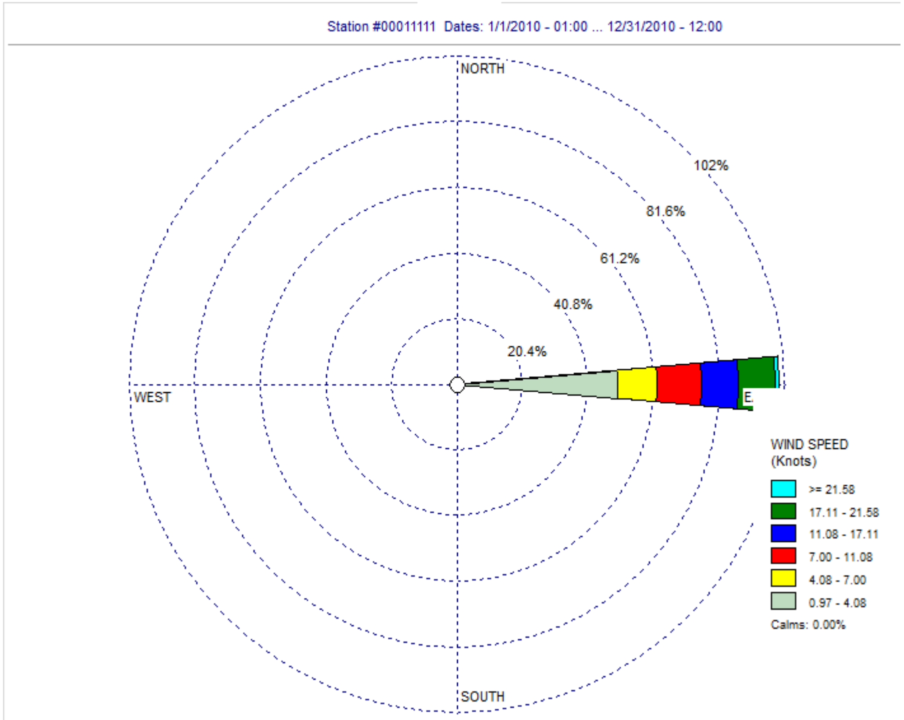
2.1.7 No Barrier, 2 Lanes, Parallel Wind

End effects were then evaluated for a parallel wind, blowing only from 90° and then from 270°. All other variables are the same as the scenario 2.2.2. Figure 8 shows the wind roses of the parallel winds while Figure 9 shows the predicted concentration patterns.

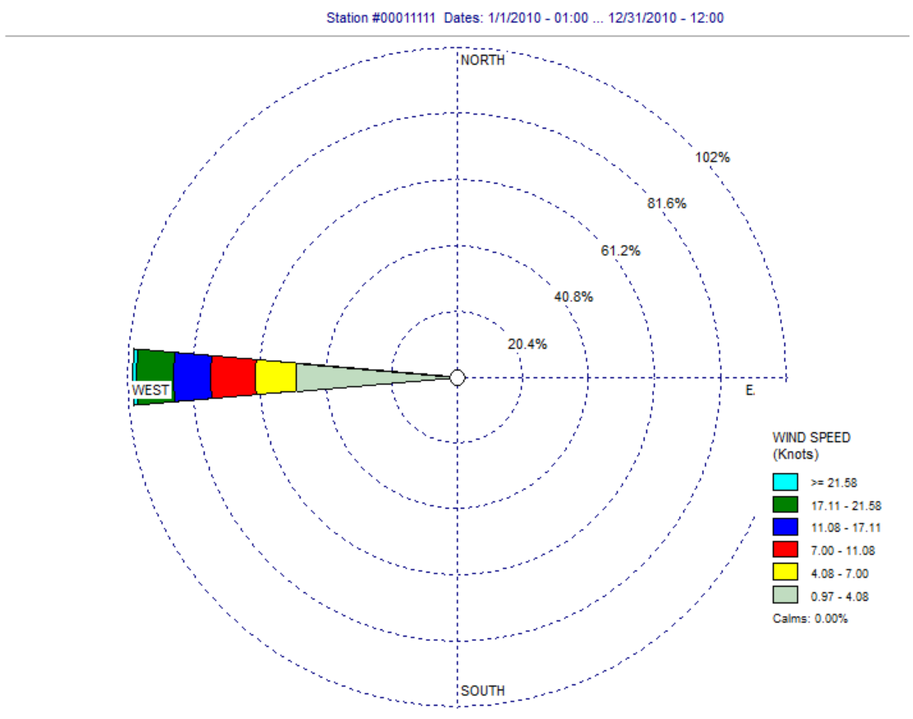
Analysis. There appears to be an accumulation of the emissions along the roadway resulting in a concentration pattern similar in shape to a point source but with increasing concentrations downwind due to the increasing emissions. In a real-world situation, the emissions would tend to accumulate along the roadway, and it cannot be determined if the effect from modeling is accurate since the accumulation tend to continue, even at large distances along the roadway. Intuitively, and from past project experience, it is thought that the concentrations would be limited at some point due to continuity along the roadway of emissions, plume rise, and increased dispersion for sources further upwind. This is an area that needs further consideration, especially since it may not be obvious with a more diverse wind pattern.

A cyclic nature of the concentration gradients is apparent at the plume edges. This is most likely caused by the point source approximation used for the line source.

A review of winds from 270°, also parallel to the roadway, show a very similar pattern (see Figure 9b).

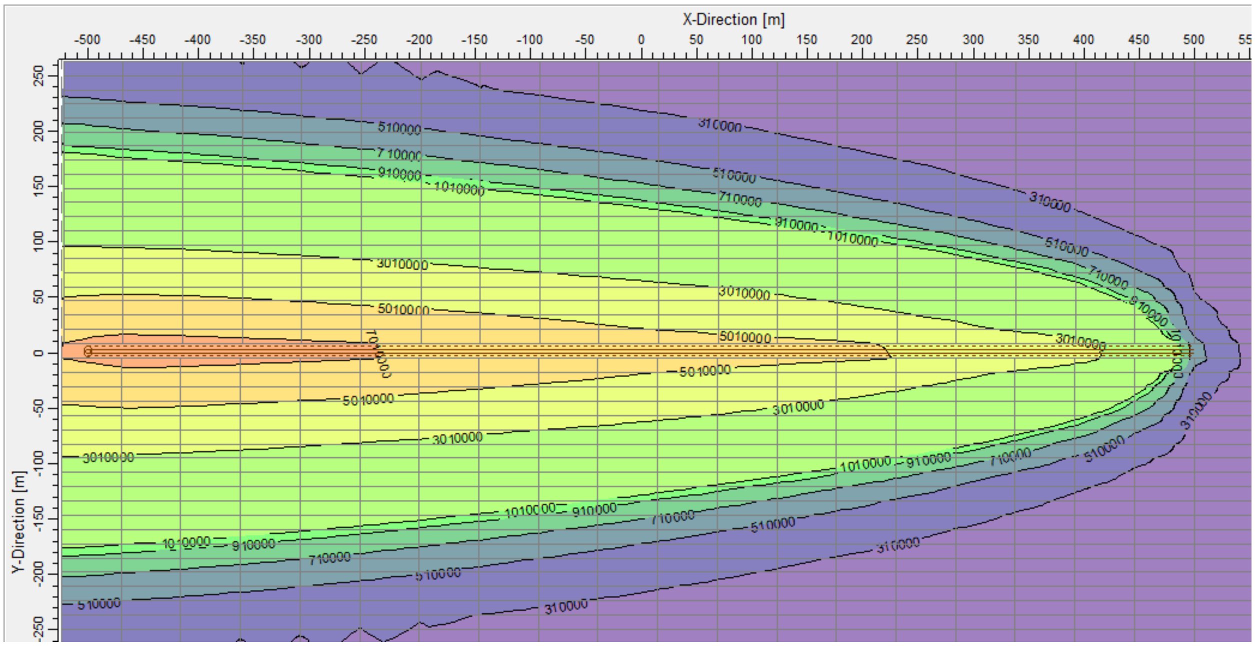


a. Wind Only From 90°

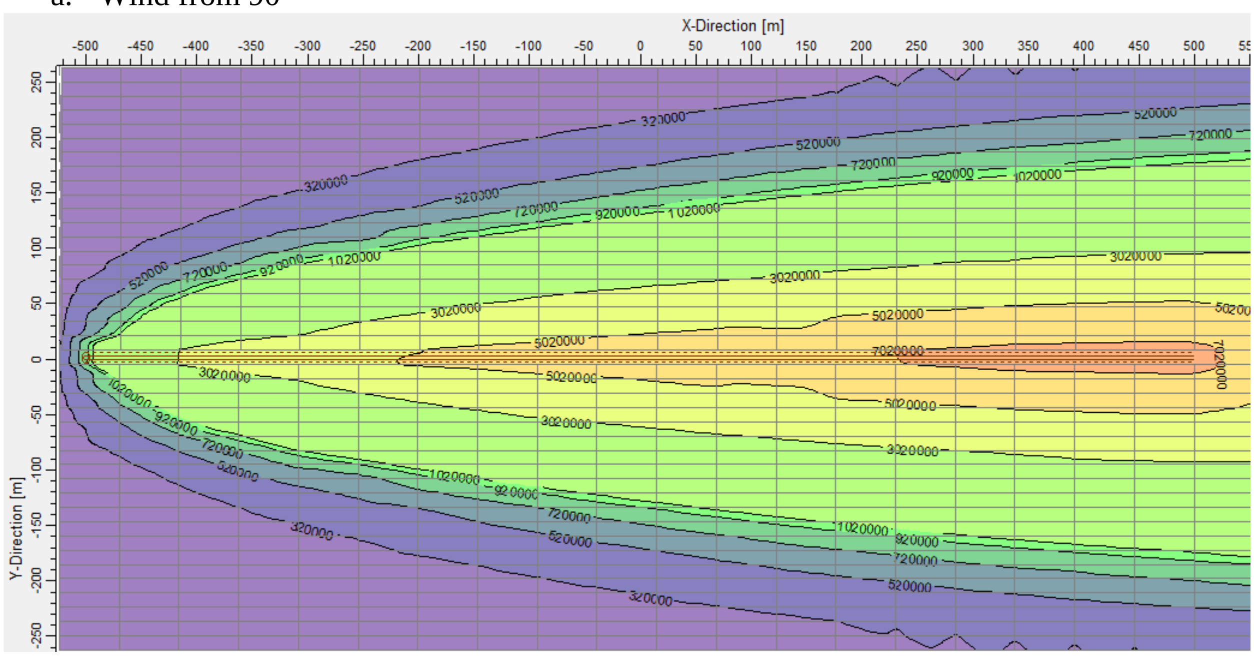


b. Wind Only from 270°

Figure 8. Wind Roses, Parallel Wind Analysis



a. Wind from 90°



b. Wind from 270°

Figure 9. Simple Roadway, Two Lanes, Parallel Winds

2.1.8 4 Lanes, With and Without Median, Parallel Wind

To further explore the effects of a parallel wind, a four-lane roadway was analyzed with and without a 3-meter median. Winds as previously used are only from the west (270°). Figure 10a shows the plotted results without a median while Figure 10b shows results with the median.

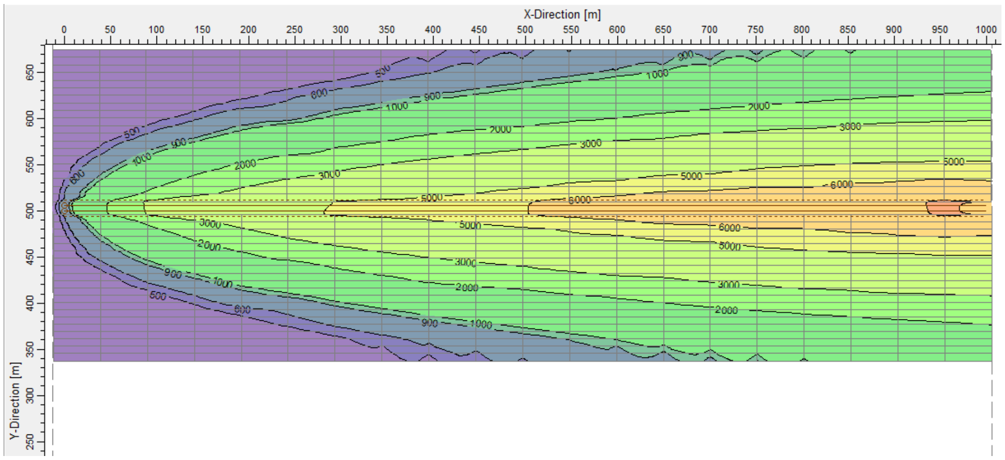
Analysis. Similar effects occur as with the 2-lane scenario. The resulting plume is similar in shape to a point source but with ever increasing concentrations occurring downwind. While an increase due to accumulating emissions would be expected, the degree to which this would occur is unknown and as such cannot be evaluated. Additionally, the "hot-spots" of increased concentrations at various intervals along the roadway should not occur and are again most likely due to the point source approximation scheme. Cyclic changes in concentrations occur at just over 100 meters from the roadway. The cyclic nature of concentrations away from the roadway should not be occurring and is most likely due to the point source iterative process.

The inclusion of a median has minor effects.

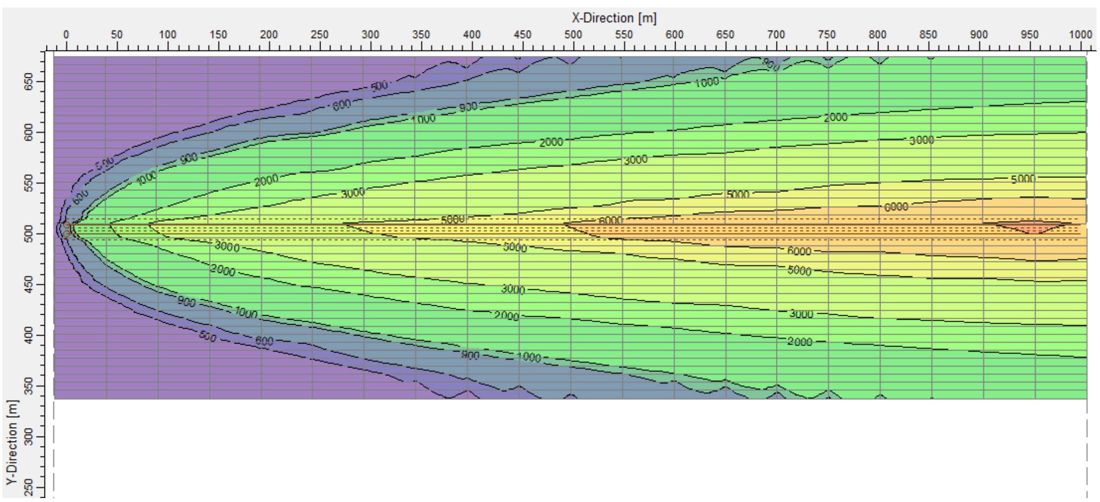
2.1.9 8 Lanes, No Median, Parallel Wind

To further explore the effects of a cross wind, an eight-lane roadway with no median was analyzed. Winds are only from the west (270°). Results are shown in Figure 11.

Analysis. Similar effects occur as with the single lane but with greatly increased concentrations. Emission factors had to be reduced to permit a valid AERMOD output file and so the predicted concentrations are not directly comparable, but trends can still be compared. The plume remains similar in shape to a point source but with ever increasing concentrations occur downwind. Cyclic changes in concentrations are visible away from the roadway. Again, the accumulating emissions resulting in the concentration pattern and the cyclic nature should be further evaluated.



a. No Median



b. With 3 Meter Median

Figure 10. 4-Lane Roadway, Parallel Wind

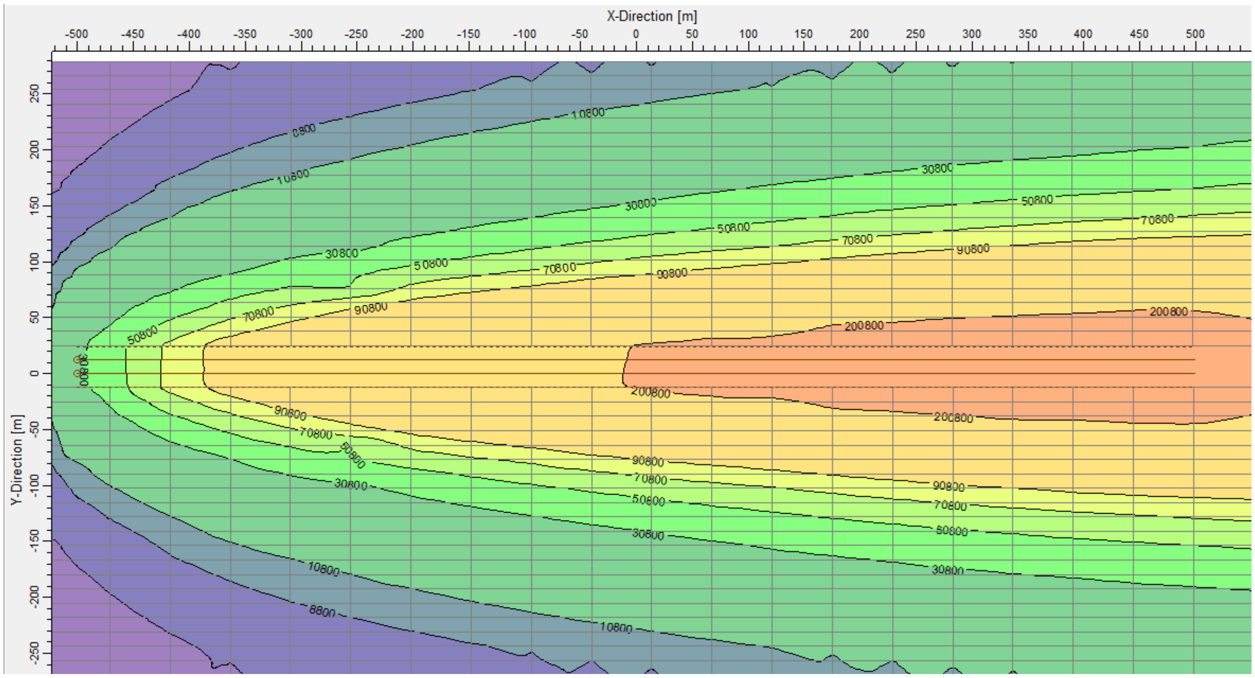


Figure 11. 8-Lane Roadway, No Median, Parallel Wind

2.2 Effects of Source Height

In this section source height effects on dispersion characteristics of RLINE are evaluated. Additionally, the effect of an initial vertical dimension (initial vertical dimension) of 2.2 meters is compared to the optional[11] initial vertical dimension of zero meters for various sources heights. Various sources recommend different values for these inputs. These inputs are critical because initial vertical dimension is sigma z, a measure of the plume height, and controls the initial concentration profile across the plume in the vertical. The source height interacts with this variable in terms of the height of the centerline concentration. This has a direct effect on receivers of various heights. In this document, the terminology initial vertical dimension is to correspond to the text in the AERMOD User Guide[12] and other texts. The optional vertical dimension leads to no input which results in a value of zero for the input.

2.2.1 Passenger Car Release Heights

The first test scenarios are an evaluation of release height commonly assumed for a passenger car while also evaluating the initial vertical dimension. The initial vertical dimension is varied from the optional input and again at 2.2 meters.

[11] U.S. EPA, Guidance on New R-LINE Additions to AERMOD 19191 for Refined Transportation Projects, EPA-420-B-19-042, 2019.
[12] U.S. EPA, User's Guide for the AMS/EPA Regulatory Model (AERMOD), EPA-454/B-19-027, 2019.

2.2.1.1 Passenger Car Release Height, Assumed 1.3 Meters

Using guidance[13] as suggested by EPA, a source height of 1.3 meters was included to simulate the release on a flat terrain of a passenger car. In this first scenario the initial vertical dimension is set at 2.2 meters to simulate a typical traffic mix. The wind rose as was shown in Figure 1 while Figure 12 is a plot of the results.

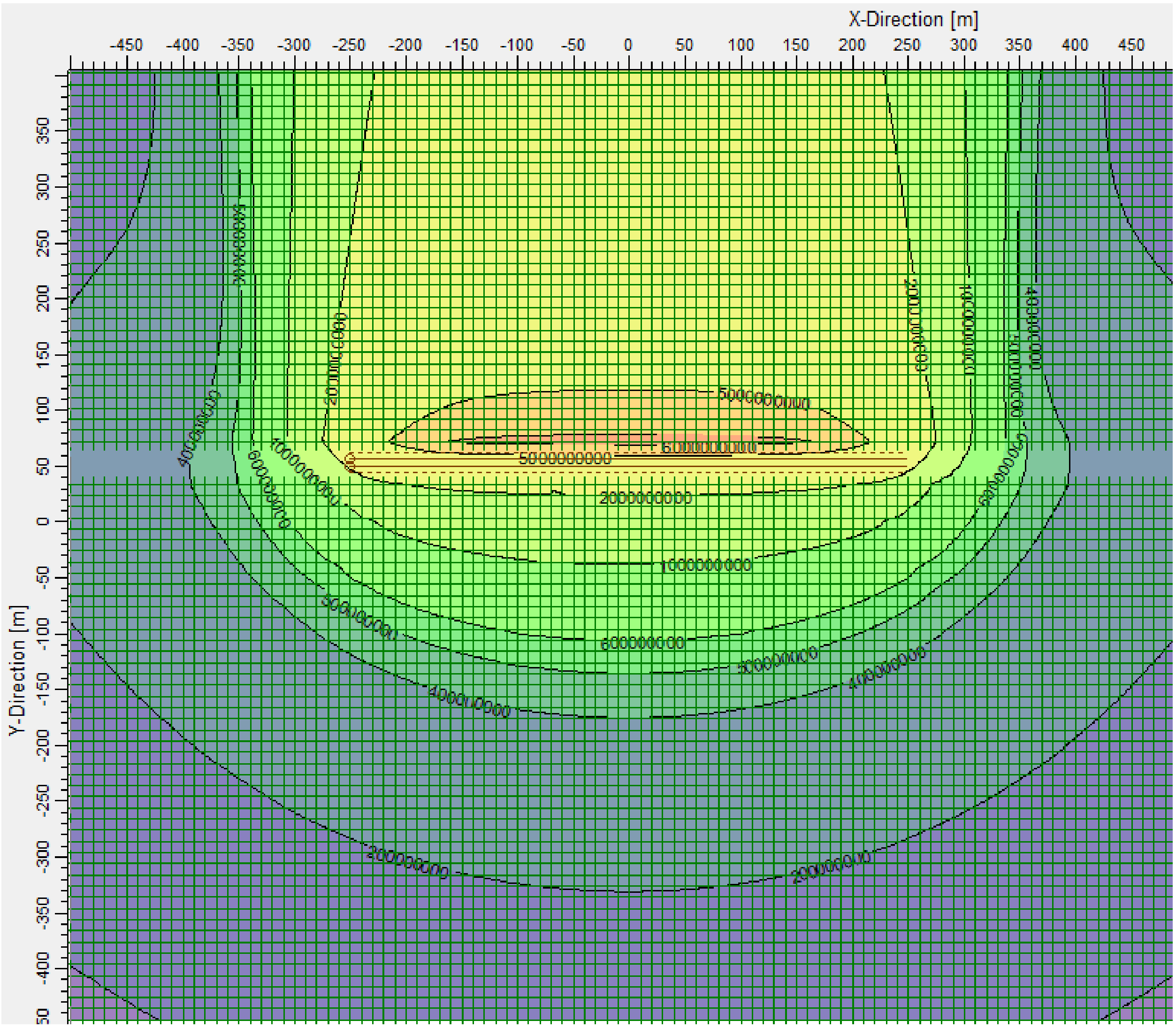


Figure 12. 2-Lane Roadway, No Median, Release Height 1.3 Meters

Analysis. As in all cases, end effects are still very prominent. For this 500-meter roadway, only about the center 250 meters would provide similar concentrations with distance from the roadway for the critical first row of homes downwind. Small inconsistencies are also shown near

[13] U.S. EPA, Module 4, Using AERMOD for PM Hot-Spot Analysis, Completing Quantitative PM Hot-spot Analysis, 3 Day Course, 2018.

the roadway. Upwind concentrations gradients extend a substantial distance and would appear to be more than could be expected from meander as the wind is limited to be from 180°.

2.2.1.2 Passenger Car Release Height, Assumed 1.3 Meters, Optional Initial Dimension

In this scenario, all inputs were held constant as in 2.2.1.1 except the initial vertical dimension which was excluded as optional input. Results are plotted and shown in Figure 13.

Analysis. A comparison of Figures 12 and 13 show significant differences. Concentrations for the optional initial dimension are substantially greater. There is a greater rate of change downwind of the roadway for the concentrations. The inconsistencies near the roadway have become more prominent and the upwind elevated concentrations again appear to extend too far upwind and change at a different rate than in 2.2.1.1.

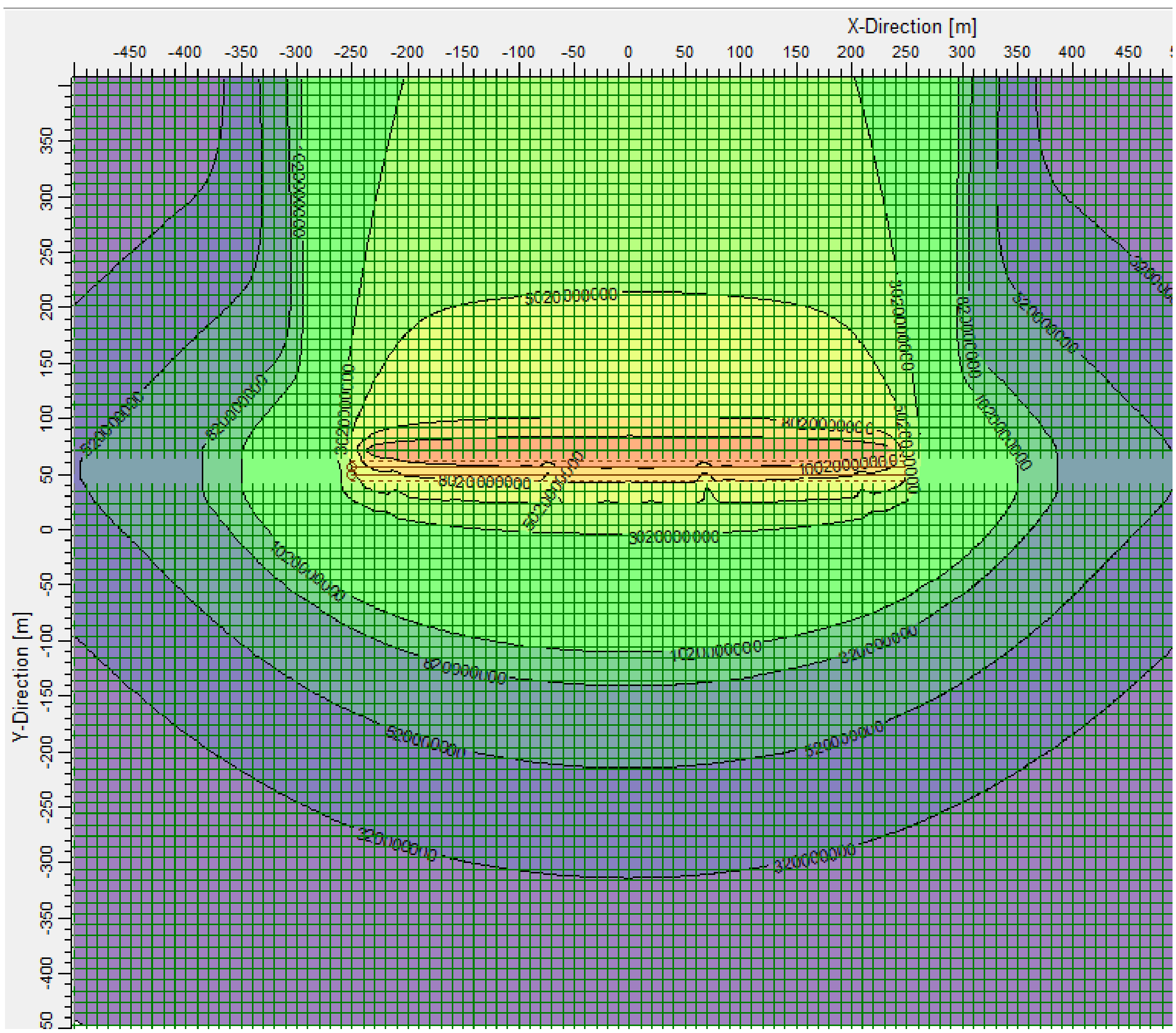


Figure 13. 2-Lane Roadway, No Median, Release Height 1.3 Meters, Optional Initial Vertical Dimension

2.2.2 Truck Release Height

In this series of tests, the release height was moved to 3.4 meters to simulate releases from truck traffic as suggested by the EPA Guidance. Two scenarios were evaluated: with an initial vertical dimension of 2.2 meters and with the optional initial vertical dimension (zero meters). Two roadways were included with a 6-meter width to simulate a two-lane roadway in each direction.

2.2.2.1 Truck Release Height, Assumed 3.4 Meters, Initial Vertical Dimension of 2.2 Meters

For this analysis, variables remain constant as discussed in 2.2.1.1 except the release height is now assumed to be from a truck at 3.4 meters above the roadway. Winds were again from the south. Results are shown in Figure 14.

Analysis. As was shown for passenger cars, end effects reduce the true modeling regime to about 250 meters, centered along the 500-meter roadway. The concentration gradient reduces at a more gradual downwind and near the roadway has a smaller "island" of increased concentration and concentrations for the 1.8-meter receptor height are much less. Upwind concentration gradients fall off at a greater rate than for passenger cars, and concentrations are much less but still are greater than would be expected upwind.

2.2.2.2 Truck Release Height, Assumed 3.4 Meters, Optional Initial Vertical Dimension

Continuing the testing of these two variables, a separate run was accomplished with the same parameters as 2.2.2.1 except the optional vertical dimension of zero meters was used. Again, for consistency, a south wind was used. Results are shown in Figure 15.

Analysis. As shown in Figure 15, there is a different dispersion pattern with the concentration "island" disappearing and concentrations are less. End effects still occur. Major perturbations in concentrations upwind of the roadway now occur and concentrations still seem to be too high at extended upwind distance from the roadway.

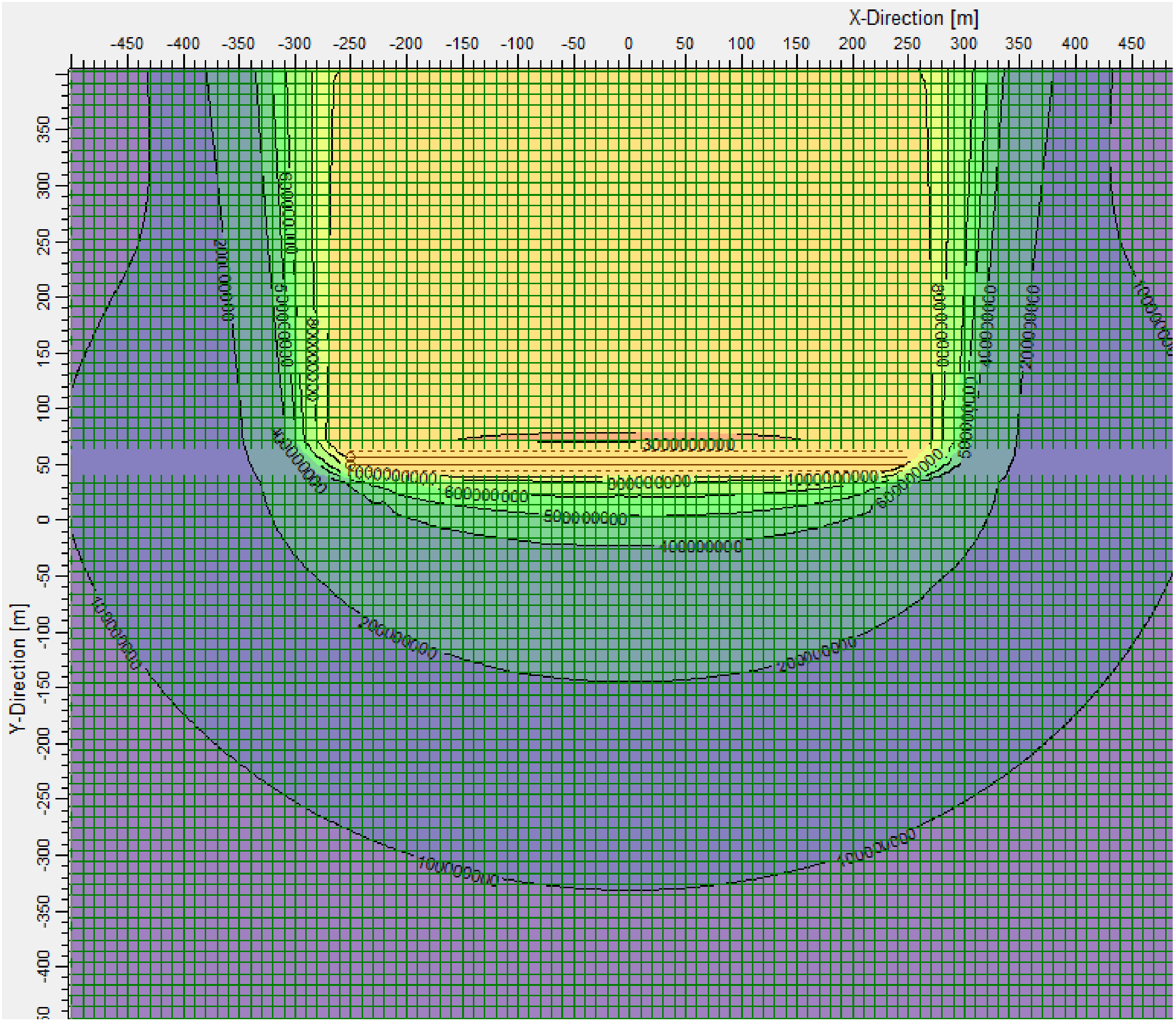


Figure 14. 2 Simple Roadway; Wind from 180°, 2 Lanes Each Direction, Initial Vertical Dimension 2.2, Release Height 3.4 Meters

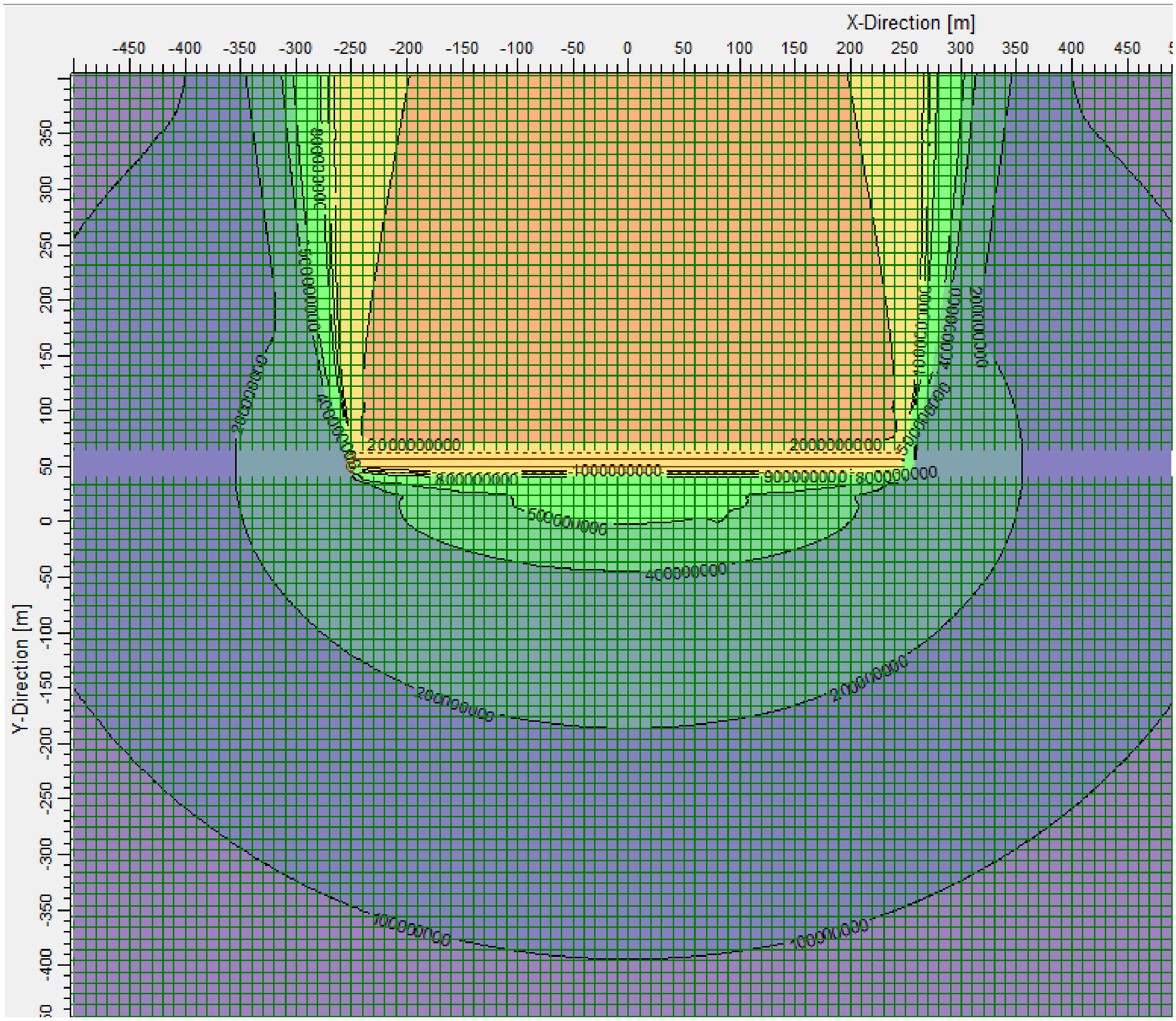


Figure 15. Simple Roadway; Wind from 180°, 2 Lanes Each Direction, Optional Initial Vertical Dimension, Release Height 3.4 Meters

2.2.3 Elevated Release Height, Assumed 10 Meter Bridge Height

Many roadways are on fill or elevated structures and as such are above the local ground plane. How to model these has not been well defined and multiple considerations are needed. For example, the emissions cannot go through concrete. As such, plume expansion in the vertical is limited and reflection could occur. Accordingly, innovative ideas such as not modeling the roadway along the vehicle path but rather at the edge of the fill or structure. Additionally, elevated structures may also have parapet walls. Modeling with RLINEXT by placing a barrier at the structure edge and defining the total height to be at the top of the parapet wall may be another option. In this series of tests, the roadway was first simply elevated to determine the trends as compared to the release heights for cars and trucks in two scenarios and in a third scenario. Then to test the idea of using RLINEXT, a parapet wall was defined using the barrier algorithm.

2.2.3.1 Elevated Release Height, Assumed 10 Meter Bridge Height, Initial Vertical Dimension 2.2 Meters

In this scenario, a release height of 10 meters was used to simulate the plume being released from a roadway on fill or an elevated structure such as a bridge. The initial vertical dimension was 2.2 meters. Of note is that the roadway widths were not extended as would be required to extend to the edge of the bridge decking and no height was included for a parapet wall. Both considerations may need to be considered in actual project modeling. Winds are from the south and modeling results are shown in Figure 16.

Analysis. As expected, concentrations are greatly reduced near the roadway. However, for this release height, unusual results occur. In addition to end effects, there are two major areas of increased concentrations away from the roadway at approximately 100 and 300 meters. An area of increased concentration away from the roadway would be expected as the plume expansion increases downwind, and the plume comes to the ground. This is often observed for elevated stacks. Initially, it was considered that the two roadways created the two areas of increased concentrations. However, the distance between the two areas of increased concentrations would seem to be too great to be caused by the two lanes modeled and the reason can only be guessed. Additionally, the overall plume shape near the fringes of the plume between the two areas of increased concentrations indicates the plume is still expanding in the horizontal (y-direction) but does not explain the two areas of increased concentrations. Upwind concentrations appear to be higher than expected with only a wind from 180°. More work is needed on how elevated structures can be modeled and the reason for the locations of the increased concentrations and high upwind concentrations.

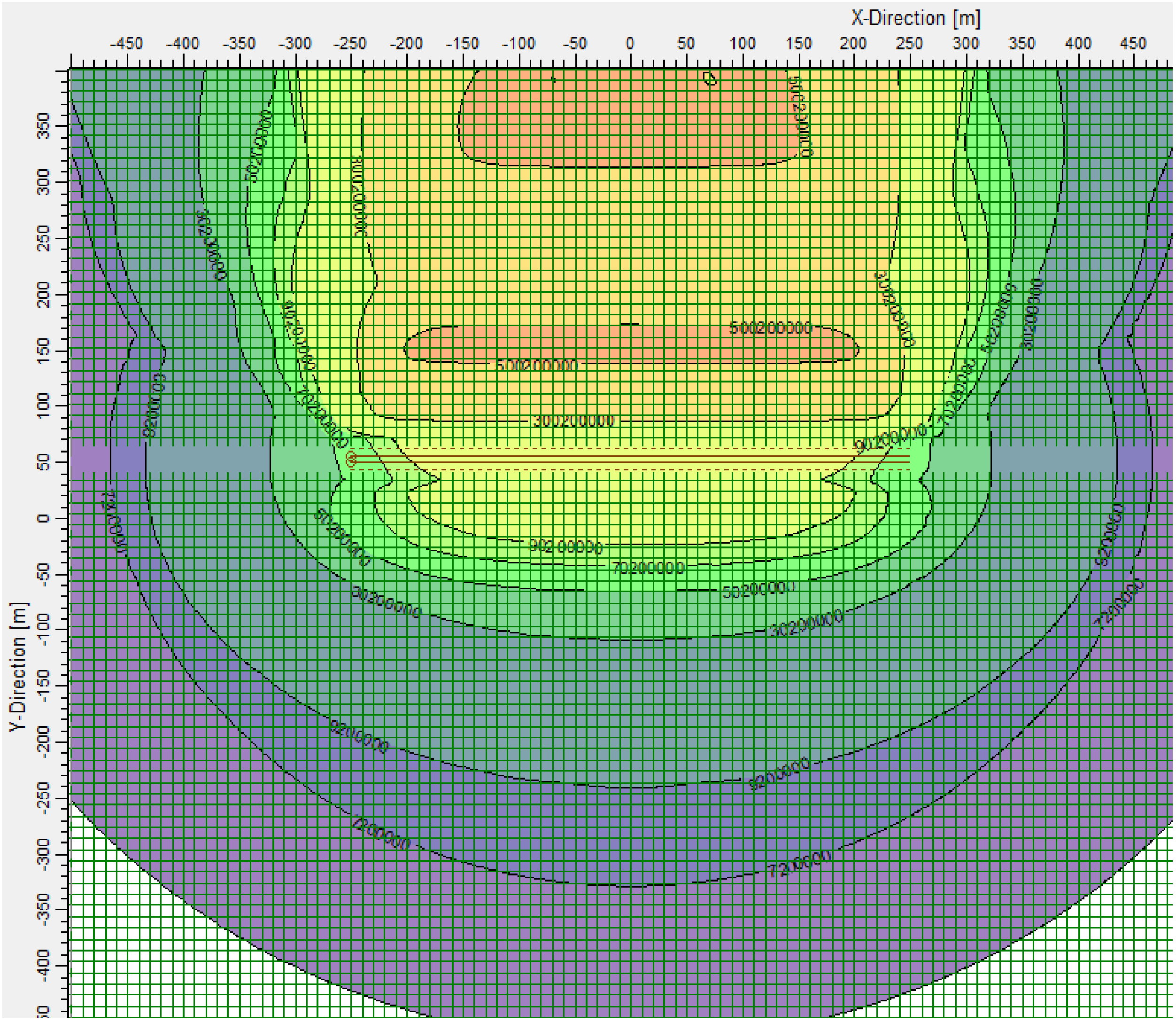


Figure 16. 2-Lane Roadway, Elevated Release Height, 10 Meters

2.2.3.2 Elevated Release Height, Assumed 10 Meter Bridge Height, Optional Initial Vertical Dimension of Zero Meters

To further investigate the effects of height, modeling was done for the same 10-meter elevated section, but with the optional initial vertical dimension set to zero meters. All other inputs were held constant. Graphical results are included in Figure 17. Again, the goal was only to review the dispersion trends and not compare absolute values.

Analysis. Results were similar from when an initial vertical dimension was used. End effects still occur and the strange differences in the contours upwind of the roadway become more prominent. This would drastically limit where valid receivers could be placed. More detailed examination is needed in future work as well as comparisons to measured data.

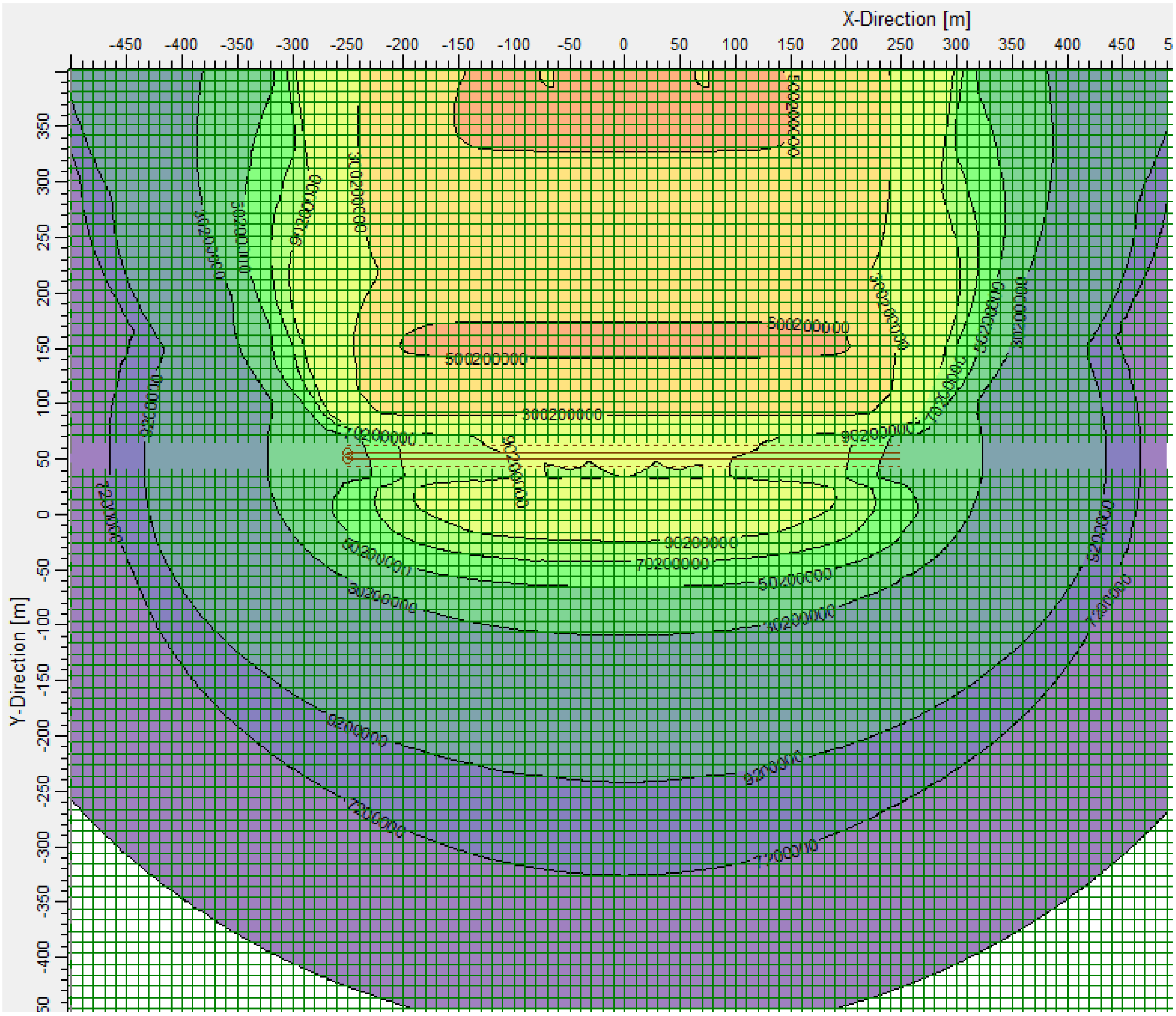


Figure 17. Simple Roadway; Wind from 180°, 2 Lanes Each Direction, Elevated Section

2.2.3.3 Elevated Section with Parapet Wall as Barrier

To evaluate another possible modeling solution for elevated roadway structures, RLINEXT was used. In this scenario, roadway sources are identical to 2.2.3.1 but a barrier has been included downwind, 5 meters from the center of the downwind roadway to simulate a small shoulder area before a parapet wall. The barrier height was set at 11.5 meters to simulate a parapet wall height of 1.5 meters. Results are shown in Figure 18.

Analysis. In this case the downwind concentrations immediately near the roadway were decreased. The barrier resulted in a more linear falloff in concentrations resulting in slightly higher concentrations further downwind from the roadway. The resulting falloff pattern resembling a dome shape and the “islands” of increased concentration no longer are predicted. Upwind cyclic perturbations are reduced. Again, concentrations seem to be too great upwind.

This scenario points to a possible methodology to model roadways on structure but can only show the differences in concentration patterns. Work to refine and real-world data for comparison is needed to be able to recommend a methodology.

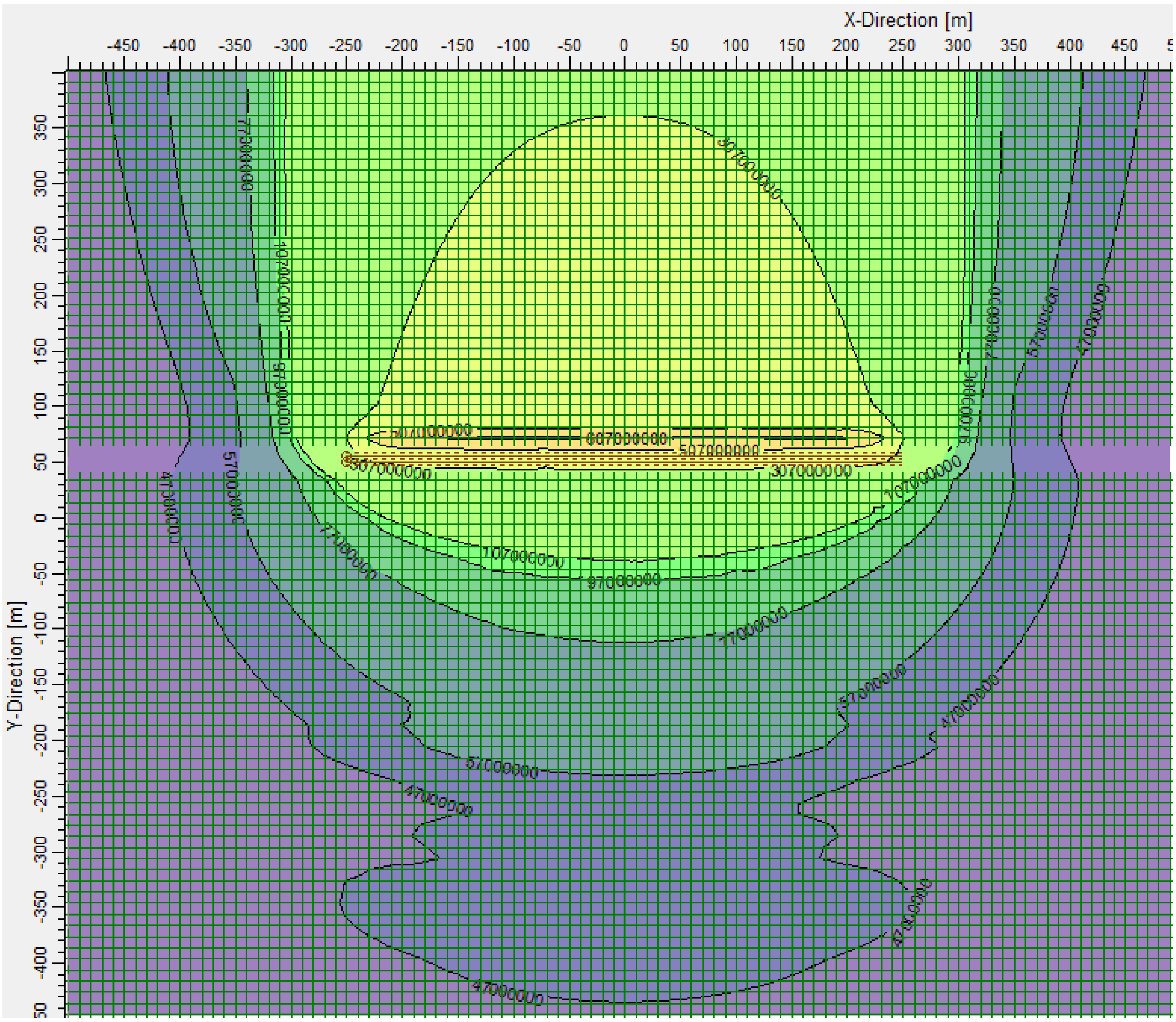


Figure 18. Two roadways with Simulated Parapet Wall Using RLINEXT

2.2.4 Comparative Evaluation of Release Heights and Initial Vertical Dimension

In previous sections, release heights from simple roadways were evaluated as was the initial vertical dimension. This testing showed that these inputs are very important and can have significant effects during modeling. Due to the importance of these inputs for heavily traveled roadways a more detailed comparative analysis was conducted. Because vehicle movements along a roadway create a pumping action, extreme mechanical turbulence and mixing occurs and this is an area of further consideration. In addition to the mechanical turbulence, thermal turbulence also occurs, and measurements have shown plume rise occurring from downwind of the roadway.[14] Increased emission source height (release height) during low wind speeds has been long been known such as in models such as TEXIN[15] and greater values of the initial vertical dimension in modeling[16] has been used for these reasons. Accordingly, the term "release height" is somewhat misleading because it is not the height of the vehicle exhaust pipe that matters, but the height of the center of the plume as it leaves the roadway. Some measurements have verified this phenomenon[17,18] but additional measurements to supply a strong database to provide needed guidance would seem to be required. Additionally, different pollutants may have varying source heights. For example, particulate matter from the brakes and tire wear could come from a different height than exhaust emissions and be dispersed in the initial mixing cell differently.

In this evaluation, release heights were varied from 1 to 10 meters in 1-meter increments for different scenarios: using the optional initial vertical dimension, with an initial vertical dimension of 2.2 meters, and for an at-grade main lane with a separate elevated ramp. The source for the first two tests shown in 2.2.4.1 and 2.2.4.2 was a 2-lane roadway and evaluated at distances from 25 to 200 meters in 25-meter increments directly downwind of the roadway. Wind speeds with a 1 m/s at a height of 10 meters were used as in all previous analysis. Winds were perpendicular cross winds. Again, since this is not a validation study but rather a study of model results, absolute values were not the goal, just relative differences and trends that occur. The 2.3-meter release height was considered the base case and all other scenarios were compared to this height by using the 2.3-meter height results as the numerator and other height results as the denominator. This normalization of data provides a perspective to how modeled concentrations would change compared to the 2.3-meter height since absolute values are not known. A value less than one shows the base values (2.3-meter release height) to be less than the modeled concentration at another height while ratios greater than one shows the base value to be greater than the newly modeled value. The ratios are important as they show the trend from a somewhat typical at-grade roadway as compared to other heights.

Directly related to the release height is the initial vertical dimension (sigma z). Various schemes have been used to attempt better estimates of the initial vertical dimension as well as release height. Accordingly, the initial vertical dimension was evaluated to determine the overall relative effect on predictions.

2.2.4.1 Optional Initial Vertical Dimension

It should be noted that the authors prefer use of an initial vertical dimension other than zero. However, since the model optional value is zero meters, testing was included for completeness.

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[14] Bullin, J.A., et al., Vehicle Emissions at Intersections, Report No. 250-2F, Texas State Dept. of Hwys and Public Trans., 1983.

[15] Messina, A.D., et. al., User's Guide for the TEXIN Model, Report No. FHWA/TX-81/541-2F, US DOT, Federal Highway Administration, 1982.

[16] Benson, P.E., CALINE4 – A Dispersion Model for Predicting Air Pollutant Concentrations Near Roadways, FHWA/CA/TL-84/15, 1984.

[17] Dabberdt, W.F., Studies of Air Quality on and Near Highways, Project 2761, Stanford Research Institute, 1975.

[18] Cadle, S.H., et. al., Results of the General Motors Sulfate Dispersion Experiment, General Motors Research Laboratories, GMR-2107, 1976.

Table 2 shows the modeled concentrations although the values presented should not be considered absolute values since as before, arbitrary large emission factors were utilized to highlight results and absolute values are unknown. Table 3 shows the resulting normalized values (ratios) as compared to the modeled results of the 2.3-meter release height. Figure 19 shows the results from this evaluation.

Table 2. Modeled Concentrations by Source Height and Distance from Roadway with Optional Initial Vertical Dimension

Release	**Distance from Centerline of Near Roadway**							
Height	*25*	*50*	*75*	*100*	*125*	*150*	*175*	*200*
1	5684.9	4668.3	4135.2	3786.4	3524.8	3314.5	1358.6	1345.7
2	6548.4	4479.5	3661.6	3230.7	2961.3	2771.3	1255.6	1244.2
3	1844.5	2321.5	2272.9	2150.3	2040.3	1952.2	1101.2	1092.5
4	761.7	897.5	931.4	1031.7	1079.4	1099.4	917.2	912.2
5	482.0	595.6	618.9	650.4	672.3	670.6	726.3	724.5
6	339.8	456.8	456.0	475.3	505.2	508.3	551.7	552.1
7	241.5	372.8	398.7	352.4	381.1	408.3	435.9	436.3
8	163.3	314.2	338.7	325.5	279.1	313.8	335.4	337.2
9	107.3	257.3	279.0	296.4	264.9	229.9	248.9	251.4
10	78.7	213.2	251.9	265.9	249.5	218.4	210.1	208.2
2.3	5379.065	4018.674	3340.865	2959.205	2717.138	2547.833	1213.737	1203.32

(Relative Concentrations Used Only for Trend Analysis)

Table 3. Normalized Values (Ratios) as Compared to 2.3 Meter Release Height with Optional Initial Vertical Dimension

Release	**Distance from Centerline of Near Roadway**							
Height	*25*	*50*	*75*	*100*	*125*	*150*	*175*	*200*
1	0.95	0.86	0.81	0.78	0.77	0.77	0.89	0.89
2	0.82	0.90	0.91	0.92	0.92	0.92	0.97	0.97
3	2.92	1.73	1.47	1.38	1.33	1.31	1.10	1.10
4	7.06	4.48	3.59	2.87	2.52	2.32	1.32	1.32
5	11.16	6.75	5.40	4.55	4.04	3.80	1.67	1.66
6	15.83	8.80	7.33	6.23	5.38	5.01	2.20	2.18
7	22.27	10.78	8.38	8.40	7.13	6.24	2.78	2.76
8	32.94	12.79	9.86	9.09	9.74	8.12	3.62	3.57
9	50.13	15.62	11.97	9.98	10.26	11.08	4.88	4.79
10	68.33	18.85	13.26	11.13	10.89	11.67	5.78	5.78

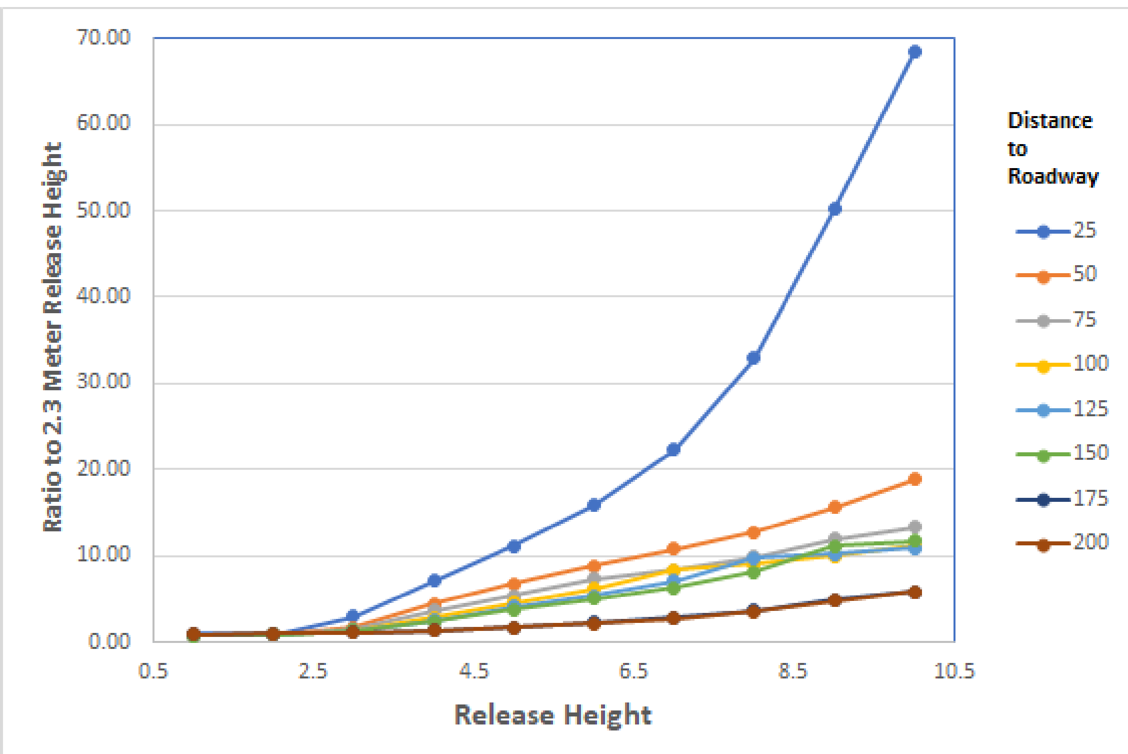


Figure 19. Trends Determined by Comparative Analysis to a Release Height of 2.3 Meters at 25 to 200 Meters from Roadway (Optional Initial Vertical Dimension)

Analysis. The general trend shown in Tables 2 and 3 is that with increased release height, predicted values decrease for receivers up to 200 meters from the roadway and receiver heights of 1.8 meters. The exception being at 25 meters for a release height of 1 meter since the plume expansion from zero (optional initial vertical dimension) has not increased enough making the receiver further from the centerline and away from the center of the plume. Differences in concentrations from the base case are most often greater closer to the roadway but not always.

To show this variation in the comparative analysis, the trends were plotted in Figure 19. In this figure, the different trend for the 25-meter position from the roadway is obvious. This is due to a much greater reduction in concentration occurring with increasing release height at this position. The effect is most likely due to the vertical plume spread algorithm. As the plume release height increases, the plume centerline and maximum plume concentrations moves further from the receptor height for the relatively close distance to the roadway. Differences from the 2.3-meter release height ranged from 0.77 to 68.33 which is quite substantial. The value of 68.33 means that at 25 meters from the roadway, and a release height of 10 meters, concentrations are over 68 times less for the 2.3-meter release height. Perhaps even more importantly, changing the release height from 2 to 3 meters still results in a change of over a factor of 2. This highlights the need for consideration of source heights and possible establishment of guidelines because of the need for near-field modeling of some pollutants. This same effect is shown to a lesser extent for the 50-meter location. At over 175 meters, the effect seems become much less.

Another, less noticeable change is that the comparative concentration trends change for some distances for release heights of 7 meters and greater, especially for the 100 to 150-meter receiver positions. The reason for this is less obvious but is a consideration during further evaluations.

2.2.4.2 Initial Vertical Dimension of 2.2 Meters

The same analysis as for the optional initial vertical dimension was completed but with an initial vertical dimension of 2.2 meters which is considered a somewhat typical value by the authors. However, the term typical value is somewhat arbitrary, and more research is needed. All other parameters remained as described in 2.2.4.1. Table 4 shows the modeled concentrations, again for completeness, but the listed concentrations should not be considered as absolute values. Table 5 shows the resulting normalized values (ratios) as compared to the modeled results of the 2.3-meter release height. Again, the ratios are important as they show the trend from a somewhat typical at-grade roadway as compared to other heights. This series of tests also allowed a comparison to the modeled results from the use of the optional initial vertical dimension. Figure 20 shows the results from this evaluation.

Table 4. Modeled Concentrations by Source Height and Distance from Roadway with Initial Vertical Dimension of 2.2 Meters

Release	**Distance from Centerline of Near Roadway**							
Height	*25*	*50*	*75*	*100*	*125*	*150*	*175*	*200*
1	3663.3	3260.1	3002.9	2812.3	2661.1	2535.8	1211.2	1200.0
2	2937.8	2671.0	2495.8	2363.5	2256.7	2167.2	1131.1	1121.5
3	2058.5	1926.4	1838.7	1771.3	1716.0	1668.6	1010.0	1002.7
4	1261.4	1222.7	1200.5	1184.2	1170.5	1158.3	863.1	858.3
5	673.1	680.8	696.5	712.5	726.4	737.5	706.8	704.5
6	377.8	474.7	466.3	501.6	512.5	524.1	555.5	555.0
7	277.9	374.8	396.6	369.7	402.2	415.7	438.3	438.0
8	203.6	318.9	341.9	322.5	302.6	330.8	347.2	348.1
9	144.2	266.5	287.0	295.0	262.9	253.0	266.7	268.4
10	100.2	216.9	251.6	266.1	248.0	217.2	208.5	206.6
2.3	2677.468	2453.893	2306.019	2193.65	2102.516	2025.666	1098.446	1089.5

(Relative Concentrations Used Only for Trend Analysis)

Table 5. Normalized Values (Ratios) as Compared to 2.3 Meter Release Height with Initial Vertical Dimension of 2.2 Meters

Release	**Distance from Centerline of Near Roadway**							
Height	*25*	*50*	*75*	*100*	*125*	*150*	*175*	*200*
1	0.73	0.75	0.77	0.78	0.79	0.80	0.91	0.91
2	0.91	0.92	0.92	0.93	0.93	0.93	0.97	0.97
3	1.30	1.27	1.25	1.24	1.23	1.21	1.09	1.09
4	2.12	2.01	1.92	1.85	1.80	1.75	1.27	1.27
5	3.98	3.60	3.31	3.08	2.89	2.75	1.55	1.55
6	7.09	5.17	4.95	4.37	4.10	3.87	1.98	1.96
7	9.63	6.55	5.81	5.93	5.23	4.87	2.51	2.49
8	13.15	7.70	6.74	6.80	6.95	6.12	3.16	3.13
9	18.57	9.21	8.04	7.44	8.00	8.01	4.12	4.06
10	26.72	11.31	9.17	8.24	8.48	9.33	5.27	5.27

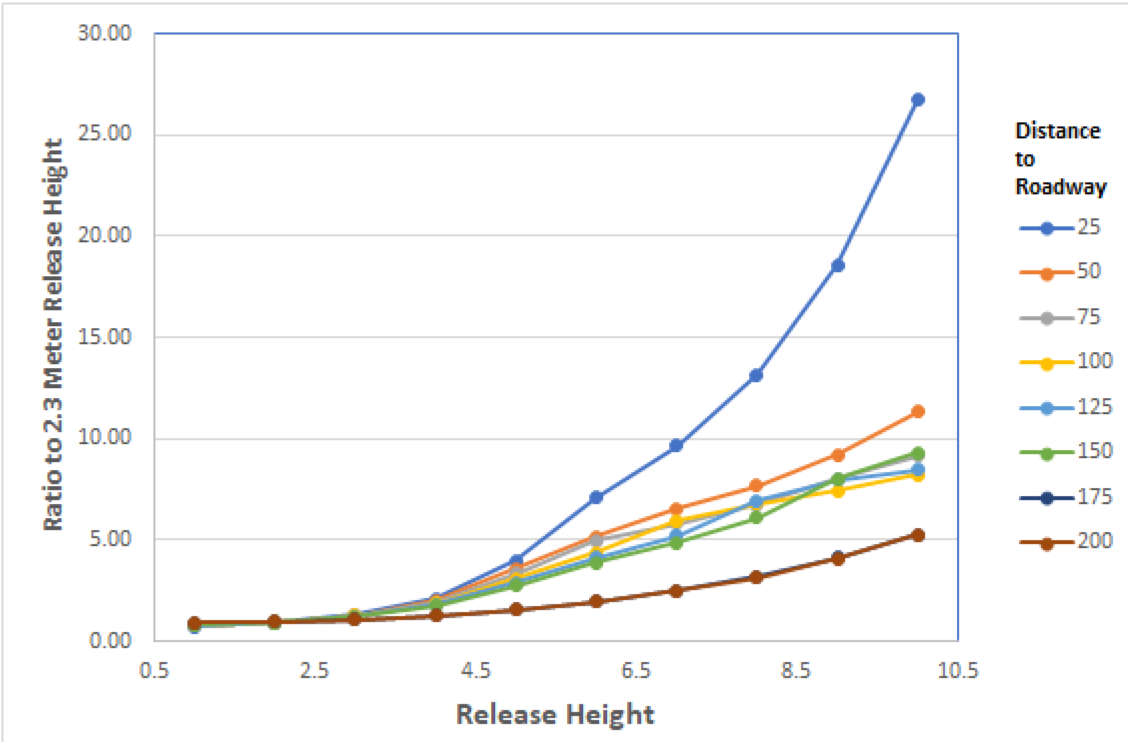


Figure 20. Trends Determined by Comparative Analysis to a Release Height of 2.3 Meters at 25 to 200 Meters from Roadway (Initial Vertical Dimension = 2.2 Meters)

Analysis. The trends in concentrations are similar with the results when the initial vertical dimension is set to zero, but with one large difference. The exception for the one-meter release height no longer occurs which would seem to be intuitively more correct. This is another reason that suggest guidance for the initial vertical dimension may be needed.

The first finding when comparing the trends in Tables 3 and 5 as well as Figures 19 and 20 is that ratios from the optional initial vertical dimension as compared to the 2.2-meter dimension are much less, meaning predicted concentrations do not change as much from the base case. However, values still range from 0.73 to 26.72 and so is not trivial. The change from a release height of 2 compared to 3 meters is only about a factor of 1.4 as compared to a factor of greater than 2 when a value of zero was used for the initial vertical dimension. The smaller changes are due to the plume not being forced to expand downwind from zero but has an initial distribution in the vertical. The increased vertical plume width results in the 1.8-meter receptors not experiencing as drastic changes from the plume centerline. This is reinforced by comparison of the relative concentrations in Tables 2 and 4. The 25-meter position still shows a greater effect with height but smaller in scale than in 2.2.4.1. Other trends as noted previously remain including the change in trends for distances of 100 to 150-meters.

The analysis reported in 2.2.4.1 and 2.2.4.2 show the importance of the vertical dimension and initial vertical dimension and the relationship of each to the other. As previously described, these are not static values but would change with traffic mix, volume, speed, and ambient temperature. Using the optional value of zero for the initial vertical dimension could result in much different predicted concentrations and is not thought by the authors to be good practice. More work is needed to define a consistent methodology for these two key variables and additional analysis is provided in 2.2.5.

2.2.4.3 Effect of Elevated Ramps or Crossovers

In sections 2.2.4.1 and 2.2.4.2, the effect due elevation of the main lanes was explored along with initial vertical dimensions. But a common occurrence for highway traffic is a difference in elevation for different lane movements for various reasons such as on-ramps to a road on fill, ramps to a depressed section, overpasses, varying terrain features that must be overcome, etc. While all of these were beyond the scope of this work, it was considered important to review results from an at-grade main lane with elevated ramps or overpass. This was accomplished in a simple fashion by modeling parallel roadways with an extended separation from centerline to centerline to avoid the initial high concentrations created by the main lanes as was previously shown (see Figures 1 and 3). The main lanes were kept at grade while the other lanes were evaluated at elevations ranging from 1 to 10 meters. The lanes that were varied in elevation were downwind of the main lanes. Receivers were downwind of both roadways and the receiver distances are from the downwind lanes. Again, for normalization purposes, a ratio to a source height of 2.3 meters was used to display trends. For simplicity, single lanes were used to avoid extra effects caused by the multiple lanes.

Table 6 shows the modeled concentrations again for completeness. The concentrations should not be considered absolute values. Table 7 shows the resulting normalized values (ratios) as compared to the modeled results of the 2.3-meter release height. In this case the ratios are important as they show the trend from a typical at-grade roadway as compared to lanes of other heights that could be for various purposes. Figure 21 shows the results from the normalized testing (results compared to 2.3-meter release height for other than main lanes).

Table 6. Modeled Concentrations by Source Height and Distance from Roadway. At grade main lanes compared to other lanes of various heights

	Distance from Centerline of Near Roadway							
Height	*25*	*50*	*75*	*100*	*125*	*150*	*175*	*200*
1	480.2	413.7	375.3	348.5	327.5	310.27	134	132.7
2	452.7	385.4	347.9	322.5	303.2	287.5	129.2	128
3	396.9	338.4	306.3	284.8	268.5	255.4	121.9	120.8
4	334.9	286.6	261.5	244.9	232.3	222	113.2	112.3
5	301.5	253.1	229.4	214.6	203.7	194.9	104	103.3
6	292.3	240.6	214.7	198.7	187.2	178.2	95.4	94.8
7	290.3	237.5	210.3	193	180.4	170.5	87.9	87.4
8	289.5	236.6	209.1	191.4	178.3	167.8	81.6	81.3
9	289.1	236.2	208.6	190.8	177.6	167	77.1	76.6
10	288.8	235.9	208.4	190.6	177.3	166.7	73.7	73.2
2.3	438.9	373	336.6	312.1	293.54	278.5	127.2	126

(Relative Concentrations Used Only for Trend Analysis)

Table 7. Normalized Values (Ratios) as Compared to 2.3 Meter Release Height with At Grade Main Lanes Compared to Other Lanes of Various Heights.

	Distance from Centerline of Near Roadway							
Height	*25*	*50*	*75*	*100*	*125*	*150*	*175*	*200*
1	0.91	0.90	0.90	0.90	0.90	0.90	0.95	0.95
2	0.97	0.97	0.97	0.97	0.97	0.97	0.98	0.98
3	1.11	1.10	1.10	1.10	1.09	1.09	1.04	1.04
4	1.31	1.30	1.29	1.27	1.26	1.25	1.12	1.12
5	1.46	1.47	1.47	1.45	1.44	1.43	1.22	1.22
6	1.50	1.55	1.57	1.57	1.57	1.56	1.33	1.33
7	1.51	1.57	1.60	1.62	1.63	1.63	1.45	1.44
8	1.52	1.58	1.61	1.63	1.65	1.66	1.56	1.55
9	1.52	1.58	1.61	1.64	1.65	1.67	1.65	1.64
10	1.52	1.58	1.62	1.64	1.66	1.67	1.73	1.72

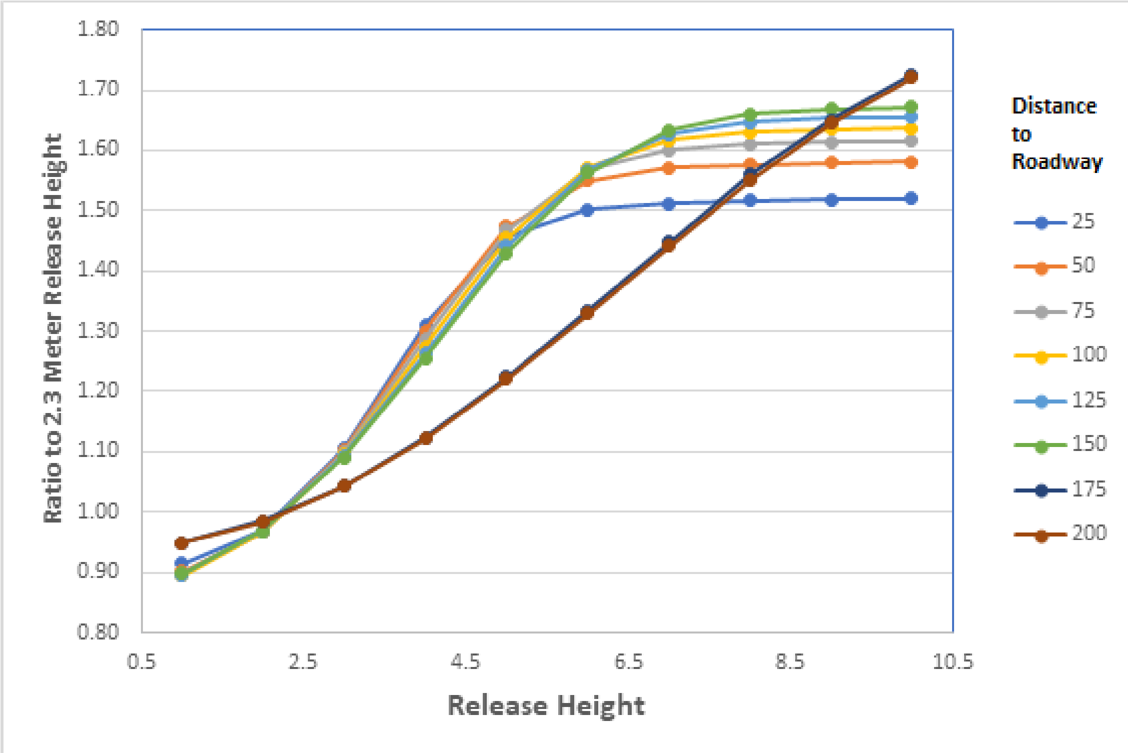


Figure 21. Trends Determined by Analysis of an At-Grade Main Lane Compared to Other Lanes at Various Heights. Comparison Relative to a Release Heights of 2.3 Meters at 25 to 200 Meters from Roadway

Analysis. As with the use of a 2.2-meter initial vertical version concentrations decreased with release height. However, as expected, changes were much less due to the distance from the main roadway and very different trends emerged. The 25-meter receiver position now follows other distances except for the 175 and 200-meter receiver positions. This resulted in much smaller comparative ratios as well, ranging from 0.91 to 1.52. These are comparable to the other results at the one- and two-meter release heights but very different at others.

Figure 21 shows a similar trend for distances of 25 to 150 meters from the downwind roadway. As would be expected, concentrations decreased when release heights became greater as receivers move farther from the plume centerline resulting in an increase as compared to the ratio to the 2.3-meter release height. This ratio then demonstrates the decrease for the different heights as compared to 2.3 meters. The trends also show that at a release height of approximately 5 meters, concentration trends become very different. At this release heights, the comparative ratio begins to flatten out and changes much less with height. Again, this shows the relationship of the plume to the receiver.

An interesting change in trends occur for distances of 175 and 200 meters from the roadway. At these distances, an almost linear trend occurs. This is thought to be due to an influence on the short distances from the near roadway that is "washed out" at the greater distances.

2.2.5 Evaluation of Initial Vertical Dimension

As was shown when comparing 2.2.4.1 and 2.2.4.2 the initial vertical dimension is an extremely important variable as well as its interaction with release height. As such, this evaluation compares predicted concentrations by varying the initial vertical dimension from 0 (the optional value) to 4 in 0.5 increments. As before, the evaluation was for a perpendicular cross wind at distances from 25 to 200 meters in 25-meter increments. Receptors were again at 1.8 meters. The source was the same as in the evaluation of release height, a two-lane roadway and the same emission factors were used.

Table 8 shows the modeled concentrations. Remember these are not absolute values but only representative values of trends that occur. Figure 22 shows the trends based on these relative concentrations.

Table 8. Comparison of Modeled Concentrations when Varying the Initial Vertical Dimension

Initial Vertical Dimension	**Distance from Centerline of Near Roadway**							
	25	*50*	*75*	*100*	*125*	*150*	*175*	*200*
0	5379.1	4018.7	3340.9	2959.2	2717.1	2547.8	1213.7	1203.3
0.5	4877.4	3777.4	3209.7	2878.4	2661.6	2505.9	1207.1	1197.4
1	3945.5	3294.3	2927.0	2691.8	2525.1	2397.8	1188.8	1178.1
1.5	3248.6	2876.1	2645.2	2481.5	2355.9	2254.2	1157.6	1147.6
2	2814.4	2563.2	2398.7	2275.2	2176.0	2093.0	1116.9	1107.6
2.5	2490.1	2298.5	2170.5	2072.1	1991.5	1923.0	1069.0	1060.5
3	2205.9	2054.8	1952.8	1873.5	1807.9	1751.7	1016.3	1008.7
3.5	1948.8	1829.6	1748.4	1684.8	1631.8	1586.1	960.9	954.2
4	1720.5	1626.3	1561.8	1511.0	1468.4	1431.5	904.8	898.9

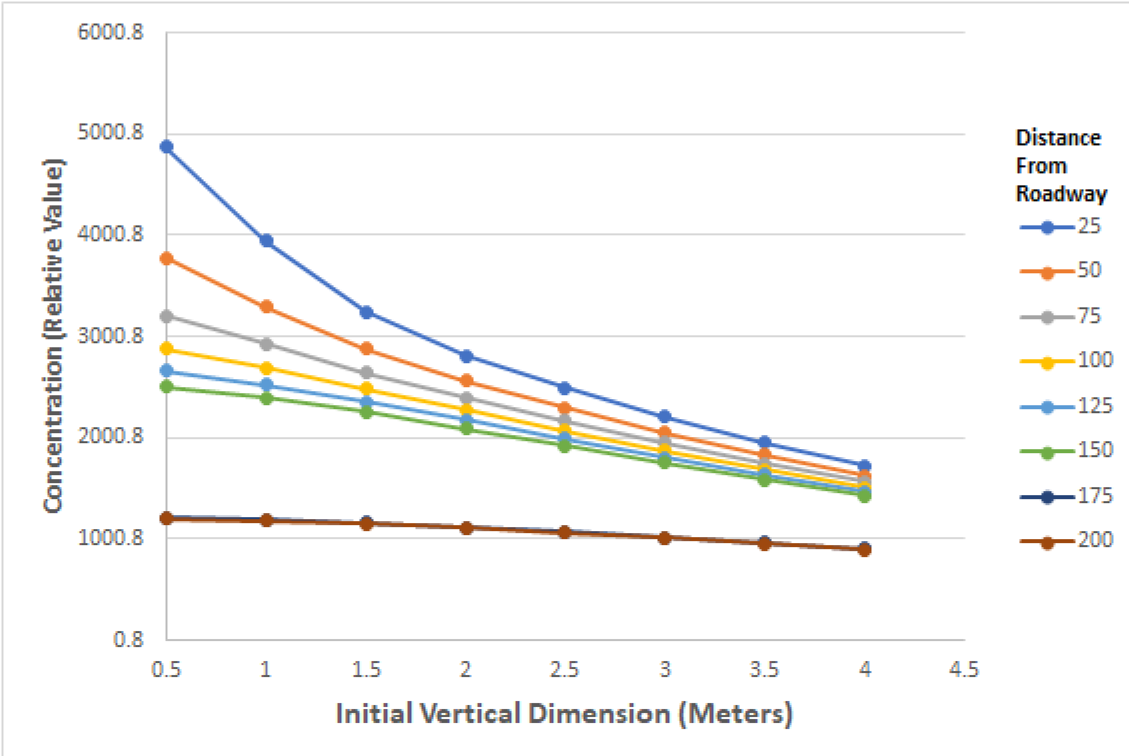


Figure 22. Comparative Results of Varying the Initial Vertical Dimension

Analysis. Concentrations decrease with increasing values of the initial vertical dimension. This is as expected since the initial vertical plume width is controlled by this parameter and larger value result in a larger initial vertical dimension representing greater vertical dispersion. The rate of decrease become less with increasing distances from the roadway. At 25 meters from the roadway, concentrations dropped by over a factor of 3 from the optional value (zero) to 4 meters. At 200 meters from the roadway, the factor for the same range of initial vertical dimensions was only 1.34. Even so, this is still a significant range of change.

As shown in Figure 22, and discussed above, there is an interaction between the initial vertical dimension and release height and there would be a change in predicted concentrations if the receptor height were varied. This trend is somewhat constant between 25 and 150-meters but suddenly changes at distances of 175 and 200-meters. This is thought to be due to the initial vertical plume width and larger value result in a larger initial vertical dimension representing greater a more constant position in the plume for receivers at a height of 1.8 meters. Guidance on the two parameters would seem to need better definition.

2.3 Curves

The next evaluation was for curved roadways. Wind directions were once again controlled by using MakeMet and multiple wind angles were considered. Emission factors were kept very high to amplify the results. The grid method for receptors was also used to allow an overall idea of dispersion and the trends to be characterized.

2.3.1 90° Curve, Wind from 270°, 4 Lanes

The first curve evaluated was a simple 90° turn with the roadway extended at 0 and 270° to allow for a normal roadway design. In this first scenario, the wind direction was held constant from 270°. The wind rose for this evaluation was previously shown in Figure 8b. The road was four lanes wide, with no median, the release height was 2.3 meters and the initial vertical dimension equal to 2.2 meters. Figure 23 shows the results from modeling.

Analysis. End effects are still obvious, especially for the roadway extending to the north. Modeled results would probably not be valid for over 200 meters from the end of the roadway. Results for the straight segments indicate similar trends to those that occurred for the simple, straight roadway analysis for parallel and cross winds with the same shape of concentration gradients appearing. There is a concentration build-up at the curve, and this intuitively seems correct as before for parallel wind along a roadway. Upwind concentrations as in all scenarios appear to be greater than would be expected in the northwest quadrant.

2.3.2 90° Curve, Wind from 90°, 4 Lanes

This scenario is the same as 2.3.1 except winds are now blowing from the east (90°). The wind rose has been previously shown (Figure 8a) and the results from modeling are shown in Figure 24.

Analysis. Trends for the parallel and cross winds to the roadway are again apparent. The leg of the roadway extending to the west shows the same buildup of concentrations for the simple roadway parallel wind scenario. The leg of the roadway extending to the north shows a slight area of increased concentrations to the west and then a constant concentration. This trend is easier to see than for the west wind which also was influenced by the west leg of the roadway. Of interest is that the area of increased concentration that appeared directly to the east of the curve for the wind from 270° is noticeable absent in this case where concentrations are shown to be lower. Based on the results of the north leg, this is incorrect and requires consideration of this modeling scenario beyond this initial work.

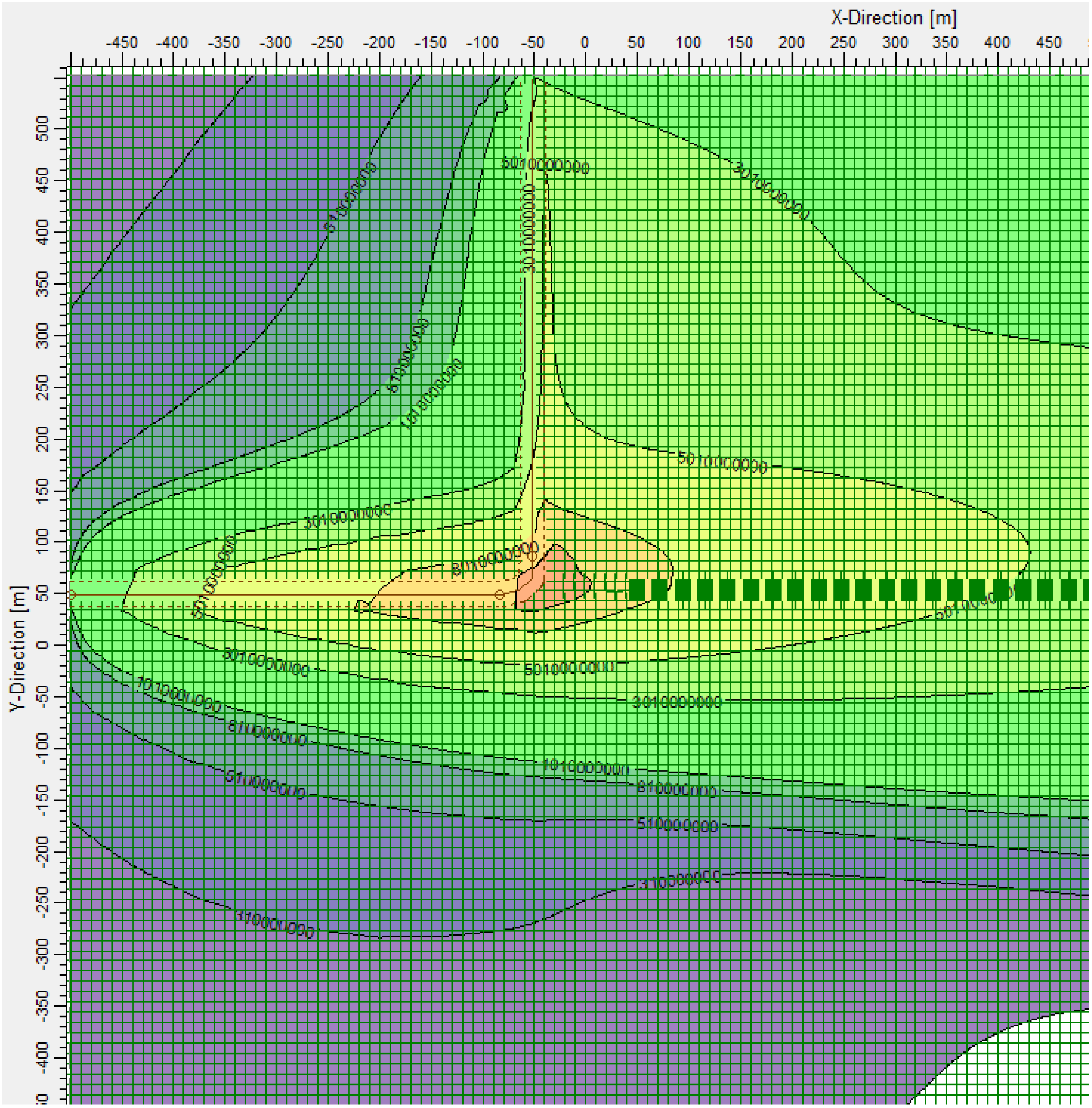


Figure 23. 90° Curve, Wind from 270°, 4 Lanes

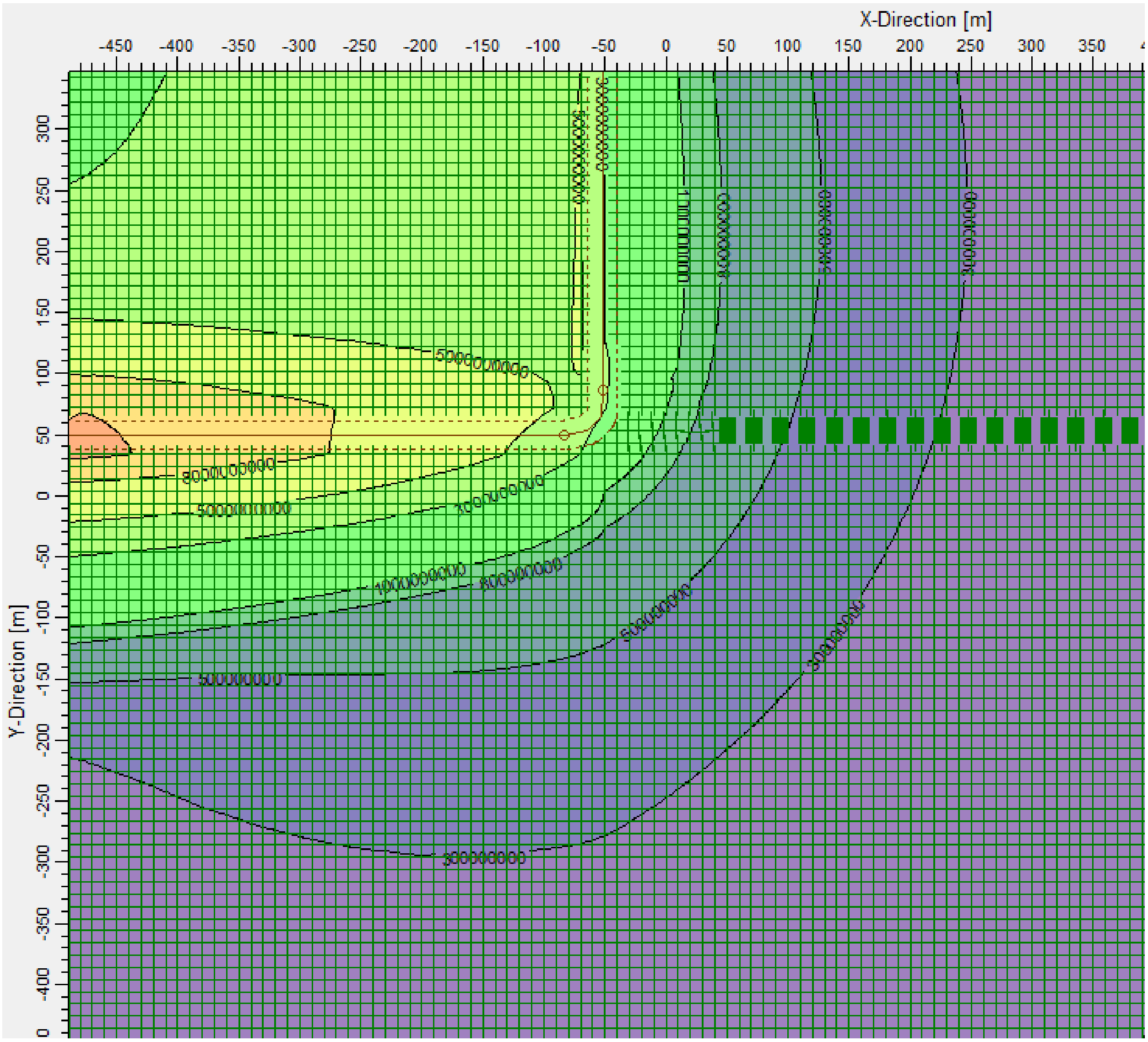


Figure 24. 90° Curve, Wind from 90°, 4 Lanes

2.3.3 90° Curve, Wind from 315°, 4 Lanes

In this case, the same roadway geometry was used as in 2.3.1 but now the wind blows directly across the curve from 315°. All other inputs remain the same as in 2.3.1. Figure 25 includes the wind rose while Figure 26 is used to show the results of modeling.

Analysis. Ever present end effects are shown. The overall concentration contours appear to correctly model the scenario except the upwind elevated concentrations seem to extend too far into the northeast quadrant as shown in Figure 26 since the wind is always from 315°. The increased area of concentrations near the curve is present again as was the scenario in winds from the west (270°) although as expected, slightly different.

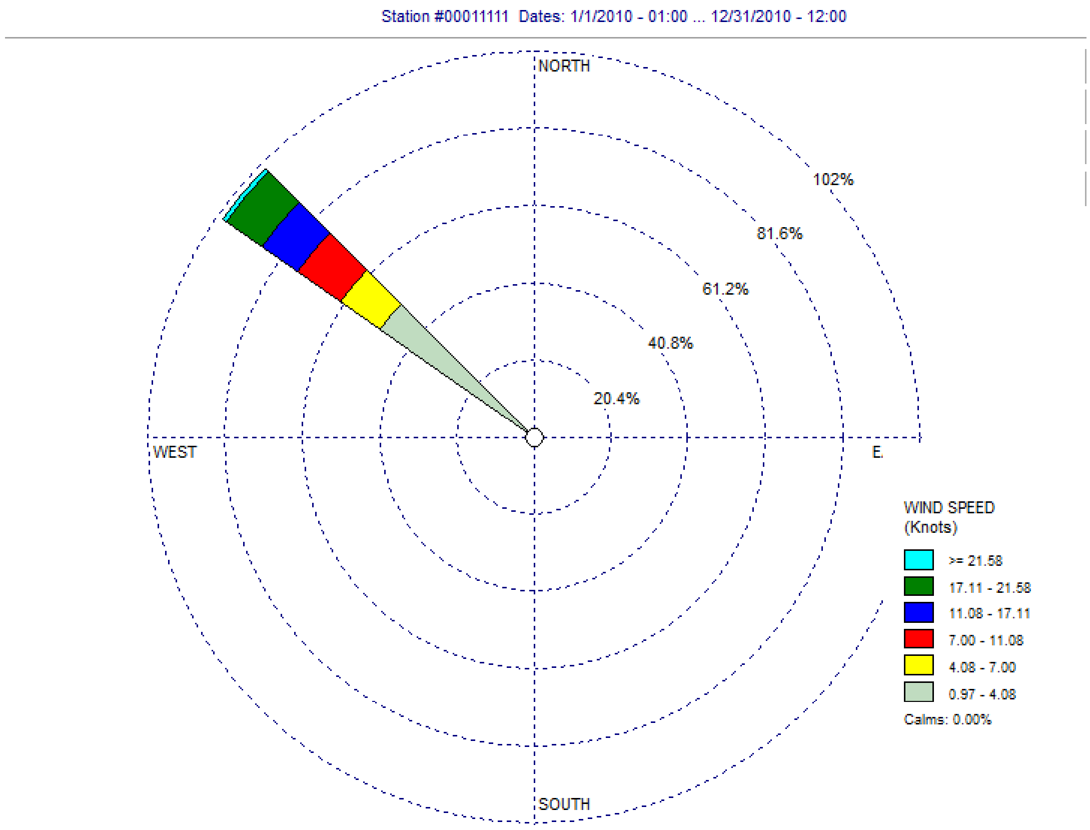


Figure 25. Wind Rose from MakeMet File, Wind from 315° (Northwest)

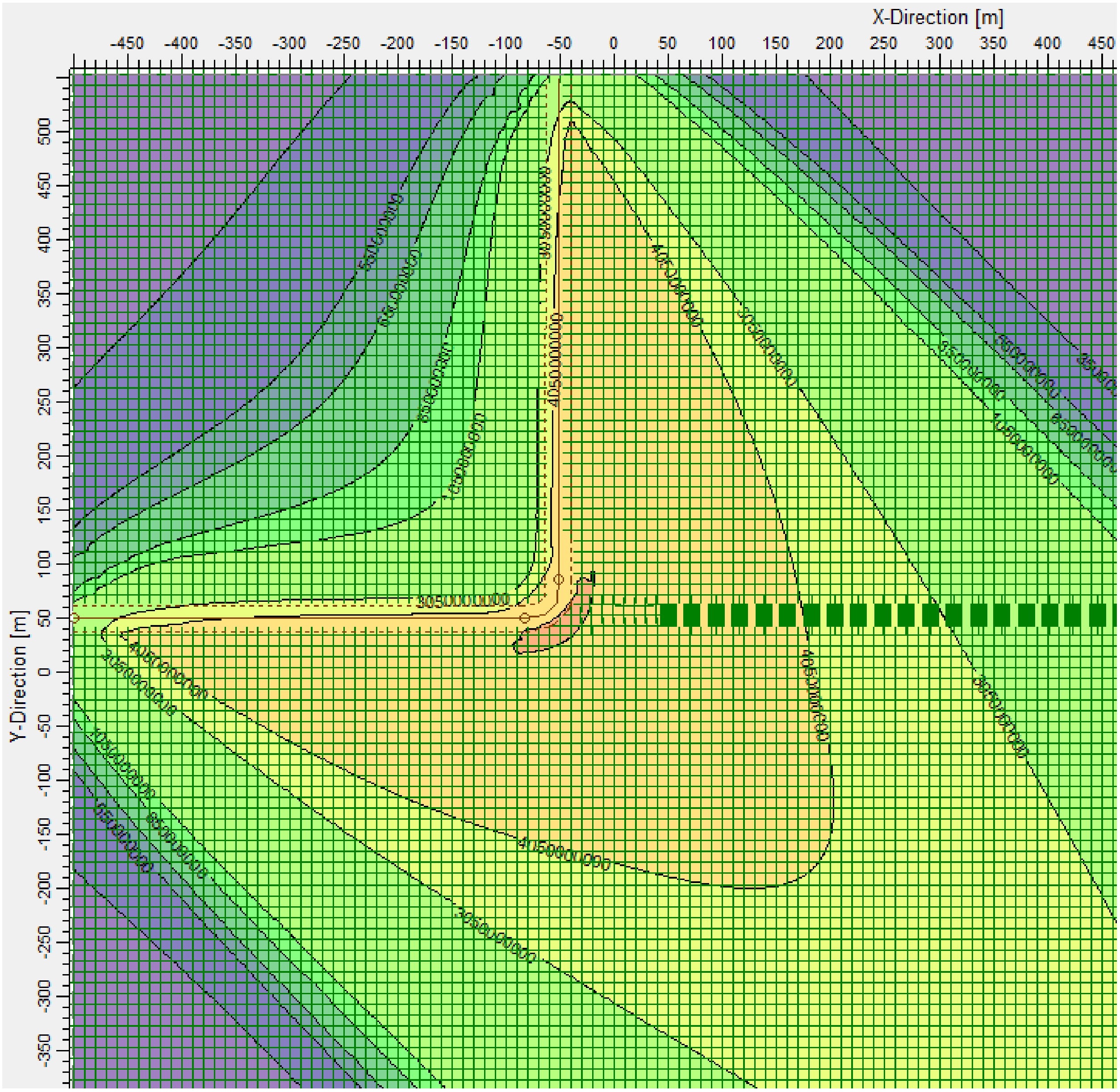


Figure 26. Curve, Wind from 315°, 4 Lanes

2.3.4 90° Curve, Wind from 135°, 4 Lanes

The curve was repeated with the same parameters as in 2.3.3 except the wind direction was rotated by 180° to 135°. All other inputs remained the same. The wind rose is shown in Figure 27 while the predicted concentrations are shown in Figure 28.

Analysis. Disregarding the usual end effects, the downwind concentration trends seem to be correct intuitively except directly downwind of the curve where it would be expected that the first contour would extend further downwind than from the straight roadway segments. Upwind concentrations appear high and extend too far from the roadway as indicated in Figure 28.

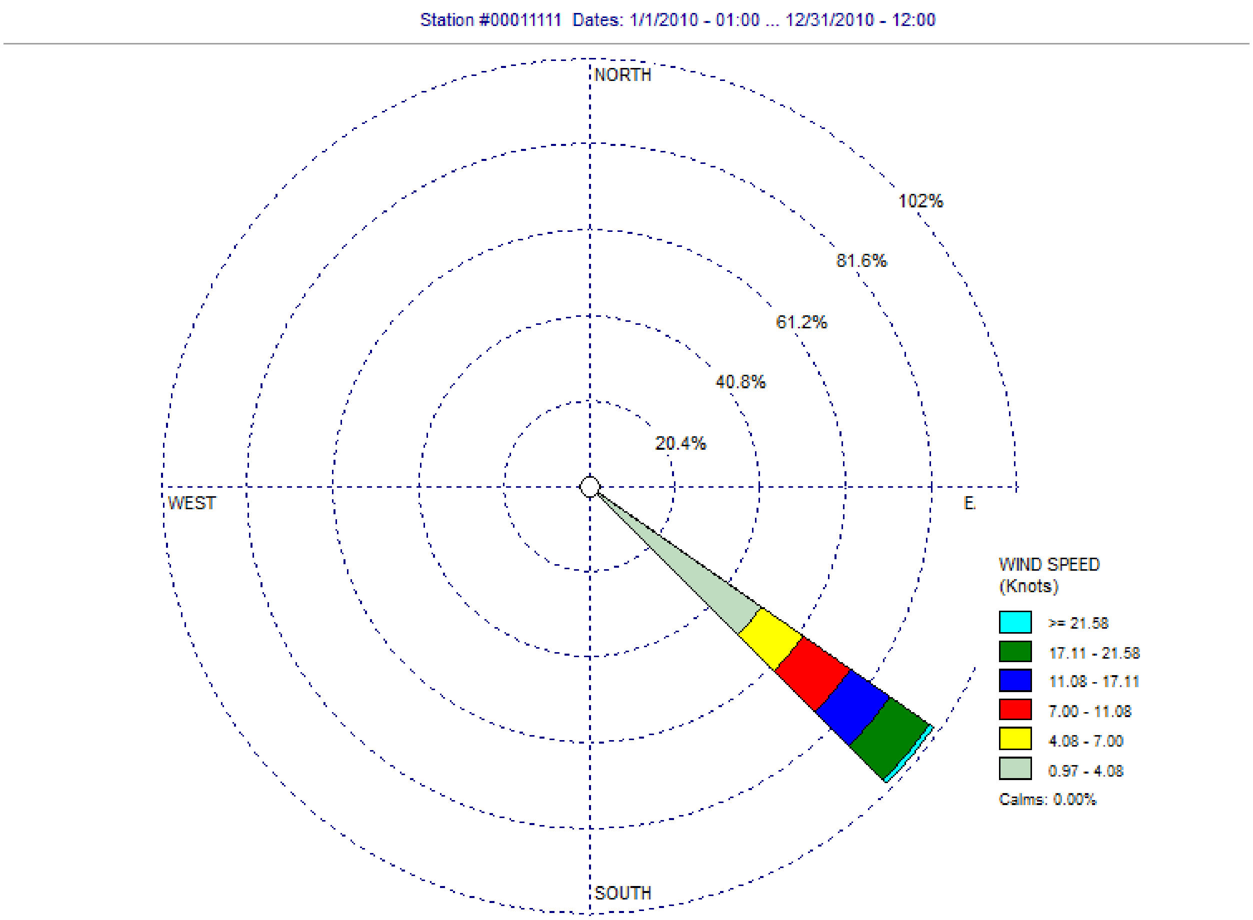


Figure 27. Wind Rose from MakeMet File, Wind from 135° (Southeast)

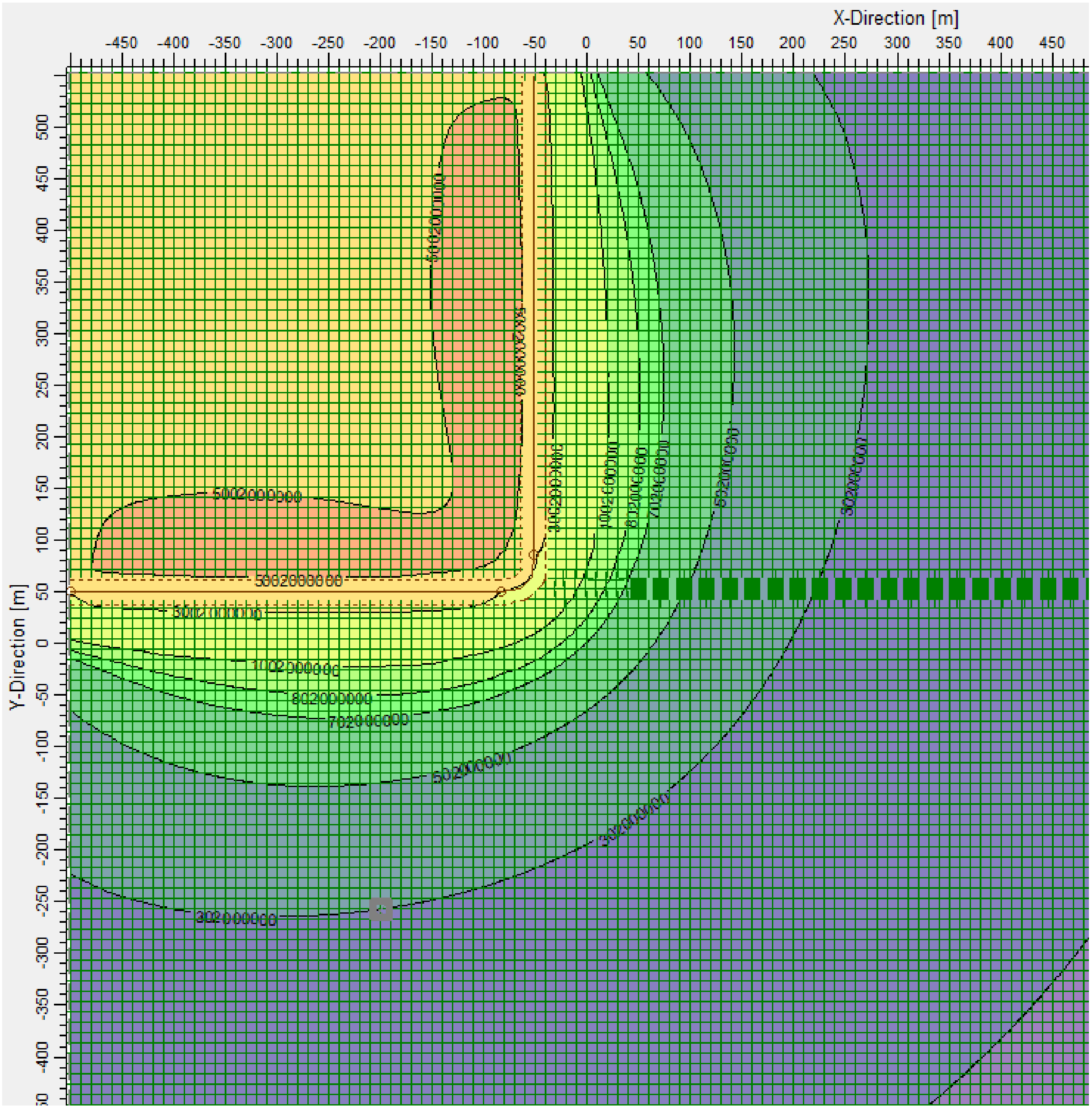


Figure 28. 90° Curve, Wind from 135°, 4 Lanes

2.3.5 90° Curve, Wind from 360°, in 10° Increments, 4 Lanes

This evaluation was to understand how winds from all directions would affect the predictions on a curve. All other inputs remained the same but this time MakeMet was used to distribute discrete winds from each 10° quadrant of the compass. Figure 29 shows the wind rose while Figure 30 shows the results of the modeling.

Analysis. Results were not as expected. As can be seen in Figure 30, greater pockets of concentrations occur in three different areas: along the north and west segments of the roadway away from the curve and at the curve. It would be expected that this would be more continuous. Multiple concentration inconsistencies occur near the roadway. Strong concentration gradients occur in the northwest quadrant. The effects of individual plumes from the point sources are very pronounced with cyclic "lobes" of concentration patterns extending from the roadway to the east and south. This would tend to make the concentration patterns suspect. Again, more work is needed for curves.

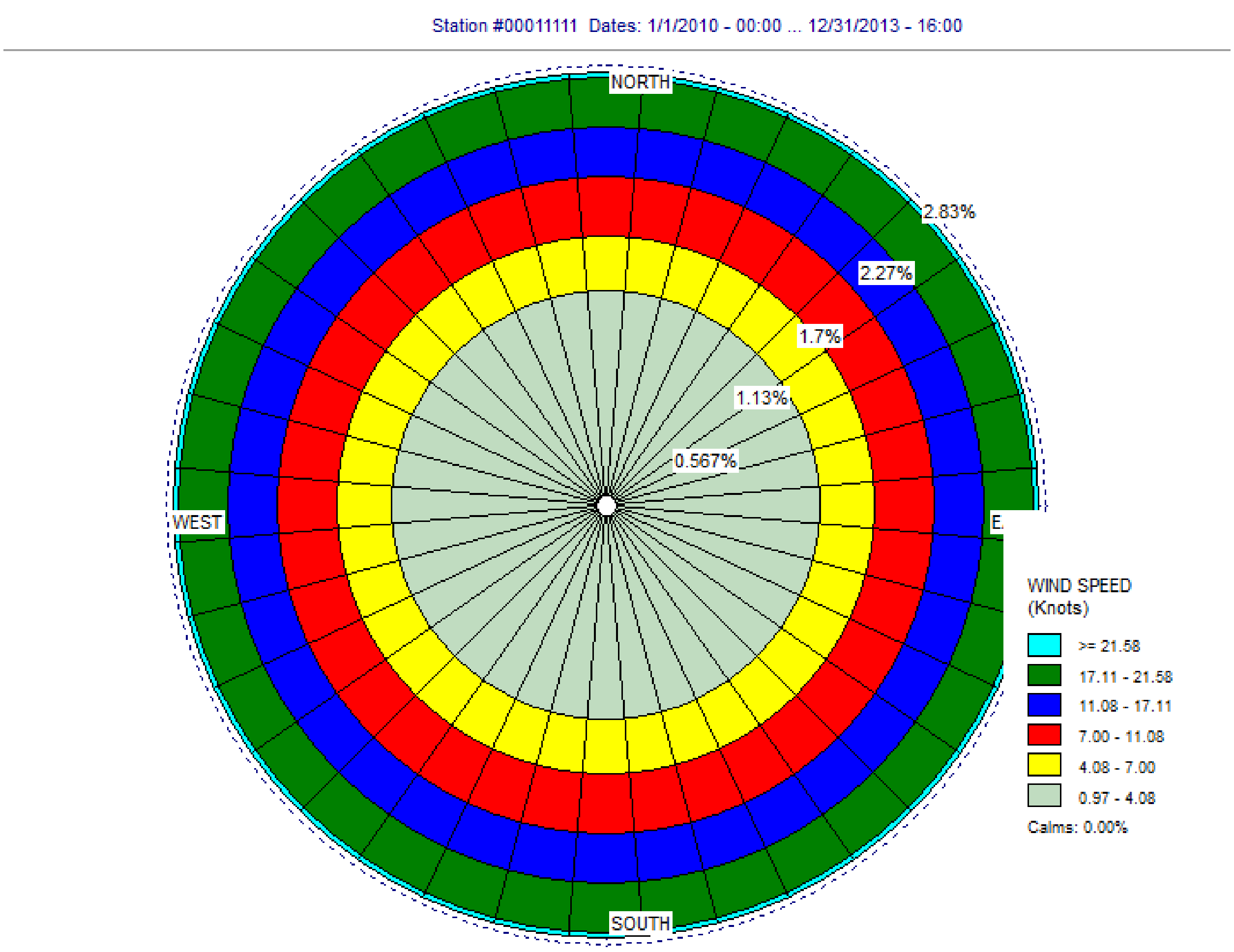


Figure 29. Wind Rose Showing Evenly Distributed Wind Patterns from 360° in 10° Increments

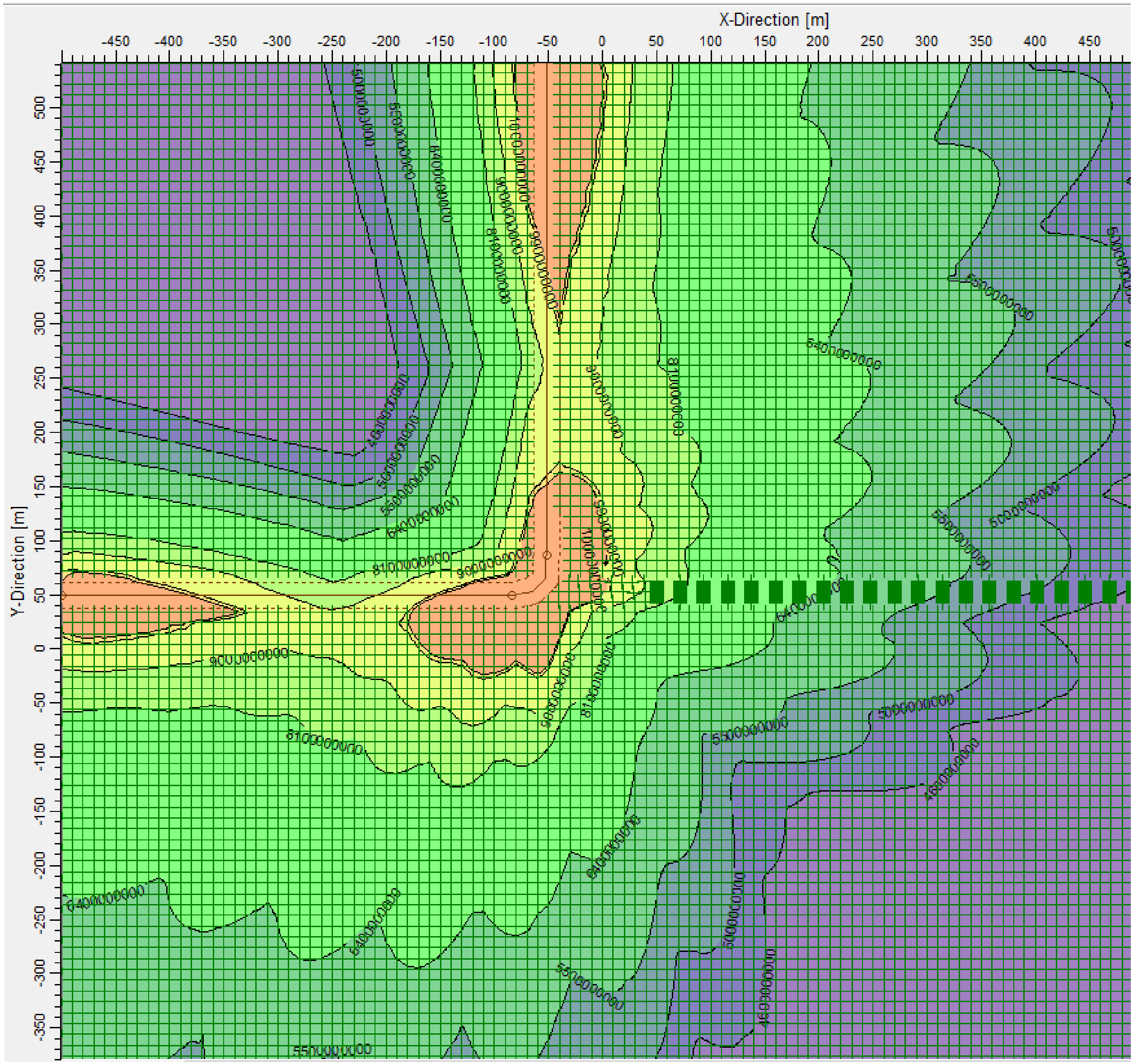


Figure 30. 90° Curve, Wind from All 360°, in 10° Increments, 4 Lanes

2.5 Barrier Section Analysis

In the next series of tests, the RLINEXT algorithm in AERMOD was evaluated using a simple 6-meter-wide roadway. Concentrations trends were evaluated for both upwind and downwind conditions. Single barriers, parallel barriers on both sides of the roadway, and different barrier heights (3 and 6 meters) were reviewed, primarily using trend analysis.

2.5.1 Simple Roadway, Barrier Height 3 Meters

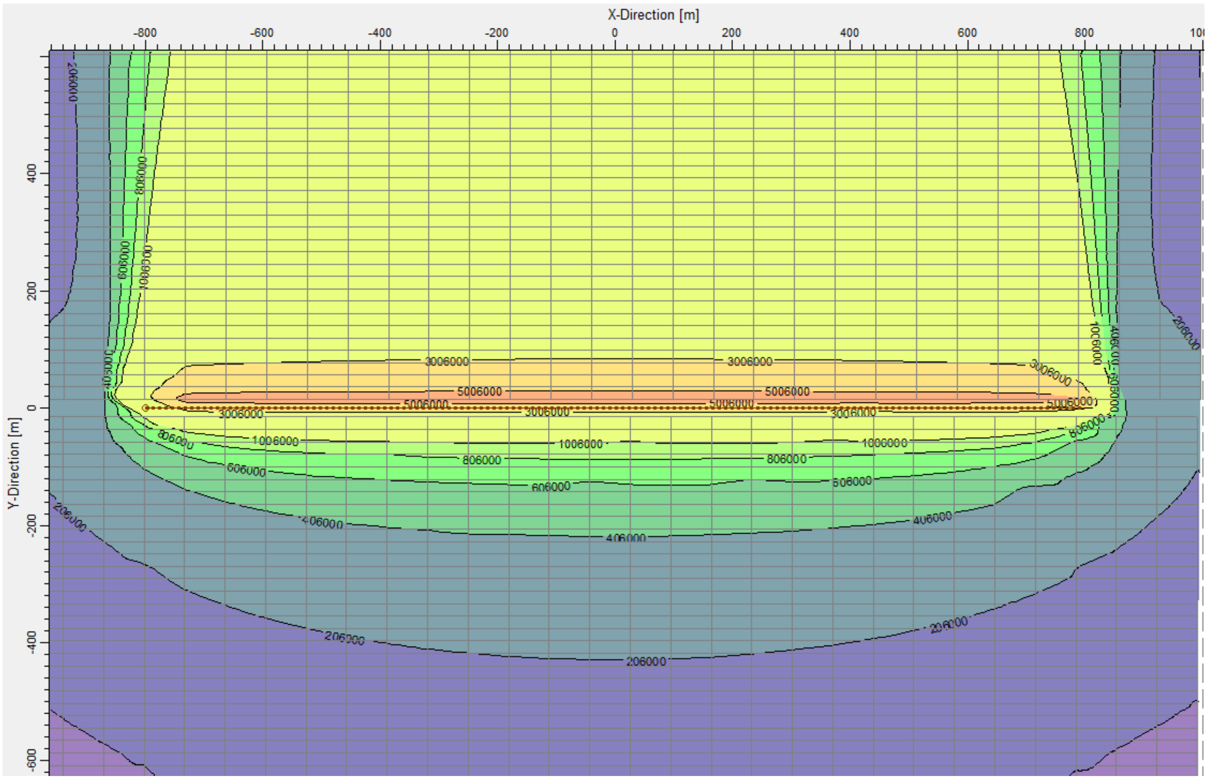
In this case, a simple east-west roadway was evaluated with the barrier and the wind coming only from the south (180°). Wind roses are as previously shown for the south wind. The roadway is a single lane for simplicity to avoid increased complexity in the analysis and is modeled with a release height of 2.3 meters. The barrier, as required, is parallel to the roadway at a distance 15 meters from the roadway centerline and is 3 meters in height. This would not be considered a large noise barrier but more of a typical low barrier design. Due to problems in reporting from AERMOD, emission factors were reduced from those used in previous analyses but are still large. A non-barrier run with the new emission factors was also run to allow a comparison. Both the optional and a typical initial vertical dimension were tested.

2.5.1.1 Optional Initial Vertical Dimension, Barrier Height = 3 Meters, Barrier Downwind

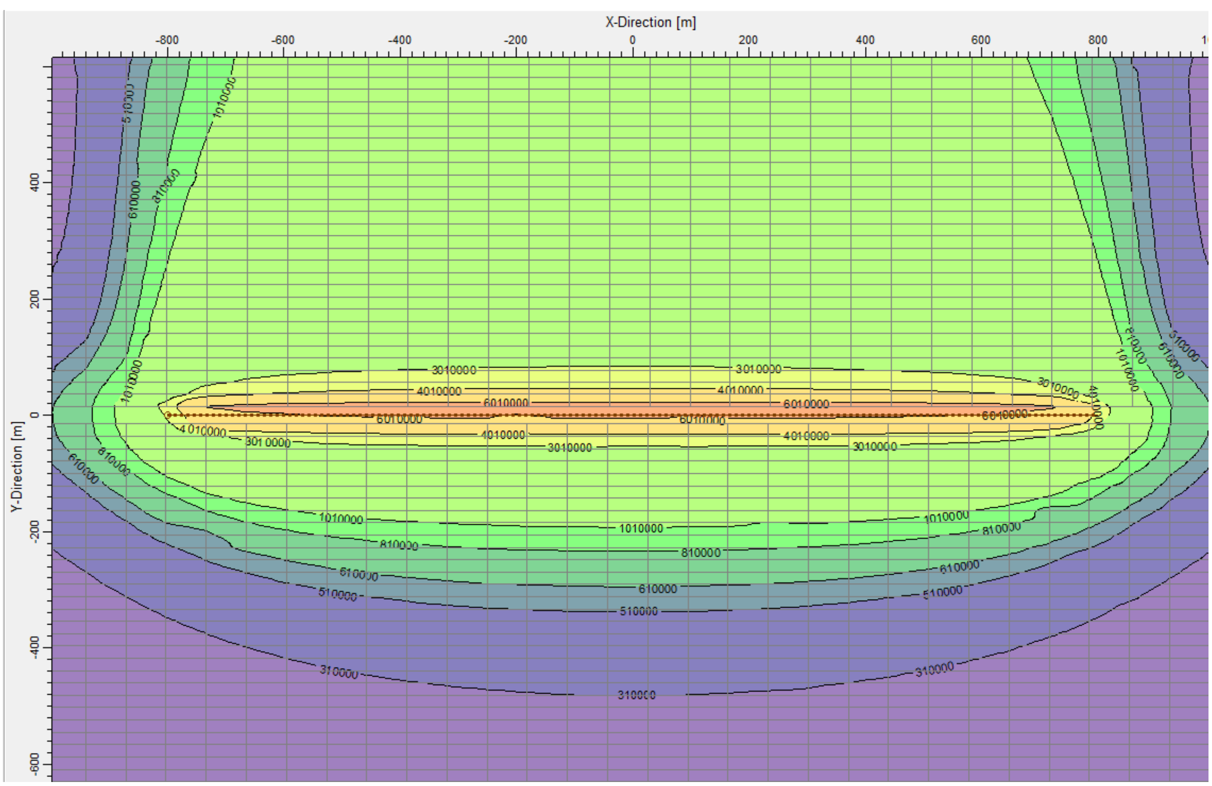
In this scenario, all inputs are as described in 2.5.1 using zero meters as the optional initial vertical dimension. The barrier is 3 meters in elevation, on the northside, and 15 meters downwind of the roadway. Modeling results are included for the overall roadway without a barrier is shown in Figure 31a while Figure 31b shows the view with the 3-meter barrier and Figure 31c is a zoomed in view to show more detail.

Analysis. As can be seen by comparing Figures 31a and b, near road concentrations are increased but higher concentrations are closer to the roadway. For the barrier scenario (Figure 3b) elevated concentrations occur and are near the same locations but the barrier tends to create a build-up of emissions reaching further upwind. This would intuitively be expected as the barrier causes changes in the wind flow and causing eddies as the wind passes over the barrier, but the increases appear to be too great. End effects occur for both the roadway and the barrier scenario but are more intensive with the barrier. Minimal perturbations in the contour profiles occur upwind of the barrier for both scenarios but increase slightly with the barrier. With the barrier, upwind concentrations are also significantly increased. Since the winds are only from the south (180°), concentrations are greater than would be expected to occur upwind and the effect extends about 200 meters upwind. How far upwind the effect should extend is an area for research.

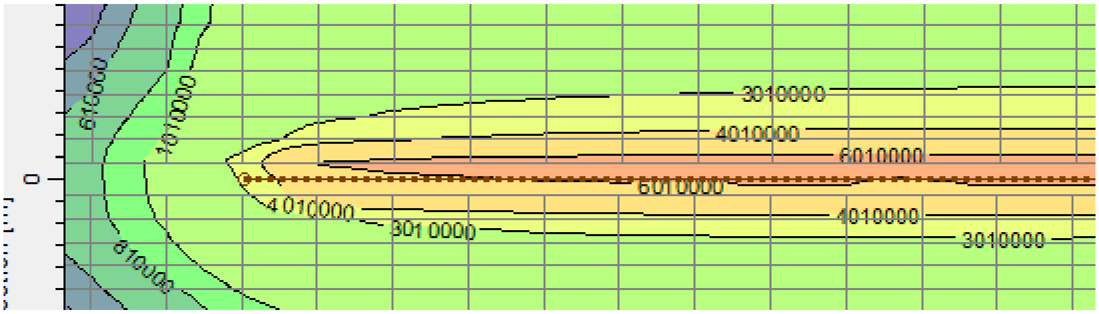
In Figure 31c, the increased end effects and upwind perturbations are shown in more detail.



a. Same Conditions Without Barrier



b. Overall View With 3 Meter Barrier



c. Detailed View of 3-Meter Barrier Run

Figure 31. Simple Road, Barrier Height 3 Meter, Downwind Barrier, Optional Initial Vertical Dimension

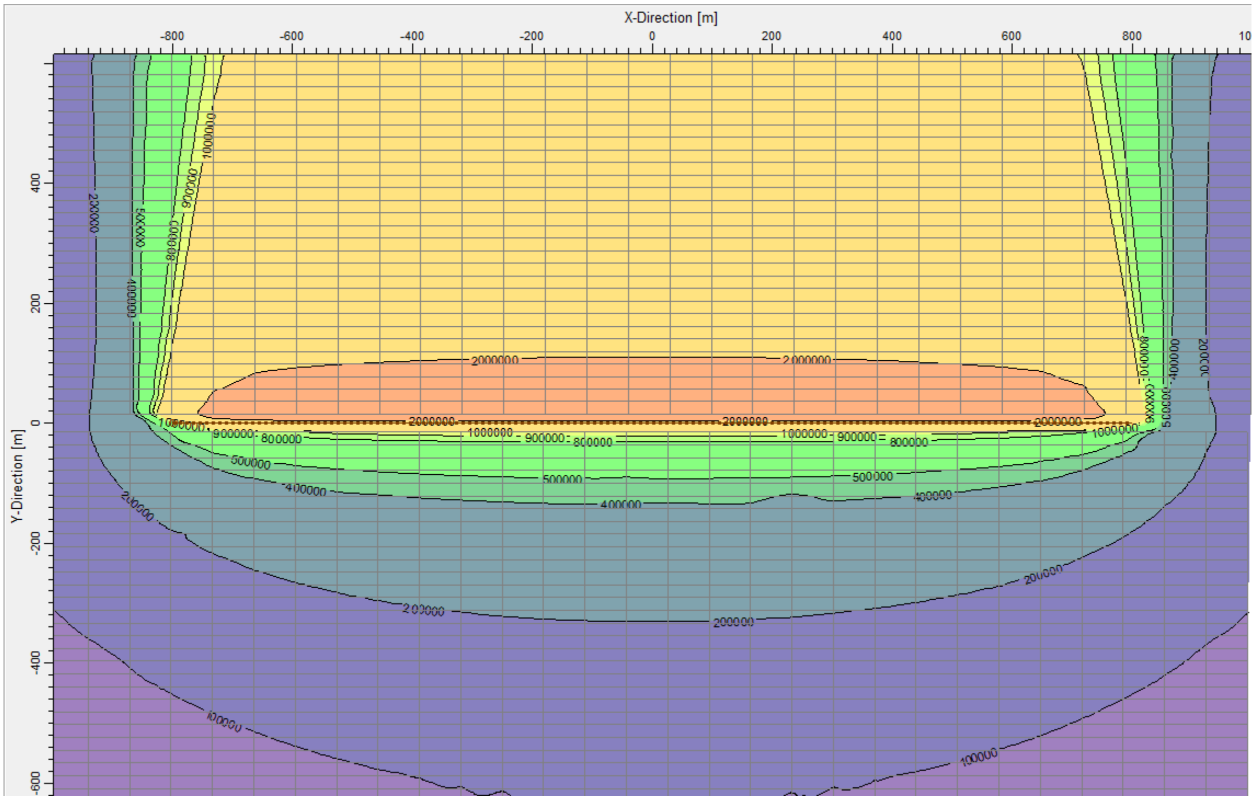
2.5.1.2 Initial Vertical Dimension of 2.2 Meters, Barrier Height 3 Meters, Barrier Downwind

In this scenario, all inputs are as described in 2.5.1 except the initial vertical dimension is set to 2.2 meters and the barrier is 15 meters downwind and on the northside of the roadway. Modeling results are included in Figure 32a for the same scenario with no barrier, an overall view in 32b, and a more detailed view in 32c.

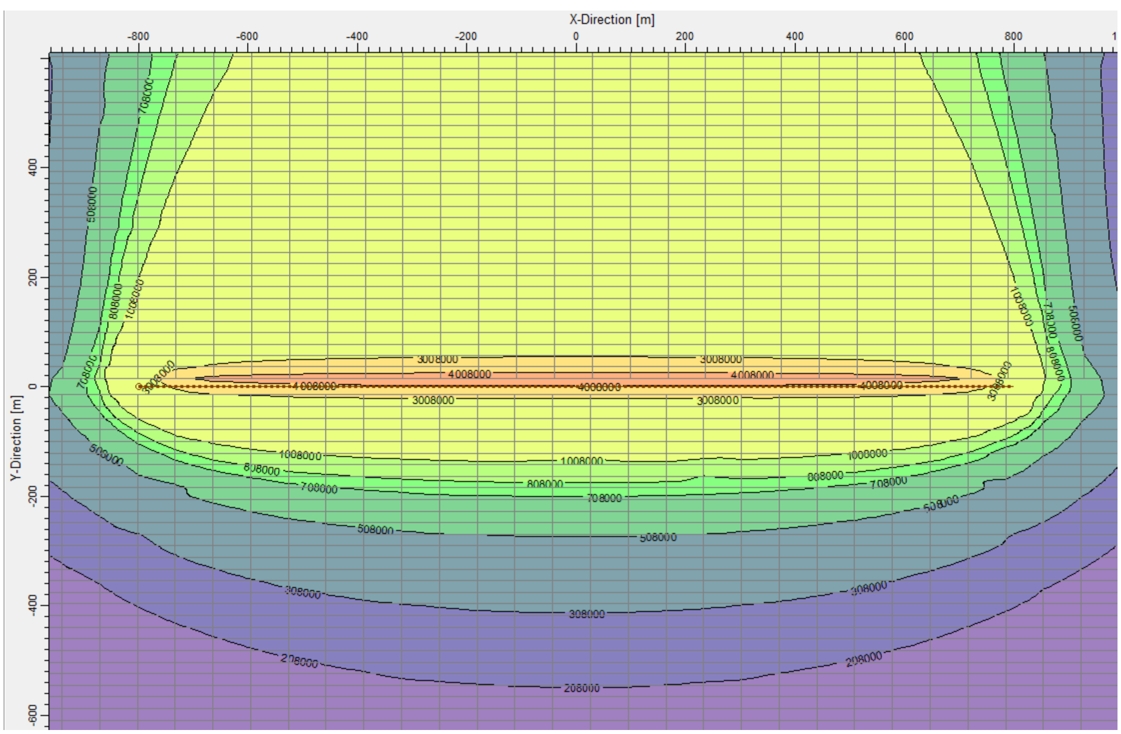
Analysis. The first thing noticeable when the two no barrier scenarios (Figures 31a and 32a) are compared, is that the concentrations decrease with the use of the initial vertical dimension near the road in both no barrier scenarios. Additionally, the initial decrease rate with distance is less. End effects are similar

A comparison of Figures 32a (no barrier) and 32b (with barrier) show an increase in concentrations with the barrier with an increased area of greater concentrations. In both scenarios the area of greatest concentrations is just downwind of the barrier. Upwind of the barrier, the concentrations are also increased and extend much further upwind. Again, the distance that effects should occur from the barrier are not known but the extended area of well over 100 meters would seem to be excessive.

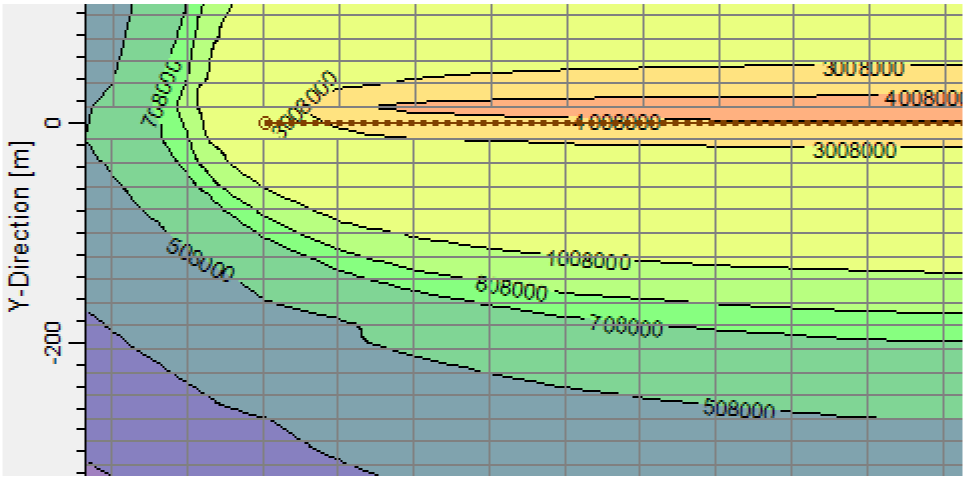
End effects occur for both the roadway and the barrier. Minor perturbations occur but not until about 100 meters upwind.



a. No Barrier



b. Overall View



c. Detailed View

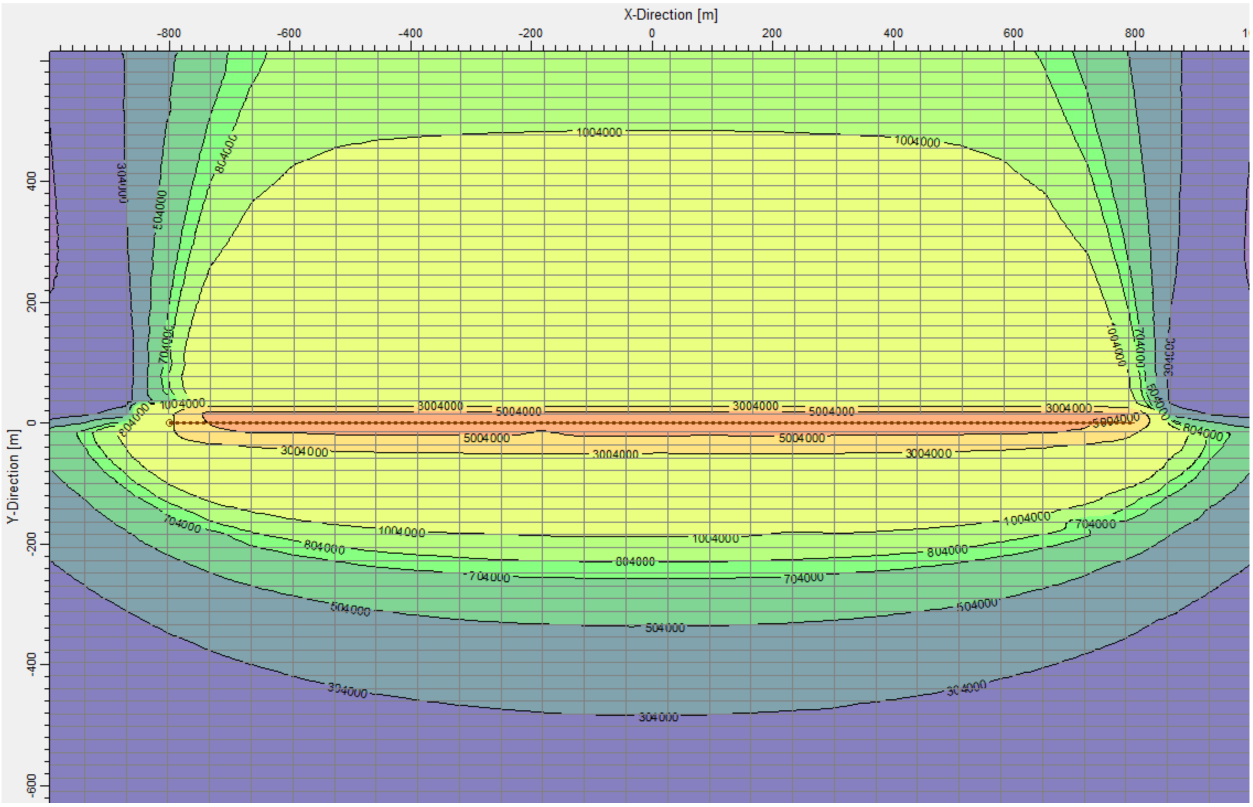
Figure 32. Simple Road, Barrier Height = 3 Meter, Upwind Barrier, Initial Vertical Dimension = 2.2 Meters

2.5.1.3 Optional Initial Vertical Dimension, Barrier Height = 3 Meters, Barrier Upwind

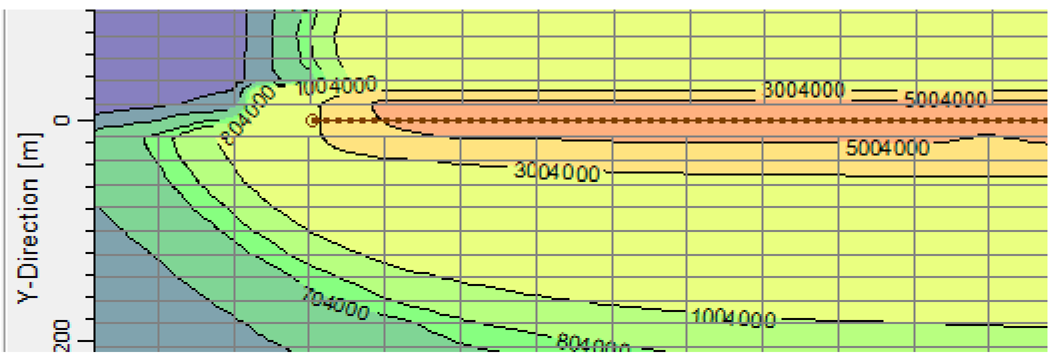
In this scenario, all inputs are as described in 2.5.1 are used but the barrier has now been moved to 15 meters upwind. Modeling results are included in Figure 33a, for the overall view and 33b for more detail.

Analysis. In this case, concentrations are similar at the roadway but falloff more slowly downwind and more quickly upwind of the roadway from the no barrier scenario (Figure 31a). The area of greatest concentration moves from north of the roadway, to somewhat centered on the roadway.

End effects, especially upwind, are more significant. This is shown in detail in Figure 33b. Additionally, the small perturbations are obvious in this zoomed in graphic.



a. Overall View



b. Detail View

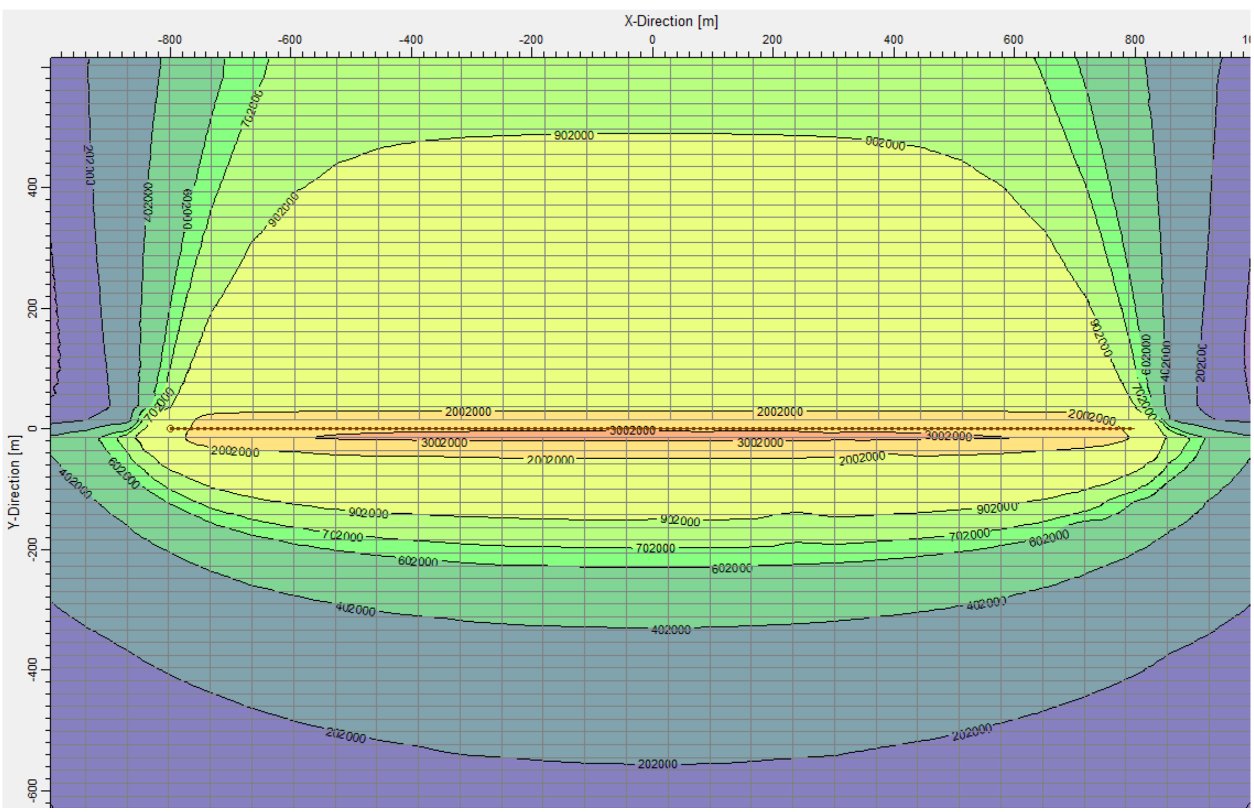
Figure 33. Simple Road, Barrier Height = 3 Meter, Upwind Barrier, Optional Initial Vertical Dimension

2.5.1.4 Initial Vertical Dimension of 2.2 Meters, Barrier Height = 3 Meters, Barrier Upwind

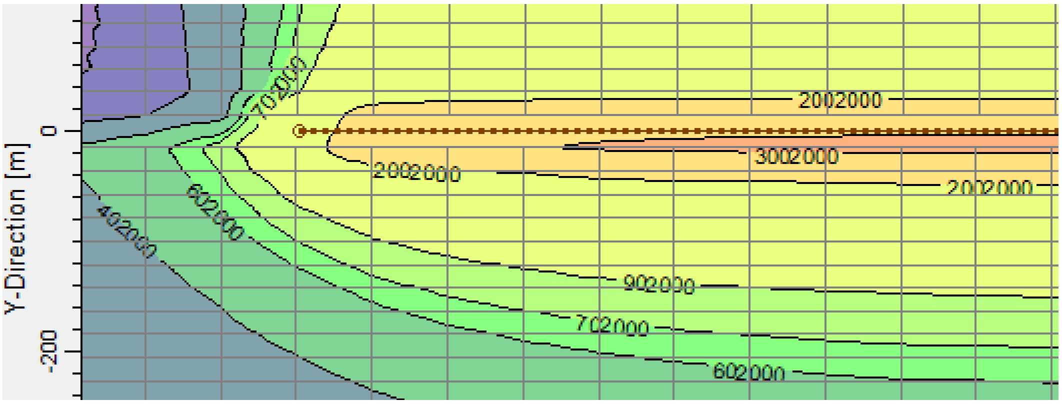
This scenario uses the same input as 2.5.1.3 with the exception that the initial vertical dimension is now 2.2 meters. Results are shown in Figure 34.

Analysis. Comparison of Figure 33a (no barrier) and 34a (with barrier and initial vertical dimension) show large differences. Concentrations are greater with the barrier but confined to a small area just south of the roadway. End effects are increased. However, a greater area of higher concentrations just downwind of the no barrier scenario exist. Falloff then occurs more quickly downwind for the barrier scenario and more slowly upwind. The large effect of the barrier extends almost 200 meters upwind which seems to be too extensive.

When comparing two similar scenarios with inclusion of the initial vertical dimension (Figure 33a) to the optional value of zero to a height of 2.2 meters (Figure 34a) the increased dispersion at the source results in decreased concentrations and a shift in the greatest concentrations to south of the roadway instead of centered upon the roadway. Fall off trends are similar for both scenarios. Other trends remain very similar such as end effects (see Figure 34b). This evaluation scenario clearly shows the need for guidance on the initial vertical dimension for near roadway receiver evaluation due to the big difference in concentration predictions.



a. Overall View



b. Detailed View

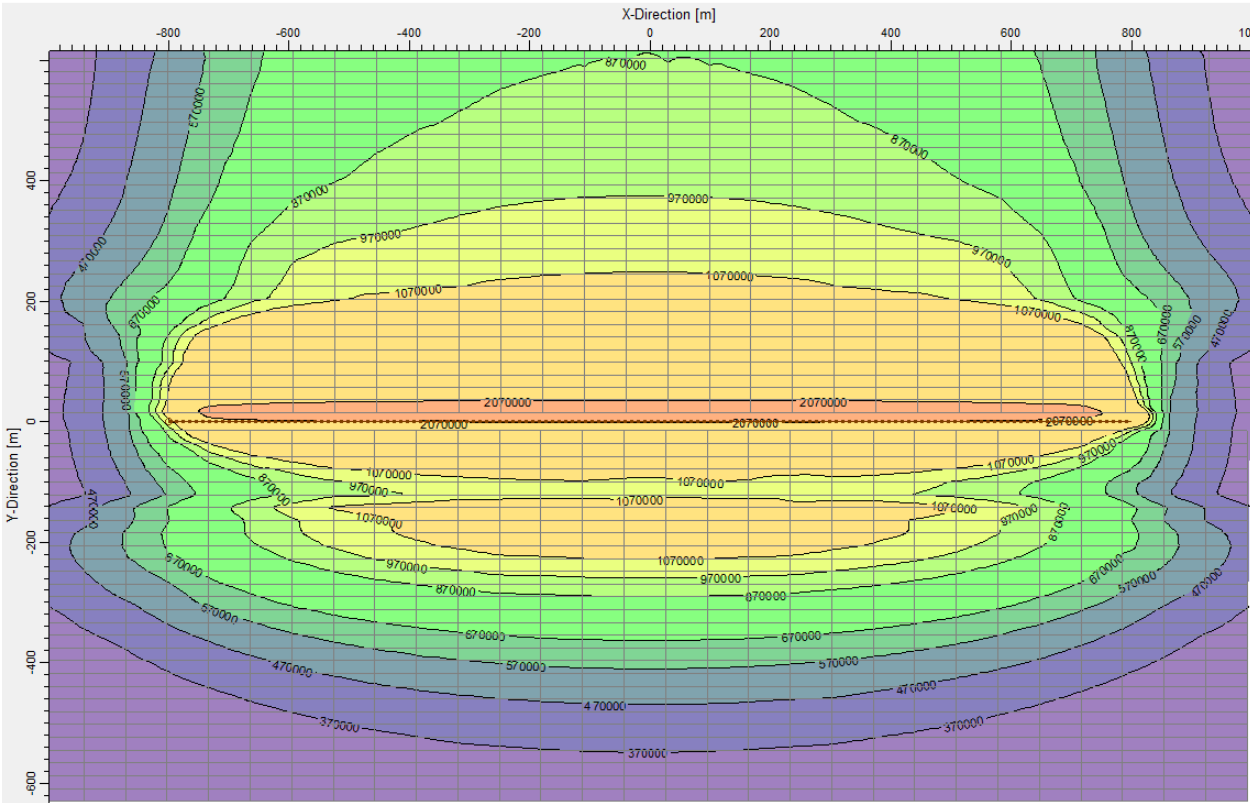
Figure 34. Simple Road, Barrier Height = 3 Meter Upwind Barrier, Initial Vertical Dimension = 2.2 Meters

2.5.2 Simple Roadway, Barrier Height = 6 Meters

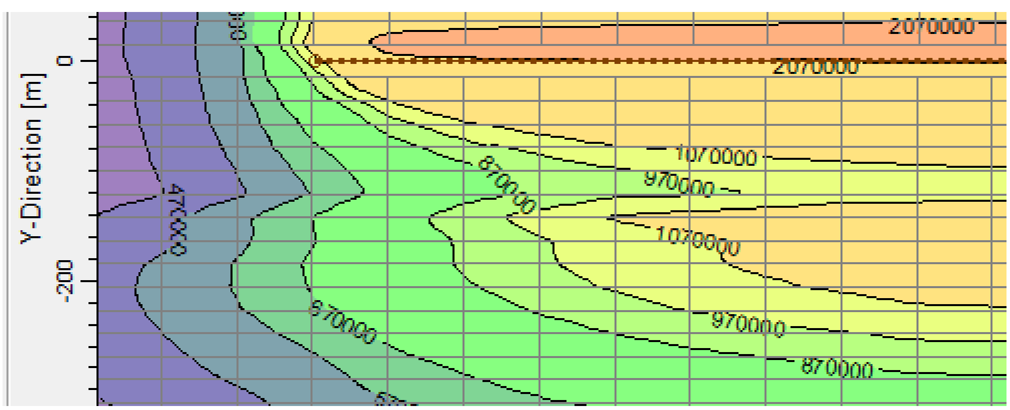
In these scenarios, both the optional and a typical initial vertical dimension are tested again with the same inputs except now the barrier has a height of 6 meters, representing a substantial noise barrier height to provide a comparison of the normal range of noise barriers.

2.5.2.1 Optional Initial Vertical Dimension, Barrier Height = 6 Meters, Barrier Downwind

In this scenario, all inputs are as described in 2.5.1.1 are used but the barrier height is 6 meters. Modeling results are included in Figure 35.



a. Overall View



b. Detailed View

Figure 35. Simple Road, Barrier Height = 3 Meter Upwind Barrier, Initial Vertical Dimension = 2.2 Meters

Analysis. The area of greatest concentrations occurs just downwind of the roadway extending to just past the barrier location. When compared to the no barrier scenario (Figure 31a) large differences are apparent, both upwind and downwind. With the 6-meter barrier, the area of greatest concentrations near the roadway are located very similarly but the concentration values are less. Moving downwind, the values are first less but at about 100 meters become greater and remain that way until about 200 meters. At this point the falloff become much more rapid for the barrier scenario.

Upwind is very different. Concentrations very near the roadway are less but with distance quickly become greater for the barrier scenario and remain so. The upwind effects cause an "island" of increased concentration beginning just over 100 meters upwind. This means the effect of the barrier is reaching hundreds of meters upwind. This would seem to be too great of an effect. The resulting upwind end effects are greatly exaggerated making the area of confidence for modeling very small.

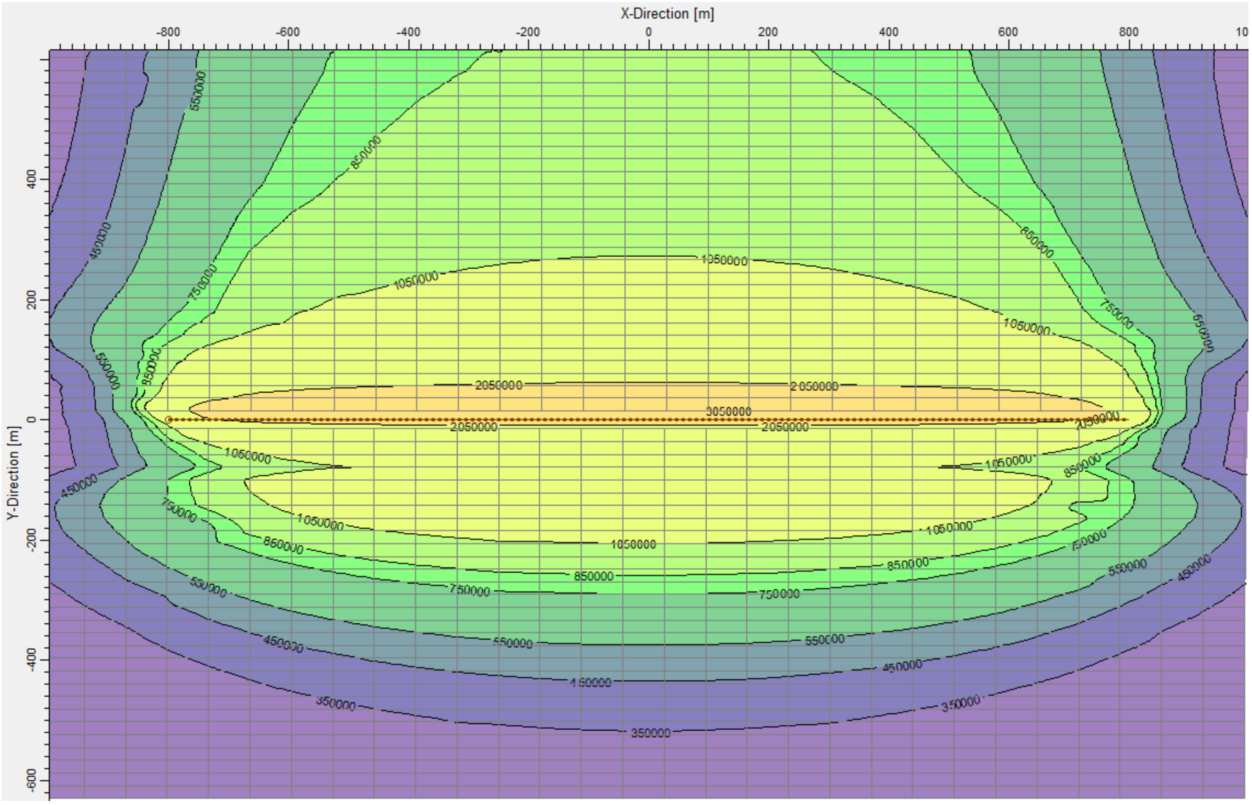
Comparing the 3 meter and 6-meter scenarios (Figures 31b and 35a) a dramatic difference in concentration trends occur with the barrier now causing very dramatic effects. A conclusion is that the barrier algorithms need to be reviewed and real data made available for comparison.

2.5.2.2 Initial Vertical Dimension = 2.2 Meters, Barrier Height = 6 Meters, Barrier Downwind

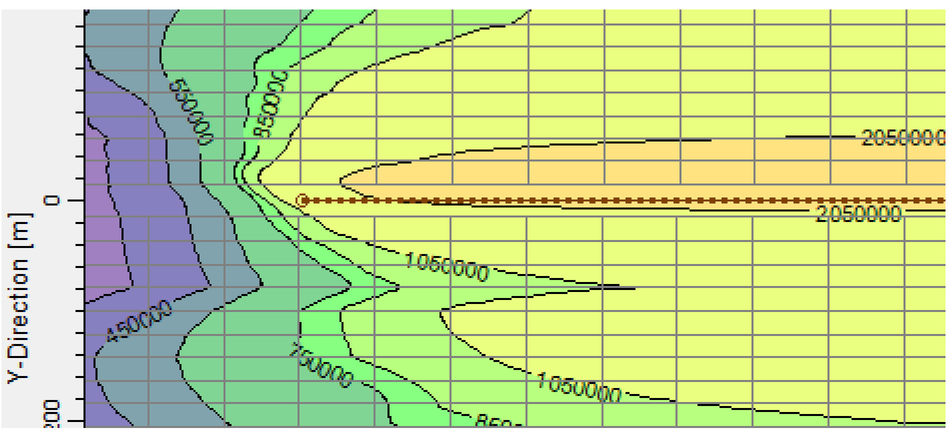
All inputs are as described in 2.5.2 are used but the barrier height is 6 meters. As in the previous scenario, the initial vertical dimension is 2.2 meters. Modeling results are included in Figure 36.

Analysis. In this scenario, while the downwind plume is closer to the shape from the 3-meter-tall barrier (compare Figures 33 and 36), the concentrations decrease more rapidly downwind.

Upwind, edge effects are more drastic with first a decrease and then an increase in size of the plume at about 100 meters from the roadway. This is shown in detail in Figure 36b. This reduces the area of confidence during dispersion modeling. This again does not seem intuitively correct that the upwind dispersion would be affected to such distances with only a wind from the south (180°). These tests show the need for a thorough review of the algorithms implemented for barrier dispersion.



a. Overall View

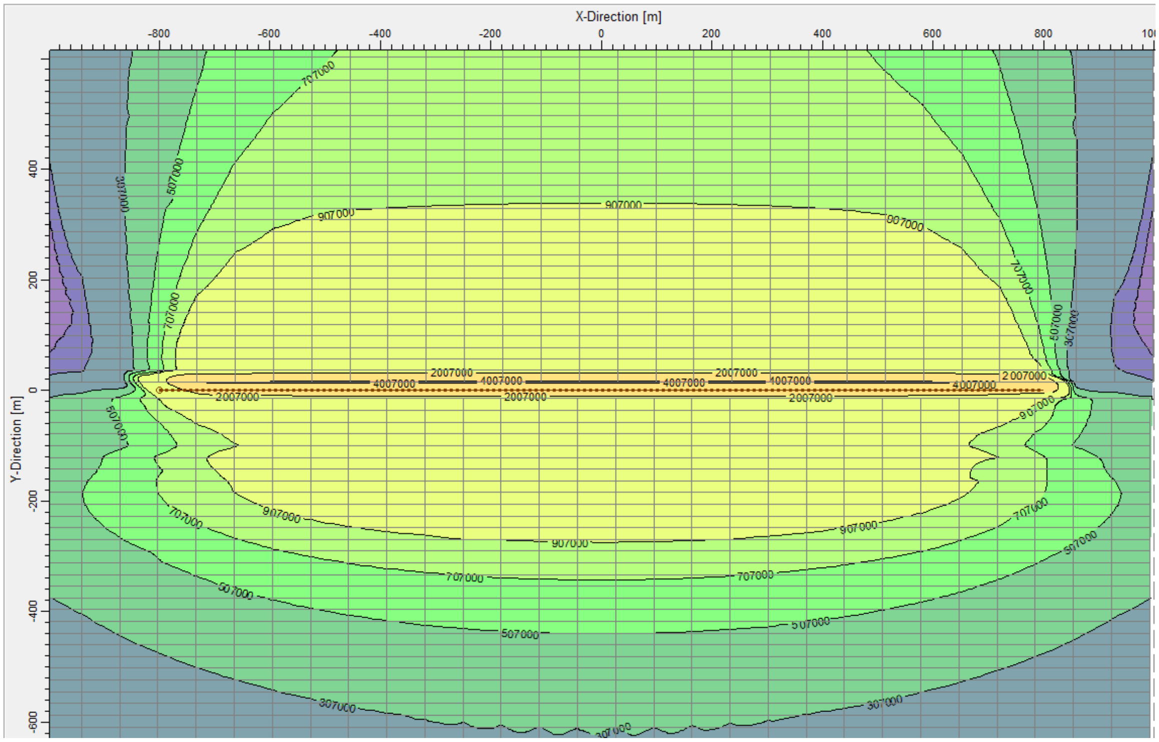


b. Detailed View

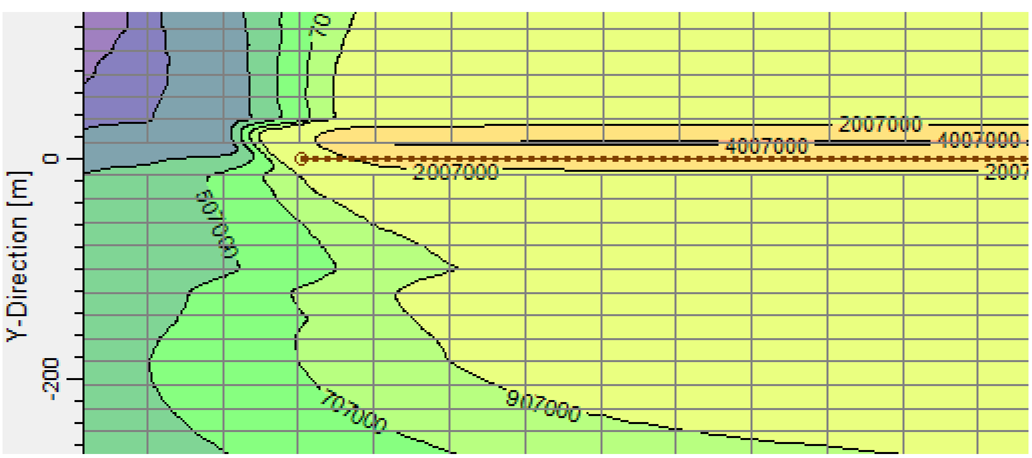
Figure 36. Simple One Lane Road, Barrier Height = 6 Meters, Downwind Barrier, Optional Initial Vertical Dimension

2.5.2.3 Optional Initial Vertical Dimension, Barrier Height = 6 Meters, Barrier Upwind

In this scenario, all inputs are as described in 2.5.1 using zero meters as the optional initial vertical dimension. The barrier top is now 6 meters above the roadway plane and 15 meters upwind of the roadway. Modeling results are included in Figure 37.



a. Overall View



b. Detail View

Figure 37. Simple Road, Barrier Height = 6 Meters, Upwind Barrier, Optional Initial Vertical Dimension

Analysis. In a comparison of this scenario to the similar input scenario with no barrier (Figure 31a) we see the concentrations at and just downwind of the roadway have decreased. Areas of high concentration are reduced. Fall off rates downwind are greater with the barrier upwind.

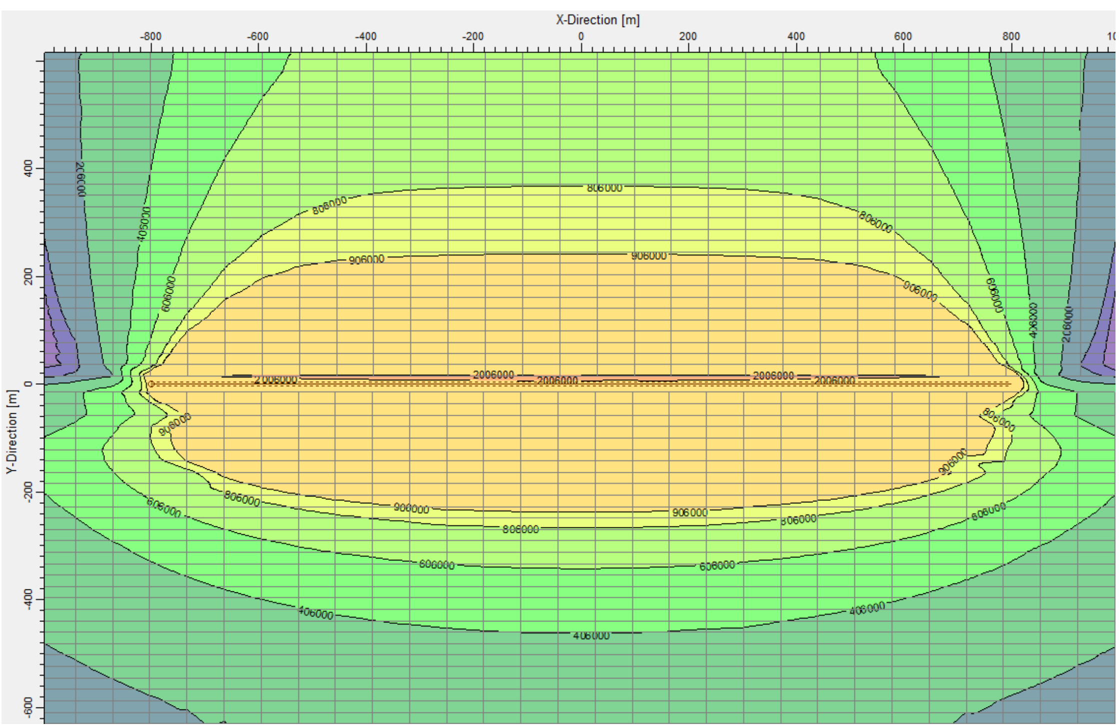
Upwind, the trend of higher concentrations as compared to the no barrier scenario continues. End effects are significant (see Figure 37b) but are reduced compared to the downwind barrier scenario.

The taller barrier height, with all other inputs remaining constant, results in a very different dispersion pattern as compared to the 3-meter barrier (compare Figure 31b and 37a). Concentrations are less at the roadway, but areas of higher concentrations cover much more area, both upwind and downwind. Near the barrier location (on South side of roadway) end effects are very apparent extending outward along the roadway, extending upwind. Upwind dispersion is affected more as demonstrated by perturbations in the upwind plume edge and increased concentrations further upwind.

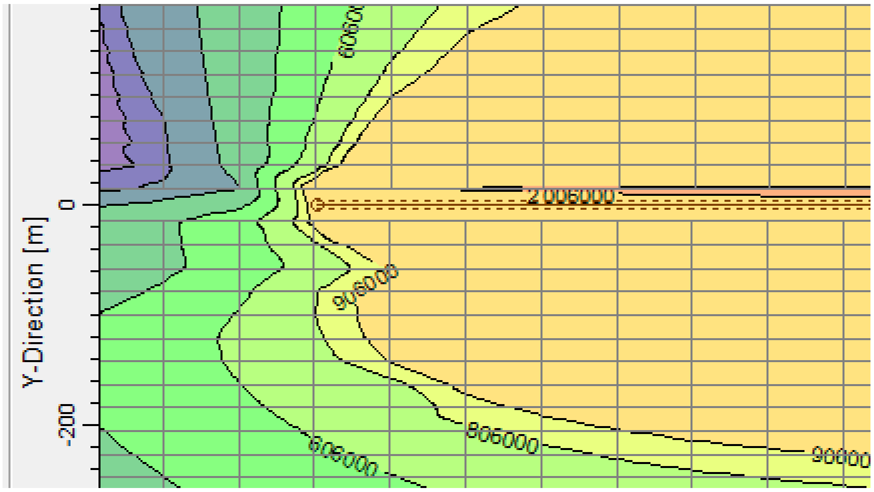
It appears that upwind dispersion needs to be examined especially near tall barriers.

2.5.2.4 Initial Vertical Dimension of 2.2 Meters, Barrier Height = 6 Meters, Barrier Upwind

In this scenario, all inputs are as described in 2.5.2.3 are used except the initial vertical dimension is set to 2.2 meters. The barrier height is 6 meters and located 15 meters upwind of the roadway. Modeling results are included in Figure 38.



a. Overall View



b. Detailed View

Figure 38. Simple One Lane Road, Barrier Height = 6 Meter Upwind Barrier, Initial Vertical Dimension = 2.2 Meters

Analysis. First comparing results to the previous scenario using the optional initial vertical dimension of zero meters, emissions are not retained as much, and concentrations are significantly lower just to the north (downwind) of the roadway with somewhat similar trends further downwind but tending to decrease more quickly with distance. Upwind, end effects are slightly reduced, and concentration trends are again similar.

Compared to the no barrier scenario (Figure 32a) concentrations are slightly higher just downwind of the barrier but fall off more rapidly. Upwind, elevated concentrations still seem to extend too far when compared to the no barrier scenario. It does not seem to follow that the barrier would have an effect of multiple hundreds of meters. These results show an effect at about 100 times upwind of the height of the barrier.

2.6 Parallel Winds and Barriers

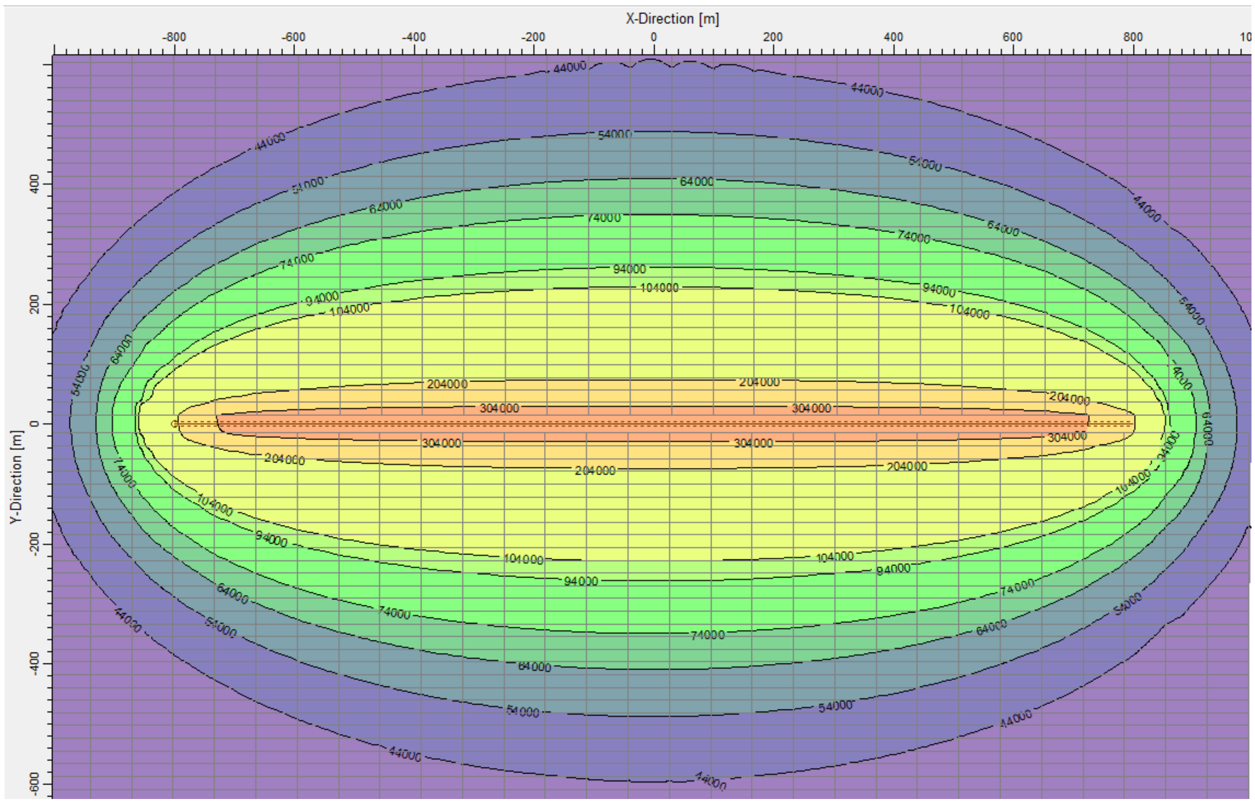
Section 2.5 discussed single barriers with perpendicular cross winds. In this section, we review what happens with a single barrier with a parallel wind. The source release height is 2.3 meters with an initial vertical dimension of 2.2 meters. Barrier heights of 3 and 6 meters were evaluated, both on the south side of the roadway. Winds from both ends of the roadway, east (90°) and west (270°), are presented here. Wind roses have been shown previously.

Figure 39, a – d, includes the results for:

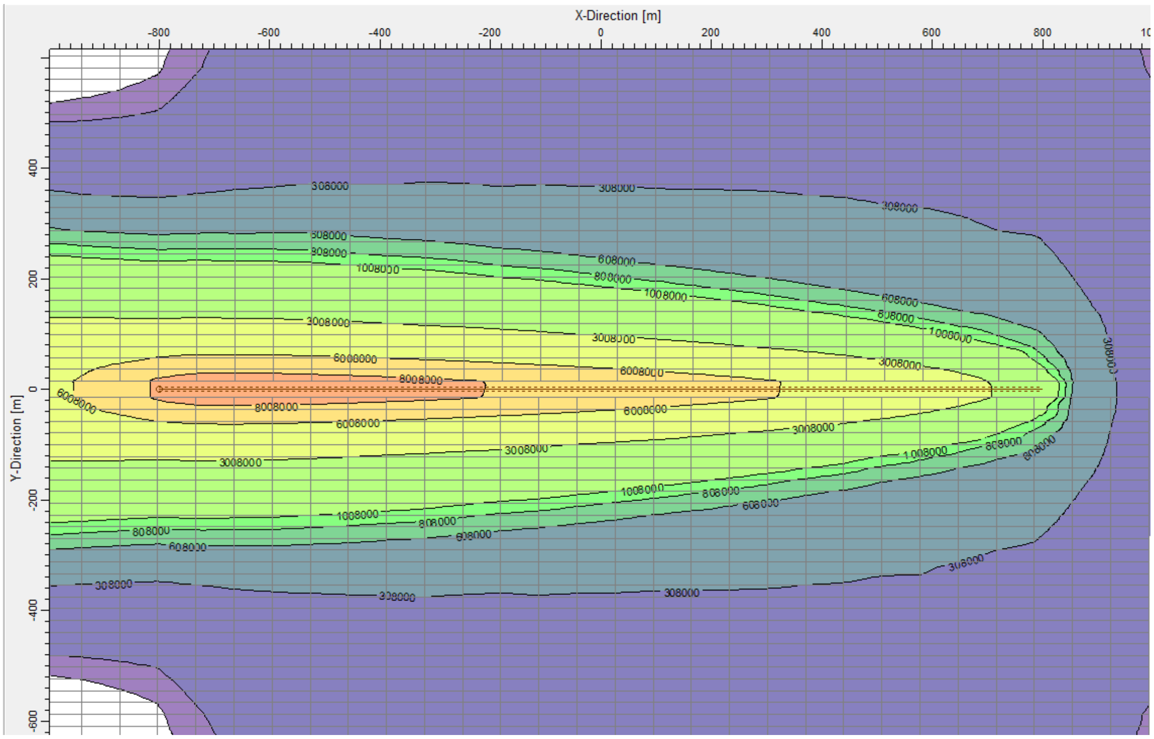
a. 3-meter barrier on north side of the roadway, wind from east
b. 3-meter barrier on south side of the roadway, wind from east

c. 3-meter barrier on north side of the roadway, wind from west
d. 3-meter barrier on south side of the roadway, wind from west

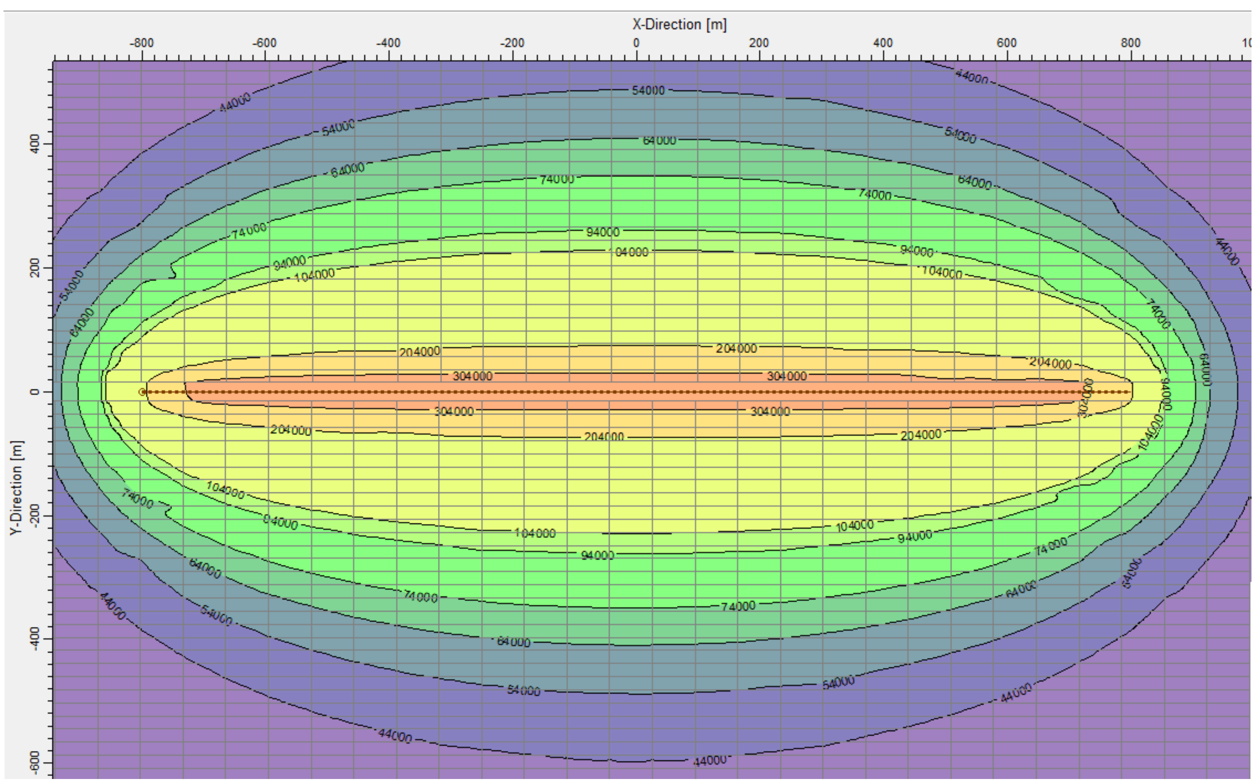
Figure 41 a – d includes the 6-meter barrier results in the same order as above for the side of the road and wind direction.



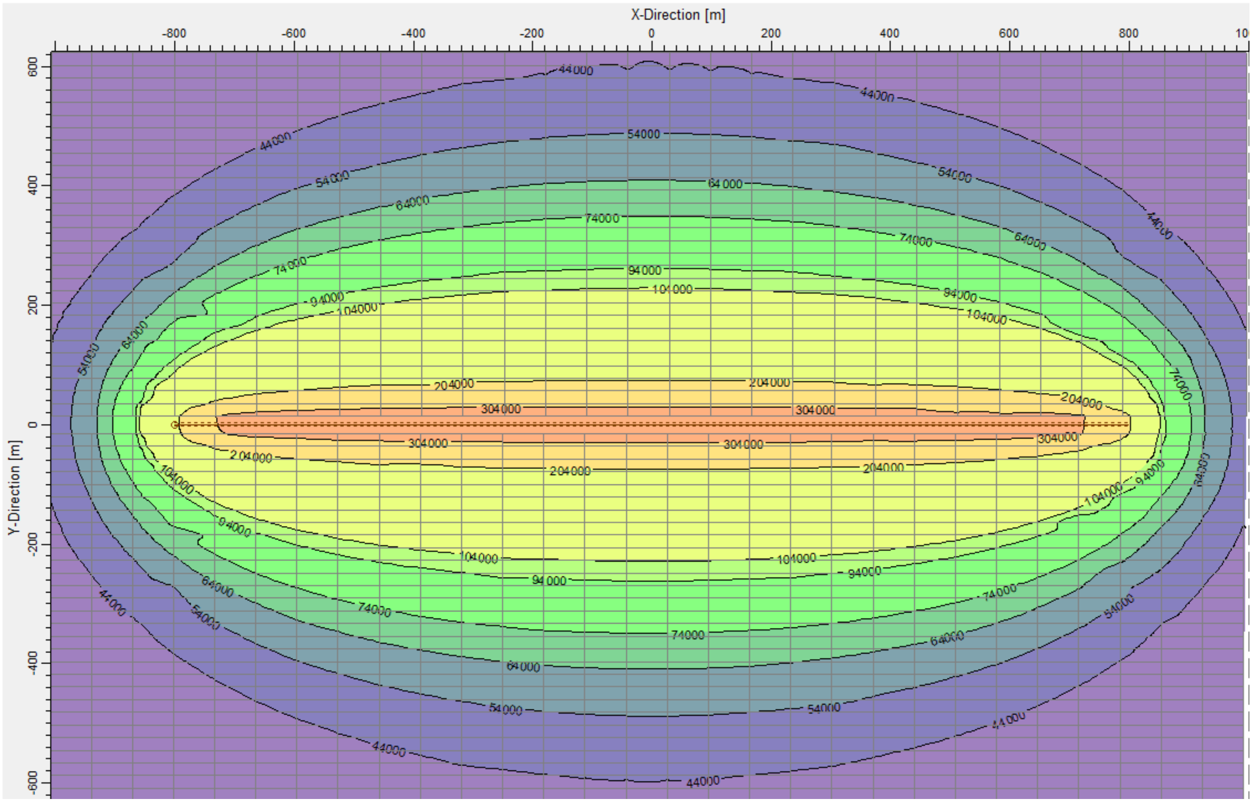
a. Wind from the East, Barrier on North Side, 3 Meter Barrier



b. Wind from the East, Barrier on South Side, 3 Meter Barrier

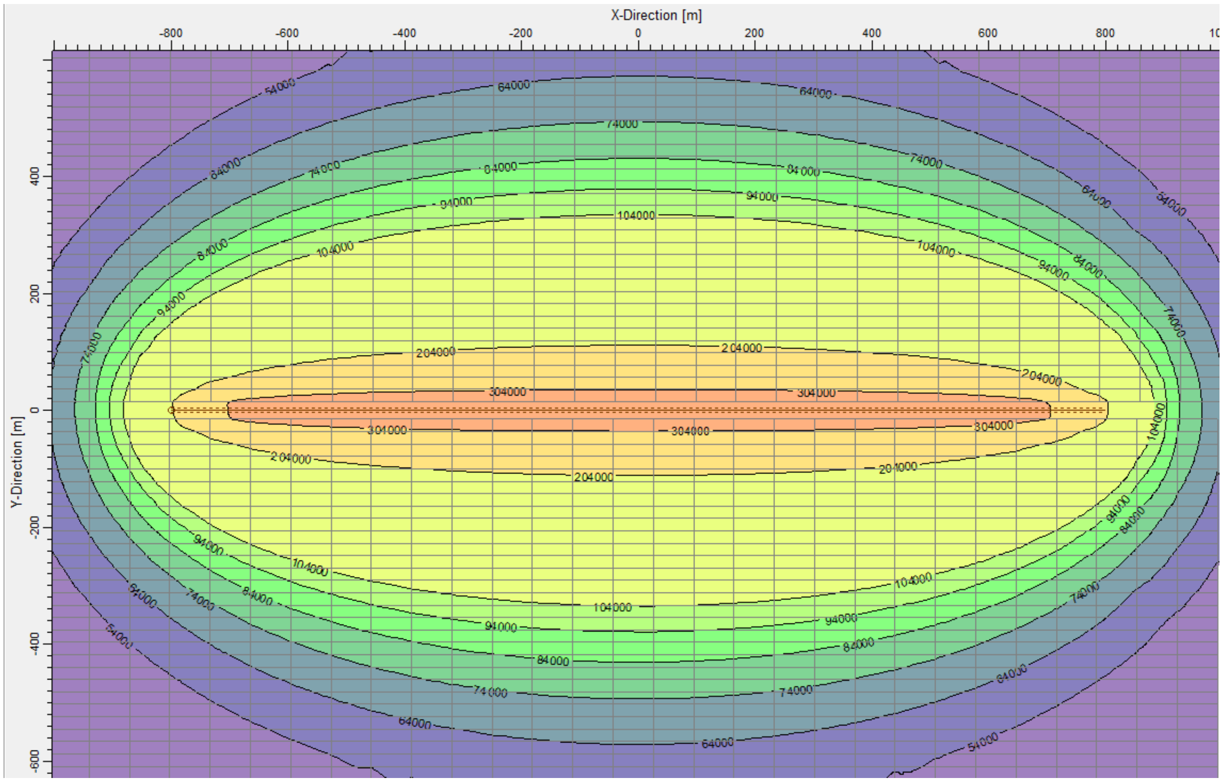


c. Wind from the West, Barrier on North Side, 3 Meter Barrier

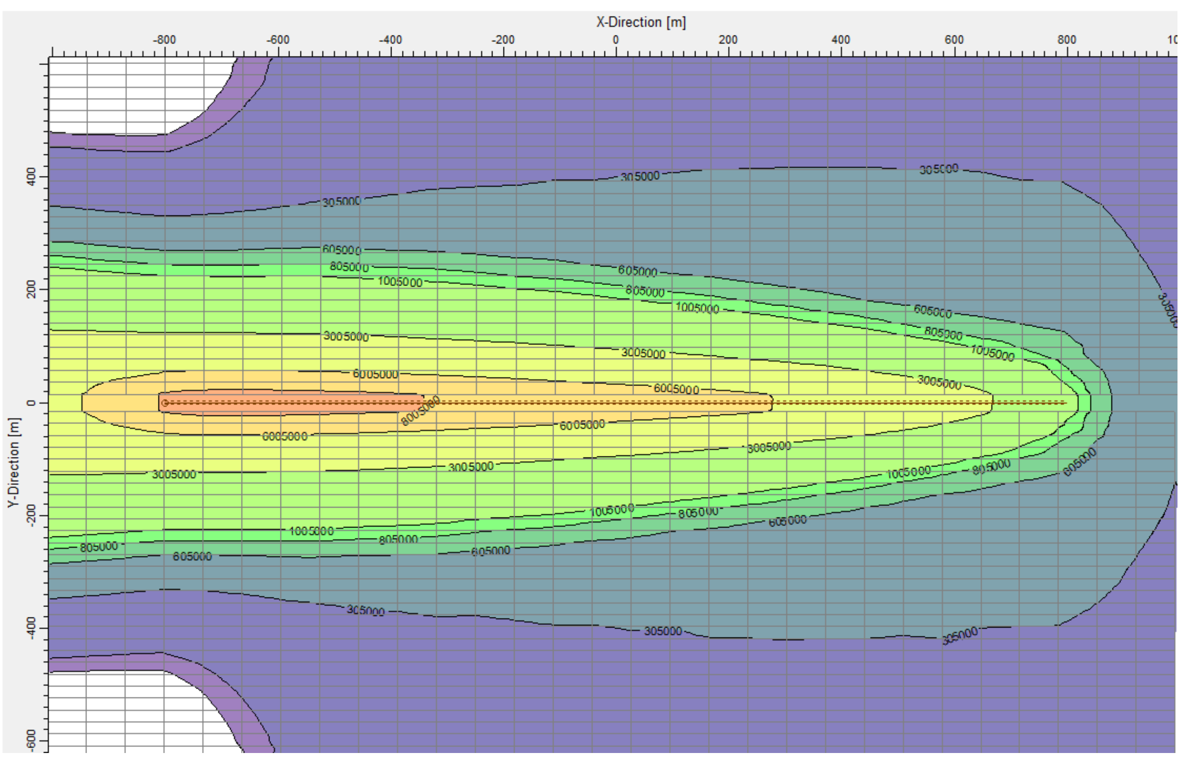


d. Wind from the West, Barrier on South Side, 3 Meter Barrier

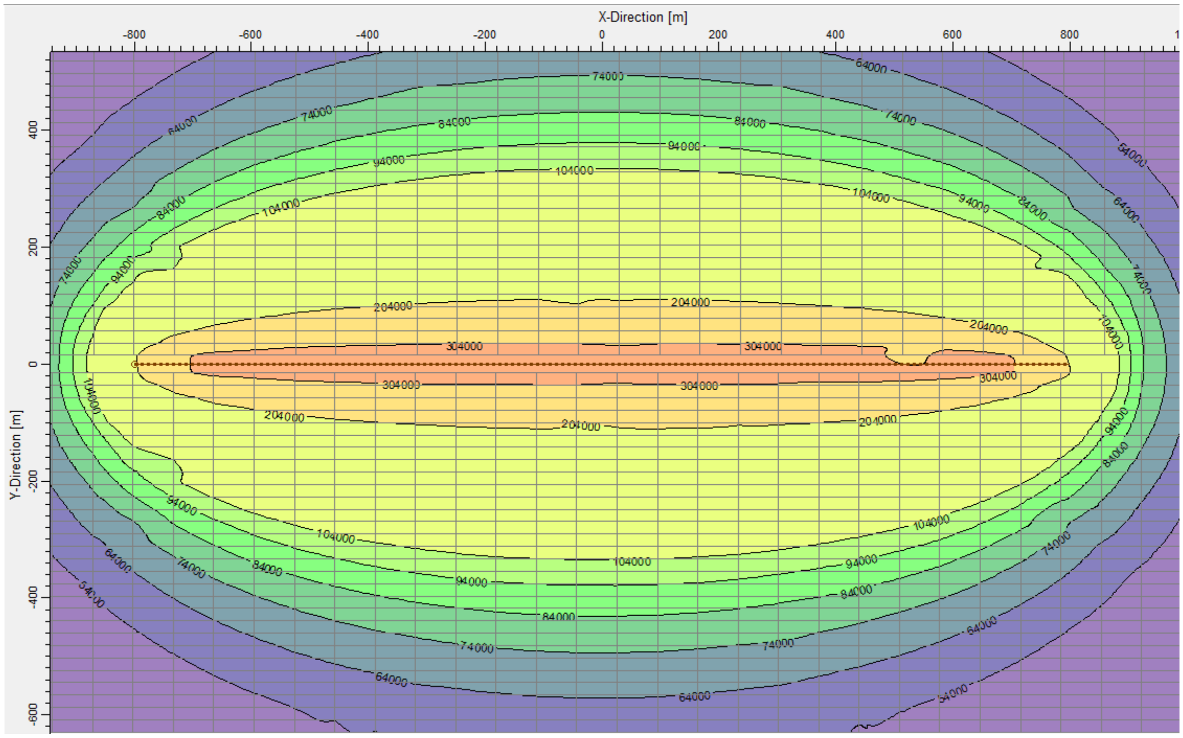
Figure 39. Parallel Wind Analysis for 3 Meter Barriers



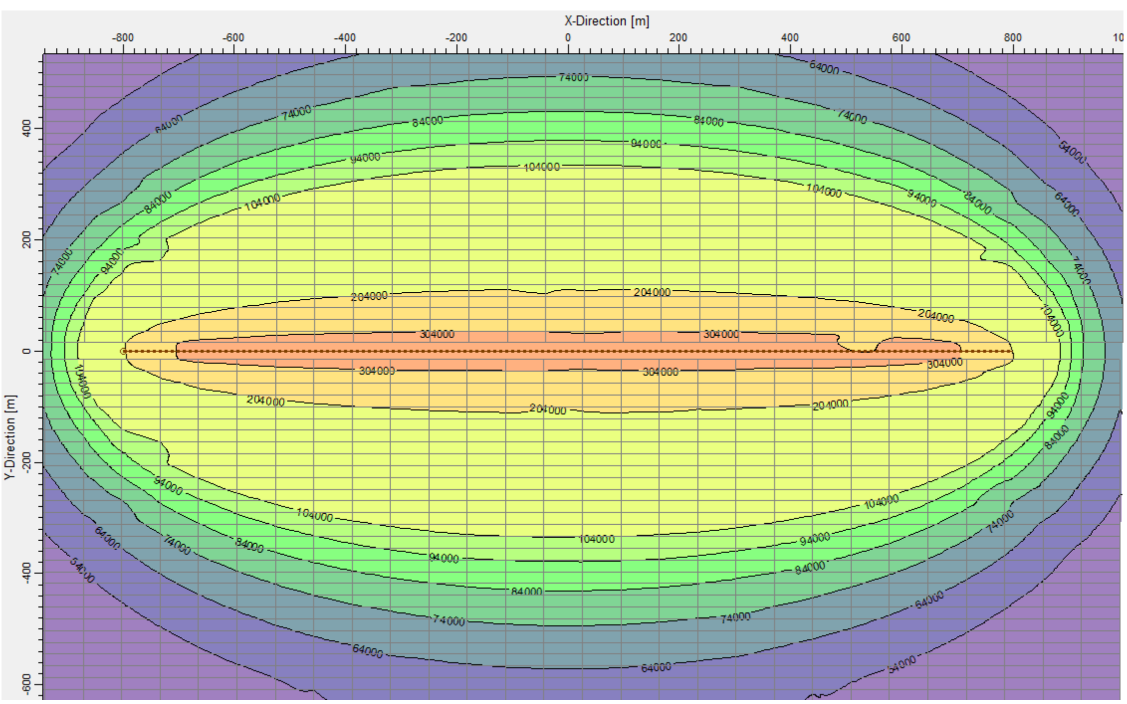
a. Wind from the East, Barrier on North Side, 6 Meter Barrier



b. Wind from the East, Barrier on South Side, 6 Meter Barrier



c. Wind from the West, Barrier on North Side, 6 Meter Barrier



d. Wind from the West, Barrier on South Side, 6 Meter Barrier

Figure 40. Parallel Wind Analysis for 6 Meter Barriers

Analysis. It appears problems with the barrier algorithm occur. When the wind is from the east and the barrier is on the south side of the roadway, a dispersion pattern occurs that would be expected based on previous testing of RLINE with a parallel wind occurs but does not really show the effect of the barrier as would be expected. For all other scenarios it appears that not only the weather effects are being ignored but so is the barrier. Predictions for these other scenarios appear to be what might be expected in a stagnant wind condition with end effects occurring and no barrier. This would appear to be a major problem in programming and should be corrected, especially since with it may go unnoticed with varying winds.

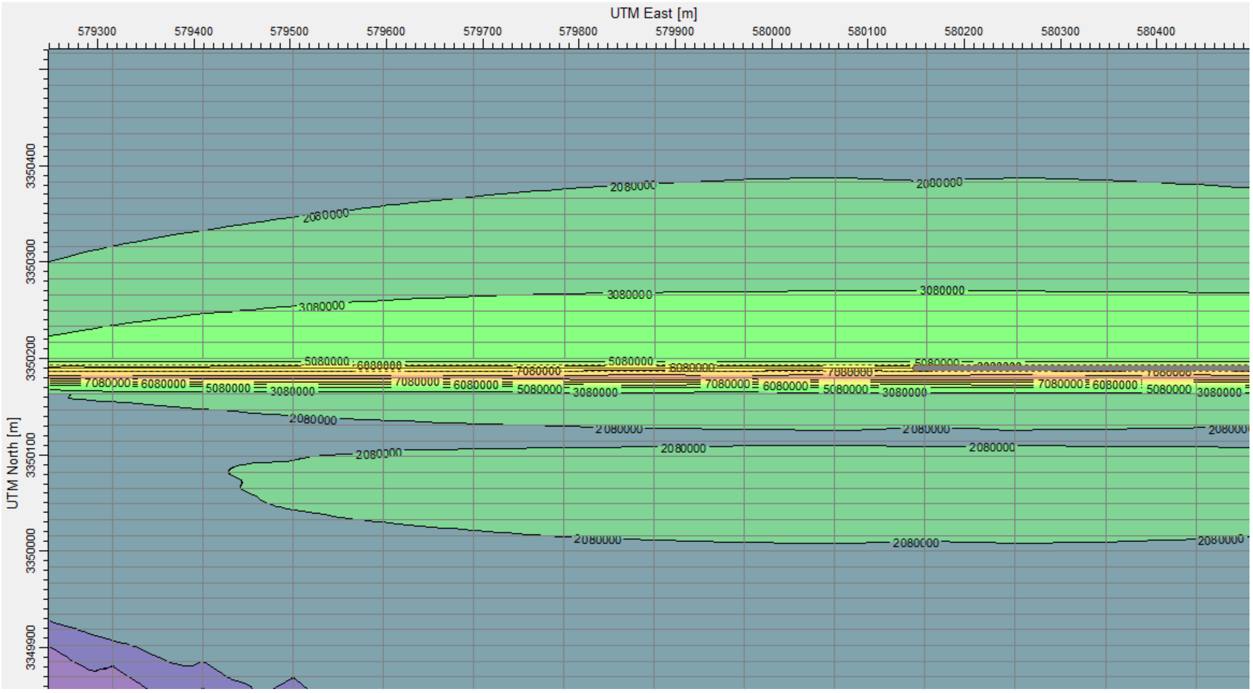
2.7 Barrier End Effects, Continued Barriers

Due to the end effects shown in Section 2.5, continued barriers were analyzed. A continued barrier is when two barriers share the same end points to allow a longer, continuous barrier. This is needed since a barrier can only be tied to a single roadway and must be parallel to the road. In the cases of curves, overlapping designs such as at exit or entrance ramps, and for changes in traffic conditions.

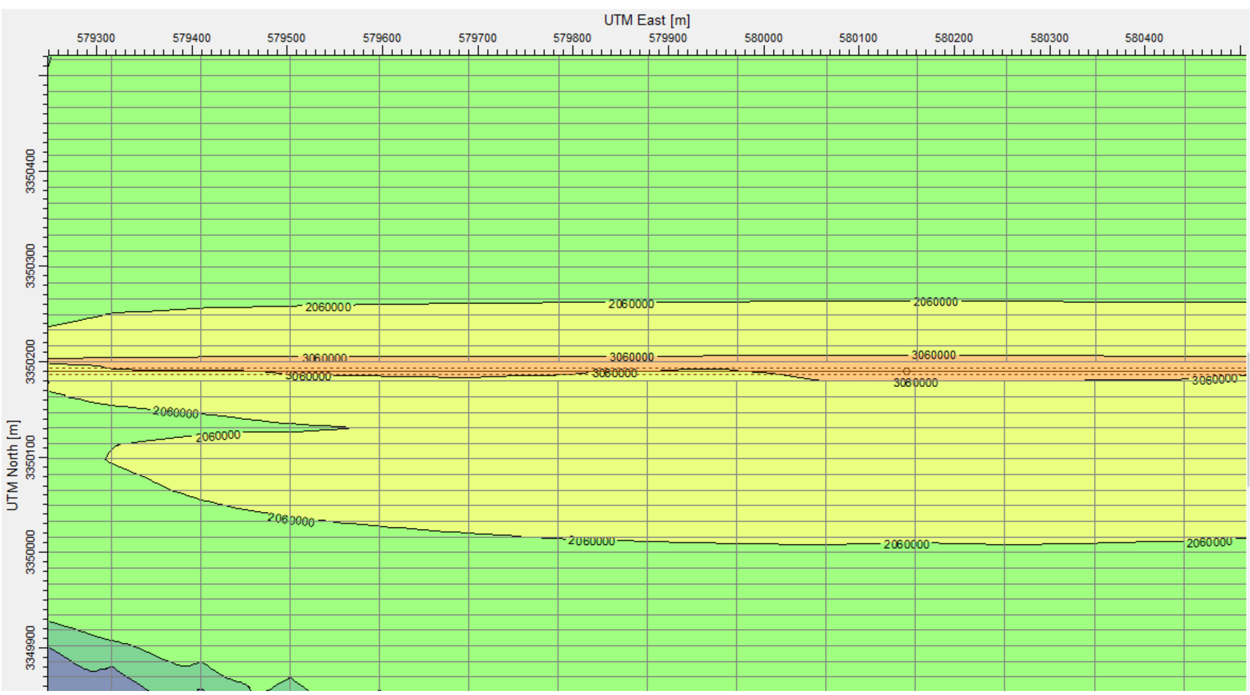
A simple evaluation was conducted by using two simple roadways where the end of the first used the exact coordinates of the second. In the first test, the roadways were continued in a straight line. In a second series of tests, a curve was evaluated. The third test was for overlapping barriers. Many more tests are recommended but beyond the scope of this project.

2.7.1 Extended, Straight Barrier

For this scenario, two, 1000-foot roadways were defined in RLINEXT with a barrier height of 6-meters for each. The release height was 2.3 meters while the initial vertical dimension was 2.2 meters. Testing was accomplished for a perpendicular, cross wind (from the south for an east/west roadway) and both the upwind and downwind conditions were analyzed. Wind roses for these conditions have been previously shown. Care was taken that the endpoints at the roadway connection shared the exact coordinates. Figure 41a shows the results when the barrier was upwind while Figure 41b shows the concentration contours when the barrier was downwind of the roadway.



a. Barrier Upwind of Roadway



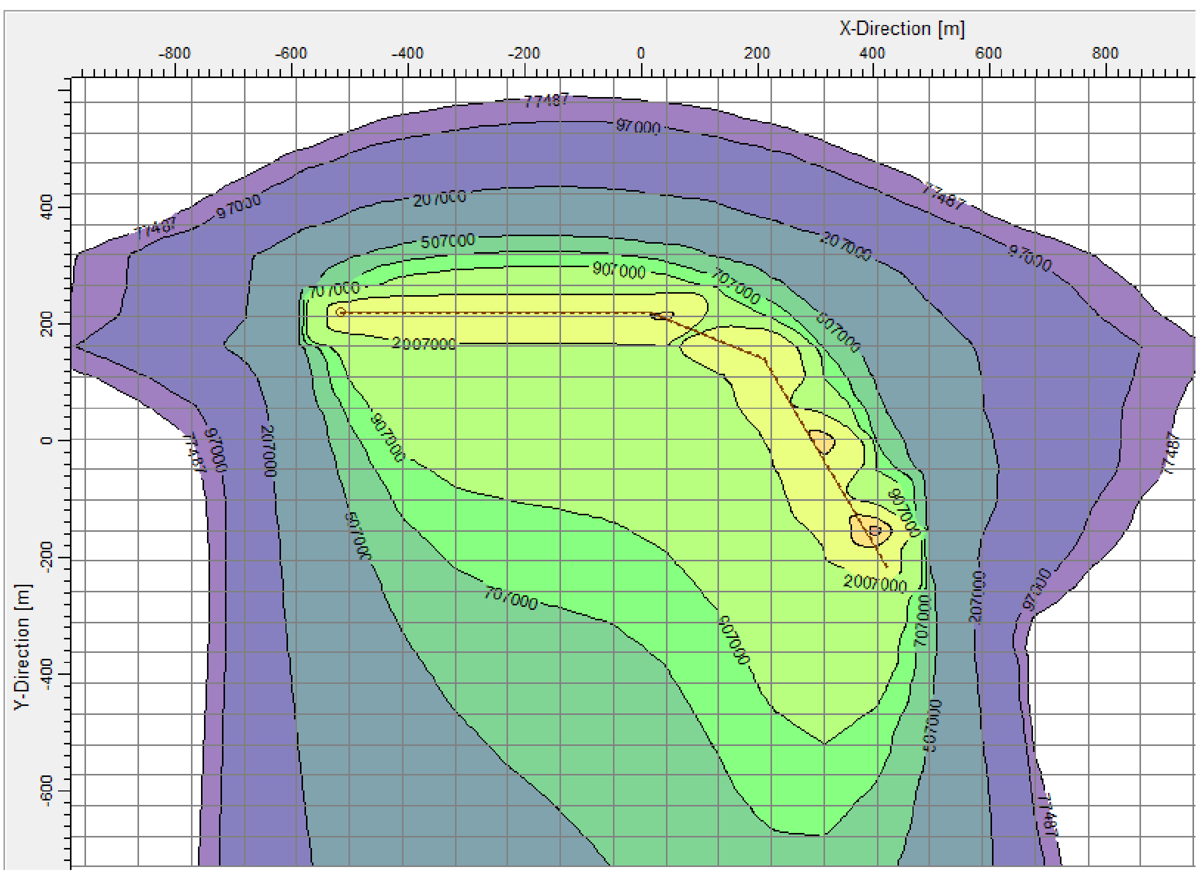
b. Barrier Downwind of Roadway

Figure 41. Extended, Continued Barrier

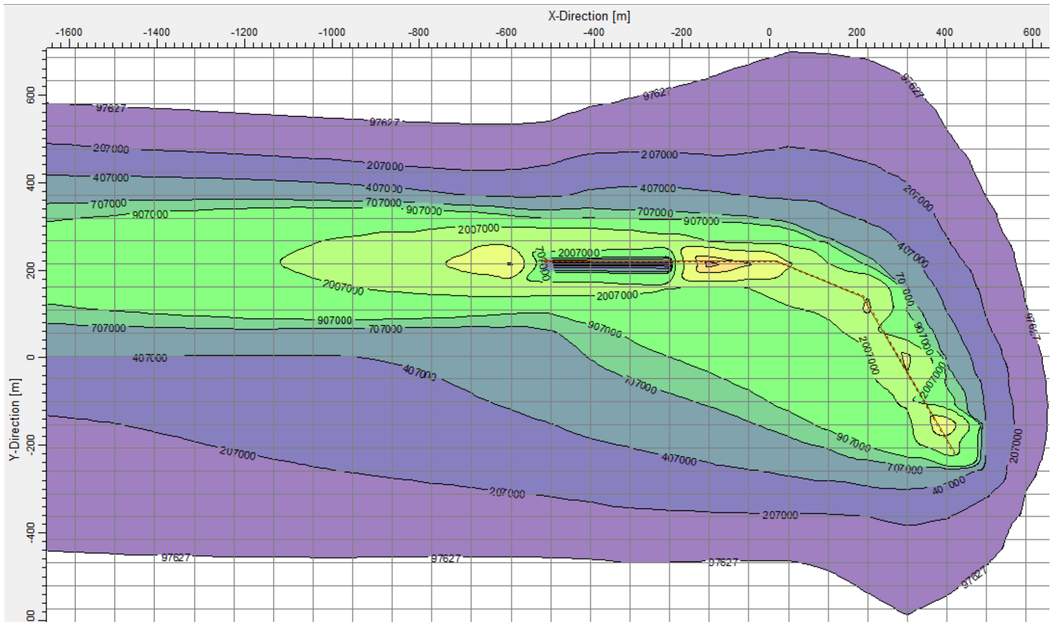
Analysis. The barrier seems to perform with the connected roadways without additional problems. However, the upwind effects continue to show a different, disjointed pattern. In the downwind condition, the upwind effects are similar in nature to the single barrier scenario.

2.7.2 Barriers on Slight Curve

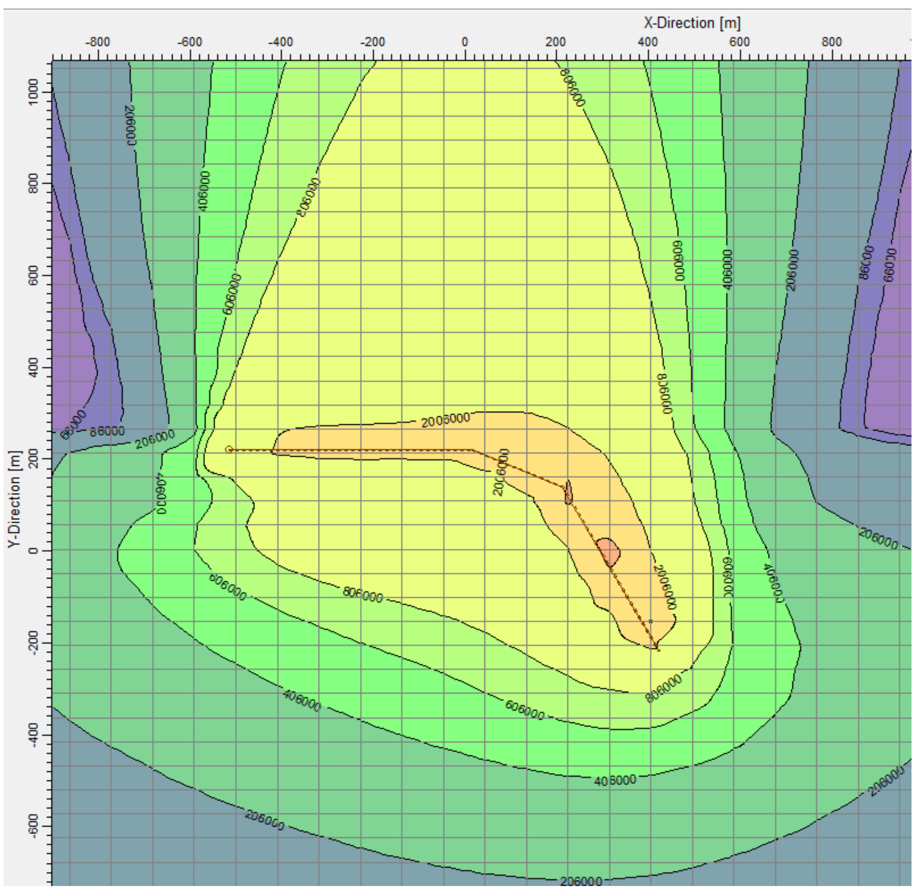
While it is beyond the scope of this project to evaluate barriers on the many different types of curves that occur and multiple barrier heights, an analysis was completed for the use of barriers a 45° curve with a barrier. RLINEXT was used for a single lane to avoid complexity, the release height was 2.3 meters, and the initial vertical dimension was 2.2 meters. The roadway segments included a west to east section composed of two segments. Then, using appropriate length segments (links), a curve of approximately 45° toward the southeast was included. The barrier was 6 meters in height and 15 meters from the roadway. Modeling was accomplished for four wind directions (north, east, west, and south) to allow a better understanding of the effects. The wind rose for each scenario have been shown previously. Figure 42 shows the trends for the four wind conditions with the barrier on the north side of the roadways while Figure 43 shows the same wind conditions with the barrier on the south side of the roadway.



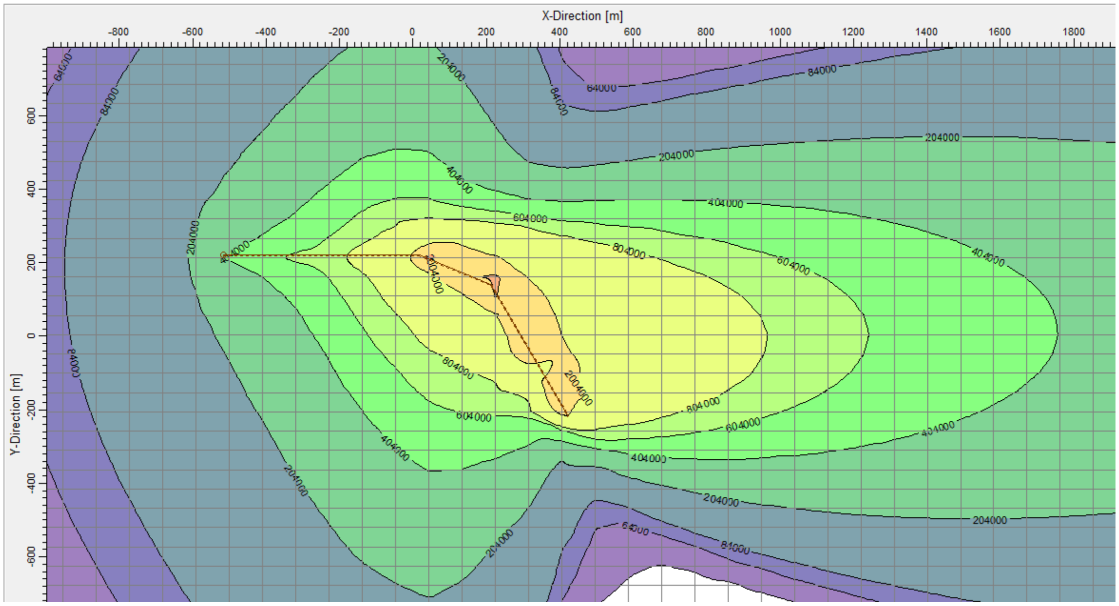
a. Wind from North (0°)



b. Wind from East (90°)

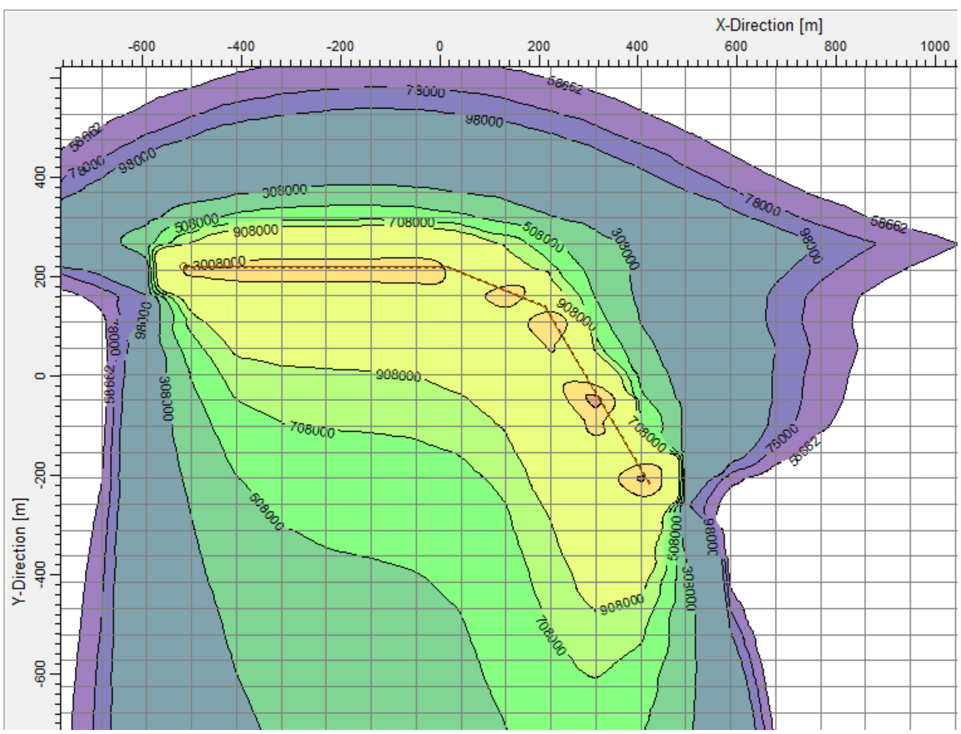


c. Wind from South (180°)

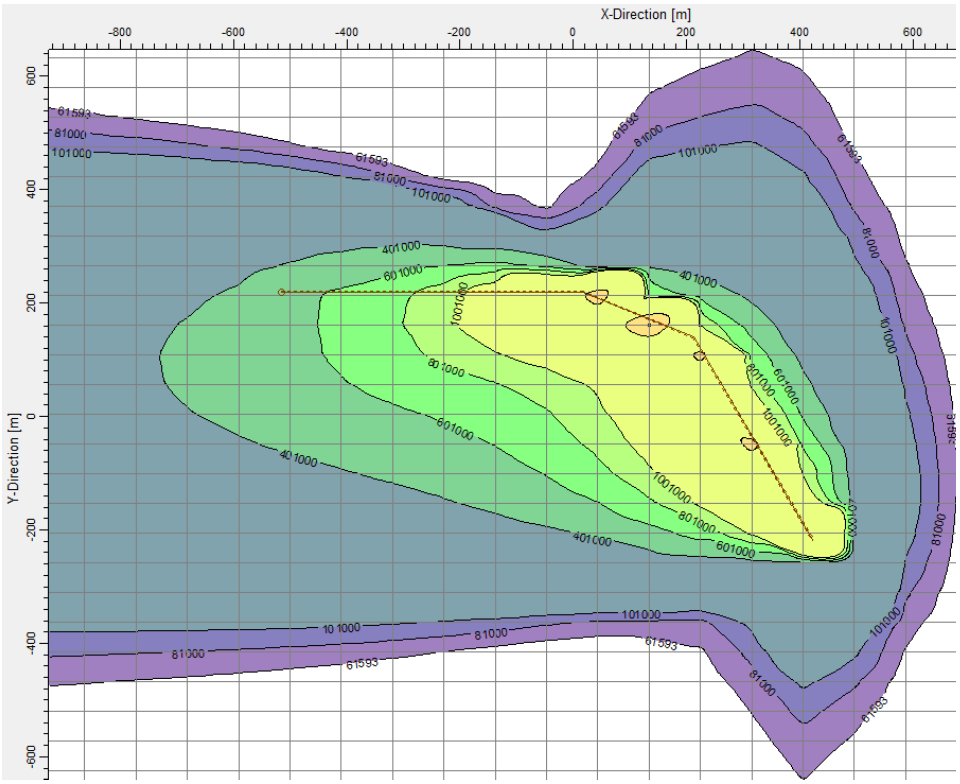


d. Wind from West (270°)

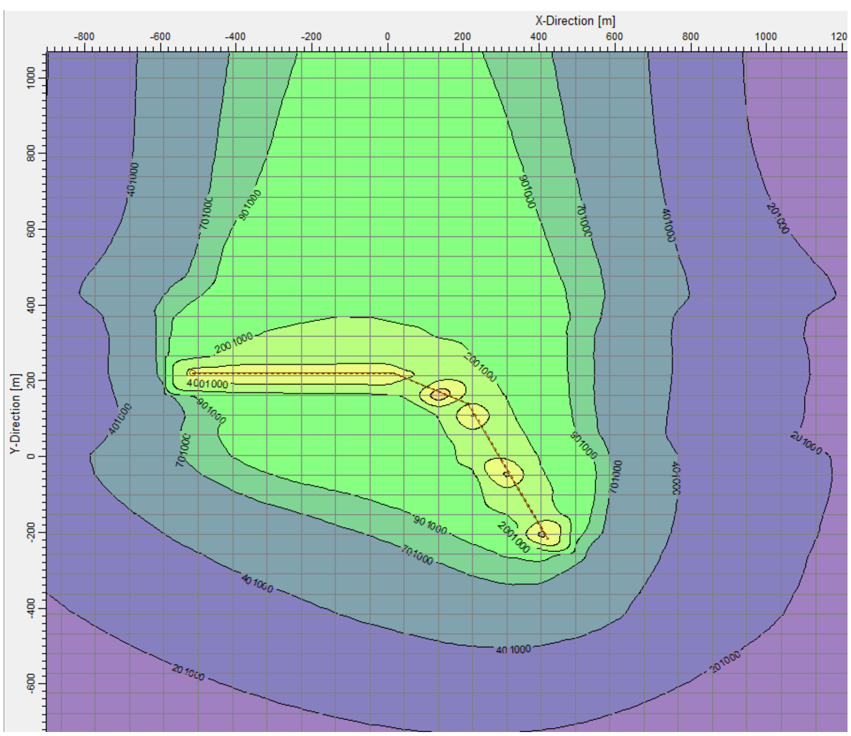
Figure 42. Barrier on Curve, Barrier on South Side of Roadway Segments



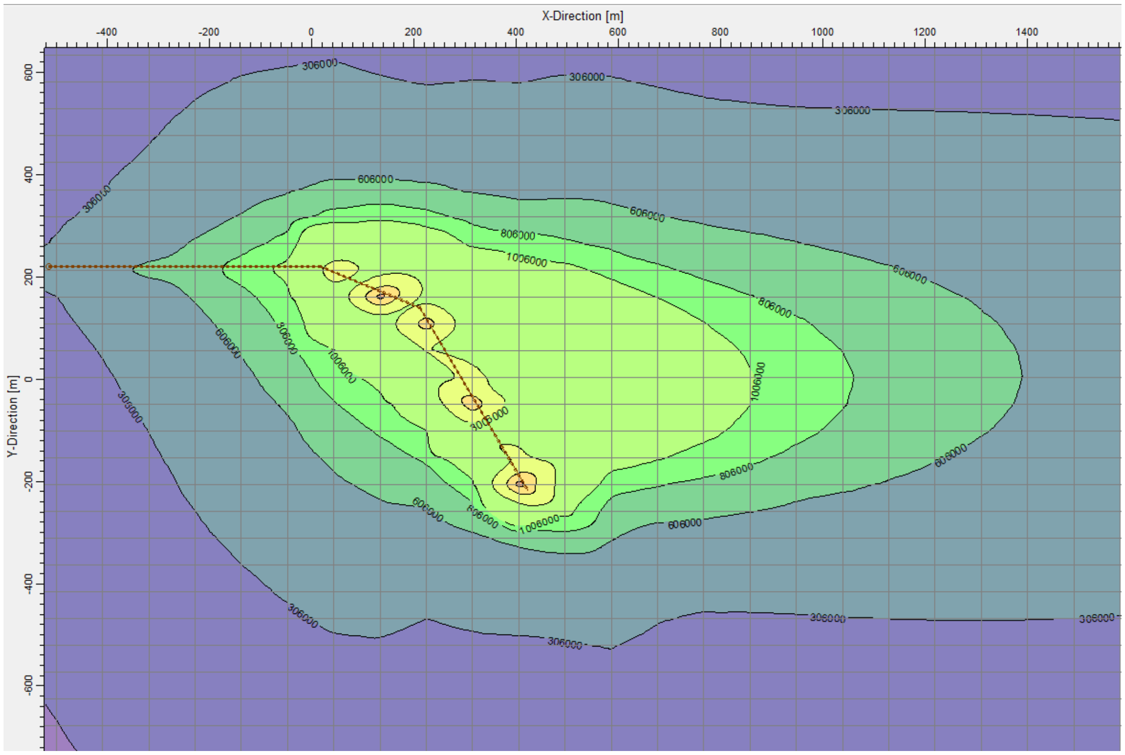
a. Wind from North (0°)



b. Wind from East (90°)



c. Wind from South (180°)



d. Wind from West (270°)

Figure 43. Barrier on Curve, Barrier on North Side of Roadway Segments

Analysis. When the barrier is on the south side of the roadway (see Figure 42), winds from the north, south and west present reasonable patterns but the effects of the barrier do not seem to influence the plume as it did in testing with the straight roadway. Based on the previous testing, it would be expected that strong concentration gradients near the roadway would form but this does not occur to the degree previously shown. Additionally, due to the setup of the roadway and equal distance barrier it also appears that the length of the barrier due to the differences in distances of the two arcs needs to be considered.

When winds are from the east, there is a strong area of concentration centered on the straight portion of the roadway on the west end as concentration buildup occurs similar with the parallel wind effects shown on the straight roadway. However, for the west end straight roadway there is no buildup of concentrations as occurred in the simple straight roadway analysis. Instead, there appears to be no effect on the west end. This same problem occurred with parallel winds on the eastern straight section with winds from the west. This supports the conclusion of problems with a parallel wind with barriers as previously discussed. Additionally, the same problem with distance adjustment for the barrier seems to occur.

Trends are somewhat similar when the barrier on the north side of the roadway (see Figure 43) in that the effects of the barrier are not readily apparent. Of interest is that the trend exhibited by the east wind when the barrier was on the south side of the roadway does not occur. Additionally, with the east wind the most eastern part of the roadway does not show a buildup of concentrations as expected but shows diminishing concentrations.

In both scenarios (south and north side barrier) small "pockets" of concentrations occur after the curved portion. This may indicate a discontinuity in the barrier due to different distances of the roadway and barrier arcs as previously noted. The question becomes, "Is the barrier extended or reduced on curves from the roadway length?" This would be required to make a continuous barrier without gaps or overlaps.

This initial testing indicates that more detailed testing and software review are needed along with measured data to determine if the barriers algorithms are performing properly.

2.8 Depressed Roadway

These analysis scenarios are similar with the analyses in Section 2.5 for barrier evaluation, but dispersion effects for depressed roadway designs were evaluated for different depths. In this analysis, depressed sections of 3, 6 and 10 meters were evaluated for the four general wind directions. Roadway parameters include a 2.2-meter initial vertical dimension and 2.3-meter release height.

2.8.1 Wind from South

The first tests were conducted with a wind direction only from the south to evaluate the different trends of increasing depth for different depressed section scenarios.

2.8.1.1 3-Meter Depth

In this scenario, the depressed section is 3 meters in depth with a top width of 16 meters and a bottom width of 12 meters. This provides a 3 to 2 side slope which is quite steep. The roadway is two lanes, allowing for a 3-meter shoulder on each side. The initial vertical dimension is 2.2 meters, and the release height is 2.3 meters. The winds are only from the south, 180°. Figure 44 shows the results.

Analysis. Effects seem to be minimum as the trends tend to follow the simple roadway patterns without a barrier or depressed section. The cut is somewhat small and without measured data for comparison it is not possible to determine if prediction trend is correct. End effects still exist.

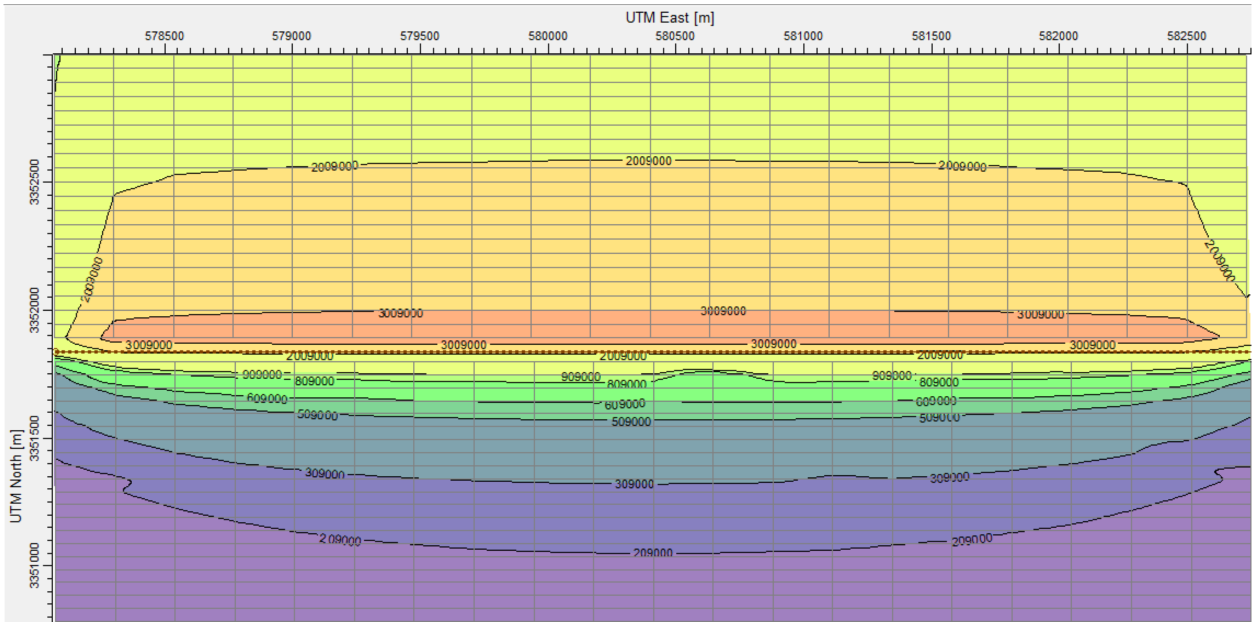


Figure 44. 3-Meter Depressed Section, Wind from South

2.8.1.2 6-Meter Depth

This test uses the same scenario as 2.8.1, but the cut is now 6 meters and to maintain the same shoulder and slope, the top width is now 24 meters. Results are shown in Figure 45.

Analysis. If Figures 44 and 45 are compared, the same overall trends are apparent except the area of increased concentrations extend further upwind and downwind. This would indicate the extent of a depressed section is being recognized but without comparative measured data it is not possible to determine if the changes in trends are accurate.

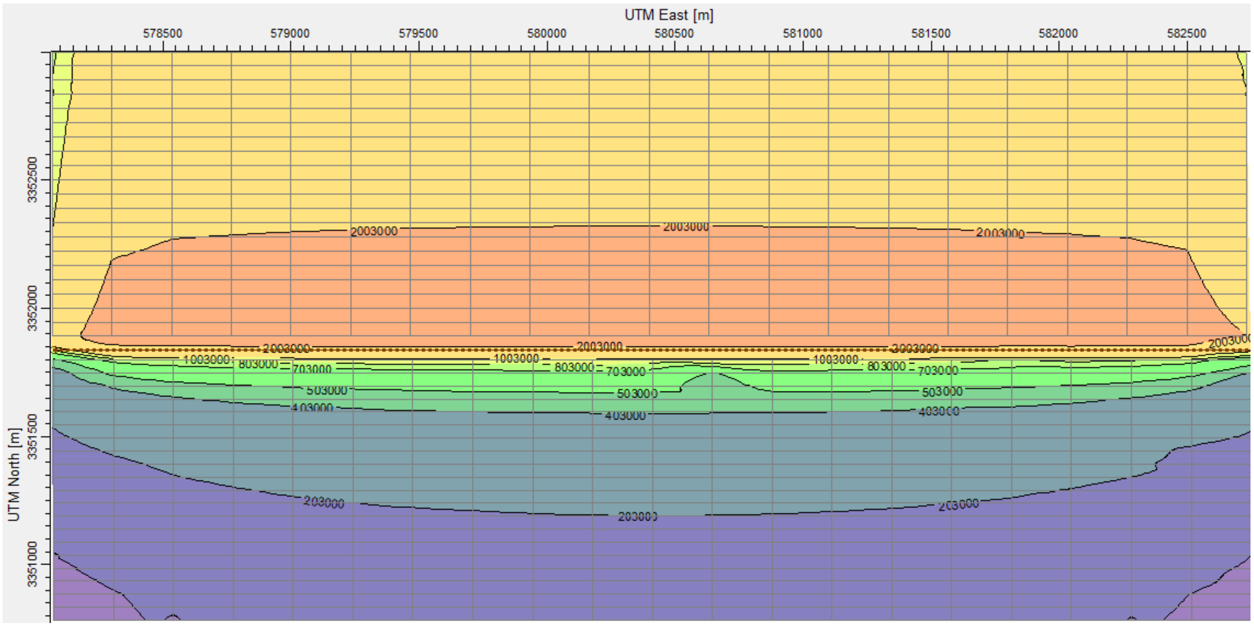


Figure 45. 6-Meter Depressed Section, Wind from South

2.8.1.3 10-Meter Depth

This test uses the same scenario as 2.8.1, but the cut is now 10 meters. This required the top width to be 29.2 meters to maintain the same shoulder and slope. Results are shown in Figure 46.

Analysis. Comparing Figures 43, 44 and 45, a constant trend occurs with increased depressed section depth. The area of increased concentrations extends further both upwind and downwind with increased cut depth. Measured data is needed to verify accuracy.

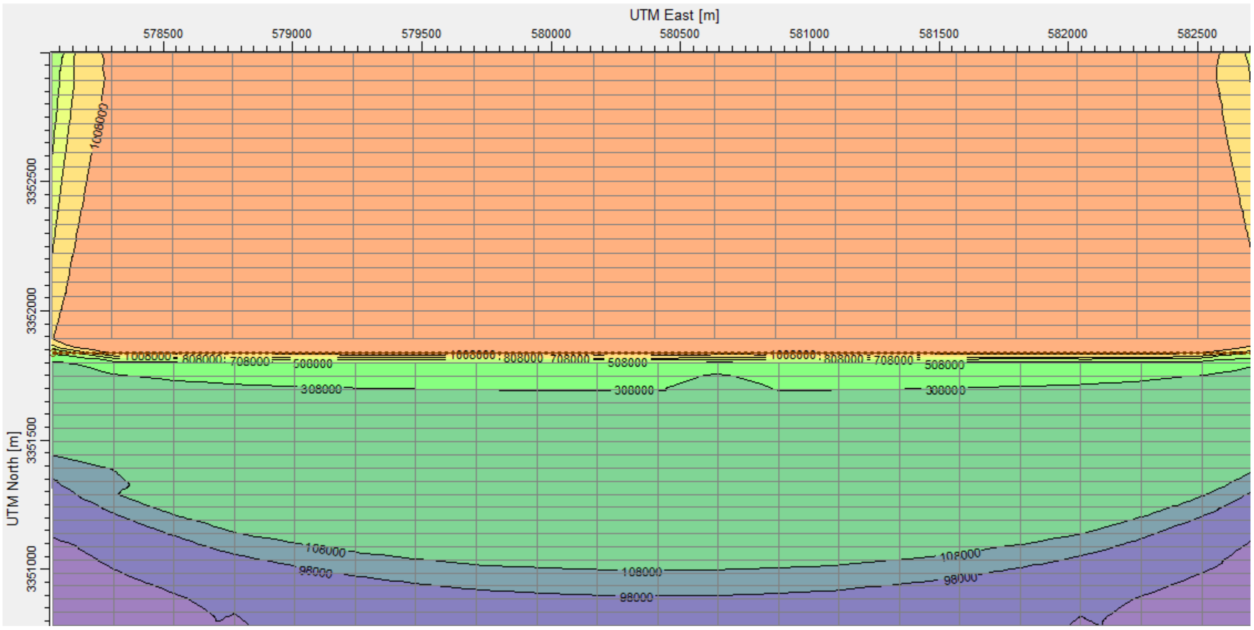


Figure 46. 10-Meter Depressed Section, Wind from South

Analysis for all depressed sections, cross winds. As expected, effects of the shallow cut section with a 2.3 release height are not substantial. Most noticeable is that the greatest downwind concentrations occur at approximately the top of the cut but otherwise results are similar with an at-grade roadway.

The effect on dispersion is apparent as the depth of the depressed section increases. Concentrations are in general less downwind, but areas of increased concentration extend further downwind as the depth increases. End effects appear to be less than in the at-grade scenario but still significant. Upwind, concentrations for the greater depths are higher very near the roadway but then decrease much more rapidly than for the lower depths using the depressed section. Near the center of the roadway, an irregular decrease in the concentration trend occurs. This is most likely due to the point source approximation algorithm.

Intuitively, the depressed algorithms appear to be preforming better than the barrier algorithms. However, to further test the concentration trends from depressed roadways, winds from other directions are evaluated in the next section.

2.8.2 Evaluation of Depressed Section for Other Wind Directions

Based on the findings for barriers at various wind directions it was deemed necessary to also test the depressed sections for wind direction as well. The roadway parameters remain unchanged and only the meteorology input was changed in the next three sections (2.8.2.1 – 2.8.2.3). To evaluate the changes more effectively, the 10-meter depth was selected.

2.8.2.1 Wind from North

The 10-meter depth for the depressed section was evaluated using winds only from the north. Results are shown in Figure 47.

Analysis. Results similar with Figure 46 were expected. Instead, a very different pattern occurred. Instead of a continuous area of higher concentrations occurring (see Figure 46), the falloff rate was much greater both upwind and downwind. End effects were also increased. Since this scenario should show the same patterns for the crosswind flows, results are questionable.

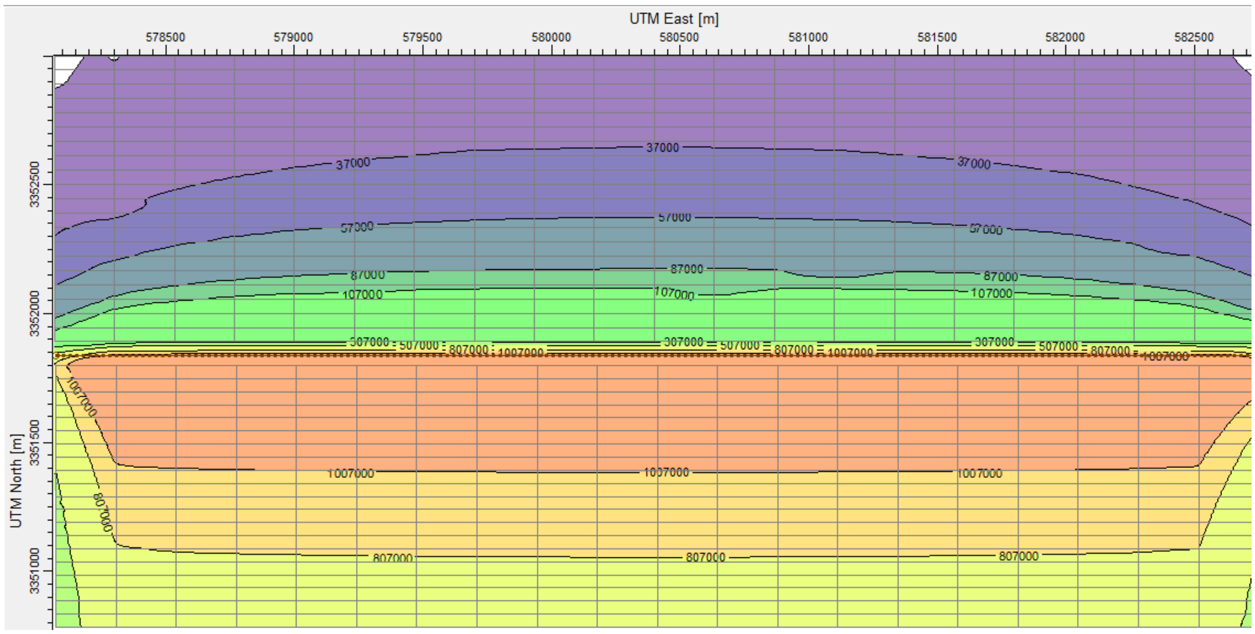


Figure 47. Winds from North, 10-Meter Depressed Section

2.8.2.2 Wind from East

The 10-meter depth for the depressed section was evaluated using winds only from the east. Results are shown in Figure 48.

Analysis. In this scenario, the expected buildup of concentrations occurs as with the simple road scenario. Greater effects from the cut section were expected but appear to be somewhat minimal.

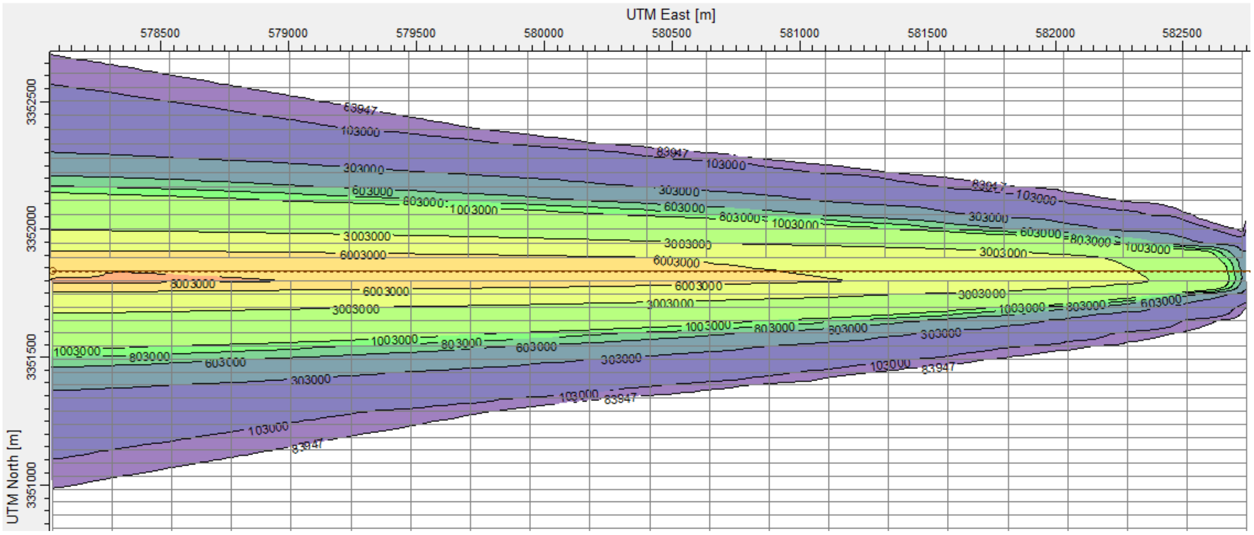


Figure 48. Winds from East, 10-Meter Depressed Section

2.8.2.3 Wind from West

The 10-meter depth for the depressed section was evaluated using winds only from the west. Results are shown in Figure 49.

Analysis. Again, an effect similar with winds for the east (parallel wind) were expected but did not occur. In this scenario there appears not to be any effect from the depressed section. A review of depressed sections would seem to be warranted.

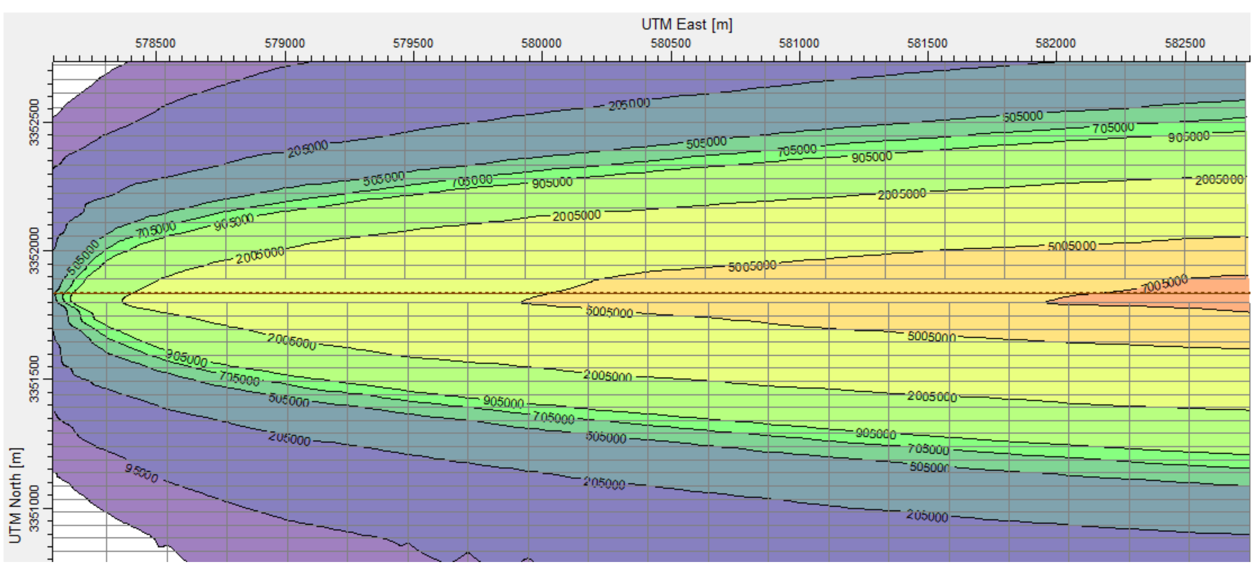


Figure 49. Winds from West, 10-Meter Depressed Section

Analysis for all depressed sections. For the scenario with the wind from the north (2.8.2.1), a trend very similar to 2.8.1.3 (same depressed design but wind from south) was expected but a very different trend occurred with areas of uniform falloff occurring rather than a large area of similar concentrations. Which scenario result is most correct is not known without measured data, but intuitively the north wind downwind pattern would seem to be better. The upwind pattern in also different, with a more regular falloff rate. Small inconsistencies still occur in the upwind contours.

Crosswinds from the east and west show the increased concentrations downwind as expected along the roadway but exhibit very different trends. It would be expected that the trends would be very similar which does not occur. Winds from the west results in lower concentrations along the roadway but wider dispersion patterns. Effects of the depressed side walls seem to be missing.

The effect of the depressed section analysis does not show the extent of the trends expected and still show discrepancies that require continued analysis and considerations.

2.9 Intersection Analysis Comparison

In highway air quality analysis, a key component is the analyses of intersections. Intersections are usually the transportation component with the greatest nearby concentrations for urban roadways and hot-spot analysis are often key during different types of analysis. The reader is reminded that there is no "gold standard" to compare to, but how results might change from previous modeling is an important consideration. Accordingly, a comparison to the legacy model, CAL3QHC[19], was performed as part of the RLINE evaluation. Consideration was given to multiple intersection analysis used in a past work but the ability for readers to retrieve the information resulted in the selection of Example Problem 2, used in the CAL3QHC User's Guide which is still readily available and can be retrieved from the EPA website. The example problem intersection is a two-way, multiphase signalized intersection that is over-capacity. Figure 50 shows the intersection and initially modeled receiver locations. Complete details can be found in the CAL3QHC user's guide.

To make this comparison, several hurdles had to be overcome. First were the emission factors. Since the emission factors are in different formats and used differently in the models, great care was taken to make sure the factors were correct. The emission factors used in the CAL3QHC (grams/veh-mi) example were converted into the appropriate units of grams/meter^2/second. To accomplish this, the conversion had to be accomplished differently for moving and idle emissions.

For moving emissions, vehicle speeds were used to convert to grams/second. Next areas were computed to allow the emission factor to be divided by the area. Finally, the emissions were

[19] U.S. EPA, User's Guide to CAL3QHC Version 2.0: A Modeling Methodology for Predicting Pollutant Concentrations Near Roadway Intersections (Revised), EPA-454/R-92-006R, 1995.

scaled for the traffic flow on each leg of the intersection. This resulted in an emission factor that could be applied to each through (moving vehicle) links and used during dispersion modeling.

Idling vehicles were computed by first reviewing the output files from CAL3QHC. During processing, CAL3QHC determines the average vehicle queue length and vehicles stopped per timing cycle and sets the emission rate to 100 grams/mi to allow a final computation of the actual emissions. Using these values, it was again possible to compute the grams/hour, allocating for vehicle times stopped and number of vehicles for each approach, which was corrected for the time in the queues and number of vehicles in each queue. This was then divided by the area of the queues to generate grams/meter^2/second. These derived emission factors, for each queue link, were then used during RLINE modeling.

Meteorological files were generated for RLINE using MakeMet. Care was taken to get wind speeds (1 m/s) at the appropriate height to match CAL3QHC. In the CAL3QHC model, multiple single wind directions can be evaluated in a single run to allow comparison of maximum concentrations from different wind angles. Since RLINE must be run for each wind angle, the wind angles from CAL3QHC with the greatest concentrations were determined for receiver locations. This resulted in a total of 14 MakeMet files to allow comparison of the maximum values at each receiver. The wind angles used are included in Table 9.

All inputs for the CAL3QHC and the required fourteen RLINE models were developed, input into the proper format, and the programs run to provide the necessary point concentrations for comparison. CAL3QHC was run to add four additional receiver locations. This was accomplished to allow a better comparison since many of the original receiver positions were very near the roadways and it was desired to see how each quadrant performed with the additional receiver locations.

Output in CAL3QHC is in parts-per-million by volume (ppm_v) at the reference temperature of 298° Kelvin. Output from RLINE is in micrograms/cubic meter. MakeMet used this temperature as in all runs and based on the same temperature for conversion, the output of RLINE was converted to ppm_v to allow a direct comparison. Table 9 shows the concentrations, receiver locations, and wind direction for the RLINE output. Concentrations for the CAL3QHC runs are shown in Table 10, a – c. There are three table since three wind angle searches were included in the CAL3QHC example problem. As previously mentioned, maximum concentrations were selected for comparison. All background concentrations for both models were assumed to be zero to allow the direct comparison.

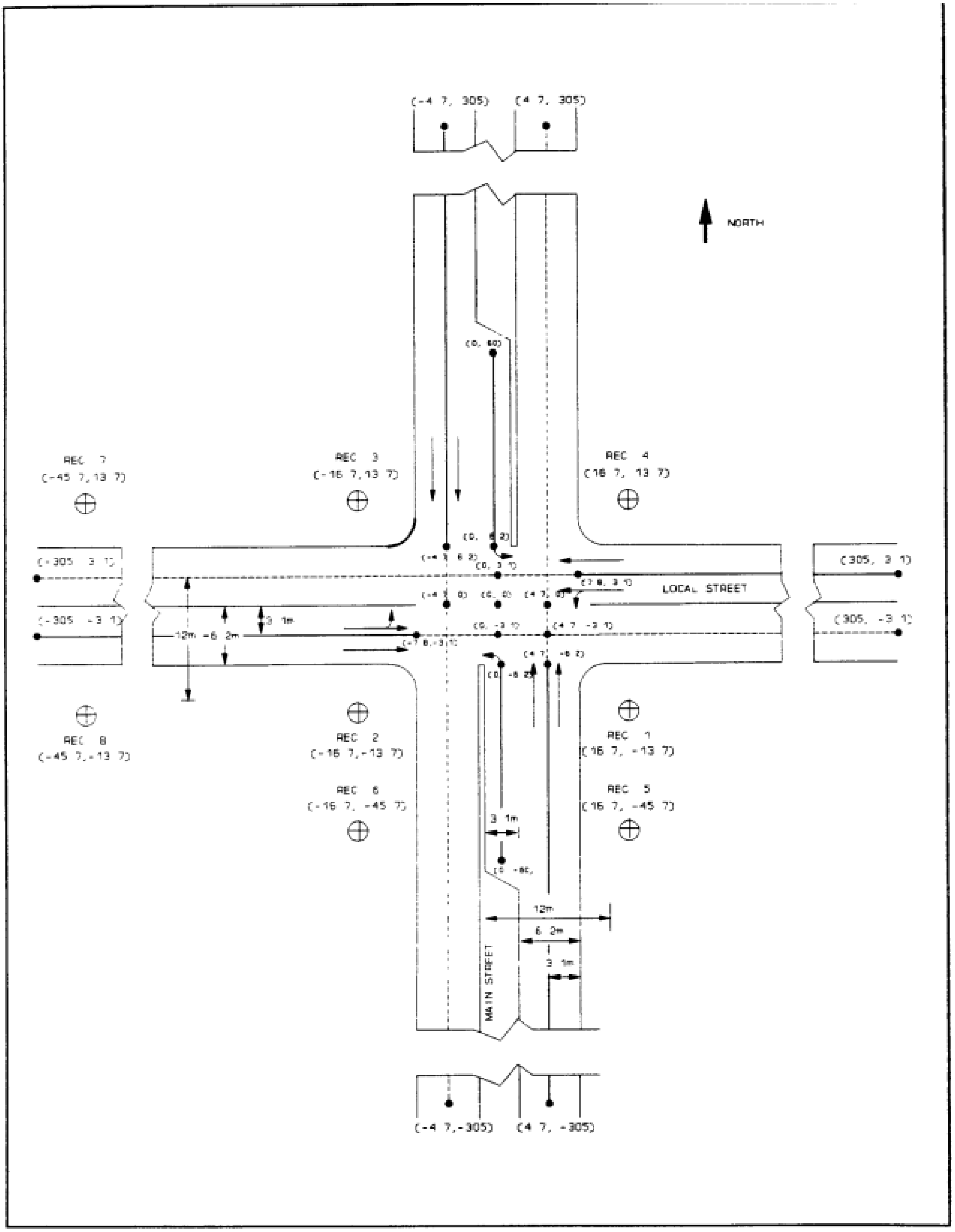


Figure 50. CAL3QHC Intersection Used in Comparison19 (units in meters)

Table 9. Predicted Concentrations from RLINE for Different Wind Angles (PPM)

	COORD.		WIND DIRECTION													
RECEIVER	X	Y	10 deg	20 deg	40 deg	70 deg	150 deg	155 deg	165 deg	195 deg	205 deg	240 deg	252 deg	290 deg	300 deg	340 deg
REC 1 (SE CORNER)	16.7	-13.7	3.3	2.1	1.4	1.5	1.5	1.7	2.1	6.6	5.4	3.5	3.4	4.0	3.8	6.1
REC 2 (SW CORNER)	-16.7	-13.7	7.2	6.0	4.3	4.3	5.3	5.8	6.9	2.0	1.6	1.1	1.2	1.5	1.4	2.2
REC 3 (NW CORNER)	-16.7	13.7	7.0	6.1	4.4	3.3	5.5	6.0	7.4	2.3	1.9	1.3	1.5	1.1	1.2	2.1
REC 4 (NE CORNER)	16.7	13.7	2.8	1.8	1.2	1.1	1.7	1.8	2.3	6.9	5.6	3.5	3.5	3.2	3.4	5.8
REC 5 (E MID-MAIN)	16.7	-45.7	3.4	2.0	1.3	1.2	1.4	1.6	2.0	6.2	5.3	3.5	3.3	3.9	4.0	6.3
REC 6 (W MID-MAIN)	-16.7	-45.7	7.6	6.5	4.8	4.2	5.2	5.7	6.6	1.9	1.5	1.0	1.0	1.2	1.2	2.0
REC 7 (N MID-LOCAL)	-45.7	13.7	3.3	4.0	3.4	2.8	4.2	4.4	4.3	1.0	0.8	1.0	1.2	0.7	0.6	0.7
REC 8 (S MID-LOCAL)	-45.7	-13.7	4.0	4.6	3.7	3.2	3.7	3.9	3.7	0.7	0.6	0.6	0.6	1.2	1.0	0.9
REC 9 (SOUTHWEST)	-40	-40	4.6	4.8	3.5	3.3	3.8	4.0	3.8	0.7	0.6	0.5	0.5	1.0	0.9	0.9
REC 10 (NORTHEAST)	40	40	0.8	0.6	0.5	0.5	0.7	0.8	1.0	4.9	4.6	3.0	3.1	2.6	2.8	3.9
REC 11 (SOUTHEAST)	40	-40	1.1	0.9	0.8	1.0	0.6	0.6	0.7	3.8	4.0	2.8	2.7	3.3	3.3	4.9
REC 12 (NORTHWEST)	-40	40	3.5	4.1	3.4	2.6	4.4	4.8	5.0	1.0	0.8	0.9	1.0	0.5	0.5	0.7

Coordinates in meters

Table 10. Predicted Concentrations from CAL3QHC for Different Wind Angles (PPM_v)

a) 5° increments, 150° - 210°

DEGREES	REC1	REC2	REC3	REC4	REC5	REC6	REC7	REC8	REC9	REC10	REC11	REC12
150	0	9.3	11.8	6.5	0	8.7	6.5	4	4	0.6	0	7.2
155	0.1	9.5	12.7	6.8	0.1	8.7	6	3.8	3.8	0.6	0	6.7
160	0.4	9.3	13.3	7.2	0.4	8.5	5.4	3.4	3.5	0.5	0	6.5
165	1	9	13.6	7.7	0.9	7.9	4.6	2.8	3	0.6	0	5.7
170	2.2	7.8	13.1	9	1.9	6.9	3.9	2.1	2.2	1.2	0.2	4.7
175	4	6.4	11.9	11	3.2	5.5	2.9	1.4	1.6	2	0.4	3.5
180	6.1	4.7	10.2	13	5.1	4	2.1	0.8	0.9	2.9	1	2.5
185	8.2	3.1	8.6	14.9	7.1	2.7	1.7	0.4	0.4	4.2	1.7	1.7
190	9.9	1.6	6.9	16.2	8.6	1.5	1.4	0.1	0.2	5.4	2.3	0.9
195	10.9	0.7	5.9	16.5	10	0.7	1.2	0	0	6.5	3.2	0.5
200	11.3	0.3	5.3	15.8	10.6	0.3	1.2	0	0	7.2	3.8	0.5
205	11.3	0.1	4.7	14.8	10.7	0.1	1.2	0	0	7.3	4.2	0.6
210	10.9	0	4.2	13.7	10.6	0	1.2	0	0	7.3	4.6	0.6

b) 3° increments, 240° - 300°

DEGREES	REC1	REC2	REC3	REC4	REC5	REC6	REC7	REC8	REC9	REC10	REC11	REC12
240	9	0	2	9	9	0	1.5	0	0	5.5	4.8	0.6
243	8.9	0	1.9	8.9	8.9	0	1.6	0	0	5.6	4.8	0.6
246	8.9	0	1.8	9	8.9	0	1.6	0	0	5.4	4.8	0.6
249	9	0	1.7	9.3	8.9	0	1.6	0	0	5.2	4.8	0.6
252	8.9	0.1	1.8	9.3	8.7	0	1.7	0.1	0	5	4.6	0.6
255	9.3	0.2	1.7	9.3	8.9	0	1.6	0.2	0	5	4.7	0.6
258	9.4	0.3	1.6	9.2	8.8	0	1.6	0.3	0	5.1	4.7	0.5
261	9.6	0.4	1.6	9	8.8	0	1.5	0.4	0	5	4.8	0.5
264	9.9	0.6	1.4	9	8.7	0	1.4	0.6	0	5	5	0.4
267	10.4	0.8	1.3	8.9	8.9	0.2	1.2	0.8	0.2	4.7	5	0.3
270	10.7	1.1	1.1	8.6	8.9	0.2	1.1	1	0.2	4.7	5	0.2
273	11.1	1.3	0.9	8.4	8.9	0.2	0.8	1.2	0.3	4.6	5.3	0.1
276	11.4	1.5	0.7	8.2	9	0.3	0.7	1.2	0.4	4.5	5.3	0.1
279	11.4	1.7	0.5	7.9	9.1	0.4	0.5	1.4	0.4	4.5	5.4	0
282	11.5	2	0.4	7.9	9.2	0.5	0.4	1.4	0.5	4.4	5.4	0
285	11.7	2.1	0.3	7.7	9.2	0.5	0.2	1.5	0.5	4.4	5.6	0
288	11.6	2.4	0.1	7.5	9.4	0.5	0.1	1.5	0.7	4.3	5.7	0
291	11	2.7	0.1	7.7	9.4	0.5	0.1	1.5	0.7	4.6	6.1	0
294	10.7	3	0	7.6	9.6	0.5	0	1.5	0.7	4.6	6.2	0
297	10.5	3.3	0	7.7	9.7	0.5	0	1.5	0.7	4.6	6.2	0
300	10.1	3.6	0	7.8	9.8	0.5	0	1.4	0.7	4.6	6.2	0

c) 10° increments, 330° - 70°

DEGREES	REC1	REC2	REC3	REC4	REC5	REC6	REC7	REC8	REC9	REC10	REC11	REC12
330	6.3	3.3	0	5	6.8	0.5	0	0.6	0.3	2.6	3.8	0
340	7.3	3.7	0.3	5.3	7.3	1	0	0.6	0.3	2.3	3.8	0
350	7.4	5.1	1.5	4.7	6.3	2.5	0.1	0.7	0.5	1.6	2.9	0.2
360	5.7	7.3	3.7	2.8	4.4	4.3	0.7	1.4	1.7	0.7	1.5	0.7
10	3.8	9.1	5.9	1	2.3	5.6	1.7	2.5	3.2	0.1	0.6	1.8
20	2.9	8.8	6.3	0.2	1	5.8	2.5	3.2	3.9	0	0.3	2.6
30	2.4	7.4	5.9	0	0.5	5.4	2.7	3.5	3.8	0	0.3	2.8
40	2.2	5.9	5.5	0	0.4	5.5	2.7	3.8	3.7	0	0.3	2.8
50	1.7	5.3	5	0	0.3	5	2.4	4	3.5	0	0.3	2.7
60	1.2	5.1	4.9	0	0.3	4.6	2.3	4.6	3.2	0	0.3	2.6
70	1	5	4.8	0	0.3	4.3	2.3	4.6	2.9	0	0.3	2.4

Analysis. Multiple comparisons were utilized. First, a simple comparison of the maximum value predicted was used. The maximum value for RLINE was 7.6 ppm_v while the maximum value for CAL3QHC was 16.5 ppm_v. However, these maximum values occurred for very different receivers and wind directions (Receiver 6 vs. 4 and 10° vs. 195°, RLINE and CAL3QHC respectively). Differences were noted in the change in concentrations with distance as well. Additionally, different assumptions for the true emission factors can result in a wide range of final concentrations. While there is no way to determine which is more accurate these results show very different results from the models.

To extend the comparison, an overall comparison of all selected wind angles was performed. Table 11 shows the comparison where values predicted by CAL3QHC were divided by those predicted by RLINE to allow a ratio of the results. Where CAL3QHC predicted zero, no analysis was performed (NA). RLINE did not predict any zero concentrations. This provides an overall indicator of the range of differences in predictions since absolute values are unknown. A value above 1 indicates a predicted concentration by CAL3QHC greater than that by RLINE while a value below 1 indicates RLINE predicted a greater concentration.

Table 11. Comparison of CAL3QHC and RLINE at an Intersection

	COORD.		WIND DIRECTION													
RECEIVER	X	Y	10 deg	20 deg	40 deg	70 deg	150 deg	155 deg	165 deg	195 deg	205 deg	240 deg	252 deg	290 deg	300 deg	340 deg
REC 1 (SE CORNER)	16.7	-13.7	1.16	1.41	1.53	0.67	NA	0.06	0.48	1.66	2.07	2.56	2.60	2.78	2.66	1.20
REC 2 (SW CORNER)	-16.7	-13.7	1.26	1.46	1.37	1.17	1.76	1.63	1.30	0.34	0.06	NA	0.09	1.77	2.65	1.68
REC 3 (NW CORNER)	-16.7	13.7	0.85	1.02	1.26	1.46	2.14	2.11	1.83	2.57	2.53	1.60	1.20	0.09	NA	0.14
REC 4 (NE CORNER)	16.7	13.7	0.35	0.11	NA	NA	3.93	3.72	3.28	2.39	2.64	2.57	2.63	2.39	2.31	0.91
REC 5 (E MID-MAIN)	16.7	-45.7	0.68	0.50	0.30	0.24	NA	0.06	0.45	1.60	2.01	2.56	2.65	2.39	2.45	1.17
REC 6 (W MID-MAIN)	-16.7	-45.7	0.74	0.89	1.14	1.01	1.67	1.53	1.19	0.36	0.07	NA	NA	0.40	0.43	0.49
REC 7 (N MID-LOCAL)	-45.7	13.7	0.51	0.62	0.80	0.83	1.54	1.36	1.06	1.25	1.47	1.52	1.36	0.15	NA	NA
REC 8 (S MID-LOCAL)	-45.7	-13.7	0.63	0.69	1.04	1.44	1.08	0.98	0.77	NA	NA	NA	0.15	1.26	1.41	0.66
REC 9 (SOUTHWEST)	-40	-40	0.69	0.81	1.05	0.87	1.06	0.96	0.79	NA	NA	NA	NA	0.69	0.76	0.33
REC 10 (NORTHEAST)	40	40	0.12	NA	NA	NA	0.83	0.76	0.61	1.32	1.59	1.81	1.59	1.77	1.67	0.59
REC 11 (SOUTHEAST)	40	-40	0.54	0.34	0.39	0.29	NA	NA	NA	0.84	1.05	1.71	1.73	1.83	1.87	0.78
REC 12 (NORTHWEST)	-40	40	0.51	0.63	0.82	0.91	1.63	1.41	1.13	0.50	0.74	0.65	0.59	NA	NA	NA
Minimum			0.12	0.11	0.30	0.24	0.83	0.06	0.45	0.34	0.06	0.65	0.09	0.09	0.43	0.14
Maximum			1.26	1.46	1.53	1.46	3.93	3.72	3.28	2.57	2.64	2.57	2.65	2.78	2.66	1.68
Average			0.67	0.77	0.97	0.89	1.74	1.33	1.17	1.28	1.42	1.87	1.46	1.41	1.80	0.80

Coordinates in meters. NA = value in CAL3QHC was zero, comparison not performed.

From Table 11, the ratio of predicted values ranged from 0.06 (six percent) to 3.93 (almost 400 percent). Figure 51 includes these results graphically to highlight some key findings. Of note is that receivers 1 to 4 include the greatest ratios, indicating the greatest relative differences at these receiver positions. This is significant since they are closest receivers to the intersection. Receivers further from the intersection (5 to 12) tend to have lower ratios. Receivers 5 to 12 represent either midblock receivers or those created to show quadrant results. This is of interest as there is a tendency for CAL3QHC to predict larger values when near the intersection but RLINE predicts greater concentrations in many scenarios away from the intersection. The rate of change with distance for concentrations from the intersection is not the same. At Receptor 6, the maximum concentration predicted by RLINE occurs at a wind angle of 10°. The maximum concentration for CAL3QHC is at Receptor 4 with a wind angle of 195°. This represents a significant difference with the wind almost exactly from the opposite direction.

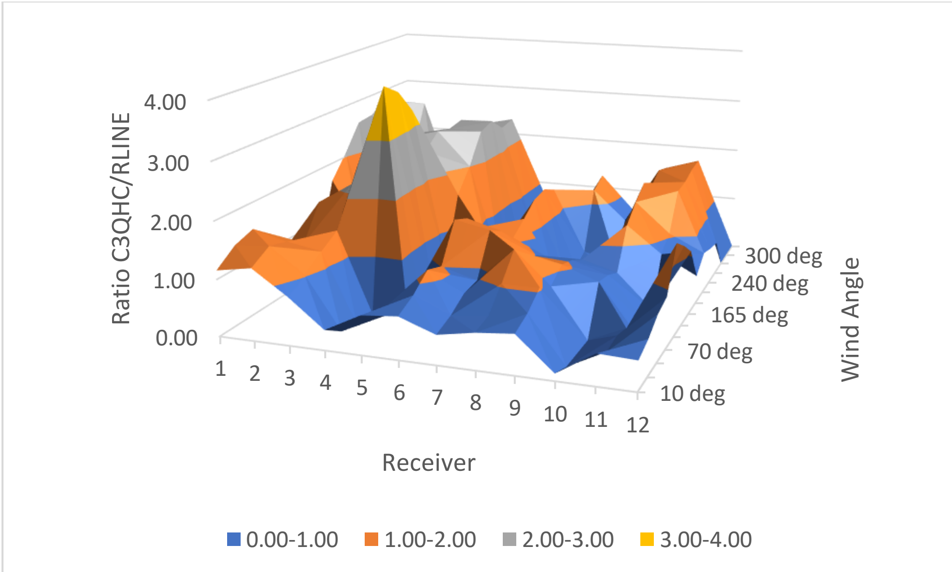


Figure 51. Graph of Comparative Ratios, CAL3QHC/RLINE

Going deeper, the greatest concentration for RLINE was predicted for a mid-block location while the greatest concentration for CAL3QHC was predicted for a receiver very near the intersection. Additionally, MakeMet allows some variation in wind direction, while CAL3QHC does not, so a variance of approximately 5° could be caused by this input, but not a difference of 185°. This indicates the real differences occurring in the overall prediction scheme during predictions.

This trend continues. Table 12 shows that for in over one-half of the scenarios evaluated, there was a difference of over 10° when the greatest concentration at any receiver was predicted, and as previously noted, in some scenarios very different wind angles. Figure 52 shows the concentration patterns for a wind direction of 10° to show detail since this is the wind angle producing the greatest concentration from RLINE. Figure 53 shows the patterns for each evaluated wind angle from RLINE. Of note, due to scaling and sizing some detail has been lost but is included to provide an overall context to the trends.

Multiple issues should be addressed including a standardized way for determination of emission factors to account for vehicle movements properly, consideration of meteorology for an intersection in urban areas, and consideration of emission dispersion differences.

Table 12. Wind Angle and Greatest Concentration at Intersection

RECEIVER	COORDINATES X	COORDINATES Y	Angle of Greatest Concentration (°) CAL3QHC	Angle of Greatest Concentration (°) RLINE
REC 1 (SE CORNER)	16.7	-13.7	205	195
REC 2 (SW CORNER)	-16.7	-13.7	155	10
REC 3 (NW CORNER)	-16.7	13.7	165	165
REC 4 (NE CORNER)	16.7	13.7	195	195
REC 5 (E MID-MAIN)	16.7	-45.7	205	340
REC 6 (W MID-MAIN)	-16.7	-45.7	150, 155	10
REC 7 (N MID-LOCAL)	-45.7	13.7	150	155
REC 8 (S MID-LOCAL)	-45.7	-13.7	70	20
REC 9 (SOUTHWEST)	-40	-40	150	20
REC 10 (NORTHEAST)	40	40	205	195
REC 11 (SOUTHEAST)	40	-40	300	340
REC 12 (NORTHWEST)	-40	40	150	165

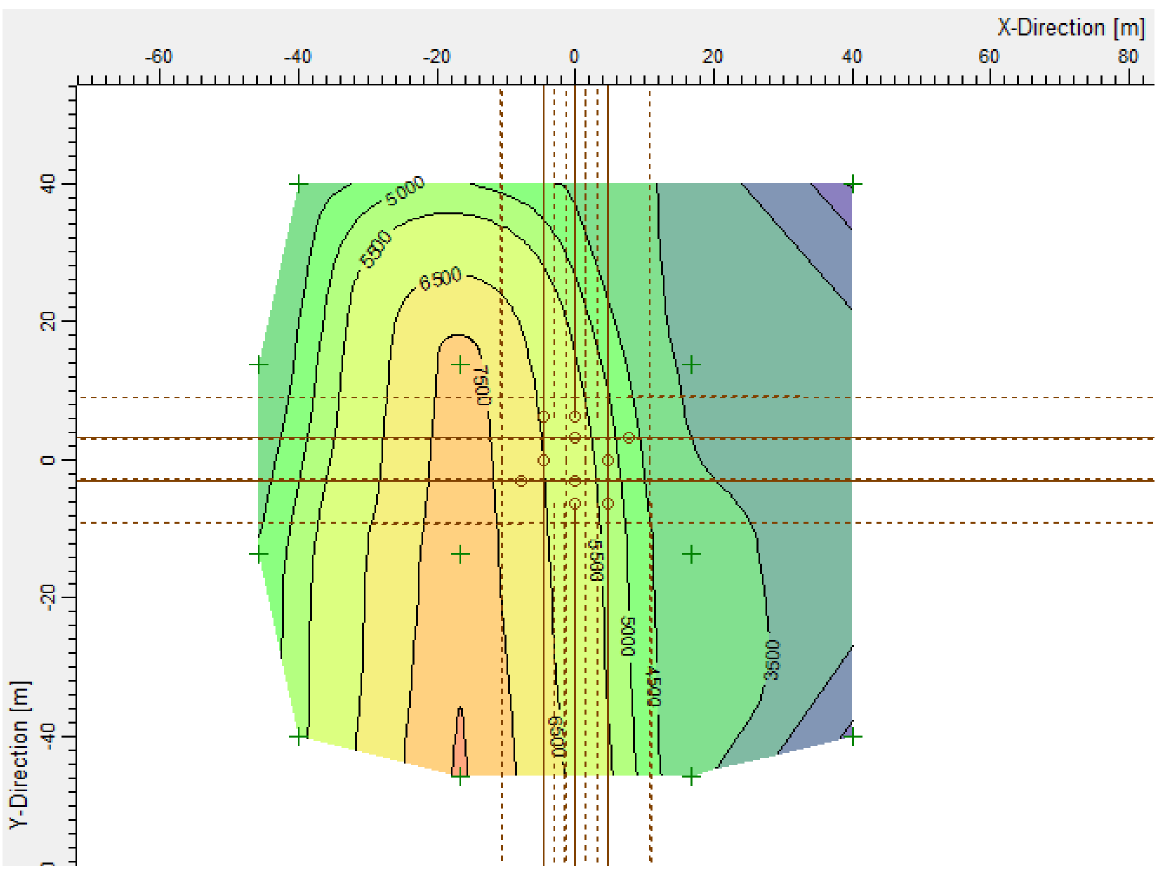


Figure 52. Intersection Modeling, Wind from 10°

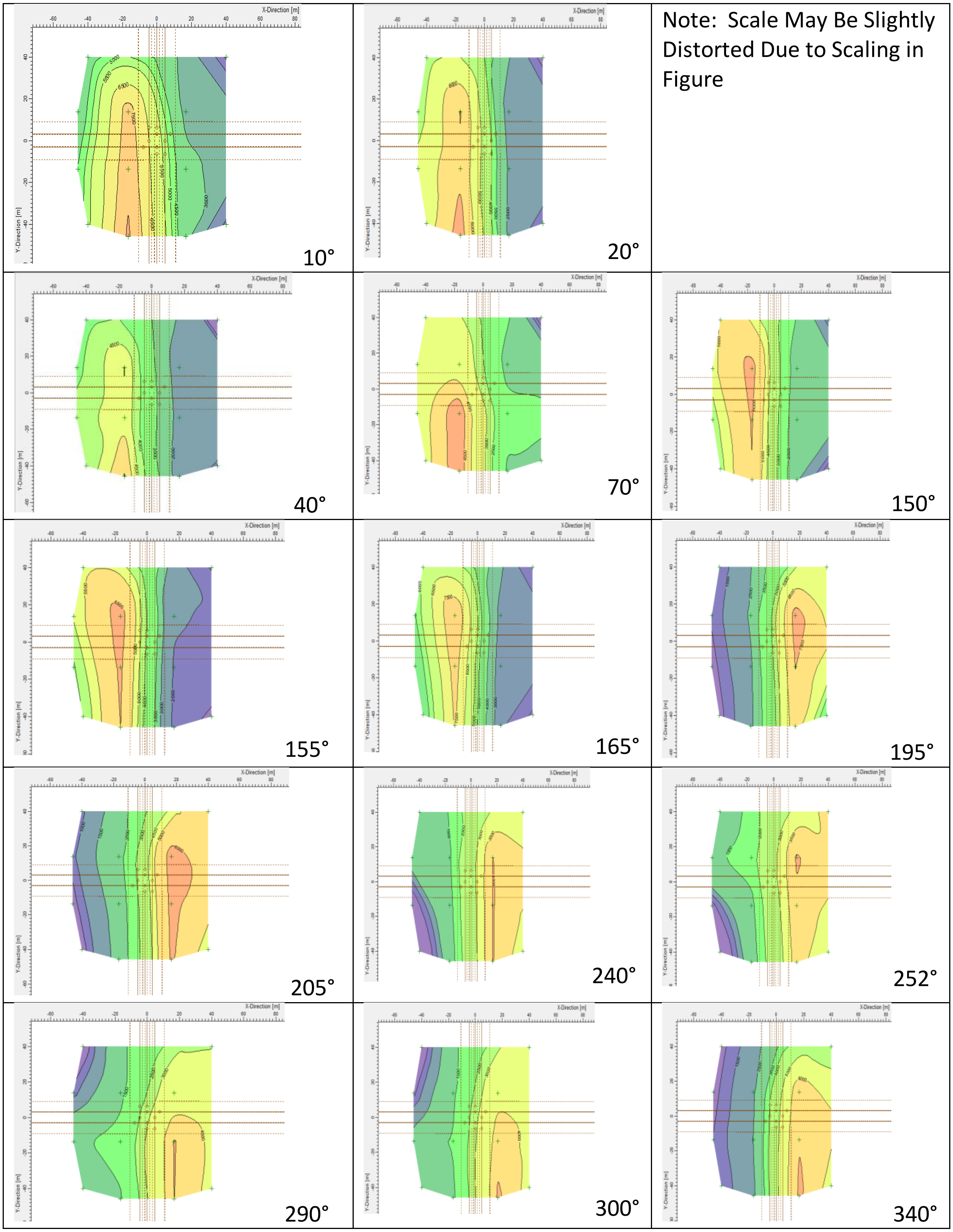


Figure 53. Concentration Patterns for Each Evaluated Wind Angle for RLINE for the Intersection

2.10 Project Level Roadway Evaluations

The Virginia Department of Transportation (VDOT) completed a significant effort to test the AERMOD RLINE/XT options in a regulatory application setting. This involved modeling of fine particulate matter ($PM_{2.5}$) in a Virginia setting for a hypothetical freeway and comparing the results to those that would have been obtained using other AERMOD modeling options.

EPA and FHWA guidance for conformity and the National Environmental Policy Act (NEPA) were followed as applicable. All modeling inputs selected were also made consistent with those specified or referenced in the VDOT Project-Level Air Quality Analysis Resource Document[20], which was subjected to inter-agency consultation for conformity for both $PM_{2.5}$ and carbon monoxide (CO) in December 2015. The most recent update was issued in 2018.

The hypothetical ten-lane freeway was assumed to be a section of 0.2 miles in length (about 1056 ft) with five lanes in each direction and a 32.8-foot (10 meter) median in Fairfax County, Virginia. The freeway segment assumed lane widths were set at a standard 12 feet (3.7 meters.)

Tests were included for the freeway segment in both at-grade and depressed sections, with and without noise walls. Tests were done for the freeway segment in both a west-east alignment and north-south, which, based on the wind rose for Dulles International Airport (Section 3.3.1), serves to test the RLINE/RLINEXT model performance for winds both perpendicular and parallel to the freeway segment.

Because of the expected interest, complexity, and extent of this work, it has been included in full as an Appendix to this report. The findings and key recommendations have been incorporated into those for the overall study. A common theme among the conclusions and recommendations for the different highway and noise wall configurations and scenarios tested is the need for enhanced model validation against field data to verify modeling results for regulatory applications for the full range of typical transportation projects (project types, configurations, etc.) both with and without noise walls.

3. Overall Findings and Conclusions

3.1 Simple, Straight Roadway Sources

Multiple analyses have been shown for a simple straight roadway with various wind speeds and orientations. Findings based on a review of trends have been noted and are presented here. The true, overall accuracy of the model could not be tested due to a lack of real data for comparison.

3.1.1 Simple Roadways with Perpendicular (Cross) Winds

The analysis began with simple testing of straight roadways with perpendicular winds. No barriers, depressed sections, or other complexities were included. Various roadway widths with and without medians were part of the initial evaluation process. MakeMet software was used to create simplified meteorology input allowing various wind angles to be evaluated.

[20] See: https://www.virginiadot.org/projects/environmental_air_section.asp

The first finding, for all scenarios, was the large end effects that occurred. End effects are prominent and extend as much as 250 meters from each end of the roadway for the evaluated scenarios. The effects also vary by perpendicular distance from the roadway. This indicates that receptor concentrations near the ends of modeled roadways should not be used and practical limits may need to be established. Any prescribed limits would require consideration of both the distance from the end of the roadway and the perpendicular distance from the roadway.

To further test for end effects, evaluations were performed by extending roadways using additional links with exact, matching coordinates where one link ends and another begins. When extending roadways with additional links, end effects were not present at the intersecting points and as such this process would seem to be valid.

Another finding, again for all scenarios, were perturbations in predicted concentrations along the roadway, even with a constant wind of a single direction. In many scenarios, the changes were cyclic in nature along the roadway. This results in areas of varying concentrations which is seen to be problematic, especially for receivers close to the roadway. This trend occurs very near the roadway and can extend to large distances from the roadway. Inclusion of a median tends to result in an extended downwind concentration gradient. Wider roadways tend to have more discontinuities in concentration predictions.

Upwind concentrations appear intuitively to be greater than should be predicted. With the wind conditions modeled in this work, smooth upwind profiles should have been generated and this was not generally the case.

Also, of note is the difference in concentration gradients that occur from varying widths. As width changes, the upwind concentration gradient changes are in many scenarios greater than would be expected. However, greater widths tended to lead to more intuitive results downwind. With the same meteorology, but just varying widths, it would be expected that concentrations and falloff rates would change but not the patterns of dispersion as observed in some cases.

Of note is that the same trends do not occur for perpendicular winds when the angle is changed 180°, that is the wind flow is from the opposite direction.

3.1.2 Simple Roadways and Parallel Winds

Many of the same trends were noted as for perpendicular winds including with end effects still occurring. Overall dispersion patterns resemble a point source but with ever increasing concentrations downwind. At the upwind first point of the roadway, concentrations have a very small degree of dispersion perpendicular to the roadway. Continuing down the roadway, in the direction of the wind, as emissions are accumulated the concentration pattern widens but with ever increasing concentrations due to the accumulated emissions. While this trend of accumulation along the roadway would exist, this effect should come to a limit due to dispersion and the emission rates being constant. The effect continues, even at modeled distances of over 8000 meters along the roadway, which seems unrealistic. It cannot be determined if the effect from modeling is accurate without a true data comparison.

Wider roadways were also evaluated as in the perpendicular wind scenarios. Similar effects occurred for the plume shape and emission increases along the roadway as for the single lane scenario, but trends were not constant.

Looking at a more microscale trend, areas of increased concentrations occur at even intervals and increase in area further downwind along the roadways source. These "hot-spots" of increased concentrations at cyclic intervals are most likely due to the point source integration technique and should not occur. A cyclic nature of the concentration gradients is also apparent away from the roadway.

Of note is that as for perpendicular winds, the same trends did not occur as expected when the wind was changed by 180°.

3.2 Release Heights

Release heights were evaluated, and a comparison of the various release heights show significant differences. End effects also change with different release heights but are still present. With greater heights, the initial concentration is greater, but the falloff rate reduces more gradually downwind. "Islands" of increased concentration often occur downwind for increased release heights.

The first evaluations were based on the recommendations for various vehicle types and based on the EPA hot spot training course. Evaluated were release heights of 1.3 meters for a passenger car and 3.4 meters for a truck. The evaluation was conducted with an initial vertical dimension and without per the optional input. Trends show the effects of changing the release heights to be very significant, beginning near the roadways a continuing with distance affecting both the downwind and upwind propagation. Effects were just as significant when changing the initial vertical dimension which is discussed in detail later in 3.3. The major finding is that more work is needed to define this release height as it is not the height of the tailpipe, but the height of the plume leaving the roadway which is affected by vehicle mix, speed, local wind speeds, and volume.

To further research this effect, release heights from 1 to 10 meters were evaluated at 25-meter intervals from the roadway from 25 to 200 meters. This was done for both settings of the initial vertical dimension. A comparative analysis to 2.3 meters was accomplished. Even a change from 2 to 3 meters has a substantial effect on the predicted concentrations. As expected, this proved that the release height is extremely important, amplifying the need for further work.

At increased heights, major perturbations in concentrations occur upwind of the roadway. When heights are increased to that of an overpass (10 meters tested) unusual results occur. In addition to end effects, there were two major areas of increased concentrations away from the roadway in some modeled scenarios. An area of increased concentration away from the roadway would be expected as the plume expansion increases downwind and the plume comes to the ground as observed for elevated stacks, but why two areas of increased concentrations occur is troublesome. The distance between the two areas of increased concentrations is too great to be caused by two, contiguous lanes as modeled.

More work is needed on how elevated structures can be modeled and the reason for the locations of the increased concentrations and high upwind concentrations. But guidance on how to model these cases is needed. The dispersion cannot go through the solid roadway and so will not disperse downward until the edge of a road deck or fill section. Reflection may occur. Walls such as parapet walls may also lead to an increased height of release. To this end, testing was done for just as the elevation difference as previously described but also included use of a barrier as a parapet wall. In this case the downwind concentrations predicted by RLINEXT were increased in the vicinity of the barrier and then had a more linear change in falloff rate. However, the use of a barrier as a parapet wall also caused much greater end effects near the roadway resulting in a falloff pattern resembling a dome shape for a cross wind.

3.3 Initial Vertical Dimension

The effects from varying the initial vertical dimension were also evaluated. As shown in the user manual, inclusion of a non-zero initial vertical dimension is optional. This idea of leaving out the initial vertical dimension (i.e., inclusion of a zero value) was tested as compared to an initial vertical dimension of 2.2 meters, thought to represent a heavily travel roadway vehicle mix. This analysis was included in other analysis but in this case, only this input was varied. With and without the vertical dimension resulted in large differences in predictions beginning close to the roadway and continuing with distance.

The analysis included evaluating an initial vertical dimension from zero (the optional value) to 4 meters in half-meter increments for distances of 25 to 200 meters from the roadway in 25-meter increments. Changes in predicted results were very substantial for different input of a vertical dimension. The effect of changing the vertical plume spread is an important consideration and this testing indicates that better definition and guidance is needed.

The analyses show the importance of the release height and initial vertical dimension and the relationship of each to the other. As previously described, these are not static values but would change with traffic mix, volume, speed, and ambient wind conditions. Using the optional value of zero for the initial vertical dimension could result in much different predicted concentrations and is not thought by the authors to be good practice for regulatory applications for transportation, although it may still be useful in model testing and research applications. Increasing the initial vertical dimension results in lower concentrations near the roadway for receptors at 1.8 meters in height. This is as expected since the initial vertical plume width is controlled by this parameter and larger value result in a larger initial vertical dimension representing greater dispersion. The interaction between the initial vertical dimension and release height needs further evaluation. More work is needed to define a consistent methodology for these two key variables.

3.4 Curves

Curved roadway alignments of 45°and 90° were evaluated. End effects are still obvious. Results for the straight segments indicate similar trends to those that occurred for the simple, straight roadway analysis for parallel and cross winds with the same shape of concentration gradients appearing.

For a 90° curve, there was a concentration build-up at the curve, and this intuitively seems correct. Upwind concentrations appear to be greater than would be expected. Different wind angles produced very different results not only in the location of the greater concentrations as would be expected but in the overall trends of concentrations. Effects of individual plumes from the point sources were very pronounced with cyclic "lobes" of concentration patterns when winds from 360° in 10° increments were tested showing effects of the point source approximation. Results were not as expected.

During the evaluation of a 45° curve, concentration inconsistencies occur near the roadway. Concentration varied considerably along the roadway with "pockets" of high concentration areas occurring.

More work is needed to evaluate wind flows at different angles and how this affects curves.

3.5 Barriers

3.5.1 Barriers and Perpendicular Winds

Barriers of various heights and configurations were evaluated. For simple, straight roadways, 3-and-6-meter heights were evaluated which represent an average noise wall height and a tall noise wall, respectively. Barrier evaluations also included scenarios with the optional initial vertical dimension (zero meters) and with an initial vertical dimension of 2.2 meters.

With barriers and a cross wind, higher concentrations occur at the roadway and are higher upwind of the barrier location. End effects occur for both the roadway and the barrier was found. Perturbations in the concentration contour profiles occur upwind of the barrier. The upwind concentrations would seem to be greater than expected and the effect extends about 200 meters upwind for 3-meter-tall barriers.

When modeled with a 2.2-meter initial vertical dimension, end effects are different than when modeled with the optional initial vertical dimension and are somewhat diminished although concentration variation predictions can occur for approximately 400 meters from the end of the roadway even though emissions and wind direction are constant.

With taller barrier heights (6 meters), and all other inputs remaining constant, a very different dispersion pattern occurs as compared to the 3-meter barrier. End effects appear to be more significant, especially upwind. Concentrations just downwind are less but falloff rates are much different out to greater distances. Areas of high concentration are more contained near the roadway from the higher barrier as would be expected. Concentrations upwind of the barrier also significantly increase. Upwind dispersion is affected more as demonstrated by perturbations in the upwind plume edge and increased concentrations further upwind. It appears that upwind dispersion needs to be examined especially near tall barriers. Results appear to be somewhat more reasonable with the initial vertical dispersion dimension at 2.2 meters rather than the option of ignoring.

3.5.2 Barriers and Parallel Winds

It appears that a major problem or "bug" occurs with the barrier algorithm for parallel winds. When the wind is from the east, for an east to west roadway, and the barrier is on the south side of the roadway, a dispersion pattern that would be expected based on previous testing of RLINE with a parallel wind occurs. That is, a build-up of emissions occurs along the roadway and a shape similar with a point source appears. However, the effect of the barrier seems to be somewhat absent. For all other wind scenarios, it appears that not only the weather effects are being ignored but so is the barrier. Predictions for these other scenarios where the wind seems to be ignored tend to represent what might be expected in a stagnant wind condition with end effects still occurring. This is very substantial problem and should be corrected, especially since with it may go unnoticed with varying winds.

3.5.3 Barrier Ends

The barrier end effects were tested for continuous barriers linked together. This was done by using straight roadways that had the exact endpoints when continued since this is how barriers are input. The barrier seems to perform with the connected roadways without any effects at the connection points.

3.5.4 Barriers on a Curve

For barriers on a curve, a 45° curve was first evaluated as this is more common than would be a 90° curve with barrier to evaluate RLINEXT. To avoid complexities, a single lane was used with a release height of 2.3 meters and an initial vertical dimension of 2.2 meters. The roadway began in the east, proceeded west to the curve, and then turned to the southeast. The barrier evaluation reviewed independently barriers on each side of the roadway of 6 meters in height and 15 meters from the center of the roadway. Wind from the four cardinal wind directions: north, east, west, and south.

With the barrier on the south side of the roadway and winds from the north, concentration patterns did not seem affected by the barrier as much as expected, especially when compared to the simple, straight roadway analysis. Based on the previous testing, it would be expected that strong concentration gradients near the roadway would form but this does not occur to the degree previously shown.

Winds from the south with the barrier on the south side provided the results that seemed the most intuitive. However, small areas of increased concentrations occurred, and this is discussed later in this section.

With winds from the east, there is a strong area of concentration centered on the straight portion of the roadway on the east end as concentration buildup occurs, similar with the straight roadway analysis. However, it does not appear the barrier is considered. With winds from the west, the same major problem with barriers and parallel winds occurs as previously discussed. This is extremely problematic and needs to be addressed.

The barrier was next modeled on the north side of the roadway for the four wind directions. With the wind only from the north, a pattern for the eastern straight roadways appeared have the expected trend. However, at and after the curve as the roadway turned to the southeast, "islands" of greater concentrations occurred. This effect was previously noted when the barrier was on the south side of the roadway. This trend continued for the scenarios with and west wind. In these scenarios, away from the roadway, normal trends for the roadway plume seemed to occur. But these “islands” of concentrations should not occur, and one possibility is that the barriers are no longer continuous as is the roadway. This could be explained by incorrect barrier lengths. Since the barrier may be defined by the same length as the roadway the lengths would not be the same needed on the inside or outside of a curve where the radius of the curve is different.

This initial testing indicates that much more detailed testing is needed along with code changes and measured data to better approximate the effect from barriers.

3.6 Depressed Roadways

Depressed roadways were also tested with varying depths of 3, 6 and 10 meters. With a cut section of 3 meters in depth, the shallow cut section with a 2.3 release height did not have a substantial effect. Most noticeable is that the greatest downwind concentrations occur at approximately the top of the cut but otherwise results are similar with an at-grade roadway.

The effect on dispersion is apparent as the depth of the depressed section increases. With the wind from the south (cross wind) for an east to west roadways, concentrations are in general less downwind than for the simple straight roadway with larger areas of similar concentrations as the depth increases. End effects appear to be less than in the at-grade scenario but still significant. Upwind, concentrations for the greater depths are higher very near the roadway but then decrease much more rapidly than for the lower depths using the depressed section. Near the center of the roadway, an irregular decrease in the concentration trend occurs. This is most likely due to the point source approximation algorithm.

To further test the concentration trends from depressed roadways, winds from other directions were also evaluated. For the scenario with the wind from the north a similar trend to a south wind was expected. This did not occur. A very different trend occurred with areas of uniform falloff occurring rather than a large area of similar concentrations. Which is most correct is not known without measured data but intuitively, the north wind downwind pattern would seem to be better. Small inconsistencies still occur in the upwind contours.

Crosswinds from the east and west show the increased concentrations downwind as expected along the roadway but exhibit very different trends for each direction. It would be expected that the trends would be very similar since each are parallel to the roadway but winds from the west resulted in lower concentrations along the roadway but wider dispersion patterns. The cut section did not seem to have effect on concentration patterns when the wind was from the west. This seems consistent with the barrier analysis where wind was ignored.

Continued analysis and code checking is also needed for depressed sections.

3.7 Intersection

CAL3QHC and RLINE were compared for modeling at an intersection. Considerable effort was put forward to match the model inputs including use of maximum predicted concentrations, adjustment of emission factors for intersection conditions including idle time, adjustments for queue lengths, adjustments for queue length, change to the same units for concentrations and weather conditions.

Maximum values occurred for very different receivers and wind directions (Receiver 6 vs. 4 and 10° vs. 195°, RLINE and CAL3QHC respectively). While there is no way to determine which is more accurate, these results show dramatic differences.

Continuing to review the trend, the maximum concentration at each receiver and the associated wind angle was determined for CAL3QHC predictions. For each of these wind angles, RLINE was also run to allow an overall comparison of all selected wind angles.

Since absolute values are unknown, the predicted values were compared dividing predicted concentrations by CAL3QHC by the corresponding receiver and wind angles by RLINE. This allowed a ratio of the results not for absolute comparison but for trends in prediction. A value above 1 indicates a predicted concentration by CAL3QHC greater than that by RLINE while a value below 1 indicates RLINE predicted a greater concentration.

The ratio of predicted values ranged from 0.06 (six percent) to 3.93 (almost 400 percent). Receivers near the intersection were generally predicted to be greater by CAL3QHC. Receivers further from the intersection tended to have lower ratios meaning receivers that represented either midblock receivers or those created to show quadrant results were predicted to be greater by RLINE. This indicates that the rate of change with distance for concentrations from the intersection is not the same. The maximum concentration predicted by RLINE occurs at a wind angle of 10°. The maximum concentration for CAL3QHC occurs at a wind angle of 195°. MakeMet allows some variation in wind direction, while CAL3QHC does not, so a variance of approximately 5° could be caused by this input, but not a difference of 185°. This represents a significant difference with the wind being almost exactly from the opposite direction. Going deeper, the greatest concentration is predicted by for a mid-block location while the greatest concentration for CAL3QHC was predicted for a receiver very near the intersection.

This trend continues. For over one-half of the scenarios evaluated, there was a difference of over 10° when the greatest concentration at any receiver was predicted, and as previously noted, in some cases very different wind angles. This indicates the real differences occurring in the overall prediction schemes utilized of CAL3QHC and RLINE.

3.8 Results from a Project Level Evaluation

The project level evaluation allowed a review of the entire process faced by DOTs. In addition to RLINE and RLINEXT, volume and line sources were evaluated. The Appendix includes all results which are briefly summarized here.

No modeling formulation stood out above others in performance. Without true validation data it was not possible to evaluate which performed the best. In terms of level-of-effort, volume sources require much more than the other formulations.

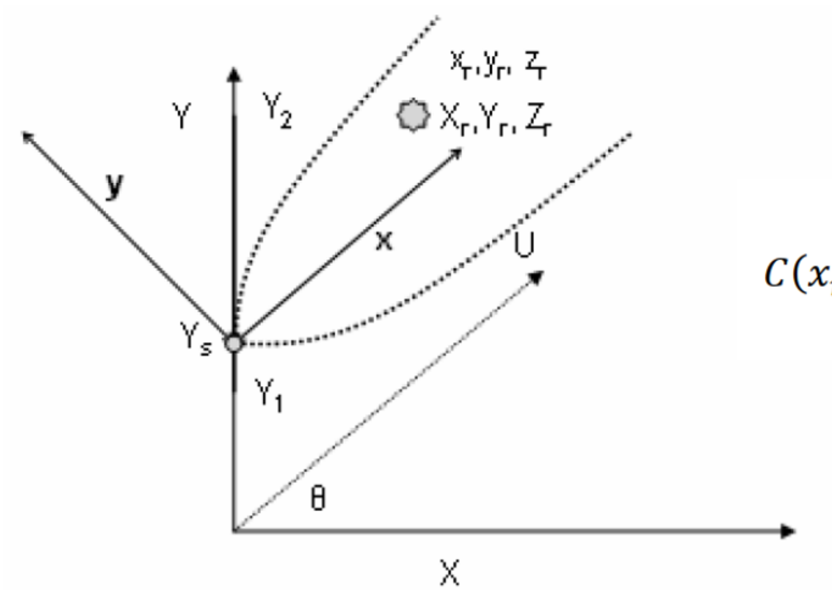
Inputs were also evaluated in terms of significant changes. Similar conclusions for the use of the initial vertical dimension were found as described in the previous sections and resulted in substantial differences in predicted model concentrations. Use of the urban setting for regulatory modeling also resulted in large differences during modeling with reduced concentrations for all sources tested (LINE, VOLUME, RLINE & RLINEXT without walls or depressed sections).

Modeled maximum concentrations for the 24-hour (8th highest) and annual $PM_{2.5}$ standards near noise walls were much higher near walls than comparable scenarios without noise walls, with significant implications for transportation agencies conducting modeling using RLINEXT for highway projects involving walls. This adds to the need for model validation against field data for noise walls, before RLINEXT is considered for regulatory application.

4. Discussion and Recommendations

4.1 Discussion

The end effects and the discontinuities in concentration predictions at evenly spaced intervals for constant wind patterns along extended roadway sources could easily affect results in any roadway air quality evaluation. The RLINE model concept is based on a steady-state Gaussian formulation to simulate a line source by numerically integrating point source emissions as shown in Figure 54.[21] It would seem that the spacing of these sources result in the end effects and are the reasons for the cyclic concentration discontinuities along the roadway. Increased roadway widths seem to reduce this problem but do not eliminate it. Since the length of the source has a direct effect on the individual point source emission rates (emission rate is mass/time*length*width) this also affected by source spacing.



$$C(x_r, y_r) = \int_{Y_1}^{Y_1+L} dC_{pt}$$

Figure 54. Use of Point Sources to Simulate a Line Source[22]

[21] Arunachalam, S., M. Snyder, A. Venkatram, D. Heist, S. Perry, AND V. Isakov. “RLINE: A Line Source Dispersion Model for Near-Surface Releases”. Presented at Annual CMAS Conference, Chapel Hill, NC, October 28 - 30, 2013.

[22] Arunachalam, S., M. Snyder, A. Venkatram, D. Heist, S. Perry, AND V. Isakov. “RLINE: A Line Source Dispersion Model for Near-Surface Releases”. Presented at Annual CMAS Conference, Chapel Hill, NC, October 28 - 30, 2013.

Individual receivers seem to be affected even though the model sets greater precision in cases where the receptor is located very near the line source with a minimum number of iterations required to ensure that the spacing between the points used to approximate the line source is smaller than the distance from receptor to the line.[23] Since limits on integration are set internally within AERMOD to produce the final accuracy, the limit now employed for the convergence routine for the Romberg integration scheme should be reviewed and a possible increase in precision or additional ways to set precision for nearby receiver locations may be required. While this would increase run time, it would reduce the undesired trends being observed.

End effects of roadway sources are very substantial and vary considerably for different configurations and wind directions. Increased precision for integration in the Romberg integration scheme may help but will never be able to eliminate this problem. For a 500-meter roadway with 2 lanes, only the center 200 meters appear to be valid for use in modeling due to the end effects. This is problematic in that concentrations near the end of a modeled roadway could be reported incorrectly. Without solid data we do not know the true impact at the end of the line sources but intuitively, with a steady crosswind, the impacts should not extend along the roadway to the degree that is now occurring. These end effects become amplified with increased source height and are during parallel winds. Without a reference it cannot be determined how the absolute values are being affected but the effect is to such an extent that it can real. It would seem necessary to provide guidance for modeling near the ends of roadways so that modeling errors may be reduced. The large errors may go unnoticed if plotting routines are not used and only individual receptor values are used.

Effects away from the roadway were also noted. End effects caused distorted patterns and discontinuities in predictions occur. At distances of over 200 meters, these modeling discrepancies start to appear. Guidance on the distance a receiver is valid from roadway may be required. The guidance for receiver locations may also need to include placement near barriers and depressed sections. Unusual trends occur near the positions of these inputs and receiver placement could lead to distorted analyses.

The width of the roadway affects the horizontal plume spread as shown in the model source code:

```
C     Calculate initial sigma-y from the road width
      SIGMAY0 = 0.0D0
      SIGMAY0 = DABS(0.5D0 * (RLSOURCE(ISRC)%WIDTH) *
     &          DCOS(THETA_LINE))
```

These effects also contribute to the cyclic concentration along the roadway, again due to the spacing and plume width of the point source approximation. A review of sigma-y while reviewing integration limits would seem warranted. This is especially true due to the turbulent nature of

[23] Snyder, M.G., et al., RLINE: A Line Source Dispersion Model for Near-Surface Releases, U.S. EPA, Office of Research and Development, 2013.

mixing along a heavily travelled roadway. This has been considered in the past and would seem to be important to consider once again.

Upwind concentrations appear intuitively to be greater than should be predicted and this effect is exacerbated when including barriers. Since the contribution of each point source at the receptor is a function of horizontal and vertical meandering contributions it could be beneficial to revisit the meander and perhaps the surface friction velocity algorithms implementation in the source code.

Sigma-z is related to the meander but also the mean plume height which can have significant effects on the overall prediction of concentrations. Accordingly, the initial plume parameters of release height and the initial vertical dimension have a significant effect on the concentrations predicted by also affecting the mean plume height, especially for near receivers and for elevated sources due to the direct effect on mean plume height:

$$\bar{z} = \sigma_z \sqrt{\frac{2}{\pi}} exp\left[-\frac{1}{2}\left(\frac{z_s}{\sigma_z}\right)^2\right] + z_s erf\left(\frac{z_s}{\sqrt{2}\sigma_z}\right)$$

Sigma-z also affects the variation of sigma-y with distance. As such, a review of the use and algorithms for release height, the initial vertical dimension (Sigma-z), may be needed concurrently with meander to permit better approximations. Ideally, measurements made for this purpose could become available for comparison. In addition, guidance is needed for the use of both the release height and the initial vertical dimension. Release height, somewhat of a misnomer, should be defined for the plume coming off the roadway and is really a factor in the mean effective height. Vehicle turbulence, the width of the roadway, vehicle speeds, vehicle mix, and volumes all effect this important variable. More work is needed to provide better guidance. The same is true for the initial vertical dimension. The authors of this document would like to discourage the terminology or use of an optional initial vertical height of zero. As with release height, many variables must be considered, and more work is needed to provide better guidance.

Barrier algorithms would appear to be problematic, especially for parallel winds. End effects are increased, and concentration profiles seem to be influenced far beyond what would be expected for perpendicular winds. For parallel winds it would seem a major software “bug” occurs resulting in very unrealistic predictions. Unless the barrier is on one defined side, winds are ignored and even then, are ignored for parallel winds from the opposite direction. These problems require both a review of the algorithms and again, data for comparison.

Barriers on curves present another consideration. The length of the barrier may need to be adjusted for inside and/or outside radius of the curve. This will depend on the degree of curvature, distance from roadway, and length of segments (links).

While the results from depressions seem better than for barriers, the parallel wind problem persists. Again, a review of the algorithms and data for comparison are needed.

4.2 Recommendations

Based on the analysis of the model trends and outputs, the following recommendations are thought to be important for further model development, evaluation, and guidance for good modeling practice. More details on certain of these recommendations as noted below are presented in Section 4 of the Appendix.

4.2.1 Model Development and Evaluation

- The limit now employed for the convergence routine for the Romberg integration scheme should be reviewed and a possible increase in precision or additional ways to set precision for nearby receivers may be required.
- The release height was shown to be a critical factor. More work is needed to define the release height considering traffic mix, speed, volume, local wind speed, and width of roadway.
- While modeled maximum $PM_{2.5}$ concentrations vary substantially by source, URBAN setting and initial vertical dimension, the effect appears greater for URBAN setting and initial vertical dimension than source. More detail on these findings and related recommendations are presented in Section 4.3 of the Appendix.
- The initial vertical dimension was also shown to be a key parameter affecting predicted concentrations. This is especially true due to the turbulent nature of mixing along a heavily travelled roadway. It is recommended that the optional value of zero not be used in regulatory applications for transportation, although it may still be useful for model testing and research. Additionally, more work is needed since this is directly related to release height and is affected by traffic mix, speed, volume, local wind speed, and width of roadway. Sigma-z also affects the variation of sigma-y with distance. As such, a review of the use and algorithms for release height, the initial vertical dimension (Sigma-z), and meander may be needed to take place concurrently.
- Effects of the initial vertical dimension change based on time of predictions (24-hour standard vs. annual standard) and should be reviewed.
- Parallel winds to the roadway and walls are not being handled well within the model. More work is needed considering the concentration build along the roadway with possible limits included and in the case of barriers troubleshooting a major software problem that causes large problems with predictions.
- RLINEXT with noise walls or barriers needs to be validated against field data, as it generates very high maximum concentrations for both the 24-hour and annual standards for $PM_{2.5}$ near the wall. This effect was observed for walls for both at-grade and depressed sections. In contrast, vertical-cut depressed sections (which effectively present a vertical barrier adjacent to the travelled roadway) without a noise wall did not exhibit this effect. RLINEXT should NOT be made applicable for regulatory analyses until it has been validated against field data near

walls. More detailed recommendations on this point are provided in Sections 4.1 and 4.2 of the Appendix.

- Prediction results from depressions seem better than for barriers, but the parallel wind problem persists. A review of the barrier algorithms in addition to the previous recommendations are needed as results appear to be affected beyond what would be expected. End effects are increased, and concentration profiles seem to be influenced at far distances from the roadway, especially upwind. Upwind concentrations appear intuitively to be greater than should be predicted and this effect is exacerbated when including barriers. Since the contribution of each point source at the receptor is a function of horizontal and vertical meandering contributions it could be beneficial to revisit this implementation in the source code.
- A review of end effects and possible ways to avoid the substantial changes in concentrations including but not limited to precision in the Romberg integration scheme.
- A review of elevated source propagation is needed.
- True validation of the model against field data for all typical transportation applications is strongly recommended. Measurements conducted away from other sources and complications are needed for many different scenarios (see Appendix Sections 4.1.2 and 4.1.3) to permit an *enhanced* model validation or evaluation process, involving not only tracer studies but also validation of the models in regulatory applications against near-road monitoring data. Care should especially be taken to evaluate the models as applied in regulatory air quality analyses of transportation projects conducted to meet federal transportation conformity requirements and for purposes of NEPA to ensure that the intended regulatory purpose of showing compliance with statistical confidence in NAAQS and build/no-build tests is met. Estimates of accuracy and uncertainty are needed as a product of validation studies for the entire traffic, emission and dispersion modeling chain including the determination of background concentrations. The enhanced process must involve transportation stakeholders including state DOTs and commit more resources, which may be accomplished with a pooled fund approach.
- Run times are a product of many variables (see Appendix Section 3.4.2). It may be possible to optimize some algorithms to improve performance.
- Model output should be enhanced to better facilitate model testing. Suggestions for this are provided in Section 4.4 of the Appendix.

4.2.2 Guidance

Specification of good modeling procedures or in some cases requirements may be needed to reduce possible modeling inconsistencies. Suggested changes are listed below.

- Until further validation is completed, it is recommended that all modeling regimes (LINE, AREA, RLINE, RLINEXT, and VOLUME) be retained as options for transportation sources.
- It is recommended that the urban setting be used wherever applicable.

- Guidance is needed for the inputs of release height and the initial vertical dimension. It is highly recommended that the optional value of zero for the initial vertical dimension is not used in regulatory applications for transportation. Use of zero for the initial vertical dimension may still be used, for example, as an option for model testing and research.
- Limits to the placement of receivers for both near the ends of roadways and distance from the roadway are needed. This may include the specification of receptor exclusion zones for areas near noise walls, at least until the model has been validated for typical transportation facilities with noise walls.
- Definition of good modeling practices of elevated sections including use of walls along the roadway are needed.
- Good modeling practice for the placement of receivers for barriers and depressed sections are needed. Incorrect placement can lead to misleading results and should be avoided.
- Guidance on use of barriers should be expanded especially for connecting barriers (connecting roadways) and barriers on curves.

4.2.3 Priority Considerations

While the previous findings and recommendations have not been ranked in terms of priority but to follow the report order, the authors considered four areas to be a priority for future work. These are:

- Extreme quality data collection for a true validation including multiple roadway configurations.
- Software updates for parallel winds.
- Further review of using increased precision for integration in the Romberg integration scheme or other methods to set precision in cases such as when near receivers.
- Issuance of guidance to allow consistency among users.

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APPENDIX

FHWA AERMOD RLINE/XT TESTING FOR A HYPOTHETICAL FREEWAY IN VIRGINIA

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1. INTRODUCTION

The Virginia Department of Transportation (VDOT) conducted this study in support of Federal Highway Administration (FHWA) research to test new functionality (RLINE and RLINEXT) provided by the Environmental Protection Agency (EPA) for transportation applications in their regulatory dispersion model AERMOD (v.21112)[24]. The general objective for the VDOT effort was to test AERMOD RLINE/XT options in regulatory applications involving modeling of fine particulate matter ($PM_{2.5}$) in a Virginia setting and compare the results to those that would have been obtained using other AERMOD options for source and other inputs.

EPA and FHWA guidance for conformity and the National Environmental Policy Act (NEPA) were followed as applicable. All modeling inputs selected were also made consistent with those specified or referenced in the VDOT Project-Level Air Quality Analysis Resource Document[25], which was subjected to inter-agency consultation for conformity for both $PM_{2.5}$ and carbon monoxide (CO) in December 2015. The VDOT Resource Document references and is consistent with all applicable EPA and FHWA guidance as appropriate and is updated periodically. The most recent update was issued in 2018.

Test Case - Hypothetical Freeway Segment in Northern Virginia

All tests were conducted for a hypothetical ten-lane freeway segment in Fairfax County, Virginia. The freeway segment was assumed to be 0.2 miles in length (about 1056 ft) and have five lanes in each direction with a 32.8-foot (10 meter) median. Lane widths were set at a standard 12 feet (3.7 meters.)

Tests were included for the freeway segment at-grade and depressed, and with and without noise walls. Tests were also done for the freeway segment in both a west-east alignment and north-south, which, based on the wind rose for Dulles International Airport (Section 3.3.1), serves to test model performance for winds both perpendicular and parallel to the freeway segment.

More detail on the configurations and scenarios tested are presented in Sections 3.1 and 3.2 respectively.

[24] https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod
[25] See: https://www.virginiadot.org/projects/environmental_air_section.asp

Report Organization

The remainder of the report is organized as follows (hyperlinks):

2. MOVES Modeling

Emission modeling was conducted using the latest version of the MOVES model (3.0.1), which was released by US Environmental Protection Agency (EPA) in March 2021.[26]

2.1 Inputs

Exhibits A-1 and A-2 summarize the main and project-level inputs respectively applied in MOVES modeling. Modeling was conducted for an assumed opening year of 2025 for running emissions (per FHWA guidance) for both $PM_{2.5}$ and, for a January AM peak hour only, CO.[27] For $PM_{2.5}$, separate emission estimates were developed for each season and daily time periods (AM and PM peak periods, midday and overnight) for a total of sixteen runs. Hypothetical but representative speeds for a freeway in Fairfax County were taken for each daily time-period.

Parameter	MOVES Input*
Scale	Project-Level Inventory Mode (g/hr/link)
Time Spans	MOVES Time Aggregation Level: Hour Year: 2025 16 runs (4 seasons x 4-hour IDs for a weekday): • January, April, July and October • Hour ID: 1 (midnight), 7 (6 a.m.), 13 (noon), and 19 (6 p.m.)
Geographic Bounds	Fairfax County
On road Vehicles	All combinations selected
Road Type	Urban Restricted Access
Pollutants and Processes	Pollutants: $PM_{2.5}$ and (Jan AM only) CO Running emissions only: • $PM_{2.5}$ and CO: Exhaust and Crankcase Exhaust • $PM_{2.5}$ only: Brake & Tire Wear
Output	Units: grams, joules, and km Activity: Distance, SHO Detail: By Source Type *(to get LDV & HDV weighting factors for AERMOD Release Height & Szinit – Initial Vertical Dispersion Coefficient/Sigma Z)*
EPA MOVES Scripts	• PM25_Grams_Per_Hour.sql • EmissionRates.sql • MOVES2AERMOD.sql • CO_CAL3QHC_EF.sql • DecodedMovesOutput.sql

* *All inputs are consistent with VDOT Project-Level Air Quality Analysis Resource Document. See: https://www.virginiadot.org/projects/environmental_air_section.asp*
Note the emission modeling conducted for this study was completed before EPA updated their PM hot-spot guidance in October 2021. No changes were made however that would substantively affect the findings or conclusions of this study.

Exhibit A-1: MOVES Inputs – Main Screen

[26] See: https://www.epa.gov/moves
[27] Given time constraints, only emission modeling was done for CO, which may support possible future testing with AERMOD.

Parameter	**MOVES Input***
Input/Output Databases	rlinext_2025_build_q1am_in (16 DBs by quarter and time period), rlinext_2025_build_m2a_xST_out
Hoteling	Not applicable
I/M Programs	Not applied (conservative assumption for CO)
Retrofit Data	MOVES Defaults
Age (Veh. Reg.) Distributions	MWCOG Regional Conformity Inputs**
Fuels	MOVES3.0.1 Defaults, consistent with EPA guidance and the VDOT Resource Document
Meteorology	Fairfax County
Links	Length: 0.2 mi (1056 ft or 321.8688 m) Road Grade: Zero**** Speed: Hypothetical but representative values for a freeway in Fairfax County • AM & PM Peaks: 55 mph • Midday: 60 mph • Overnight: 65 mph Volumes: Hypothetical but representative values for a freeway in Fairfax County • 200k AADT • Scaled to seasonal and daily hourly volumes using the fractions presented in the VDOT report "*Traffic Data for the 2017 Periodic Emission Inventory*", 2018, which was based on VDOT Traffic Monitoring System (TMS)/ Highway Performance Monitoring System (HPMS) data.***
Link Source Type Hour Fraction**	Based on 2019 VDOT TMS/HPMS Report 1236 traffic data for urban interstates in Fairfax County *(using templates from the VDOT Resource Document "Link Source Type Hour Fractions Calculation Tool" spreadsheet)****
Link Drive Schedule (opt.)	Not applied
OpMode Distribution (opt.)	
Off-Network	Not applicable

* *All inputs are consistent with VDOT Project-Level Air Quality Analysis Resource Document. See: https://www.virginiadot.org/projects/environmental_air_section.asp*

** *In this case, the age distributions were not adjusted for mileage accumulation rates, which is conservative or worst-case as it results in over-estimates of fleet-average emission factors.*

*** *Available in the online data repository for the VDOT Resource Document, for which a link is provided on the VDOT Air Quality webpage. Supporting data is available at: https://www.virginiadot.org/info/ct-TrafficCounts.asp*

**** *Higher road grades were not used for two reasons: 1) the focus of this study was on AERMOD, not MOVES, and 2) Concerns that MOVES has not been validated for higher road grades have not been resolved by EPA to date.*

Exhibit A-2: MOVES Project-Level Inputs

The annual average daily traffic (AADT) was taken as 200,000, which is a typical value for a freeway in this location. Exhibit A-3 presents the seasonal and hourly VMT fractions, which were based on traffic monitoring data specific to Fairfax County.[28]

Daily Time Period	Hour	Seasononal and Hourly VMT Fractions*							
		Winter (January)		Spring (April)		Summer (July)		Fall (October)	
		Hourly	Average	Hourly	Average	Hourly	Average	Hourly	Average
Overnight	0 (midnight)	0.01048	0.02145	0.01215	0.02323	0.01435	0.02412	0.01160	0.02282
(continued	1	0.00768		0.00887		0.01006		0.00817	
below)	2	0.00701		0.00792		0.00849		0.00744	
	3	0.00965		0.01038		0.01103		0.01032	
	4	0.02217		0.02224		0.02345		0.02298	
	5	0.04111		0.03949		0.04018		0.04071	
AM Peak	6	0.04880	0.05393	0.04837	0.05286	0.04719	0.05131	0.04704	0.05224
	7	0.05702		0.05578		0.05319		0.05439	
	8	0.05721		0.05469		0.05231		0.05497	
	9	0.05269		0.05262		0.05253		0.05257	
Midday	10	0.05036	0.05534	0.05123	0.05467	0.05511	0.05487	0.05133	0.05518
	11	0.05201		0.05357		0.05370		0.05293	
	12	0.05283		0.05335		0.05345		0.05323	
	13	0.05445		0.05400		0.05440		0.05469	
	14	0.05942		0.05678		0.05586		0.05858	
	15	0.06299		0.05911		0.05673		0.06032	
PM Peak	16	0.06493	0.05942	0.06070	0.05705	0.05810	0.05607	0.06185	0.05793
	17	0.06445		0.06106		0.05957		0.06134	
	18	0.05809		0.05589		0.05562		0.05711	
	19	0.05021		0.05054		0.05101		0.05143	
Overnight	20	0.03945		0.04412		0.04465		0.04366	
	21	0.03386		0.03755		0.03861		0.03674	
	22	0.02567		0.02924		0.02858		0.02779	
	23	0.01745		0.02035		0.02184		0.01883	
Total		**1.00000**		**1.00000**		**1.00000**		**1.00000**	

Source: Derived from data presented in the VDOT report "Traffic Data for the 2017 Periodic Emission Inventory", October 2018, available at: https://www.virginiadot.org/projects/environmental_air_section.asp

Note : For VMT fractions, averages were used for peak hours instead of peak values in order to not overestimate traffic in the peak period for this hypothetical scenario. In practice, EPA guidance to use peak activity for the peak periods and averages for other periods in the day would typically be applied, although that may overestimate emissions and concentrations in the peak periods. Additionally, based on new (2021) EPA guidance, given limited variation in emission rates by season for running emissions for PM, seasonal weighting would not be applied.

Exhibit A-3: Seasonal and Hourly VMT Fractions

Exhibit A-4 presents a summary of the estimated traffic volumes by season and daily time periods, as scaled from the AADT using the VMT fractions presented above. Exhibit A-5 presents the associated source type hour distributions, which were derived from VDOT TMS/HPMS data for 2019 for a freeway in Fairfax County.

[28] "*Traffic Data for the 2017 Periodic Emission Inventory*," 2018. The summary data presented in that report were developed based on detailed data for 2017 obtained from the VDOT Traffic Monitoring System (TMS)/ Highway Performance Monitoring System (HPMS). The report is available in the online data repository for the VDOT Resource Document. See: https://www.virginiadot.org/projects/environmental_air_section.asp

Time Period	Jan	Apr	Jul	Oct	Speeds (mph)
AM Peak (6-10am)	5,393	5,286	5,131	5,224	55
Midday (10am-4pm)	5,534	5,467	5,487	5,518	60
PM Peak (4-8pm)	5,942	5,705	5,607	5,793	55
Overnight (8pm-6am)	2,145	2,323	2,412	2,282	65 (posted)

**Inputs for five lanes in one direction based on 200k AADT. Build has five lanes in both directions.*

AADT scaled using the hourly fractions presented in the VDOT report "Traffic Data for the 2017 Periodic Emission Inventory", 2018, which was based on VDOT Traffic Monitoring System (TMS)/ Highway Performance Monitoring System (HPMS) data.

Exhibit A-4: Vehicles per Hour and Speeds - Hypothetical 2025 BUILD Scenario

MOVES sourceTypeID	MOVES Source Type	Source Type Hour Fractions
11	Motorcycle	0.0026
21	Passenger Car	0.4850
31	Passenger Truck	0.3475
32	Light Commercial Truck	0.1099
41	Intercity Bus	0.0010
42	Transit Bus	0.0029
43	School Bus	0.0019
51	Refuse Truck	0.0002
52	Single Unit Short-haul Truck	0.0098
53	Single Unit Long-haul Truck	0.0007
54	Motor Home	0.0010
61	Combination Short-haul Truck	0.0218
62	Combination Long-haul Truck	0.0157
TOTAL		1.0000

Source: Based on VDOT 2019 Traffic Management System/Highway Performance Monioring System (HPMS) Data for a freeway in Fairfax County, VA

Exhibit A-5: MOVES Link Source Type Hour Distribution

2.2 Emission Modeling Results

Exhibits A-6 and A-7 summarize the modeled emissions for each link by quarter and daily time-period, for $PM_{2.5}$ and CO respectively. Exhibit A-8 presents the percent contributions for light-duty vehicle (LDV) and heavy-duty vehicle (HDV) $PM_{2.5}$ emissions, which was used to weight specific AERMOD inputs, namely, release height and initial vertical dispersion coefficient. MOVES output in terms of $PM_{2.5}$ grams per hour per link were translated into AERMOD formats for different sources (LINE, RLINE, RLINEXT and VOLUME).

Run*		MOVES 3.0.1 EMISSION ESTIMATES**									AERMOD INPUTS		
		Links (Five Lanes)							Emissions		R/LINE/Area	RLINEXT	Volume***
		linkID	roadTypeID	linkLength (mi)	linkVolume	linkAvgSpeed (mph)	linkAvgGrade	Desc	(g/hr/link)	(g/s/link)	(g/s/m^2)	(g/s/m)	(g/s/source)
1	Q1AM	1	4	0.2	5393	55	0	WB	13.11	0.00364	6.18525E-07	1.13116E-05	8.27465E-06
1	Q1AM	2	4	0.2	5393	55	0	EB	13.11	0.00364	6.18525E-07	1.13116E-05	8.27465E-06
2	Q1MD	1	4	0.2	5534	60	0	WB	11.64	0.00323	5.49234E-07	1.00444E-05	7.34768E-06
2	Q1MD	2	4	0.2	5534	60	0	EB	11.64	0.00323	5.49234E-07	1.00444E-05	7.34768E-06
3	Q1PM	1	4	0.2	5942	55	0	WB	14.44	0.00401	6.81490E-07	1.24631E-05	9.11701E-06
3	Q1PM	2	4	0.2	5942	55	0	EB	14.44	0.00401	6.81490E-07	1.24631E-05	9.11701E-06
4	Q1ON	1	4	0.2	2145	65	0	WB	4.52	0.00126	2.13460E-07	3.90375E-06	2.85567E-06
4	Q1ON	2	4	0.2	2145	65	0	EB	4.52	0.00126	2.13460E-07	3.90375E-06	2.85567E-06
5	Q2AM	1	4	0.2	5286	55	0	WB	12.89	0.00358	6.08313E-07	1.11248E-05	8.13803E-06
5	Q2AM	2	4	0.2	5286	55	0	EB	12.89	0.00358	6.08313E-07	1.11248E-05	8.13803E-06
6	Q2MD	1	4	0.2	5467	60	0	WB	11.54	0.00321	5.44701E-07	9.96149E-06	7.28703E-06
6	Q2MD	2	4	0.2	5467	60	0	EB	11.54	0.00321	5.44701E-07	9.96149E-06	7.28703E-06
7	Q2PM	1	4	0.2	5705	55	0	WB	13.91	0.00386	6.56532E-07	1.20067E-05	8.78311E-06
7	Q2PM	2	4	0.2	5705	55	0	EB	13.91	0.00386	6.56532E-07	1.20067E-05	8.78311E-06
8	Q2ON	1	4	0.2	2323	65	0	WB	4.92	0.00137	2.32132E-07	4.24523E-06	3.10547E-06
8	Q2ON	2	4	0.2	2323	65	0	EB	4.92	0.00137	2.32132E-07	4.24523E-06	3.10547E-06
9	Q3AM	1	4	0.2	5131	55	0	WB	12.61	0.00350	5.95130E-07	1.08837E-05	7.96167E-06
9	Q3AM	2	4	0.2	5131	55	0	EB	12.61	0.00350	5.95130E-07	1.08837E-05	7.96167E-06
10	Q3MD	1	4	0.2	5487	60	0	WB	11.69	0.00325	5.51637E-07	1.00883E-05	7.37983E-06
10	Q3MD	2	4	0.2	5487	60	0	EB	11.69	0.00325	5.51637E-07	1.00883E-05	7.37983E-06
11	Q3PM	1	4	0.2	5607	55	0	WB	13.78	0.00383	6.50340E-07	1.18934E-05	8.70027E-06
11	Q3PM	2	4	0.2	5607	55	0	EB	13.78	0.00383	6.50340E-07	1.18934E-05	8.70027E-06
12	Q3ON	1	4	0.2	2412	65	0	WB	5.16	0.00143	2.43341E-07	4.45022E-06	3.25543E-06
12	Q3ON	2	4	0.2	2412	65	0	EB	5.16	0.00143	2.43341E-07	4.45022E-06	3.25543E-06
13	Q4AM	1	4	0.2	5224	55	0	WB	12.74	0.00354	6.01178E-07	1.09944E-05	8.04259E-06
13	Q4AM	2	4	0.2	5224	55	0	EB	12.74	0.00354	6.01178E-07	1.09944E-05	8.04259E-06
14	Q4MD	1	4	0.2	5518	60	0	WB	11.65	0.00324	5.49782E-07	1.00544E-05	7.35500E-06
14	Q4MD	2	4	0.2	5518	60	0	EB	11.65	0.00324	5.49782E-07	1.00544E-05	7.35500E-06
15	Q4PM	1	4	0.2	5793	55	0	WB	14.13	0.00392	6.66659E-07	1.21919E-05	8.91859E-06
15	Q4PM	2	4	0.2	5793	55	0	EB	14.13	0.00392	6.66659E-07	1.21919E-05	8.91859E-06
16	Q4ON	1	4	0.2	2282	65	0	WB	4.83	0.00134	2.28034E-07	4.17029E-06	3.05065E-06
16	Q4ON	2	4	0.2	2282	65	0	EB	4.83	0.00134	2.28034E-07	4.17029E-06	3.05065E-06

** For this hypothetical scenario, speeds were assigned as 55 mph for the AM and PM peak periods, 60 mph for midday, and 65 mph (posted speed) overnight.*
Volumes were based on 200k AADT and adjusted to hourly using VDOT TMS/HPMS data for 2017 (latest available).

*** The emission estimates include exhaust (including crankcase) as well as brake and tire wear, consistent with EPA guidance ("Transportation Conformity Guidance for Quantitative Hot-spot Analyses in PM2.5 and PM10 Nonattainment and Maintenance Areas", EPA-420-B-15-084. November 2015, Section 2.5.2. Road dust is not included as the area is not subject to conformity for PM2.5. Note, even if the previously applicable PM2.5 SIP and conformity requirements did apply, the previously applicable SIP did not specify road dust as a significant contributor to the PM2.5 levels. Therefore following EPA guidance Section 2.5.3, road dust would still not be included in the emission estimates.*
MOVES 3.0.1 run with output by source type. For the FHWA Model, output by source type was not selected (i.e., fleet average emission factors were output).

**** For volume sources, the per source emisson estimate assumes 88 volume sources per lane (880 for all ten lanes).*

Exhibit A-6: $PM_{2.5}$ Emission Estimates for a 2025 Build Scenario for a Hypothetical Freeway in Fairfax County, VA

MOVES 3.0.1 EMISSION ESTIMATES**											AERMOD INPUTS		
Run*		Links (Five Lanes)							Emissions		R/LINE/Area	RLINEXT	Volume***
		linkID	roadTypeID	linkLength (mi)	linkVolume	linkAvgSpeed (mph)	linkAvgGrade	Desc	g/hr/link	g/s/link	(g/s/m^2)	(g/s/m)	(g/s/source)
1	Q1AM	1	4	0.2	5393	55	0	WB	2053.09	0.57030	9.68858E-05	1.77185E-03	1.29614E-03
1	Q1AM	2	4	0.2	5393	55	0	EB	2053.09	0.57030	9.68858E-05	1.77185E-03	1.29614E-03

** For this hypothetical scenario, speeds were assigned as 55 mph for the AM and PM peak periods, 60 mph for midday, and 65 mph (posted speed) overnight.*
Volumes were based on 200k AADT and adjusted to hourly using VDOT TMS/HPMS data for 2017 (latest available).

*** The emission estimates include exhaust and crankcase exhaust, consistent with guidance.*

**** For volume sources, the per source emisson estimate assumes 88 volume sources per lane (880 for all ten lanes).*

Exhibit A-7: CO Emission Estimates for a 2025 Build Scenario for a Hypothetical Freeway in Fairfax County, VA

Run		LDVs (MOVES ST 11, 21, 31, 32)		HDVs (MOVES ST 41-62)		Total
		PM2.5 Emissions* (g/hr/link)	%	PM2.5 Emissions* (g/hr/link)	%	Emissions (g/hr/link)
1	Q1AM	4.08	31.10%	9.03	68.90%	13.11
2	Q1MD	3.66	31.47%	7.98	68.53%	11.64
3	Q1PM	4.49	31.10%	9.95	68.90%	14.44
4	Q1ON	1.32	29.10%	3.21	70.90%	4.52
5	Q2AM	4.04	31.32%	8.85	68.68%	12.89
6	Q2MD	3.66	31.72%	7.88	68.28%	11.54
7	Q2PM	4.36	31.32%	9.56	68.68%	13.91
8	Q2ON	1.45	29.38%	3.47	70.62%	4.92
9	Q3AM	4.01	31.83%	8.60	68.17%	12.61
10	Q3MD	3.78	32.31%	7.91	67.69%	11.69
11	Q3PM	4.39	31.83%	9.39	68.17%	13.78
12	Q3ON	1.55	30.02%	3.61	69.98%	5.16
13	Q4AM	3.99	31.32%	8.75	68.68%	12.74
14	Q4MD	3.70	31.72%	7.95	68.28%	11.65
15	Q4PM	4.42	31.32%	9.70	68.68%	14.13
16	Q4ON	1.42	29.38%	3.41	70.62%	4.83
Annual Average:			**31.0%**		**69.0%**	

** Running emissions only, i.e., PM2.5 exhaust and crankcase exhaust, and brake & tire wear.*

Exhibit A-8: Percent Contributions for Light-Duty Vehicle (LDV) and Heavy-Duty Vehicle (HDV) $PM_{2.5}$ Emissions

3. AERMOD Modeling

AERMOD version 21112 was applied in this study, with almost all runs done in batch mode in DOS. One run was done with vendor software – once it had been updated to include v21112 of AERMOD – to generate contour plots for a three-dimensional array of receptors for a run done previously with a two-dimensional array of receptors (at flagpole height) that resulted in high modeled concentrations.

3.1 Test Configurations

Exhibits A-9 and A-10 present the two configurations for link direction that were assessed, one with the links-oriented west-east and the other with the same links oriented north-south. Based on the wind rose (Section 3.3.1) for data from the Dulles International airport (IAD), these two configurations served effectively to test AERMOD for two meteorological conditions of interest, namely one in which a substantial component of the wind field was perpendicular to the freeway and one in which it was parallel or nearly so.

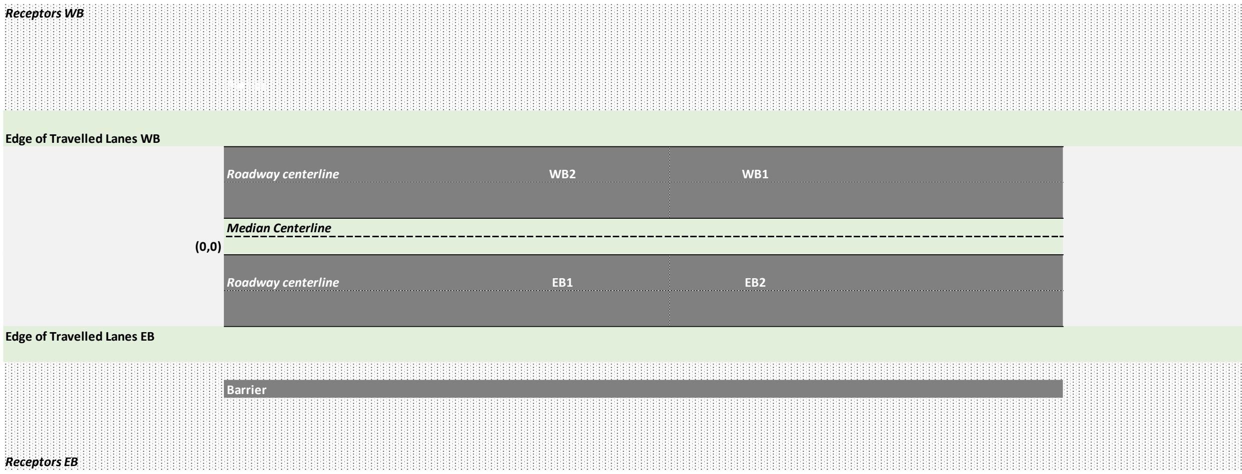

Exhibit A-9: Hypothetical Freeway in Fairfax County, VA (West-East Orientation)

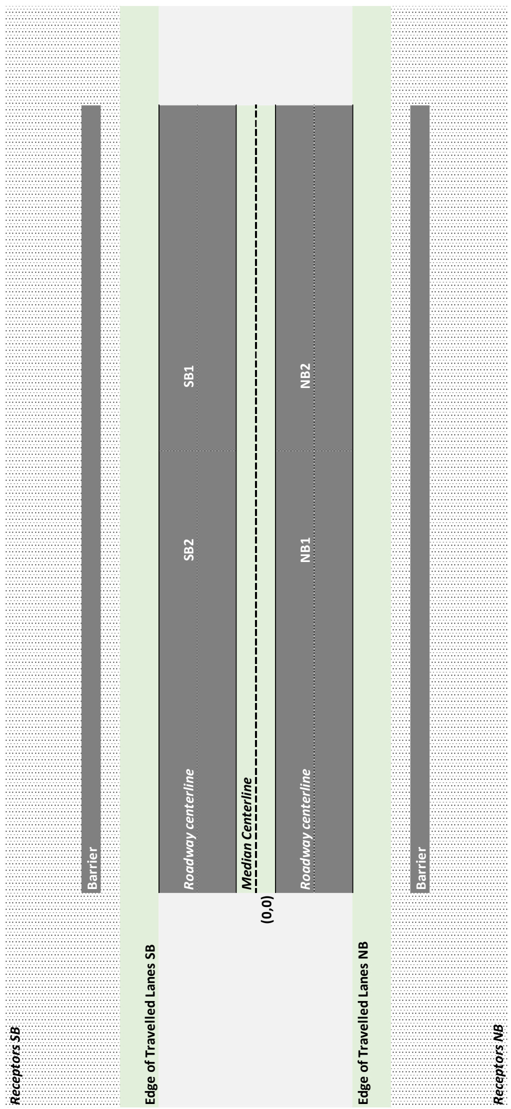

Exhibit A-10: Hypothetical Freeway in Fairfax County, VA (North-South Orientation)

3.1.1 Noise Walls

Typical ranges for noise walls heights and distances in Virginia as presented in Exhibit A-11 were also tested.

Distance (ft)*	Height (ft)**		
20	15	20	25
40	15	20	25
60	15	20	25

** Distance measured from the edge of the nearest traffic lane (not from the shoulder).*

*** Shaded heights are less prevalent for the given distance.*

**** Overlapping walls may be modeled at a 3:1 ratio, e.g., a 30 ft overlap with 10 ft separation.*

Source: P.Comm. from R.Hudnall, VDOT Noise

Exhibit A-11: Typical Ranges for Noise Walls Heights and Distances in Virginia

3.1.2 Depressed Section

A depressed section was also tested, both with and without a noise wall. In the absence of typical values for depressed sections in Virginia, AASHTO Green Book[29] specifications for a depressed section with minimum depth (16 feet), vertical walls and shoulder lanes were assumed.

[29] AASHTO, "A Policy on Geometric Design of Highways and Streets", 2011. See: www.transportation.org

3.2 Test Scenarios

Consistent with the general intent noted above to test the new AERMOD RLINE/XT options in regulatory applications in a Virginia setting and compare the results to those that would have been obtained using other available options for source type and other inputs, several sets of scenarios were tested (Sets A to G, as presented below.) For each set, both link configurations (west-east and north-south) were tested unless otherwise noted. The scenarios selected for testing include a mix of general options of interest from a state DOT perspective (Set A) and sensitivity testing of the new RLINEXT option for both noise walls and a depressed section (Sets C-G.)

A: General Options (No Walls or Depressed Sections). General options of interest to DOTs were tested, including:

- **Receptor Spacing & Run Time Tests**: Sensitivity of modeled 24-hour and annual maximum $PM_{2.5}$ concentrations, run times and run speeds (receptors processed per minute) to receptor spacing (ranging from 5 m to the value specified in EPA guidance of 25 m) and source (LINE, VOLUME, RLINE, and RLINEXT with and without walls or a depressed section.)
- **Source Comparisons**: Maximum 24-hour and annual $PM_{2.5}$ concentrations for various AERMOD sources (LINE, VOLUME, RLINE, and RLINEXT) were modeled with and without options specified.
- **URBAN Setting Sensitivity, by Source**: Sensitivity of modeled 24-hour and annual maximum $PM_{2.5}$ concentrations to the URBAN setting, including testing for LINE sources for populations ranging from 100 thousand to 6.2 million.

B: RLINEXT - Two Noise Walls per Link *(planned but dropped)*[30]

C: RLINEXT - One Noise Wall per Link – Westbound lanes for the West-East Link Configuration, and Southbound Lanes for the North-South Link Configuration. The full range of typical wall heights and distances from the travelled roadway for Virginia were tested.

D: RLINEXT – Sensitivity Testing for Receptor Offset Distances from the Noise Wall (One Noise Wall per Link). Given high modeled concentrations from initial testing of RLINEXT with noise walls, which had the first receptor row only one meter from the noise wall, a range of receptor offset distances (as a multiple of wall height) were tested. The results of this test may support development of guidance for receptor placement near noise walls, i.e., a receptor exclusion zone, if the model is determined in future model validation studies to be overestimating concentrations near the wall compared to field data for freeways with noise walls. This testing also supports a recommendation that the model be rigorously and systematically validated

[30] This set was planned to test the new feature in AERMOD (v.21112) that allows for two noise walls to be specified for each source link. In initial testing, however, warning messages were received indicating that the model read the wall locations to be on the same side of the road even through the distance to the centerline (DCLs) for the respective walls had opposing signs. The warning messages and input files were provided to FHWA who forwarded them EPA for resolution.

against field data for a range of typical wall heights and distances before being considered for regulatory applications.

E: RLINEXT – Half-Length Noise Walls (One per Link). This was done to assess the potential for differences in modeling results for a noise wall in cases in which only a portion of the project includes a noise wall.

F: RLINEXT – Depressed Section, with and without a Noise Wall (One per Link). Runs were done for a depressed section with shoulders, vertical walls, and minimum depth based on AASHTO Green Book specifications, with and without a noise wall, and with and without the URBAN setting. The noise wall selected for testing with the depressed section was one for which relatively high concentrations were modeled in Set C. *(Note: In the absence of data on typical depths and widths for depressed sections, additional sensitivity testing for depressed sections was deferred.)*

G: RLINEXT - One Noise Wall per Link – Eastbound lanes for West-East Links, and Northbound Lanes for North-South Links. The full range of typical wall heights and distances from the travelled roadway for Virginia was tested. Comparisons of the results for this set to those from Set C show the effect of the sources being upwind or downwind of the prevailing wind direction.

3.3 AERMOD Inputs

Exhibit A-12 presents the inputs for AERMOD as applied in this study. EPA and FHWA guidance as applicable was followed in the development of these inputs.

AERMOD (v.21112) Parameter	**Input***
Modeling Options (MODELOPT)	CONC, FLAT, DFAULT, ALPHA, BETA as applicable
Pollutant	PM25
Averaging Time (AVERTIME)	24 hour (eighth highest specified for output) and annual
Urban Setting (URBANOPT)	• Tested for each source types • For LINE sources, also tested a range of urban populations from 100k to 6.2 million, with the latter corresponding to 2019 data for the DC-MD-VA-WV core-based statistical area that had an average population density of 956 people per square mile. See: https://censusreporter.org/profiles/31000US47900-washington-arlington-alexandria-dc-va-md-wv-metro-area/
Receptor Height (FLAGPOLE) (m)	1.8*
Release Height (m)	2.74** *(Calculated with LDV & HDV weighting based on* $PM_{2.5}$ *emissions for a freeway in Fairfax County, VA.)*
Initial Vertical Dispersion Coefficient (Sz) (m)	2.55** *(Calculated with LDV and HDV weighting based on* $PM_{2.5}$ *emissions for a freeway in Fairfax County, VA.)*
Sources (LOCATION)	• Ten-lane freeway (five lanes each direction) segment, with a 10-meter median • Two configurations: 1. Links west-east 2. Links north-south • LINE – Two links each WB and EB, each for five lanes (total of four sources) • VOLUME – By lane for ten lanes (diameter set at lane width), for a total of 880 sources (440 each direction) • RLINE – As for LINE • RLINEXT – As for LINE *Note: Split links in both directions were specified to allow for later testing of adjacent freeway segments with and without noise walls.*
Sources (SRCPARAM)	Emission rate: 1 *(Nominal value; Actual rates specified with EMISFACT)*
Noise Walls (RBARRIER)	Tested typical noise wall heights (15-25 ft) and distances (20-60 ft) for Virginia (see table below)
Depressed Section (RDEPRESS)	• Minimum Depth: 16 ft (per AASHTO 2011 Green Book) • Vertical Walls • Includes shoulder lanes but otherwise the same geometry as at-grade freeway links

AERMOD (v.21112) Parameter	**Input***
Seasonal Weighting (EMISFACT SEASHR)	• MOVES3AERMOD (EPA MOVES Model Script) used to generate AERMOD inputs for EMISFACT SEASHR (4 seasons x 24 hours) • MOVES2AERMOD factors confirmed with manual calculations. • Output translated for use with RLINEXT and VOLUME sources in post-processing

Receptor Locations (RE)	• Testing for 5, 10, 15, 20 and 25 m uniform spacing.
	  o Also tested nested receptors, including 5 and 10 m spacing for the inner grid and 25 m spacing for the outer.
	• Receptors extended 50% of the link length past the end of roadway links, and between 120 and 200 m away from the roadway links
	• All receptors were placed outside of noise walls and outside of the exclusion zone that would apply for VOLUME sources.
	• The nearest receptor to roadway taken as the max of 5 meters or the noise wall location plus an offset:
	  o The noise wall offset started at 1 meter and was tested for multiples of wall height up to ten.
	  o For purposes of comparing runs with noise walls to a no-wall base case, the first row of receptors for the base case was made coincident with the first row for a noise wall with an offset of 1 meter. This was done as most modeled maxima occurred in the first row of receptors (given the test case of straight-line freeway segment), and receptor distance to the roadway has a strong influence on the modeled concentrations.

Meteorological Data (ME) • SURFFILE • PROFILE: • PROFBASE	 • IAD_STR_2016_2020.SFC • IAD_STR_2016_2020.PFL • 88 m (the base elevation specified by VDEQ for the Sterling, VA profile data site) ** Note: Surface and profile data for Dulles International Airport (IAD) for 2016-2020 were provided by year by VDEQ and combined into one file respectively for modeling:*
Output (OU)	• RECTABLE 24 EIGHTH • PLOTFILE 24 All Eighth Run_C1_plot_24hr8th.plt • PLOTFILE Annual ALL Run_C1_plot_annual.plt

** Defaults as specified in the VDOT Resource Document, which were developed based on EPA guidance. Note the modeling conducted for this study was completed before EPA updated their PM hot-spot guidance in October 2021. No changes were made however that would substantively affect the findings or conclusions of this study.*

*** Calculated following EPA guidance as presented in their 2018 PM Hotspot Materials: https://www.epa.gov/state-and-local-transportation/project-level-training-quantitative-pm-hot-spot-analyses*

Exhibit A-12: AERMOD Inputs

3.3.1 Meteorology

Consistent with the general intent to test AERMOD for regulatory applications, meteorological data for a full five-year period (2016-2020) were employed, as would be required in regulatory analyses conducted following EPA guidance. Special purpose meteorological data sets designed to test highly specific meteorological conditions, e.g., short-term data sets with only parallel winds, were *not* applied.

The Virginia Department of Environmental Quality (VDEQ) provided meteorological data for Dulles International Airport (IAD) for the five-year period of 2016-2020. IAD was specified as the representative site in the VDOT Resource Document (Appendix I2) for projects in Fairfax County that are in “areas closer to IAD,” as is the case for this hypothetical project. As shown in Exhibit A-13, winds for IAD occur about one-quarter of the time each from the northwest and from the south. Calms occurred 0.47% of the time.

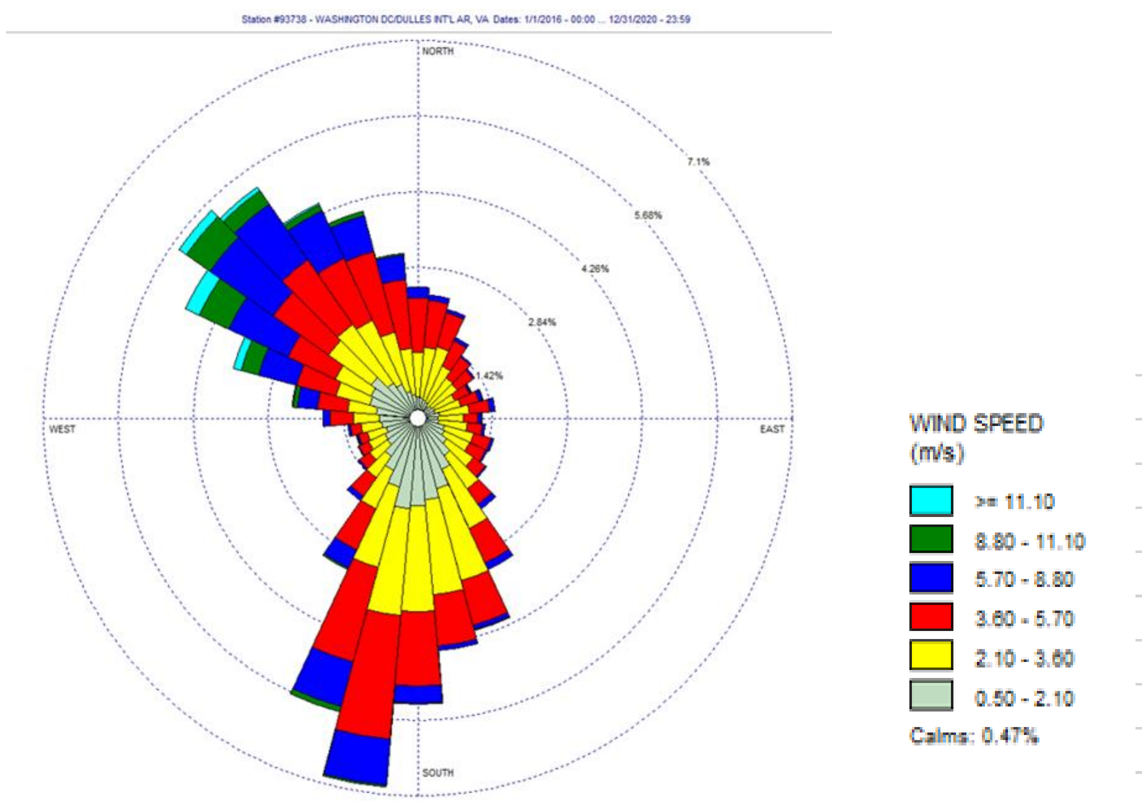

Exhibit A-13: Wind Rose for IAD 2016-2020

3.3.2 Background Concentrations

Design values (DVs) for comparison to the national ambient air quality standards (NAAQS) for $PM_{2.5}$ were calculated following EPA guidance, using background concentrations specified in the VDOT Resource Document. Background concentrations for projects in northern Virginia are specified in Table 4 of Appendix H1 of the VDOT Resource Document for the annual $PM_{2.5}$ NAAQS (as well as eight-hour CO NAAQS), for which the region was in maintenance at the time the Resource Document was prepared.

For the annual $PM_{2.5}$ NAAQS, the background concentration specified in the VDOT Resource Document for jurisdictions in northern Virginia outside of Arlington County and the City of Alexandria is 8.9 micrograms per cubic meter, based on data for 2011-2013 for the Loudoun County monitoring site.

Design values (DVs) for comparison to the 24-hur $PM_{2.5}$ NAAQS specifically were calculated following the first-tier approach specified in EPA guidance, using background concentrations as noted below along with the eighth-highest modeled roadway contribution.[31] As a value for the 24-hour $PM_{2.5}$ background concentration was not specified in the VDOT Resource Document (as the region has never been in nonattainment or maintenance for that standard,) it was taken as the value reported by VDEQ of 20 micrograms per cubic meter for the same site (Loudoun County) and years (2011-2013) specified in the Resource Document as noted above for the annual average. VDEQ data for the 24-hour standard (98th percentile) for 2011-2013 are presented in Exhibit A-14.

Virginia Department of Environmental Quality
2011-2013 PM2.5 24-hour Averages, 98th Percentile Values
Units, Micrograms per Cubic Meter

County/City	AIRS ID	2011	2012	2013	Design Value (NAAQS = 35 ug/m3)	Complete 3-Year Avg. (Yes or No)
Northern Virginia Area:						
Arlington Co.	510130020	***21.2***	21.8	21.2	21	No
Loudoun Co.	511071005	20.5	20.6	19.9	20	Yes
Fairfax Co. - Lee Park	510590030	24.1	21.1	21.0	22	Yes

Exhibit A-14: Background Concentrations –VDOT 24-Hour $PM_{2.5}$ Standard (Loudoun County Site)

VDOT Resource Document protocols provide that updates to background concentrations may be developed following the same procedures as the original estimates, consistent with EPA guidance. Attachment C presents more data for background concentrations for 2017-2019 that

[31] EPA. "Transportation Conformity Guidance for Quantitative Hot-spot Analyses in $PM_{2.5}$ and PM_{10} Nonattainment and Maintenance Areas", EPA-420-B-15-084, November 2015. p.137ff

could be applied for projects in northern Virginia, which reflect a general downward trend over time in $PM_{2.5}$ concentrations in the region. The values based on data for 2011-2013 were applied in this study as a more conservative approach and in recognition of the fact that that future NAAQS revisions may offset in whole or in part the reduced background concentrations based on more current monitoring data.

3.4 General Option and Sensitivity Testing (No Walls or Depressed Sections) (SET A)

3.4.1 Receptor Spacing Tests

Sensitivity testing for receptor spacing was conducted for uniform grids from 5 to 25 meters, for LINE sources with links oriented both west-east and north south. As shown in Exhibits A-15 to A-17:

- Receptor spacing did not have a strong effect on modeled $PM_{2.5}$ concentrations for LINE sources. For a uniform receptor spacing of 25 meters, the modeled maximum concentrations for the 24-hour and annual $PM_{2.5}$ standards were greater than 99.9% of those for 5-meter spacing, with considerable savings in run time. (Run times are presented in detail in the next section.)
    - The results were consistent for both link orientations tested.
    - The results support continued use of not less than 25 m for default receptor spacing, at least for sources not involving noise walls or depressed sections.
- Modeled maximum concentrations for the annual standard are higher (by nearly 17%) for a freeway segment with more parallel winds (the north-south links in this case) than perpendicular (the west-east links.)
- While link orientation did not have a strong effect for the 24-hour standard, it did for the annual standard.

Link Direction	Receptor Spacing (m)	24 Hr* (µg/m3)	*Index_ 24Hr** (to 5m)	*%Change _24Hr** (NS/WE)	Annual (µg/m3)	*Index_ Annual* (to 5m)	*%Change _Annual* (NS/WE)
West-East	5	2.9918	1.0000	0.000%	1.1222	1.0000	0.000%
West-East	10	2.9901	0.9994	0.000%	1.1222	1.0000	0.000%
West-East	15	2.9880	0.9987	-	1.1222	1.0000	-
West-East	20	2.9880	0.9987	-	1.1212	0.9991	-
West-East	25 (EPA Guidance)	2.9901	0.9994	0.000%	1.1219	0.9998	0.000%
North-South	5	3.0355	1.0000	1.459%	1.3106	1.0000	16.793%
North-South	10	3.0335	0.9994	1.451%	1.3106	1.0000	16.793%
North-South	25 (EPA Guidance)	3.0355	1.0000	1.516%	1.3099	0.9994	16.754%

** Eighth highest value*

Exhibit A-15: Receptor Spacing Sensitivity Test - LINE Sources $PM_{2.5}$

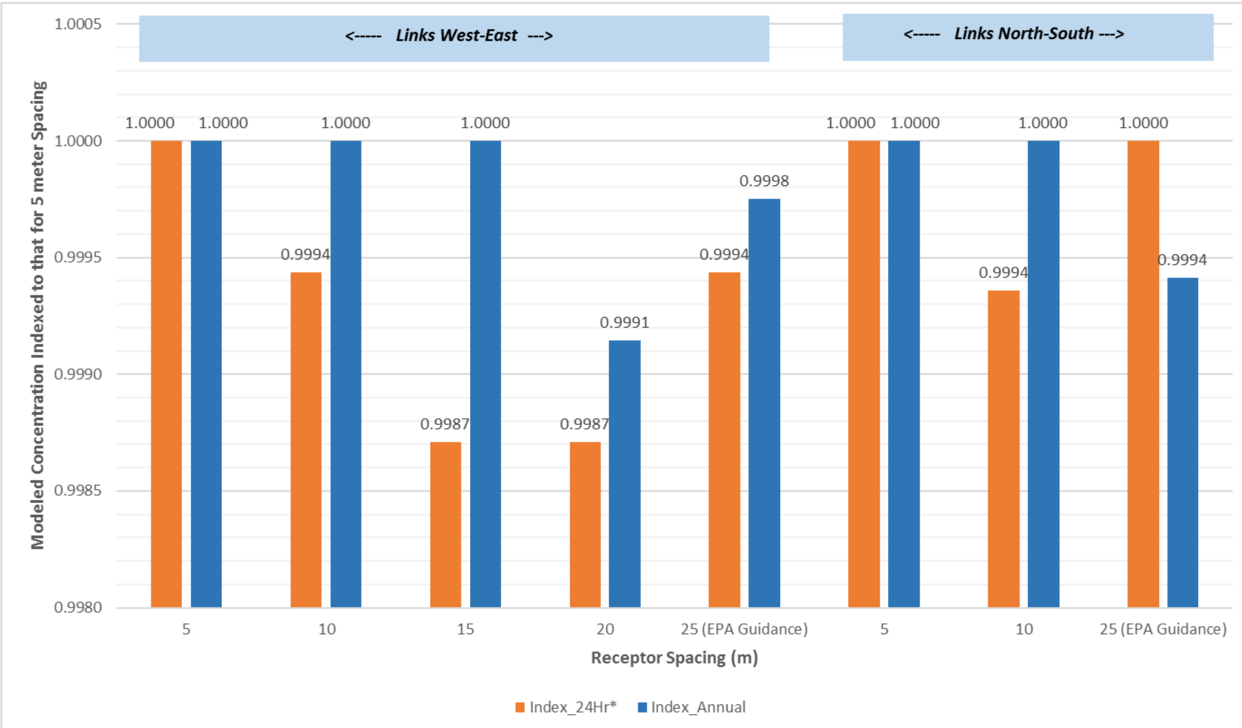

Exhibit A-16: Receptor Spacing Sensitivity Test - LINE Sources $PM_{2.5}$

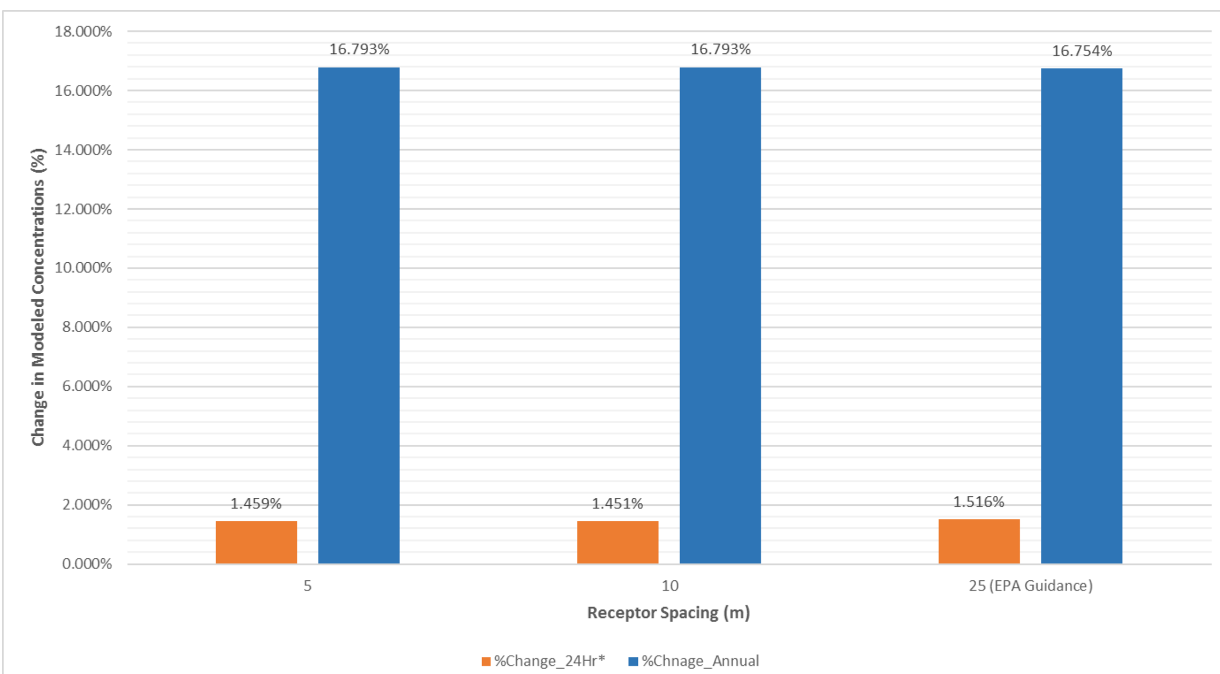

Exhibit A-17: Percent Increase in Maximum $PM_{2.5}$ *Concentrations for North-South Links Compared to West-East*

3.4.2 Run Time Tests

Run time and speeds (receptors processed per minute) were compared for different receptor spacing, source types, and the use of RLINEXT options for a barrier and/or depressed section. The results are presented in Exhibits A-18 to A-21. In summary:

- Run Times
  - The longest run times were generally for runs with:
    - A high number of receptors, for both 2D and 3D modeling
    - VOLUME sources
    - RLINEXT, when modeling noise walls

  - For LINE sources specifically, run times increase almost linearly with number of receptors.

  - For RLINEXT sources:
    - Run time for RLINEXT *without* walls was relatively low.
    - Run times for RLINEXT *with* a barrier were significantly higher, with the effect greater for higher walls. This effect diminished with increasing noise wall distance from the roadway.
    - For RLINEXT *with* a noise wall and a 3D receptor grid, run times increased dramatically from the same run without a 3D receptor grid. The relative increase in run times (about a factor of 6.1) was close to but less than the relative increase in the number of receptors (about a factor of 7).
    - For a vertical cut depressed section of minimum depth with than three times the number of receptors relative to the at-grade run, run time was slightly higher than that for an at-grade section with a 15 ft wall at 20 ft distance. For the same depressed section with a 20 ft wall at 20 ft distance, the run time increased significantly and was higher than any of the at-grade sections with walls.

  - For runs with the same spacing (10 m) and number of receptors (2080), and using the run time for LINE sources with uniform ten meter spacing as a reference case:
    - Run time for VOLUME sources was much greater (by a factor of about 13) than that for LINE. The ratio of the number of sources, 880 for VOLUME sources versus 4 for LINE sources, is 220, greatly exceeded the corresponding ratio for run time. The number of sources may therefore contribute to the relative increase in run time for VOLUME sources but is not the primary factor.
    - The run time for RLINE sources was about two-thirds of that for LINE sources.
    - The run time for RLINEXT sources *without* a noise wall or depressed section (and with a 10/25 m nested grid) was about one-third of that for LINE sources.

- Receptors Processed per Minute (RPPM):
  - The fastest processing (number of RPPM) by a significant margin was for RLINE at 48.4. The next higher RPPM was for RLINEXT without walls, at 36.6.
  - For line sources with uniform receptor spacing, the number of RPPM was in the range of 33 to 36 for all numbers of receptors tested, which is very close to the speed noted for RLINEXT without walls.
  - RPPM drops dramatically for RLINEXT sources *with* walls (and more so for 20- and 25-ft walls) and VOLUME sources, compared to RLINEXT *without* walls.
    - For RLINEXT with 15 ft walls at all distances tested (20-60 ft), RPPM was in the range of 10.9 to 12.
    - For RLINEXT with 20 to 25 ft walls at all distances tested (20-60 ft), RPPM dropped to the range of 2.6 to 4.
    - For RLINE XT:
      - Increasing wall height significantly increases run time and reduces RPPM.
      - Increasing distance from the wall slightly reduces run time and increases RPPM.
    - For VOLUME sources, RPPM was tied at 2.6 with RLINEXT with a 25 ft high wall at 20 ft. This was the lowest RPPM for all test scenarios.
  - RPPM for RLINEXT DEPRESS (33.0) was comparable to the RPPM for LINE and close to RLINEXT for no wall. For cases with a depressed section with an at-grade wall (H20/D20), the RPPM dropped to 5.2 if no shoulder lane was included in the depressed section and to 5.5 if an empty shoulder lane is included in the depressed section.

Source (Wall Ht/Distance in meters) (*At-grade unless otherwise noted)*	**Receptor Spacing (m)**	**No. of Receptors**	***Index_ Rec***	**Minutes**	***Index_ Min***	**Receptors/ Minute**	***Index_R PM***
LINE	5	7998	*3.8452*	232	*3.8033*	34.5	*1.0110*
LINE (Reference Case)	*10*	*2080*	*1.0000*	*61*	*1.0000*	34.1	*1.0000*
LINE	15	774	*.3721*	23	*.3770*	33.7	*.9869*
LINE	20	462	*.2221*	13	*.2131*	35.5	*1.0422*
LINE	25	364	*.1750*	11	*.1803*	33.1	*.9705*
Volume	10	2080	*1.0000*	805	*13.1967*	2.6	*.0758*
RLINE	10	2080	*1.0000*	43	*.7049*	48.4	*1.4186*
LINE	10/25	806	*.3875*	24	*.3934*	33.6	*.9849*
RLINEXT (No Wall)	10/25	806	*.3875*	22	*.3607*	36.6	*1.0744*
RLINEXT (H15/D20)	10/25	806	*.3875*	74	*1.2131*	10.9	*.3194*
RLINEXT (H20/D20)	10/25	806	*.3875*	241	*3.9508*	3.3	*.0981*
RLINEXT (H25/D20)	10/25	806	*.3875*	307	*5.0328*	2.6	*.0770*
RLINEXT (H15/D40)	10/25	806	*.3875*	69	*1.1311*	11.7	*.3426*
RLINEXT (H20/D40)	10/25	806	*.3875*	211	*3.4590*	3.8	*.1120*
RLINEXT (H25/D40)	10/25	806	*.3875*	261	*4.2787*	3.1	*.0906*
RLINEXT (H15/D60)	10/25	806	*.3875*	67	*1.0984*	12.0	*.3528*
RLINEXT (H20/D60)	10/25	806	*.3875*	203	*3.3279*	4.0	*.1164*
RLINEXT (H25/D60)	10/25	806	*.3875*	242	*3.9672*	3.3	*.0977*
RLINEXT RDEPRESS (Vert.Cut/Min.Depth, Empty Shoulder Lane)(No Wall)	5/25	2736	*1.3154*	83	*1.3607*	33.0	*.9667*
Depressed as above but w/at-grade wall (H20/D20), no shoulder lane	5/25	2736	*1.3154*	522	*8.5574*	5.2	*.1537*
Depressed as above but w/ at-grade wall (H20/D20), empty shoulder lane	5/25	2736	*1.3154*	499	*8.1803*	5.5	*.1608*
RLINEXT (H20/D20) 3D (Receptors on north side only)	10/25	5460	*2.6250*	1481	*24.2787*	3.7	*.1081*

Exhibit A-18: Run Times by Number of Receptors and Source (Links West-East)

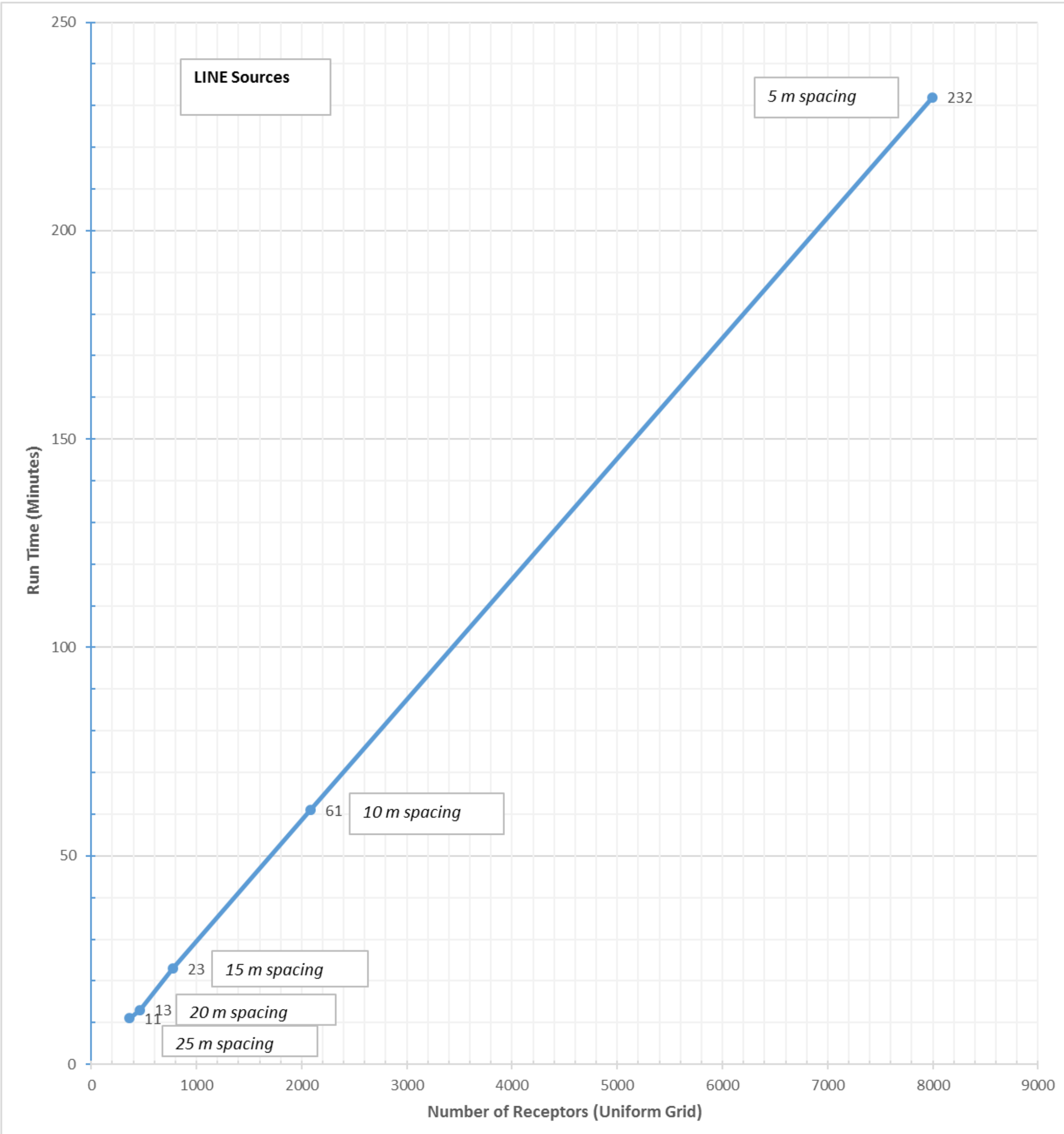

Exhibit A-19: Run Times by Number of Receptors and Source – LINE Sources with Uniform Receptor Grids

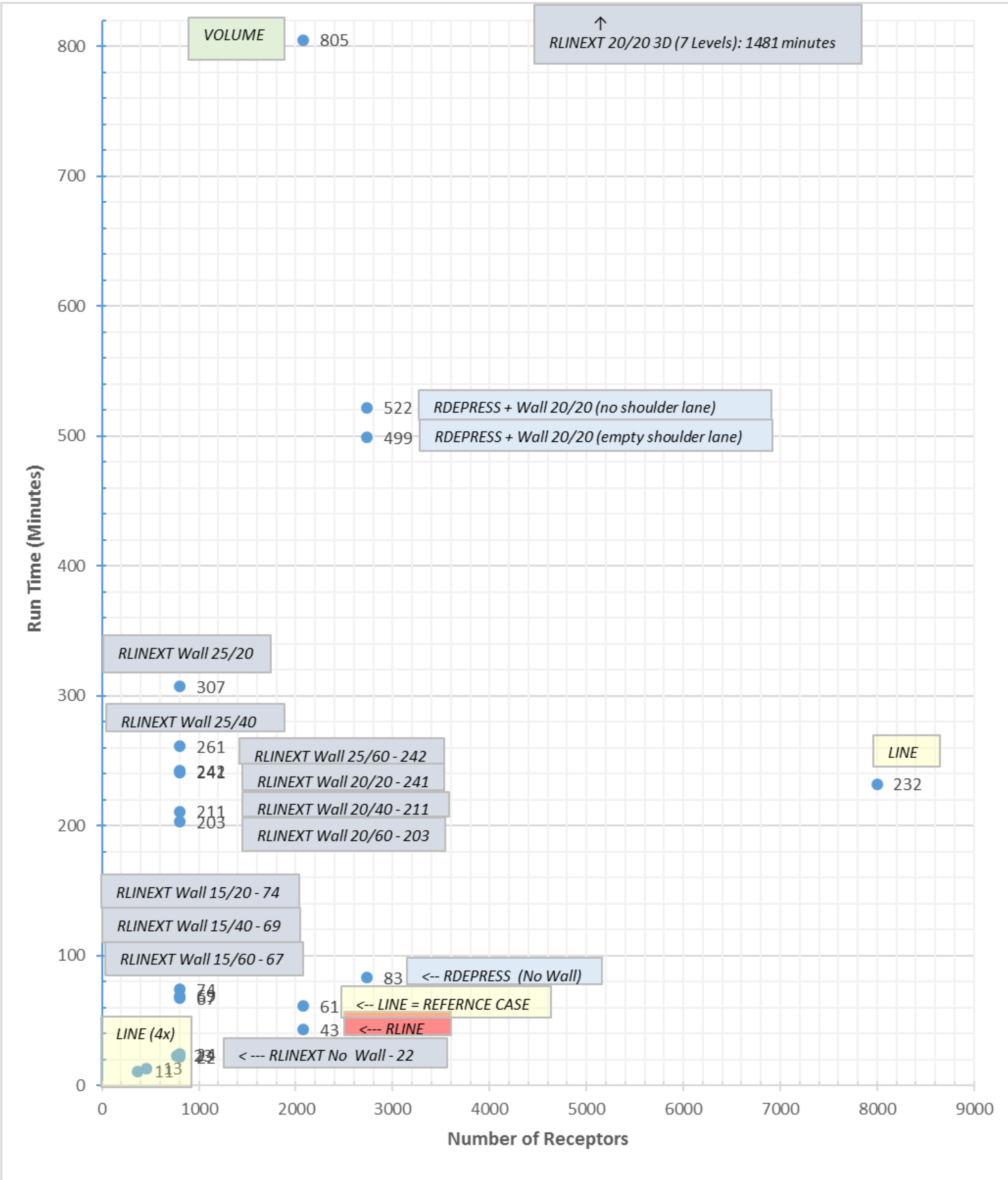

Exhibit A-20: Run Times by Number of Receptors and Source (Uniform and Nested Receptor Grids)

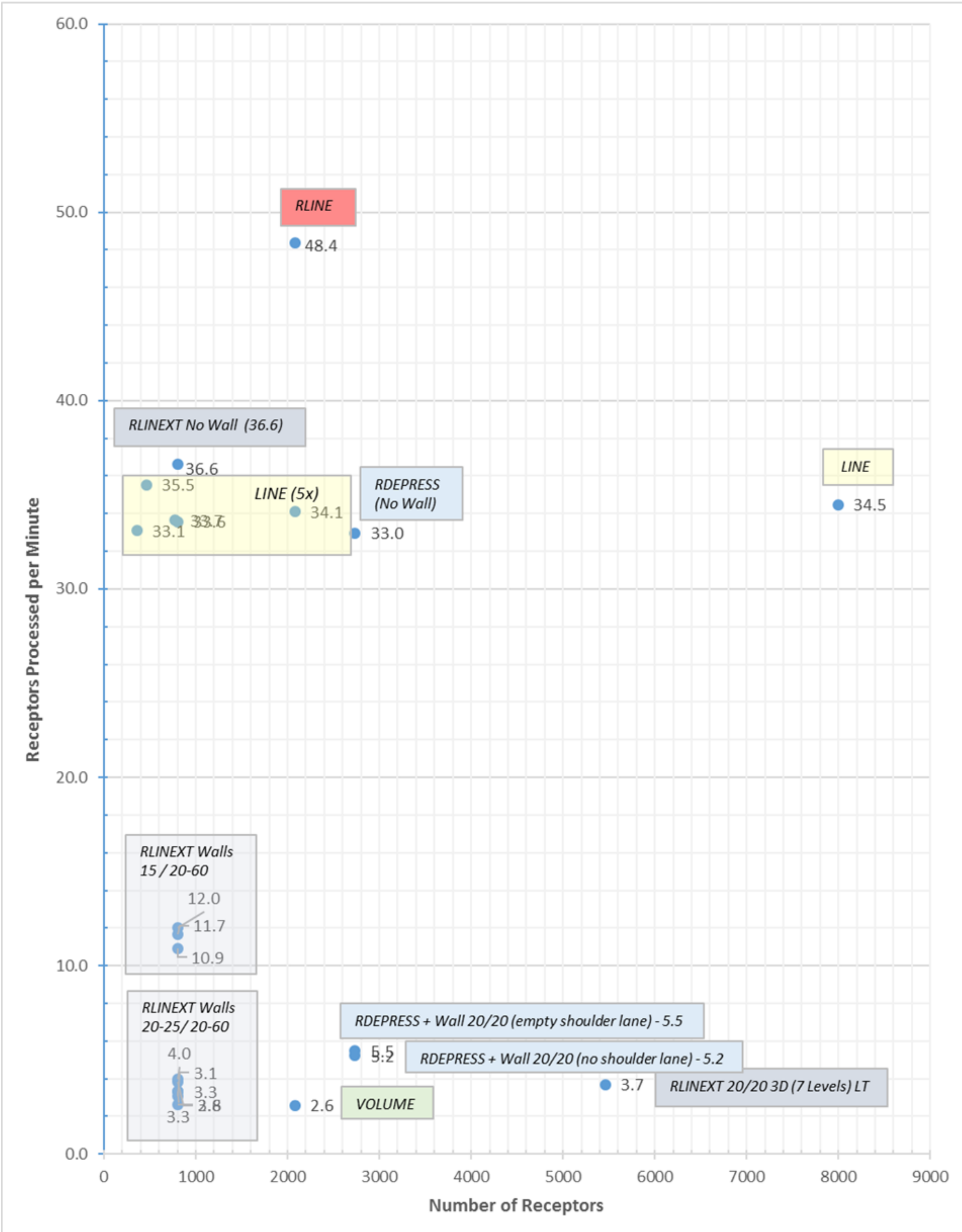

Exhibit A-21: Receptors Processed per Minute, by Number of Receptors and Source

3.4.3 Number of Links – URBAN LINE Sources

A spot check was conducted for number of links for LINE sources and the effect on maximum concentrations and run time. The results are presented in Exhibits A-22 and 23.

- With the caveat that only a very small number of links were modeled, small but non-zero differences in maximum concentrations were observed for different numbers of links. More specifically, for the very simple case tested, run time increased by almost 64%) with the doubling (i.e., the increase from two to four) of the number of links.
- The results suggest – for relatively simple LINE sources at least – that minimizing the number of links for a given run may help minimize run times, with only minimal differences in modeling results. However, results may differ for different facility types and configurations, e.g., interchanges, intersections, arterial streets etc., not to mention that the relative differences in maximum concentrations and run times may differ for runs involving a greater number of links. Additional sensitivity testing would be needed to better define the relationship between number of links and facility type and configuration with maximum concentrations and run times.

No. of Links	Index_Links	24 Hr*** (µg/m3)	%_24Hr	Annual (µg/m3)	%_Annual	Run Time (minutes)	Index_Minutes
2	1.00	2.1024	100.000%	0.8883	100.000%	83.0000	1.000
4	2.00	2.1009	99.928%	0.8879	99.955%	136.0000	1.639

** No wall or depressed roads* *** Urban population: 6.2m* **** Eighth highest value*

Exhibit A-22: Sensitivity of Maximum $PM_{2.5}$ Concentrations and Run Time to Number of Links – URBAN LINE Sources

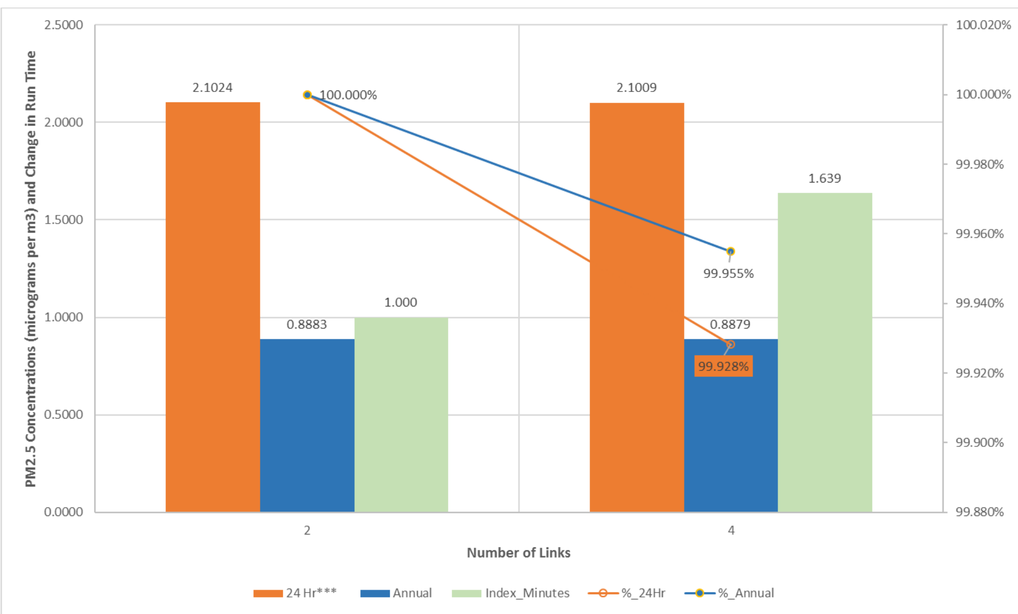

Exhibit A-23: Sensitivity of Maximum $PM_{2.5}$ Concentrations and Run Time to Number of Links – URBAN LINE Sources

3.4.4 Population – URBAN LINE Sources

Exhibits A-24 and 25 presents results for LINE sources in an URBAN setting covering a range of population from 100 thousand to 6.2 million, with the latter corresponding to the population for the northern Virginia portion of the DC-MD-VA-WV Core Based Statistical Area.[32] The URBAN setting generated significantly lower estimates for maximum concentrations for all population levels tested for LINE sources, with relatively little sensitivity to the population level. That is, for the range of populations tested, the results in terms of percent reduction of maximum modeled $PM_{2.5}$ concentrations from a non-urban LINE source ranged from about 24 to 30% for the 24-hour standard and from about 16 to 21% for the annual standard.

In other words, for both the 24-hour and annual standards, while percent reductions increased slightly with population level within these relatively narrow ranges, most of the reduction appears to be attributable to the specification of the URBAN setting for any population level. For this reason, the URBAN setting should be applied wherever applicable (meets EPA criteria specified in Appendix W), even for lower populations. Sensitivity testing for other sources is recommended.

URBAN Option	**Population (m)**	***%_Pop _Max***	**24 Hr***	***%_24_Hr***	***%_Reduction _24Hr***	**Annual**	***%_Annual***	***%_Reduction _Annual***
na	na	*na*	2.9901	*100.0%*	*0.0%*	1.1222	*100.0%*	*0.0%*
Urban	0.1	*1.6%*	2.2775	*76.2%*	*23.8%*	0.9418	*83.9%*	*16.1%*
Urban	1.0	*16.1%*	2.1833	*73.0%*	*27.0%*	0.9114	*81.2%*	*18.8%*
Urban	3.0	*48.4%*	2.1400	*71.6%*	*28.4%*	0.8972	*80.0%*	*20.0%*
Urban	4.0	*64.5%*	2.1239	*71.0%*	*29.0%*	0.8936	*79.6%*	*20.4%*
Urban	5.0	*80.6%*	2.1135	*70.7%*	*29.3%*	0.8906	*79.4%*	*20.6%*
Urban	6.2	*100.0%*	2.1009	*70.3%*	*29.7%*	0.8879	*79.1%*	*20.9%*

** Eighth highest value*

Exhibit A-24: Sensitivity of Maximum $PM_{2.5}$ Concentrations to Urban Population for LINE Sources

[32] See: https://censusreporter.org/profiles/31000US47900-washington-arlington-alexandria-dc-va-md-wv-metro-area/

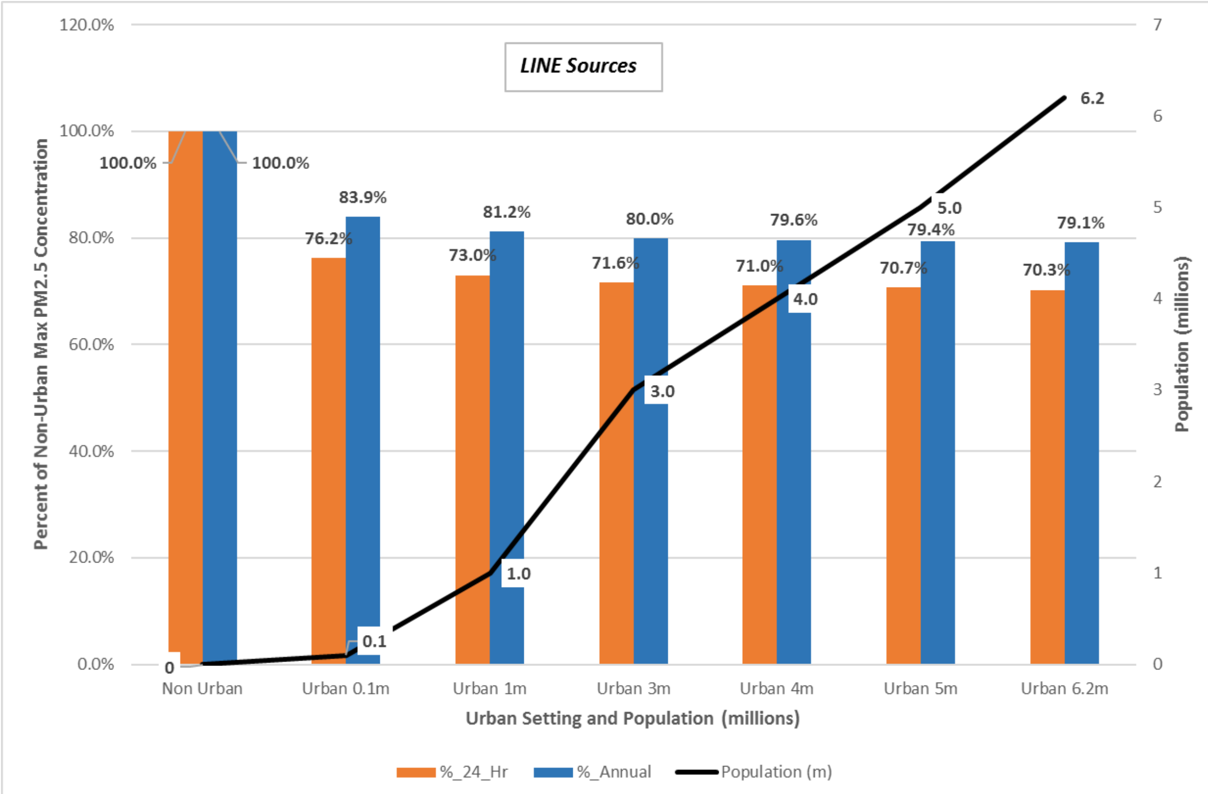

Exhibit A-25: Sensitivity of Maximum $PM_{2.5}$ Concentrations to Urban Population for LINE Sources

3.4.5 Source Selection (LINE, VOLUME, RLINE and RLINEXT), URBAN Setting and Szinit

LINE, VOLUME, RLINE, and RLINEXT sources were compared for at-grade configurations with no barriers for both URBAN and non-urban settings. All sources were also tested with Szinit set to zero or to the project-specific value of 2.55, which was calculated following EPA guidance using HDV and LDV emission-weighting as noted previously. Comparisons were made using the following categories for URBAN setting and Szinit: I- Non-urban with an Szinit of zero, II - Non-urban with an Szinit of 2.55, III – URBAN with an Szinit of zero, and IV - URBAN with an Szinit of 2.55. The following caveats apply:

- The results may vary if different values for urban population and Szinit were applied. Lower values for one or both parameters may have reduced effect than reported here. Note the urban population was set to that for the entire DC-MD-VA CBSA, which was 6.2 million.
- As the modeling was done for a straight-line highway segment only, the magnitude of the effects may vary somewhat for other project types, configurations, and operating conditions although the effect would directionally be the same.
- AERMOD must be validated in field studies (model-to-monitor comparisons) for all typical transportation project types, configurations, and operating conditions to confirm the modeling results.

For reference:

- LINE and VOLUME sources may be applied in regulatory project-level analyses for NEPA and conformity, while at present RLINE and RLINEXT are BETA and ALPHA respectively. The relative performance of LINE and VOLUME sources is therefore of particular interest to modelers for state DOTs.
- While VOLUME and RLINEXT require an input for Szinit, it is an optional input for LINE and RLINE that defaults to zero if not specified.

Exhibits A-26 and A-27 present roadway contributions to $PM_{2.5}$ concentrations (i.e., concentrations not including background values) by source and category of URBAN setting and Szinit. Exhibit A-28 presents the modeled maximum concentrations in relative terms, i.e., as percentages of the respective (non-urban with an Szinit of zero) base cases for each source. In summary:

- Modeled maximum $PM_{2.5}$ concentrations vary substantially by source, URBAN setting and Szinit, with differing but greater effect for URBAN setting and Szinit than source.
- Category I (non-urban base case with zero Szinit):
  - Modeled maximum concentrations are significantly reduced for VOLUME sources compered to LINE sources, but only slightly reduced for RLINE and RLINEXT sources. More specifically:
    - For the 24-hour standard, the modeled maximum concentrations for VOLUME sources are about 92% of those for LINE sources, while those for RLINE and RLINEXT sources are more comparable to (about 98% of) those for LINE sources.

        - For the annual standard, the modeled maximum concentrations for VOLUME sources are comparable to (about 98% of) those for LINE sources. The results for RLINE and RLINEXT are slightly higher than (104% of) those for LINE sources.
    - While the use of a zero value for the initial vertical dimension (Szinit) is not recommended here for use by state DOTs, if it is used for projects in non-urban settings in areas where the margin with the NAAQS is small, VOLUME sources may be preferred over other sources with zero Szinit if model validation exercises against field data confirm its accuracy for on-road vehicles.
- Category II (non-urban with Szinit of 2.55):
    - Relative to Case I with zero Szinit, the use of a value of 2.55 for Szinit significantly reduces modeled maximum concentrations for all sources for both the 24-hour and annual standards, with greater effect for RLINE and RLINEXT than for LINE and VOLUME sources. More specifically:
        - For the 24-hor standard, the modeled maximum concentrations for LINE and VOLUME sources for an Szinit of 2.55 are about 84% of those for the same source with an Szinit of zero, which corresponds to "reductions" of 16% for each source. For RLINE and RLINEXT, the corresponding reductions are significantly greater, at 23%.
        - For the annual standard, modeled maximum concentrations for LINE and VOLUME sources are reduced by nearly 16%, which is almost identical to the reductions observed for the 24-hour standard for these sources. For RLINE and RLINEXT, the modeled maximum concentrations are reduced by about 20% with the use of an Szinit of 2.55 compared to an Szinit of zero, which is still substantial but slightly smaller than the value of 23% observed for the 24-hour standard.
    - Based on these results, use of a non-zero value for Szinit is strongly recommended for all projects for all sources.
- Category III (URBAN with an Szinit of zero):
    - For the 24-hour standard, URBAN setting has a stronger effect on modeled maximum concentrations for all sources than observed for an Szinit of 2.55. For the annual standard, the results are mixed: the reductions are almost five percentage points greater for LINE and VOLUME sources with use of the URBAN option than for an Szinit of 2.55, but only slightly higher (less than one percentage point) for RLINE and RLINEXT sources for the URBAN option than an Szinit of 2.55. More specifically:
        - For the 24-hour standard, the reduction in modeled maximum concentrations with use of the URBAN setting compared to non-urban, is about 30% for LINE sources. The reduction is greatest for VOLUME sources at about 42%. The reduction for both RLINE and RLINEXT is about 37%, which is substantial but about five points less than observed for VOLUME sources.
        - For the annual standard, the reductions in modeled maximum concentrations with use of the URBAN setting is about 20% for VOLUME sources and slightly higher at about 21% for LINE, RLINE and RLINEXT sources. While still substantial, the reductions for all sources are significantly less than those observed for the 24-hour standard.
    - Based on these results, use of the URBAN setting is strongly recommended for all projects that meet EPA criteria for its use.

- Category IV (Combined use of the URBAN setting and an Szinit of 2.55):
    - The combined use of the URBAN setting with an Szinit of 2.55 results in the greatest reductions in modeled maximum concentrations for all sources. Note that, as expected, the reductions for the individual settings are not additive, i.e., the reductions for the combined settings are less than the sum of the reductions for the individual settings. More specifically:
        - For the 24-hour standard, the combined reductions are 38% for LINE sources, 48% for VOLUME sources, and 50% for RLINE and RLINEXT sources.
        - For the annual standard, the combined reductions are 31% for LINE sources, 30% for VOLUME sources, and 36% for RLINE and RLINEXT sources.
    - Use of the combined settings (URBAN where EPA criteria are met, and a non-zero value for Szinit) are strongly recommended for all sources for all projects.

Exhibit A-29 presents maximum $PM_{2.5}$ concentrations by the same categories of urban setting and Szinit but with a base case of LINE sources in the same category, i.e., with the same urban setting and Szinit. That is, the effect (benefit or disadvantage) of the selection of source is shown for each category.

- The results for Category II and III exhibit very similar trends, i.e., the relative differences in modeled maximum concentrations is significantly larger for the 24-hour standard than the annual standard, which are smaller.
- The source with the lowest modeled concentration varied with the category for URBAN setting and Szinit.
    - VOLUME sources generate the lowest modeled maximum concentrations for Category I, although the differences are not large, about 8% for the 24-hour standard and 2% for the annual standard. Both RLINE and RLINEXT had smaller reductions (2%) for the 24-hour standard and slight increases (4%) for the annual standard.
    - For Category II, RLINE and RLINEXT generated modeled maximum concentrations for the 24-hour standard that were 11% lower than the LINE source base case, compared to 7% for VOLUME sources. For the annual standard, VOLUME sources generated modeled maximum concentrations about 2% lower than the LINE source base case for this category, while the results for RLINE and RLINEXT were only 1% lower than the same LINE source base case.

      Based on these results, the use of VOLUME sources for motor vehicles may be preferred projects in areas in this category that have small margins with the annual $PM_{2.5}$ NAAQS, while the use of RLINE once it is made regulatory (as it is beta at present) may be preferred for areas needing to show compliance with the 24-hour standard. For projects in this category in areas needing to show compliance with both standards, either may be preferred depending on the relative margins with the two standards. These recommendations are made with the caveat that each source is shown in model validation against field data for transportation applications to meet criteria for accuracy.
    - For Category III, for the 24-hour standard, VOLUME, RLINE and RLINEXT sources generated modeled maximum concentrations that were 23%, 13% and 13% lower than

for LINE sources. For the annual standard, VOLUME source generated 2% lower values while RLINE and RLINEXT generated values that were 4% higher.

- For Category IV, for the 24-hour standard, the use of VOLUME, RLINE and RLINEXT sources resulted in modeled maximum concentrations that were significantly lower (by about 11%) than that for LINE sources. In contrast, the results for the annual standard were about the same for LINE and VOLUME sources, while the results for RLINE and RLINEXT were about 4% lower than that for the LINE sources.

  For projects in this category, for areas needing to show compliance with the 24-hour standard, VOLUME, RLINE and RLINEXT (without walls) may be preferred to LINE sources. For the annual standard, RLINE may be preferred. These recommendations are made with the caveat that each source is shown in model validation against field data for transportation applications to meet criteria for accuracy.

Exhibit A-30 shows the effect of urban setting and Szinit on maximum $PM_{2.5}$ concentrations grouped by *source*, relative to the non-urban LINE source base case with Szinit of zero. These results show the overall performance of each combination of source, Szinit and urban setting relative to the same base case.

- The results for all sources exhibit similar trends, with the highest modeled maximum concentrations for Category I, lowest for Category IV, and intermediate values for Categories II and III. This was observed for both the 24-hour and annual standards.
- For the 24-hour standard:
  - For Category II projects (non-urban with an Szinit of 2.55): Selection of VOLUME sources reduced the modeled maximum $PM_{2.5}$ concentrations by about 22% from that for the LINE source base case (non-urban with Szinit of zero,) and RLINE and RLINEXT sources likewise reduced the modeled maximum concentrations by about 25%.
  - For Category IV projects (URBAN with an Szinit of 2.55): Selection of VOLUME, RLINE and RLINEXT sources reduced the modeled maximum $PM_{2.5}$ concentrations by about 51% each from that for the LINE source base case (non-urban with Szinit of zero.)
- For the annual standard:
  - For Category II projects (URBAN with an Szinit of 2.55): Selection of VOLUME, RLINE and RLINEXT sources reduced the modeled maximum $PM_{2.5}$ concentrations by about 17% each from that for the LINE source base case (non-urban with Szinit of zero.)
  - For Category IV projects (URBAN with an Szinit of 2.55): Selection of VOLUME sources reduced the modeled maximum $PM_{2.5}$ concentrations by about 31% from that for the LINE source base case (non-urban with Szinit of zero,) and RLINE and RLINEXT sources likewise reduced the modeled maximum concentrations by about 33%.
- Overall:
  - VOLUME, RLINE and RLINEXT (without walls) may be preferred over line sources. As VOLUME sources are the only one of these three that may be used in regulatory applications at present (as RLINE is beta and RLINEXT alpha), the use of VOLUME sources may be preferred at present. Again, these recommendations are made with the caveat

that each source is shown in model validation against field data for transportation applications to meet criteria for accuracy.
  - The URBAN setting should be selected wherever applicable (i.e., EPA criteria are met.)
  - The use of a non-zero value for Szinit is strongly recommended for all projects.

Exhibits A-31 and A-32 present design values determined following EPA guidance. As they were based on northern Virginia-specific background concentrations and MOVES3.0.1 emission estimates, they represent reasonable estimates of what may be expected in practice for modeling using AERMOD of a freeway segment in this location.

- For the current 24-hour NAAQS of 35 micrograms per cubic meter:
  - For non-urban sources, the margin by which the hypothetical standard would be passed was between 12 and 12.8 micrograms per cubic meter or 34.3% to 36.4% of the NAAQS.
  - For URBAN sources, the margin increased slightly to 13.2 to 13.5 micrograms per cubic meter or 37.6% to 38.7% of the NAAQS.
  - The widest margins as expected were for Category IV, which ranged from 37.6% for LINE sources to 38.7% for VOLUME, RLINE and RLINEXT sources. The margins for Category I were smaller but still substantial, ranging from 34.3% for LINE sources to 35% for VOLUME.
- For the current annual NAAQS of 12 micrograms per cubic meter:
  - For non-urban sources, the margin was 1.9 to 2.2 micrograms per cubic meter or 16.1% to 18.1% of the NAAQS.
  - For URBAN sources, the margin ranged only slightly, from 2.3 to 2.4 micrograms per cubic meter or 19.4% to 19.6% of the NAAQS.
  - The widest margins again as expected were for Category IV, which were 19.4% for LINE and VOLUME sources and 19.6% for RLINE and RLINEXT. The margin for Category I was smaller, ranging from 16.1% for RLINE and RLINEXT to 16.5% for LINE and 16.6% for VOLUME.
- Overall:
  - For both the 24-hour and annual standards, the selection of source has a relatively small effect on the margin compared to the effects for URBAN setting and input value for Szinit.
  - In the absence of noise walls or depressed sections, the hypothetical project would pass the current 24-hour and annual NAAQS in all scenarios tested. However, if the NAAQS were to be revised and made more stringent in the future, then this conclusion might change.
  - The results in terms of meeting the NAAQS may differ substantially for other typical transportation project types (interchanges, intersections etc.), configurations (with or without noise walls, skew angles etc.) and/or operating conditions (higher volume/ congestion and/or higher truck diesel truck and bus percentages.)

Source*	Szinit (m)	URBAN Setting**	24 Hr*** (µg/m3)	% of Case I	%Reductions (1-Case I%)	% of LINE	Annual (µg/m3)	% of Case I	%Reductions (1-Case I%)	% of LINE
I - Non-urban with Szinit = 0 *(REFERENCE CASES)*										
Line	0	Non-Urban	2.9901	*100.0%*	-	*100%*	1.1222	*100.0%*	-	*100%*
Volume	0	Non-Urban	2.7620	*100.0%*	-	*92.4%*	1.1028	*100.0%*	-	*98.3%*
RLINE	0	Non-Urban	2.9191	*100.0%*	-	*97.6%*	1.1704	*100.0%*	-	*104.3%*
RLINEXT	0	Non-Urban	2.9191	*100.0%*	-	*97.6%*	1.1704	*100.0%*	-	*104.3%*
II - Non-urban with Szinit = 2.55 *Szinit calculated per EPA Guidance with weighting based on LDV & HDV emissions.*										
Line	2.55	Non-Urban	2.5112	*84.0%*	*16.0%*	*100%*	0.9453	*84.2%*	*15.8%*	*100%*
Volume	2.55	Non-Urban	2.3287	*84.3%*	*15.7%*	*92.7%*	0.9301	*84.3%*	*15.7%*	*98.4%*
RLINE	2.55	Non-Urban	2.2467	*77.0%*	*23.0%*	*89.5%*	0.9352	*79.9%*	*20.1%*	*98.9%*
RLINEXT	2.55	Non-Urban	2.2467	*77.0%*	*23.0%*	*89.5%*	0.9352	*79.9%*	*20.1%*	*98.9%*
III - URBAN with Szinit = 0										
Line	0.00	URBAN	2.1009	*70.3%*	*29.7%*	*100%*	0.8879	*79.1%*	*20.9%*	*100%*
Volume	0.00	URBAN	1.6163	*58.5%*	*41.5%*	*77%*	0.8780	*79.6%*	*20.4%*	*99%*
RLINE	0.00	URBAN	1.8380	*63.0%*	*37.0%*	*87%*	0.9255	*79.1%*	*20.9%*	*104%*
RLINEXT	0.00	URBAN	1.8380	*63.0%*	*37.0%*	*87%*	0.9255	*79.1%*	*20.9%*	*104%*
IV - COMBINED: URBAN with Szinit = 2.55										
Line	2.55	URBAN	1.8459	*61.7%*	*38.3%*	*100%*	0.7754	*69.1%*	*30.9%*	*100%*
Volume	2.55	URBAN	1.4500	*52.5%*	*47.5%*	*78.6%*	0.7717	*70.0%*	*30.0%*	*99.5%*
RLINE	2.55	URBAN	1.4552	*49.9%*	*50.1%*	*78.8%*	0.74705	*63.8%*	*36.2%*	*96.3%*
RLINEXT	2.55	URBAN	1.4552	*49.9%*	*50.1%*	*78.8%*	0.74704	*63.8%*	*36.2%*	*96.3%*

** No wall or depressed roads* *** Urban population: 6.2m* **** Eighth highest value for PM2.5*

Exhibit A-26: Maximum $PM_{2.5}$ Concentrations by Source and by Category of URBAN Setting and Szinit

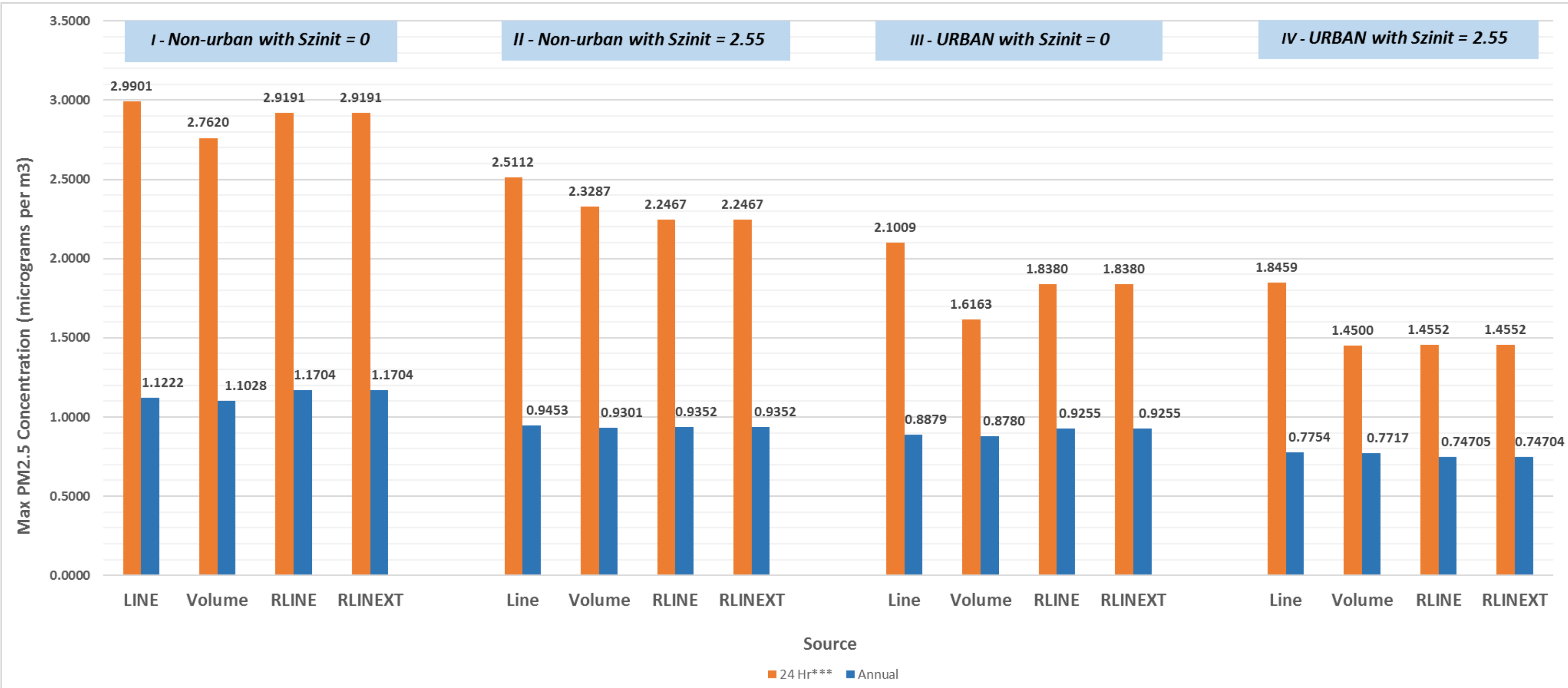

Exhibit A-27: Maximum $PM_{2.5}$ Concentrations by Source and by Category of URBAN Setting and Szinit

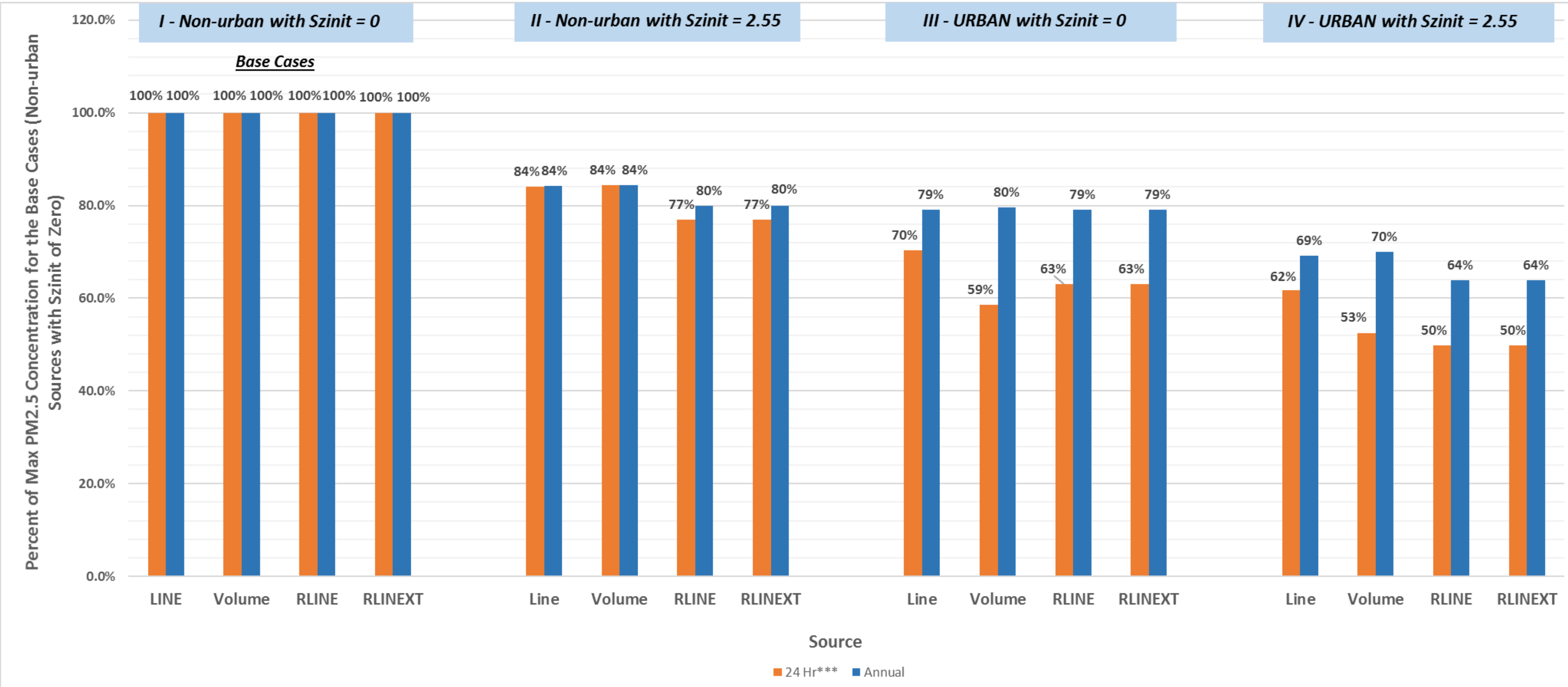

Exhibit A-28: Relative Maximum $PM_{2.5}$ Concentrations by Source and by Category of URBAN Setting and Szinit (Percentage of Base Case Non-Urban Source with SZINIT of Zero)

Exhibit A-29: Maximum $PM_{2.5}$ Concentrations by Source and by Category of URBAN Setting and Szinit, Relative to LINE Sources in the Same Category of URBAN Setting and Szinit

Exhibit A-30: Maximum $PM_{2.5}$ Concentrations by Source and by Category of URBAN Setting and Szinit, Relative to the Overall Non-Urban LINE Source Base Case with Zero Szinit

Source*	URBAN**	24hr PM2.5 DV (µg/m3)	NAAQS Test (35)	Margin (NAAQS-DV)	Margin % of NAAQS	Annual PM2.5 DV (µg/m3)	NAAQS Test (12)	Margin (NAAQS-DV)	Margin % of NAAQS
I - Non-urban with Szinit = 0 (REFERENCE CASES)									
Line	Non-Urban	23.0	PASS	12.0	34.3%	10.0	PASS	2.0	16.5%
Volume	Non-Urban	22.8	PASS	12.2	35.0%	10.0	PASS	2.0	16.6%
RLINE	Non-Urban	22.9	PASS	12.1	34.5%	10.1	PASS	1.9	16.1%
RLINEXT	Non-Urban	22.9	PASS	12.1	34.5%	10.1	PASS	1.9	16.1%
II - Non-urban with Szinit = 2.55									
Line	Non-Urban	22.5	PASS	12.5	35.7%	9.8	PASS	2.2	18.0%
Volume	Non-Urban	22.3	PASS	12.7	36.2%	9.8	PASS	2.2	18.1%
RLINE	Non-Urban	22.2	PASS	12.8	36.4%	9.8	PASS	2.2	18.0%
RLINEXT	Non-Urban	22.2	PASS	12.8	36.4%	9.8	PASS	2.2	18.0%
III - URBAN with Szinit = 0									
0.0000	0.0000	22.1	PASS	12.9	36.9%	9.8	PASS	2.2	18.4%
0.0000	0.0000	21.6	PASS	13.4	38.2%	9.8	PASS	2.2	18.5%
RLINE	URBAN	21.8	PASS	13.2	37.6%	9.8	PASS	2.2	18.1%
RLINEXT	URBAN	21.8	PASS	13.2	37.6%	9.8	PASS	2.2	18.1%
IV - COMBINED: URBAN with Szinit = 2.55									
Line	URBAN	21.8	PASS	13.2	37.6%	9.7	PASS	2.3	19.4%
Volume	URBAN	21.5	PASS	13.5	38.7%	9.7	PASS	2.3	19.4%
RLINE	URBAN	21.5	PASS	13.5	38.7%	9.6	PASS	2.4	19.6%
RLINEXT	URBAN	21.5	PASS	13.5	38.7%	9.6	PASS	2.4	19.6%
NON-URBAN	Maximum	23.0		12.8	36.4%	10.1		2.2	18.1%
	Minimum	22.2		12.0	34.3%	9.8		1.9	16.1%
	Average	22.6		12.4	35.4%	9.9		2.1	17.2%
URBAN	Maximum	21.8		13.5	38.7%	9.7		2.4	19.6%
	Minimum	21.5		13.2	37.6%	9.6		2.3	19.4%
	Average	21.6		13.4	38.4%	9.7		2.3	19.5%

** No wall or depressed roads* *** Urban population: 6.2m*

Exhibit A-31: $PM_{2.5}$ Design Values by Source and by Category of URBAN Setting and Szinit

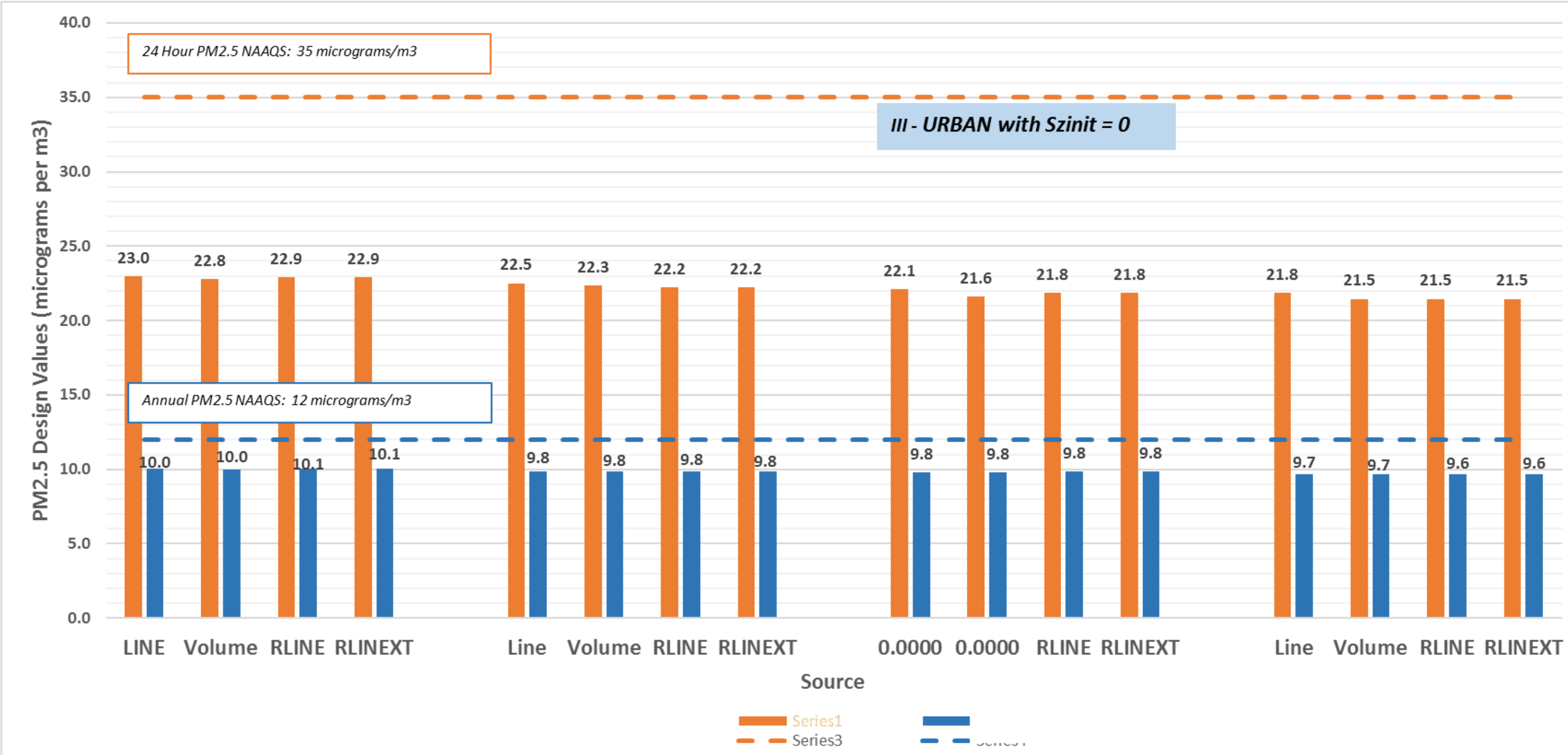

Exhibit A-32: PM$_{2.5}$ Design Values by Source and by Category of URBAN Setting and Szinit

3.5 Sensitivity Testing - One Noise Wall per Link, at Typical Heights and Distances from the Roadway

3.5.1 Wall on Westbound Links Only (SET C)

Sensitivity testing was conducted for a noise wall on westbound links (WB1 & WB2) for a range of typical heights and distances for noise walls in Virginia, i.e., heights of 15, 20 and 25 feet at distances of 20, 40 and 60 feet from the edge of the traffic lanes. A noise wall was not specified for the eastbound links. All links were at-grade. For this testing:

- Given the wind rose presented earlier, this configuration means the noise walls were downwind of the sources for winds from the south.
- Receptor placement:
  - For all the modeling runs in this test, and in the absence of guidance otherwise, the first row of receptors was placed one meter outside of the noise wall (away from the roadway).
  - For use as a base case, one run was done with RLINEXT in which noise walls were not specified. To better compare modeling results for the base case and the cases with walls, the receptors for the base case were placed to be coincident with the receptors for walls at 20 ft.

Exhibits A-33 to A-35 present the maximum $PM_{2.5}$ concentrations for both the 24-hour and annual $PM_{2.5}$ standards for this test, as well as indices calculated as the ratio of the modeled maximum concentration for the noise wall height and distance with the base case with no wall. Tabulations of minimum, maximum and average values are also provided. In summary:

- Overall, AERMOD (v21112) RLINEXT predicts *increased* maximum concentrations when there is a wall compared to the base case of RLINEXT with no wall, for a receptor field starting at one meter from the wall.
  - For the 24-hour standard, the increase in maximum concentrations with a wall over that for the base case without a wall ranged from 9.5% to 112.9%. The average increase was 62.6%.
  - For the annual standard, the increase in maximum concentrations with a wall over that for the base case without a wall ranged from 40.9% to 163.3%. The average increase was 104.3%. The worst-case result was for a wall of intermediate height (20 ft) at a minimum distance tested of 20 ft.
- Wall height had a strong effect on maximum concentration, peaking for a wall height of 20 ft for each of the three distances tested of the wall from the roadway. For each distance tested:
  - The maximum concentration observed was for a wall height of 20 ft, with an average increase of 107.7% from the base case for the 24-hour standard and 153.6% for the annual standard. In other words, the maximum concentrations observed were not for the maximum wall height, but the intermediate height pf 20 ft. As only three

different wall heights were tested, it is possible that the actual maximum concentrations may be for a different height, e.g., at a height between 15 and 25 ft.
  - The minimum increases were for a wall height of 15 feet, with an average increase of 16.6% from the base case for the 24-hour standard and 51.5% for the annual standard. Note these are not insignificant increases, although they were the minima observed for the cases tested.
  - The increase for wall heights of 25 feet fell between those for 15 and 20 ft, with an average increase of 63.5% from the base case for the 24-hour standard and 107.8% for the annual standard.
- Maximum concentrations decreased with distance of the wall from the road, although that effect was substantially less than for wall height.
  - For the 24-hour standard, the average increase in maximum concentrations from the no-wall base case ranged from 68.3% for 20 ft to 56.9% at 60 ft.
  - For the annual standard, the average increase in maximum concentrations from the no-wall base case ranged from 114% at 20 ft to 94.9% at 60 ft.
- While the modeled increases in maximum concentrations relative to the no-wall base case are high, they diminish with increasing offset distance to the first row of receptors. As an offset of only one meter was applied for this test, sensitivity testing was done for higher offset distances as a multiple of wall height. Those results are presented in Section 3.5.4.

Noise Wall				24 Hr* (µg/m3)	Index_24Hr*	Annual (µg/m3)	Index_Annual
Links	Height (ft)	Distance (ft)	Receptor Offset				
WB1-WB2	0	0	na	2.2086	1.000	0.9063	1.000
WB1-WB2	15	20	1 m	2.7345	1.238	1.4739	1.626
WB1-WB2	20	20	1 m	4.7014	2.129	2.3865	2.633
WB1-WB2	25	20	1 m	3.7170	1.683	1.9580	2.160
WB1-WB2	15	40	1 m	2.5723	1.165	1.3676	1.509
WB1-WB2	20	40	1 m	4.5838	2.075	2.2964	2.534
WB1-WB2	25	40	1 m	3.6125	1.636	1.8821	2.077
WB1-WB2	15	60	1 m	2.4177	1.095	1.2774	1.409
WB1-WB2	20	60	1 m	4.4736	2.026	2.2123	2.441
WB1-WB2	25	60	1 m	3.5020	1.586	1.8092	1.996
Minimum Overall:				2.4177	1.095	1.2774	1.409
Maximum Overall:				4.7014	2.129	2.3865	2.633
Average Overall:				3.5905	1.626	1.8515	2.043
Average for 15 ft walls				2.5748	1.166	1.3729	1.515
Average for 20 ft walls				4.5863	2.077	2.2984	2.536
Average for 25 ft walls				3.6105	1.635	1.8831	2.078
Average for 20 ft distance				3.7176	1.683	1.9395	2.140
Average for 40 ft distance				3.5895	1.625	1.8487	2.040
Average for 60 ft distance				3.4644	1.569	1.7663	1.949

Exhibit A-33: RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall on WB Links

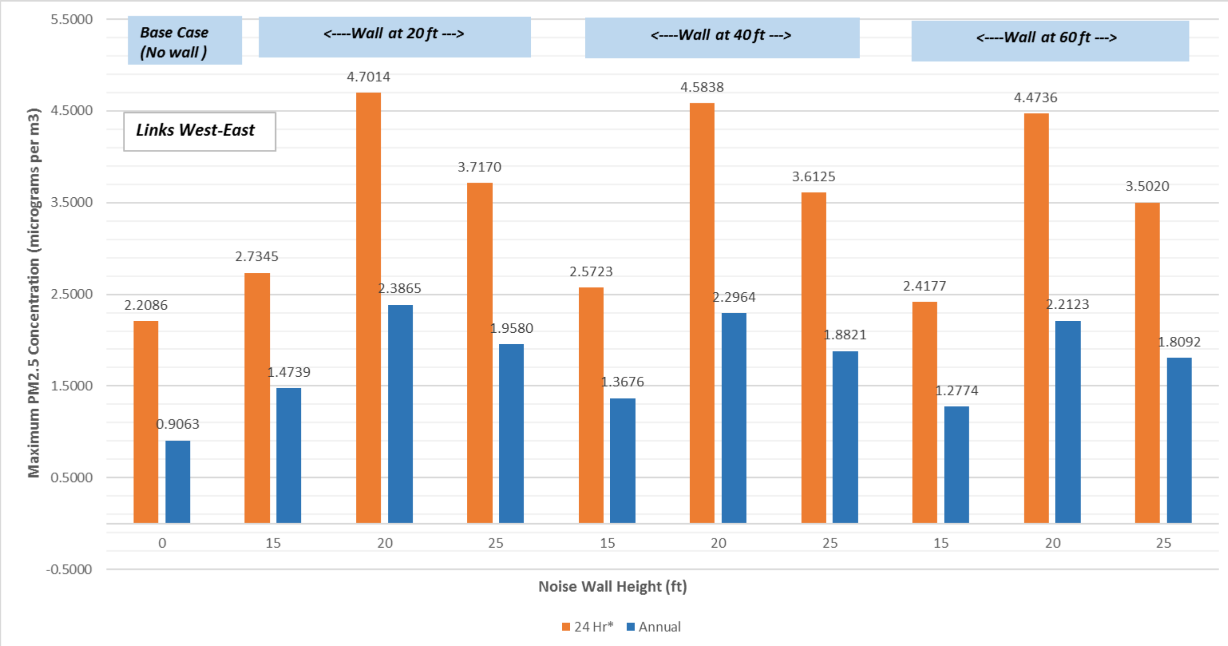

Exhibit A-34: RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall on WB Links

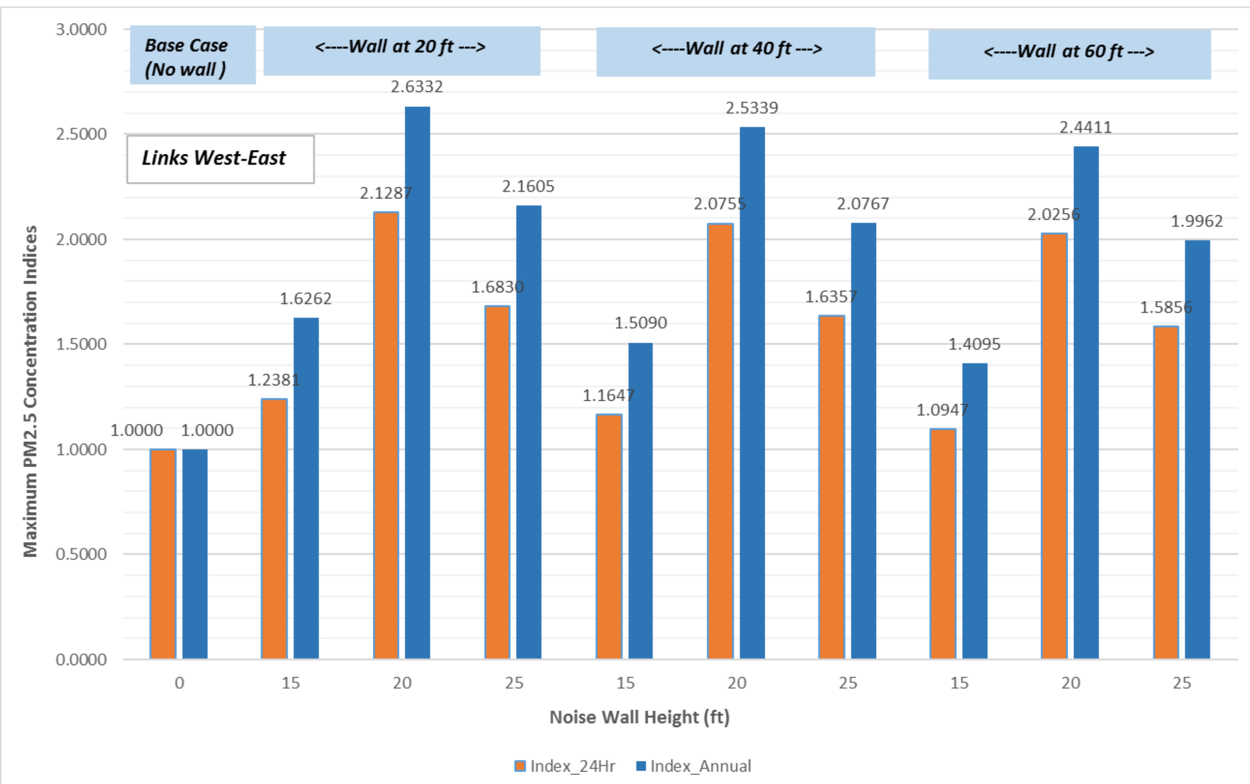

Exhibit A-35: RLINEXT Maximum $PM_{2.5}$ Concentration Indices for One Noise Wall on WB Links

Exhibits A-36 and A-37 present the design values (modeled maximum concentrations plus background) for both the 24-hour and annual $PM_{2.5}$ standards for this test, showing that the hypothetical project would meet the applicable NAAQS for each combination of noise wall height and distance. It also presents the margins by which the NAAQS are met, both in terms of micrograms per cubic meter and as a percent of the applicable NAAQS. In summary:

- While the applicable NAAQS are met in each case for this hypothetical project, the margins differ significantly for the 24-hour and annual standards.
    - The 24-hour NAAQS of 35 micrograms per cubic meters would be met by a significant margin ranging from 10.3 to 12.6 micrograms per cubic meter or 29.4% to 35.9% of the NAAQS.
    - The annual standard of 12 micrograms per cubic meter in contrast would be met by relatively narrow margins of 0.7 to 1.8 micrograms per cubic meter, or 5.9% to 15.2% of the NAAQS.
    - The minimum margins were observed for the intermediate height of 20 ft wall at all distances, with the overall minimum at the minimum distance tested of 20 ft, for both the 24-hour and annual standards.
- While the NAAQS was met in all cases, the relatively narrow margins for the annual standard is an indication that projects of greater scope and/or complexity than the simple straight-line freeway segment assessed here – such as interchanges with adjacent congested intersections with high diesel truck and/or bus percentages, or simply a higher volume freeway – could pose more of a challenge to meeting the annual NAAQS.

	Noise Wall			24hr PM2.5 DV*	NAAQS Test	Margin		Annual PM2.5 DV	NAAQS Test	Margin	
Links	Height (ft)	Distance (ft)	Receptor Offset	*(µg/m3)*	*(35)*	*(µg/m3)*	% of NAAQS	*(µg/m3)*	*(12)*	*(µg/m3)*	% of NAAQS
WB1-WB2	0	0	na	22.2	PASS	12.8	36.5%	9.8	PASS	2.2	18.3%
WB1-WB2	15	20	1 m	22.7	PASS	12.3	35.0%	10.4	PASS	1.6	13.6%
WB1-WB2	20	20	1 m	24.7	PASS	10.3	29.4%	11.3	PASS	0.7	5.9%
WB1-WB2	25	20	1 m	23.7	PASS	11.3	32.2%	10.9	PASS	1.1	9.5%
WB1-WB2	15	40	1 m	22.6	PASS	12.4	35.5%	10.3	PASS	1.7	14.4%
WB1-WB2	20	40	1 m	24.6	PASS	10.4	29.8%	11.2	PASS	0.8	6.7%
WB1-WB2	25	40	1 m	23.6	PASS	11.4	32.5%	10.8	PASS	1.2	10.1%
WB1-WB2	15	60	1 m	22.4	PASS	12.6	35.9%	10.2	PASS	1.8	15.2%
WB1-WB2	20	60	1 m	24.5	PASS	10.5	30.1%	11.1	PASS	0.9	7.4%
WB1-WB2	25	60	1 m	23.5	PASS	11.5	32.9%	10.7	PASS	1.3	10.8%
Overall:			*Minimum*	22.4		10.3	29.4%	10.2		0.7	5.9%
			Maximum	24.7		12.6	35.9%	11.3		1.8	15.2%
			Average	23.6		11.4	32.6%	10.8		1.2	10.4%
Minimum Height Tested			*Average*	22.6	*1.000*	12.4	35.5%	10.3	*1.000*	1.7	14.4%
Moderate Height Tested			*Average*	24.6	*1.089*	10.4	29.8%	11.2	*1.090*	0.8	6.7%
Maximum Height Tested			*Average*	23.6	*1.046*	11.4	32.5%	10.8	*1.050*	1.2	10.1%
Minimum Distance Tested			*Average*	23.7	*1.000*	11.3	32.2%	10.8	*1.000*	1.2	9.7%
Moderate Distance Tested			*Average*	23.6	*0.995*	11.4	32.6%	10.7	*0.992*	1.3	10.4%
Maximum Distance Tested			*Average*	23.5	*0.989*	11.5	33.0%	10.7	*0.984*	1.3	11.1%

** Eighth highest value*

Exhibit A-36: RLINEXT $PM_{2.5}$ Design Values and Margins for One Noise Wall on WB Links

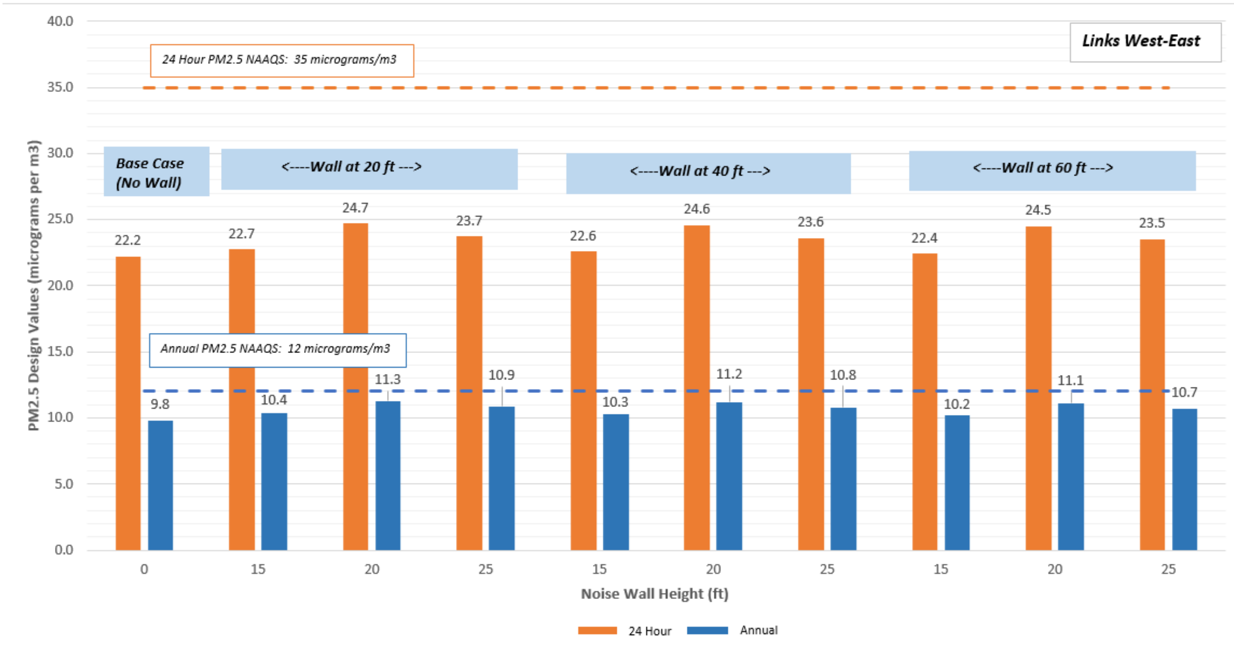

Exhibit A-37: RLINEXT $PM_{2.5}$ Design Values and Margins for One Noise Wall on WB Links

3.5.2 Three-Dimensional Receptor Array for a Run with a Noise Wall with High Modeled Concentrations Using a Two-Dimensional Receptor Array (SET C)

Attachment A presents modeling results for a three-dimensional receptor grid for links-oriented west-east, from which select results for the annual $PM_{2.5}$ standard are excerpted below as Exhibits A-38 to A-41. The modeling and 3D charts were generated using Trinity Breeze software for AERMOD v21112.

- The 3D run was based on the 2D run that had high modeled concentrations, which was a configuration involving a 20-ft wall at 20 feet from the roadway as presented in the previous section.
- Detailed output for the 3D run was generated for both the annual $PM_{2.5}$ standard and the maximum eighth-highest 24-hour $PM_{2.5}$ standard.
- Note the modeled maximum $PM_{2.5}$ concentration for a 3D run may be higher and occur at a different receptor height than used for the corresponding 2D run (1.8 meters).
- End effects for the links/walls are prominent.
- The contours for the x-y plane (presented in the appendix) show that the maximum concentrations occur at or near the center of the links/walls and not at the ends.

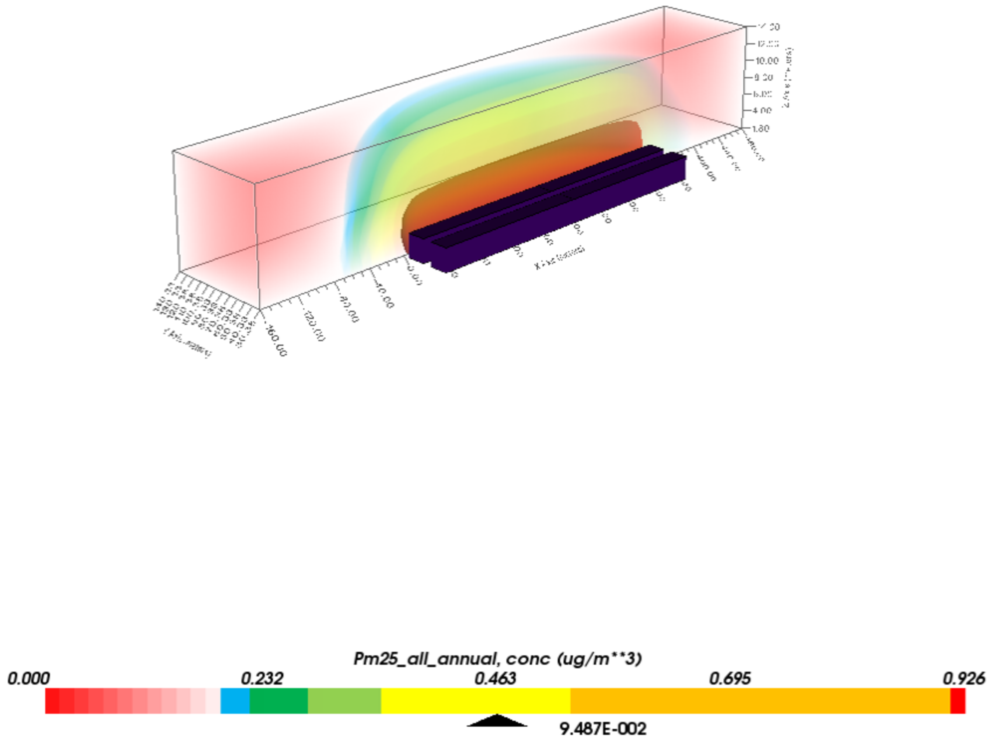

Exhibit A-38: RLINEXT 3D/Isosurface for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$

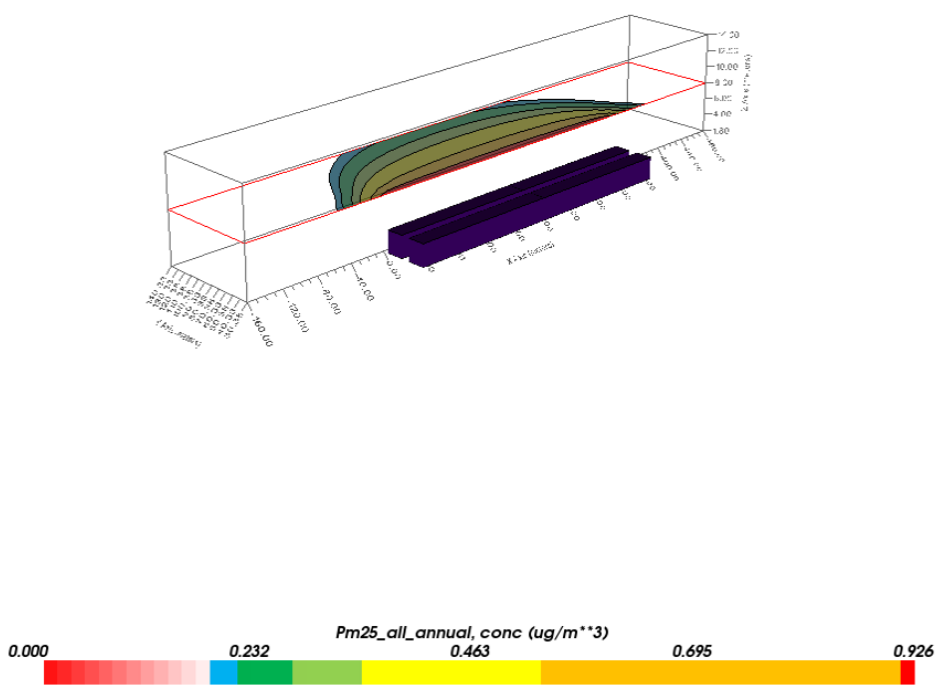

Exhibit A-39: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$ (XY Contours)

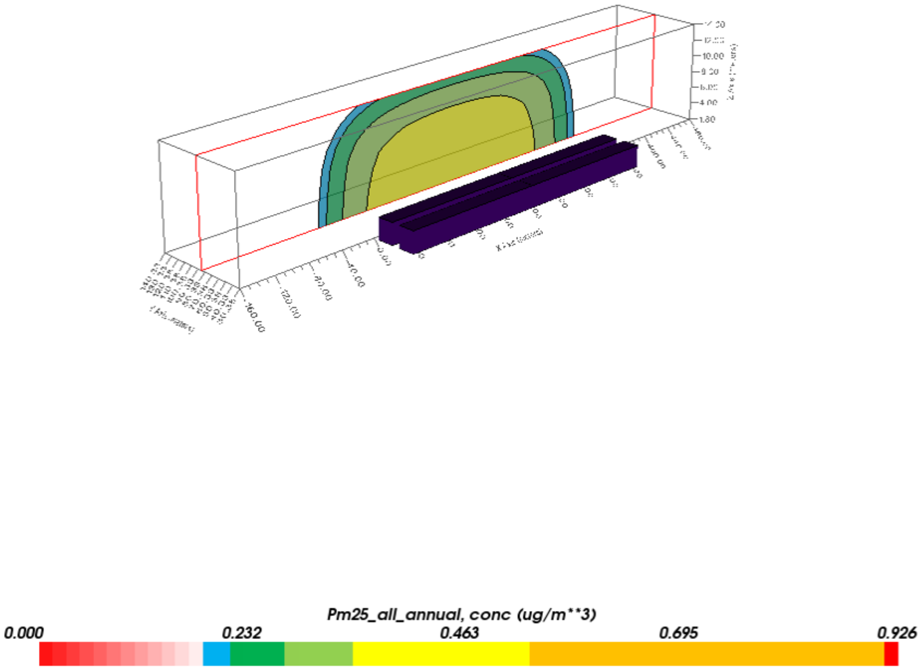

Exhibit A-40: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$ *(XZ Contours)*

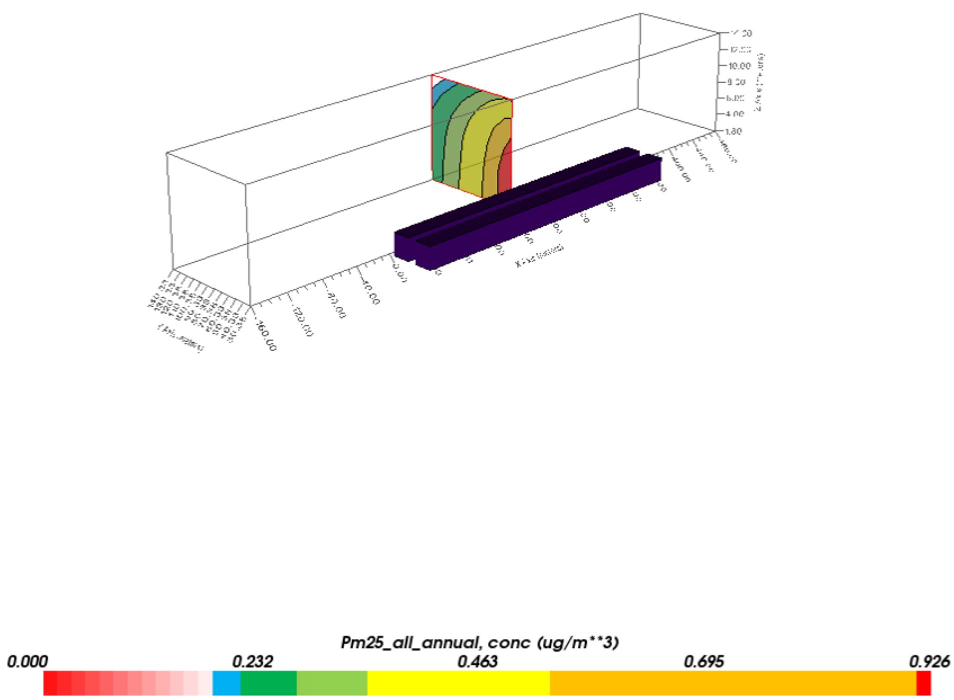

Exhibit A-41: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$ *(YZ Contours)*

3.5.3 One Wall on Southbound Links (SET C)

Sensitivity testing was conducted for a noise wall on southbound links (SB1 & SB2) at the typical heights and distances for noise walls in Virginia as presented in Section 3.1.1, i.e., for heights of 15, 20 and 25 feet at distances of 20, 40 and 60 feet from the edge of the traffic lanes. A noise wall was not specified for the northbound links. All links were at-grade. For this testing:

- Given the wind rose presented in Section 3.3.1, this configuration means the roadway links and noise wall were parallel or nearly so to winds from the south.
- Receptor placement:
  - For all the modeling runs in this test, and in the absence of guidance otherwise, the first row of receptors was placed one meter outside of the noise wall (i.e., away from the roadway).
  - For use as a base case, one run was done with RLINEXT in which a noise wall was not specified. To better compare modeling results for the base case and the cases with walls, the receptors for the base case were placed to be coincident with the receptors for the wall at 20 ft.

Exhibits A-42 to A-44 present the maximum $PM_{2.5}$ concentrations for both the 24-hour and annual $PM_{2.5}$ standards for this test along with indices calculated as the ratio of the modeled maximum concentration for the noise wall height and distance with the base case with no wall. Tabulations of minimum, maximum and average values are also presented. In summary:

- Overall, AERMOD (v21112) RLINEXT predicts increased maximum concentrations when there is a wall compared to the base case of RLINEXT with no wall, for a receptor field starting at one meter from the wall.
  - For the 24-hour standard, the increase in maximum concentrations with a wall over that for the base case without a wall ranged from 7.3% to 101.1%. The average increase was 54.7%.
  - For the annual standard, the increase in maximum concentrations with a wall over that for the base case without a wall ranged from 23.1% to 138.7%. The average increase was 82.2%.
- Wall height had a strong effect on maximum concentration, peaking for the intermediate wall height of 20 ft for each of the three distances tested of the wall from the roadway, with the overall maximum located at the minimum distance from the roadway of 20 ft. For each distance tested:
  - The maximum concentration was for a wall height of 20 ft, with an average increase of 101.1% from the base case for the 24-hour standard and 138.7% for the annual standard.
  - The minimum increases were for a wall height of 15 feet, with an average increase of 18.4% from the base case for the 24-hour standard and 36.1% for the annual standard. These are not insignificant increases, although they were the minima observed for the cases tested.

  - The increase for wall height of 25 feet fell between those for 15 and 20 ft, with an average increase of 53.7% from the base case for the 24-hour standard and 85.1% for the annual standard.
- Maximum concentrations decreased with distance of the wall from the road, although that effect was substantially less than for wall height.
  - For the 24-hour standard, the average increase in maximum concentrations from the no-wall base case ranged from 64.3% for 20 ft to 45.6% at 60 ft.
  - For the annual standard, the average increase in maximum concentrations from the no-wall base case ranged from 95% for 20 ft to 69.5% for 60 ft.
- While the modeled increases in maximum concentrations relative to the no-wall base case are high, they diminish with increasing offset distance to the first row of receptors.

Noise Wall				24 Hr* (µg/m3)	Index_24Hr	Annual (µg/m3)	Index_Annual
Links	Height (ft)	Distance (ft)	Receptor Offset				
SB1-SB2	0	0	na	2.3383	1.0000	1.1025	1.0000
SB1-SB2	15	20	1 m	3.0401	1.3001	1.6487	1.4954
SB1-SB2	20	20	1 m	4.7036	2.0115	2.6321	2.3874
SB1-SB2	25	20	1 m	3.7815	1.6172	2.1681	1.9665
SB1-SB2	15	40	1 m	2.7567	1.1789	1.4951	1.3561
SB1-SB2	20	40	1 m	4.4802	1.9160	2.4822	2.2514
SB1-SB2	25	40	1 m	3.5904	1.5355	2.0426	1.8527
SB1-SB2	15	60	1 m	2.5101	1.0735	1.3573	1.2311
SB1-SB2	20	60	1 m	4.2924	1.8356	2.3356	2.1184
SB1-SB2	25	60	1 m	3.4110	1.4587	1.9122	1.7344
Minimum Overall:				2.5101	1.073	1.3573	1.231
Maximum Overall:				4.7036	2.011	2.6321	2.387
Average Overall:				3.6184	1.547	2.0082	1.822
Average 15 ft walls				2.7690	1.184	1.5004	1.361
Average 20 ft walls				4.4920	1.921	2.4833	2.252
Average 25 ft walls				3.5943	1.537	2.0410	1.851
Average 20 ft distance				3.8417	1.643	2.1496	1.950
Average 40 ft distance				3.6091	1.543	2.0066	1.820
Average 60 ft distance				3.4045	1.456	1.8684	1.695

** Eighth highest value*

Exhibit A-42: RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall on SB Links

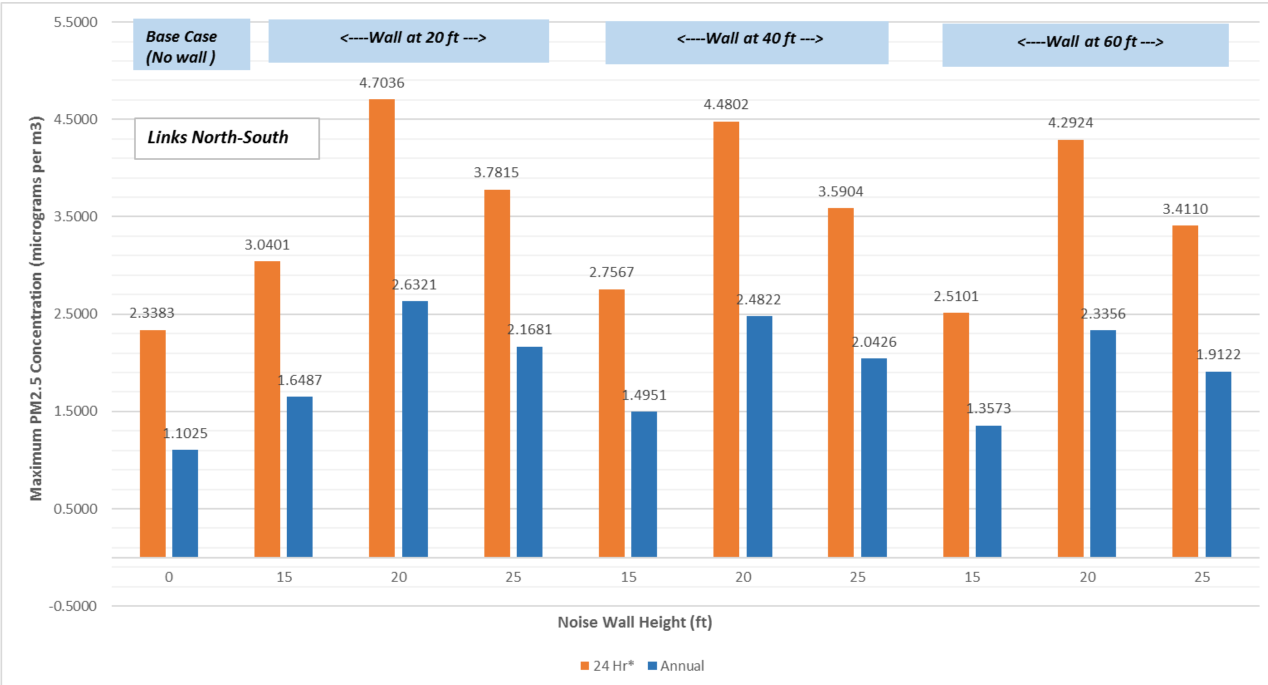

Exhibit A-43: RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall on SB Links

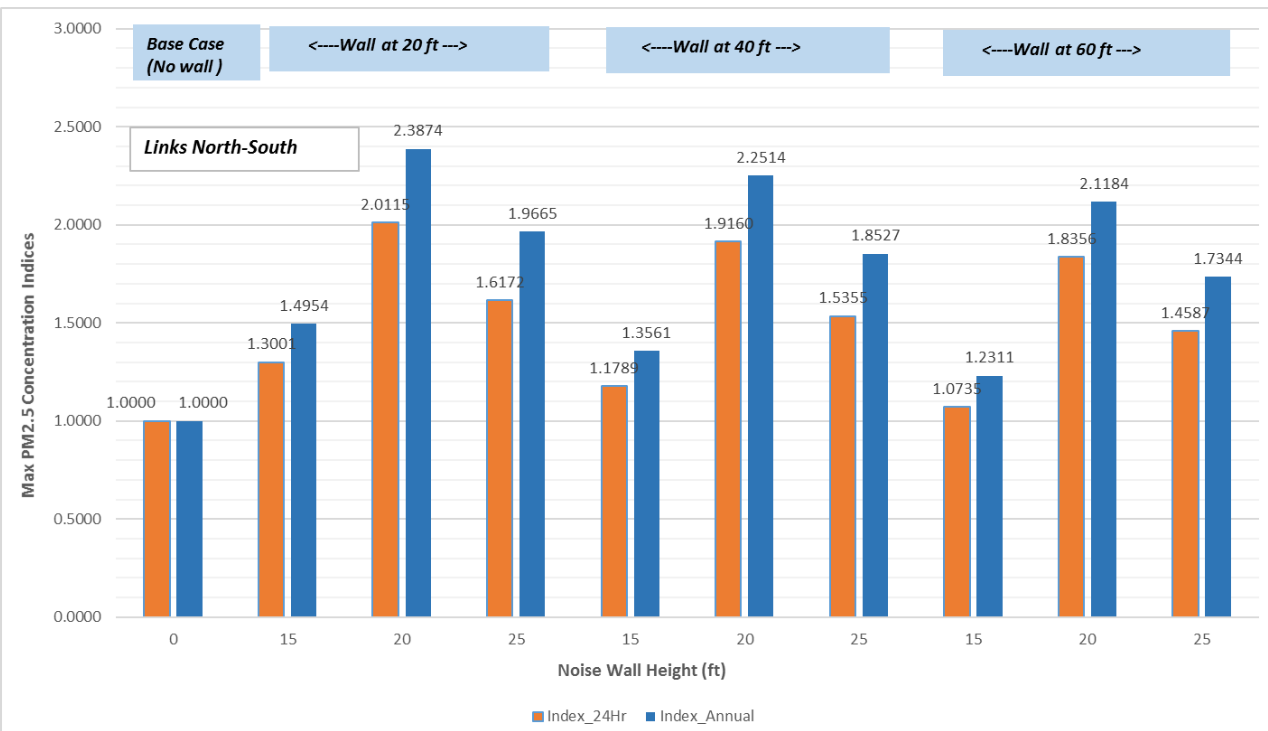

Exhibit A-44: RLINEXT Maximum $PM_{2.5}$ Concentrations Indices for One Noise Wall on SB Links

Exhibits A-45 and A-46 present the design values (modeled maximum concentrations plus background) for both the 24-hour and annual $PM_{2.5}$ standards for this test, showing that the hypothetical project would meet the applicable NAAQS for each combination of noise wall height and distance. It also presents the margin by which the NAAQS would be met, both in absolute terms and as a percent of the applicable NAAQS. In summary:

- While the applicable NAAQS are met in each case for this hypothetical project, the margins differ significantly for the 24-hour and annual standards.
    - The 24-hour NAAQS of 35 micrograms per cubic meters would be met by a significant margin ranging from 10.3 to 12.5 micrograms per cubic meter or 29.4% to 35.7% of the NAAQS.
    - The annual standard of 12 micrograms per cubic meter in contrast would be met by relatively narrow margins of 0.5 to 1.7 micrograms per cubic meters, or 3.9% to 14.5% of the NAAQS.
    - The minimum margins were observed for the intermediate height of 20 ft wall at all distances, with the overall minimum at the minimum distance tested of 20 ft, for both the 24-hour and annual standards.
- While the NAAQS was met in all cases, the relatively narrow margins for the annual standard is an indication that projects of greater scope and/or complexity than the simple straight-line freeway segment assessed here – such as interchanges with adjacent congested intersections with high diesel truck and/or bus percentages, or even simply a higher volume freeway – could pose more of a challenge to meeting the annual NAAQS.

	Noise Wall			24hr PM2.5 DV*	NAAQS Test	Margin		Annual PM2.5 DV	NAAQS Test	Margin	
Links	Height (ft)	Distance (ft)	Receptor Offset	(µg/m3)	(35)	(NAAQS-DV)	% of NAAQS	(µg/m3)	(12)	(NAAQS-DV)	% of NAAQS
SB1-SB2	0	0	na	22.3	PASS	12.7	36.2%	10.0	PASS	2.0	16.6%
SB1-SB2	15	20	1 m	23.0	PASS	12.0	34.2%	10.5	PASS	1.5	12.1%
SB1-SB2	20	20	1 m	24.7	PASS	10.3	29.4%	11.5	PASS	0.5	3.9%
SB1-SB2	25	20	1 m	23.8	PASS	11.2	32.1%	11.1	PASS	0.9	7.8%
SB1-SB2	15	40	1 m	22.8	PASS	12.2	35.0%	10.4	PASS	1.6	13.4%
SB1-SB2	20	40	1 m	24.5	PASS	10.5	30.1%	11.4	PASS	0.6	5.1%
SB1-SB2	25	40	1 m	23.6	PASS	11.4	32.6%	10.9	PASS	1.1	8.8%
SB1-SB2	15	60	1 m	22.5	PASS	12.5	35.7%	10.3	PASS	1.7	14.5%
SB1-SB2	20	60	1 m	24.3	PASS	10.7	30.6%	11.2	PASS	0.8	6.4%
SB1-SB2	25	60	1 m	23.4	PASS	11.6	33.1%	10.8	PASS	1.2	9.9%
Overall:			*Minimum*	22.5		10.3	29.4%	10.3		0.5	3.9%
			Maximum	24.7		12.5	35.7%	11.5		1.7	14.5%
			Average	23.6		11.4	32.5%	10.9		1.1	9.1%
Minimum Height Tested			*Average*	22.8	*1.000*	12.2	34.9%	10.4	*1.000*	1.6	13.3%
Moderate Height Tested			*Average*	24.5	*1.076*	10.5	30.0%	11.4	*1.095*	0.6	5.1%
Maximum Height Tested			*Average*	23.6	*1.036*	11.4	32.6%	10.9	*1.052*	1.1	8.8%
Minimum Distance Tested			*Average*	23.8	*1.000*	11.2	31.9%	11.0	*1.000*	1.0	7.9%
Moderate Distance Tested			*Average*	23.6	*0.990*	11.4	32.5%	10.9	*0.987*	1.1	9.1%
Maximum Distance Tested			*Average*	23.4	*0.982*	11.6	33.1%	10.8	*0.975*	1.2	10.3%

** Eighth highest value*

Exhibit A-45: RLINEXT $PM_{2.5}$ Design Values and Margins for One Noise Wall on SB Links

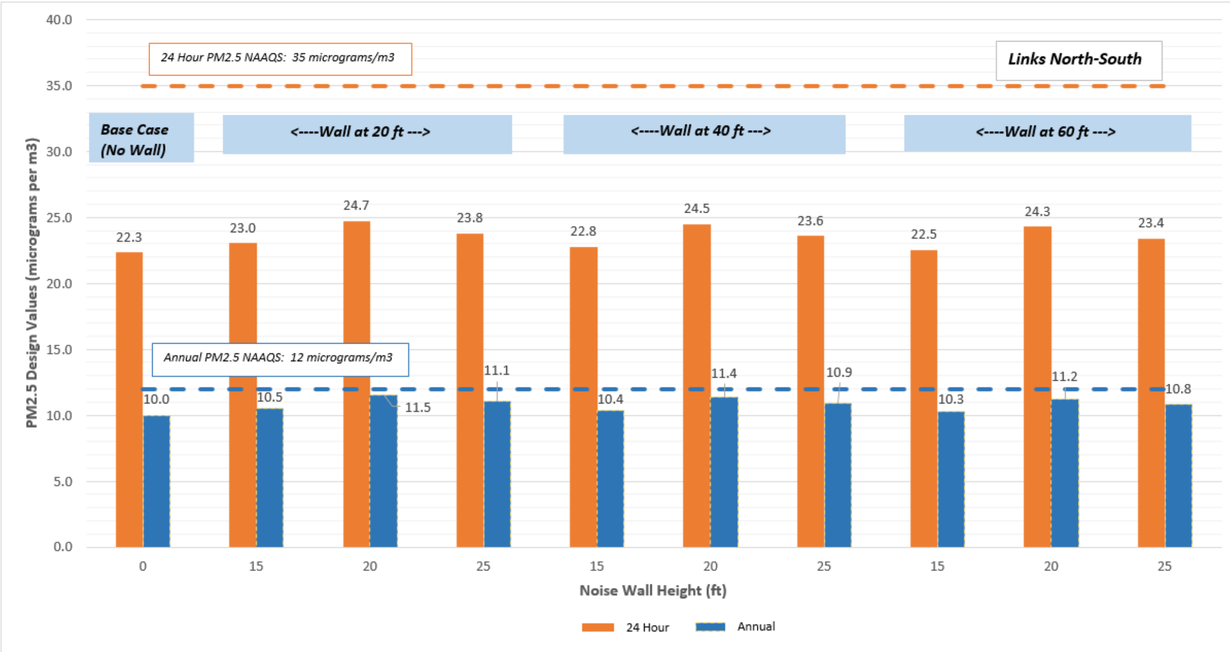

Exhibit A-46: RLINEXT $PM_{2.5}$ Design Values and Margins for One Noise Wall on SB Links

3.5.4 One Wall with Offset Receptors (Multiple of Wall Height) (SET D)

Given the results of the previous two sets showing relatively high modeled concentrations for one case with noise walls on westbound lanes and one with noise walls on southbound lanes, both with receptors offset from the noise wall starting at one meter only (0.05 x/H), sensitivity testing was done with different offset distances for receptors up to a multiple of wall heights of ten. The highest modeled concentrations in the previous two sets were for a wall of intermediate height (20 ft) located at a minimum distance tested (20 ft) the roadway links; that same wall height and distance were therefore applied for testing of offset receptors.

The modeling results presented here may inform future consideration of the need for a receptor exclusion zone to be specified in guidance for receptors near the wall, if the model is determined in future model validation studies to overestimate concentrations near the wall compared to field data. Exhibits A-47 and A-48 present the resulting modeled maximum $PM_{2.5}$ concentrations by offset distance. Exhibit A-49 presents the modeled concentrations on a relative basis, indexed to the base case (no wall) results. Overall, the results show:

- Modeled maximum concentrations for noise walls on westbound and southbound links do not drop to the values for the respective (no-wall) base cases until the receptor offset distance reaches a multiple of wall height, which differs slightly for the 24-hour and annual standards.
    - For the 24-hour standard, modeled concentrations do not drop to the modeled base case no-wall value until between one- and three- wall heights from the wall, for both the wall on westbound lanes and the wall on the southbound lanes. This shows it is a direct result of wind flow approximation at the barrier.
    - For the annual standard, the results are different for the wall on the westbound lanes versus southbound lanes.
        - For a noise wall on the westbound lanes, modeled concentrations do not drop to the modeled base case no-wall value until a little over three wall heights from the wall.
        - For a noise wall on the westbound lanes, modeled concentrations do not drop to the modeled base case no-wall value until between one and three wall heights from the wall, as observed for the 24-hour standard.
- If AERMOD is determined in model validation exercises to be overestimating maximum concentrations near noise walls compared to field data, and a receptor exclusion zone is therefore implemented to address this issue:
    - Based on the modeling results for this freeway segment test case, the receptor exclusion zone should extend no less than three wall heights from the wall.
    - Protocols or guidance used to locate air quality monitoring sites near walls may also be a consideration in the specification of a receptor exclusion zone.

	Noise Wall			24 Hr* (µg/m3)	Index_24Hr	Annual (µg/m3)	Index_Annual
Links	Height (ft)	Distance (ft)	Receptor Offset (x/H)				
WB1-WB2	na	na	No Wall	2.2086	*1.000*	0.9063	*1.000*
WB1-WB2	20	20	0.05	4.7014	*2.129*	2.3865	*2.633*
WB1-WB2	20	20	1	2.9485	*1.335*	1.5813	*1.745*
WB1-WB2	20	20	3	1.9153	*0.867*	0.9070	*1.001*
WB1-WB2	20	20	5	1.4891	*0.674*	0.6478	*0.715*
WB1-WB2	20	20	10	1.0054	*0.455*	0.3975	*0.439*
SB1-SB2	na	na	No Wall	2.3383	*1.000*	1.1025	*1.000*
SB1-SB2	20	20	0.05	4.7036	*2.011*	2.6321	*2.387*
SB1-SB2	20	20	1	3.5010	*1.497*	1.8783	*1.704*
SB1-SB2	20	20	3	2.0078	*0.859*	0.9814	*0.890*
SB1-SB2	20	20	5	1.3568	*0.580*	0.6054	*0.549*
SB1-SB2	20	20	10	0.9004	*0.385*	0.3765	*0.341*

** Eighth highest value*

Exhibit A-47: RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall (WB/SB Links), with Receptors Offset by a Multiple of Wall Height

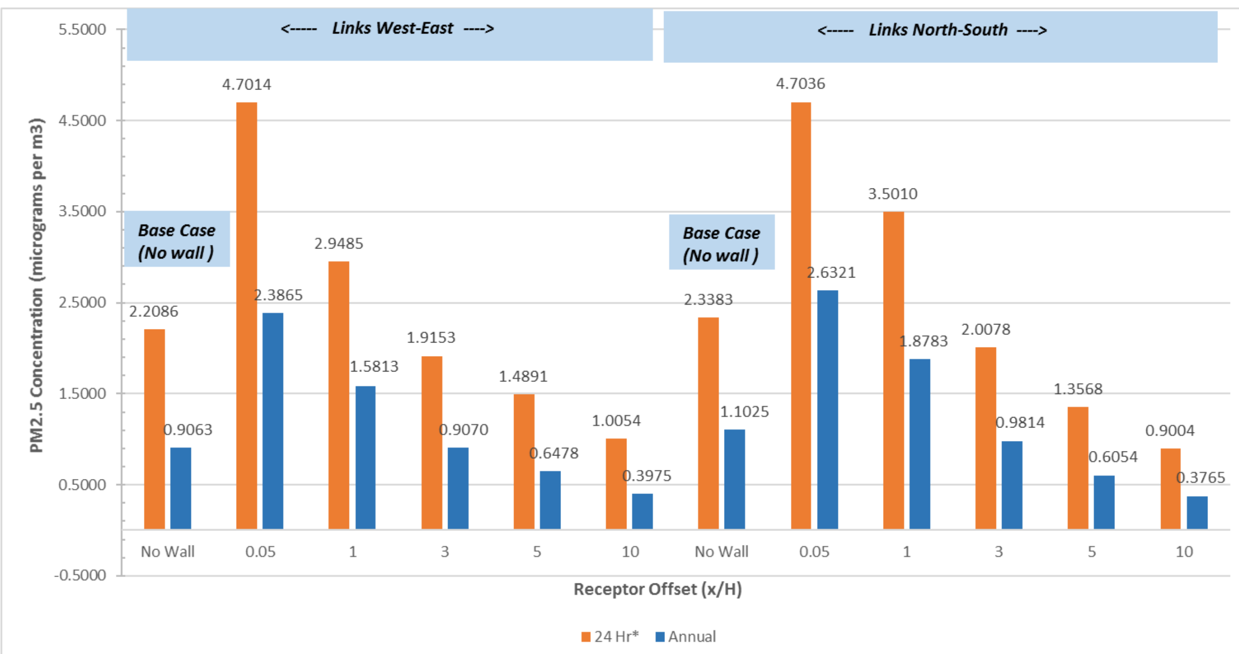

Exhibit A-48: RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall (WB/SB Links), with Receptors Offset by a Multiple of Wall Height

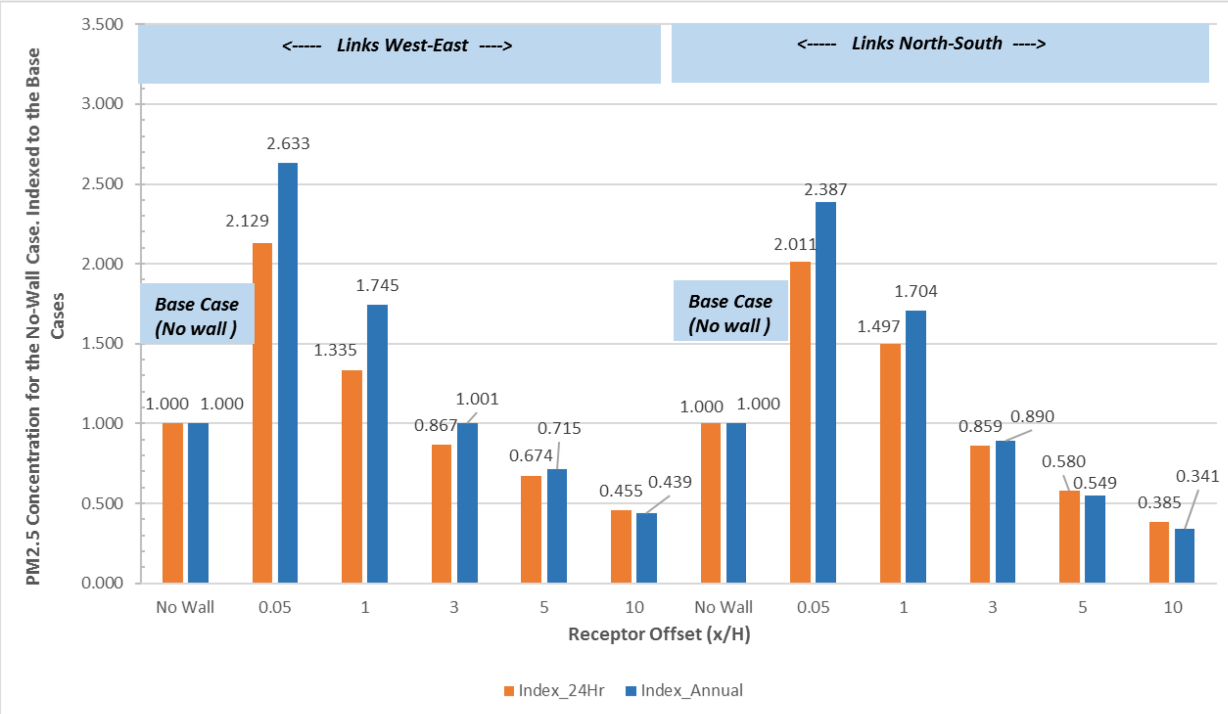

Exhibit A-49: RLINEXT Maximum $PM_{2.5}$ Concentrations Relative to the No-Wall Case, with Receptors Offset by a Multiple of Wall Height

3.5.5 Noise Walls on both Northbound and Southbound Links (SET C)

One wall per link was specified for both northbound and southbound links for comparison to runs with one wall per link in one direction only. Exhibits A-50 to A-52 present the modeled maximum concentrations for roadway concentrations without background concentrations, while Exhibits A-53 and A-54 present the design values relative to the applicable 24-hour and annual $PM_{2.5}$ NAAQS.

Overall, the trends in modeled maximum $PM_{2.5}$ concentrations observed were similar to those observed for one wall per link in one direction only, which may be expected since using RLINEXT with one wall specified per link limits the model to accounting for only that wall and no others. In summary:

- Maximum concentrations increased with the presence of a wall in all cases, relative to the base case with no wall, for both the 24-hour and annual $PM_{2.5}$ standards.
- Maximum concentrations varied substantially with both wall height and distance of the wall from the roadway for a range of typical wall heights and distances implemented in Virginia, with wall height exerting a stronger effect over the range of distances tested than distance, for both the 24-hour and annual $PM_{2.5}$ standards.
- For both the 24-hour and annual standards, the maximum concentration was observed for walls of intermediate height (20 ft) for each of the three distances tested, with the highest maxima overall for each of the two standards occurring for the minimum distance tested of 20 ft.

Design values also exhibited trends that were similar to those observed for testing one wall in one direction only:

- The margin of compliance for the 24-hour NAAQS was about one-third of the NAAQS in each case tested.
- For the annual $PM_{2.5}$ standard:
  - The margin was slimmest for 20 ft walls, at only 4.8%. The margins were 6.2% at 40 ft, and 7.5% at 60 ft.
  - The average margin ranged from to 8.7% for all wall heights at 20 ft distance to 11.2% at 60 ft distance, and for all distances from 6.2% for 20 ft high walls to 14% for 15 ft high walls.
  - The greatest margin for the annual $PM_{2.5}$ standard was 15.4%.

Noise Wall				24 Hr* (µg/m3)	Index_24Hr	Annual (µg/m3)	Index_Annual
Links	Height (ft)	Distance (ft)	Receptor Offset				
SB1-SB2, NB1-NB2	0	0	na	2.3383	1.0000	1.1025	1.0000
SB1-SB2, NB1-NB2	15	20	1 m	2.9691	1.2697	1.5881	1.4405
SB1-SB2, NB1-NB2	20	20	1 m	4.4866	1.9187	2.5217	2.2873
SB1-SB2, NB1-NB2	25	20	1 m	3.5534	1.5196	2.0643	1.8724
SB1-SB2, NB1-NB2	15	40	1 m	2.6555	1.1356	1.4062	1.2754
SB1-SB2, NB1-NB2	20	40	1 m	4.2467	1.8161	2.3546	2.1357
SB1-SB2, NB1-NB2	25	40	1 m	3.3625	1.4380	1.9306	1.7511
SB1-SB2, NB1-NB2	15	60	1 m	2.3679	1.0126	1.2514	1.1351
SB1-SB2, NB1-NB2	20	60	1 m	4.0577	1.7353	2.2026	1.9978
SB1-SB2, NB1-NB2	25	60	1 m	3.2014	1.3691	1.7970	1.6299

** Eighth highest value*

Exhibit A-50: RLINEXT Maximum $PM_{2.5}$ Concentrations for Noise Walls on NB and SB Links

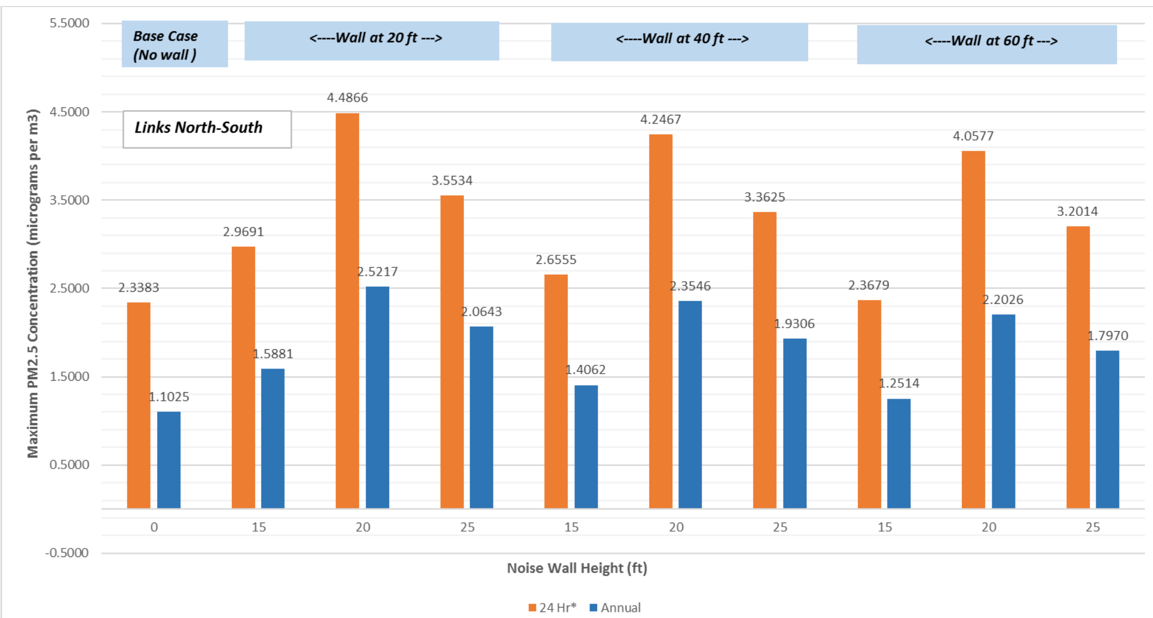

Exhibit A-51: RLINEXT Maximum $PM_{2.5}$ Concentrations for Noise Walls on NB and SB Links

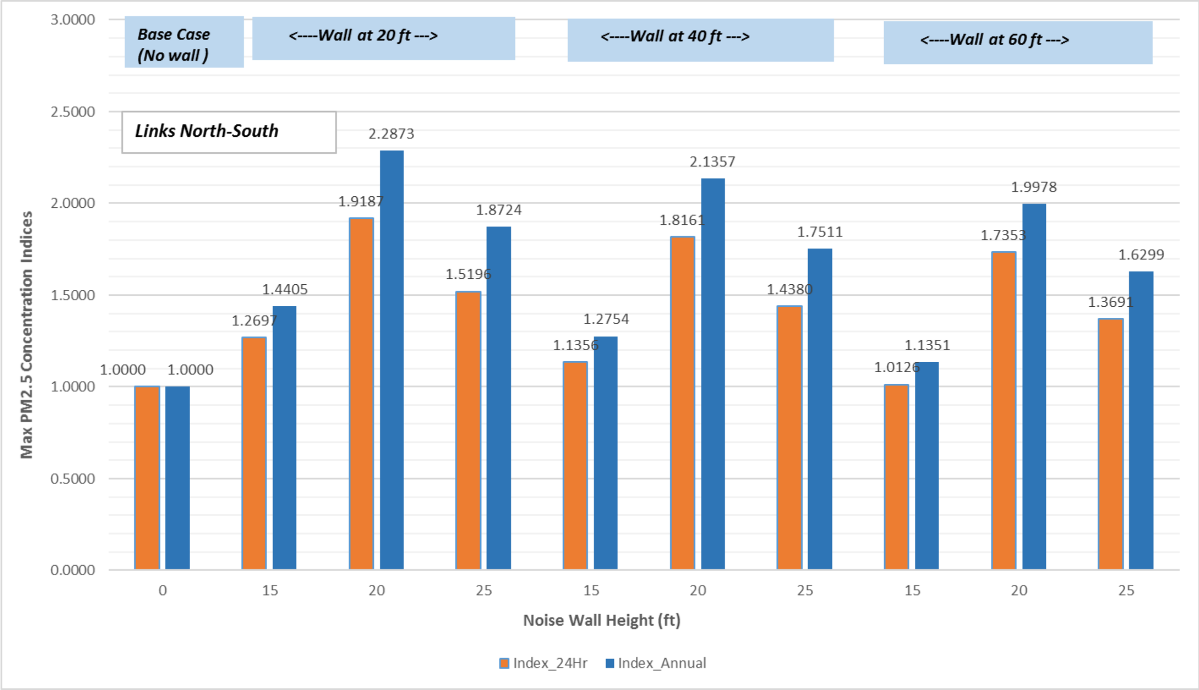

Exhibit A-52: RLINEXT Maximum $PM_{2.5}$ Concentrations for Noise Walls on NB and SB Links, Indexed to the No-Wall Base Case

Noise Wall				24hr PM2.5 DV*	NAAQS Test	Margin		Annual PM2.5 DV	NAAQS Test	Margin	
Links	Height (ft)	Distance (ft)	Receptor Offset	(µg/m3)	(35)	(NAAQS-DV)	% of NAAQS	(µg/m3)	(12)	(NAAQS-DV)	% of NAAQS
SB1-SB2, NB1-NB2	0	0	na	22.3	PASS	12.7	36.2%	10.0	PASS	2.0	16.6%
SB1-SB2, NB1-NB2	15	20	1 m	23.0	PASS	12.0	34.4%	10.5	PASS	1.5	12.6%
SB1-SB2, NB1-NB2	20	20	1 m	24.5	PASS	10.5	30.0%	11.4	PASS	0.6	4.8%
SB1-SB2, NB1-NB2	25	20	1 m	23.6	PASS	11.4	32.7%	11.0	PASS	1.0	8.6%
SB1-SB2, NB1-NB2	15	40	1 m	22.7	PASS	12.3	35.3%	10.3	PASS	1.7	14.1%
SB1-SB2, NB1-NB2	20	40	1 m	24.2	PASS	10.8	30.7%	11.3	PASS	0.7	6.2%
SB1-SB2, NB1-NB2	25	40	1 m	23.4	PASS	11.6	33.3%	10.8	PASS	1.2	9.7%
SB1-SB2, NB1-NB2	15	60	1 m	22.4	PASS	12.6	36.1%	10.2	PASS	1.8	15.4%
SB1-SB2, NB1-NB2	20	60	1 m	24.1	PASS	10.9	31.3%	11.1	PASS	0.9	7.5%
SB1-SB2, NB1-NB2	25	60	1 m	23.2	PASS	11.8	33.7%	10.7	PASS	1.3	10.9%
Minimum Distance Tested			*Average*	23.7	*1.000*	11.3	32.4%	11.0	*1.000*	1.0	8.7%
Moderate Distance Tested			*Average*	23.4	*0.990*	11.6	33.1%	10.8	*0.985*	1.2	10.0%
Maximum Distance Tested			*Average*	23.2	*0.981*	11.8	33.7%	10.7	*0.972*	1.3	11.2%
Minimum Height Tested			*Average*	22.7	*1.000*	12.3	35.2%	10.3	*1.000*	1.7	14.0%
Moderate Height Tested			*Average*	24.3	*1.071*	10.7	30.7%	11.3	*1.092*	0.7	6.2%
Maximum Height Tested			*Average*	23.4	*1.031*	11.6	33.2%	10.8	*1.050*	1.2	9.7%

** Eighth highest value*

Exhibit A-53: RLINEXT $PM_{2.5}$ Design Values and Margins for Noise Walls on NB and SB Links

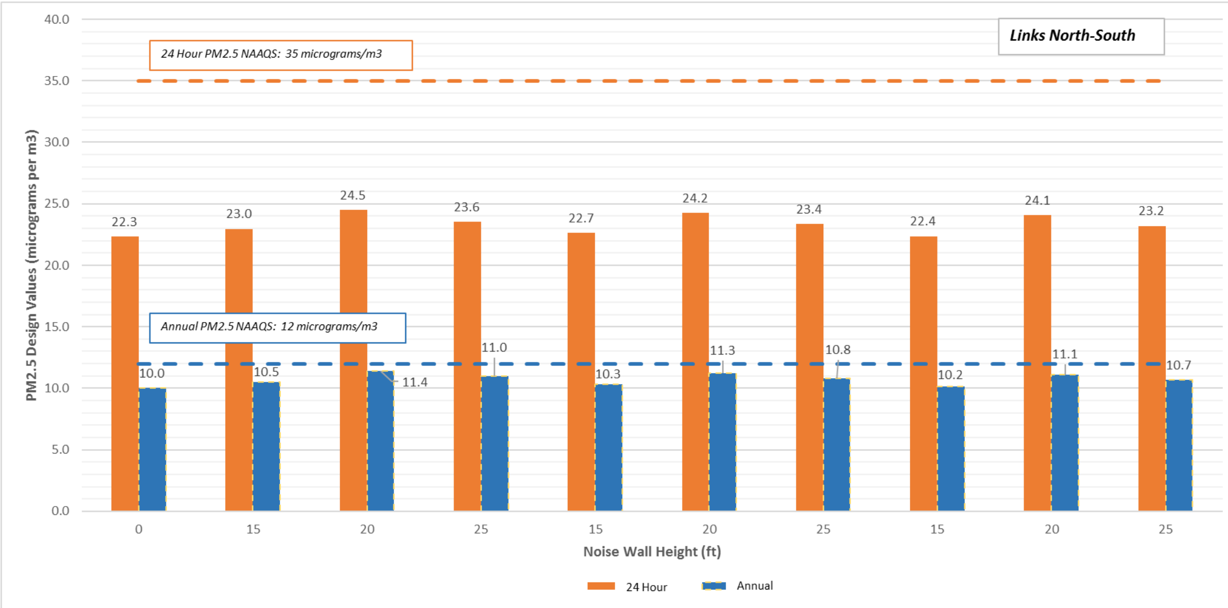

Exhibit A-54: RLINEXT $PM_{2.5}$ Design Values and Margins for Noise Walls on NB and SB Links

3.5.6 Noise Wall on Eastbound Links Only (SET G)

Testing was done for one noise wall per link on eastbound links only, which puts the wall upwind of the roadway links for winds from the south. Comparisons of this run to the run with one noise wall per link in the westbound direction are presented in Section 3.7.2. Exhibits A-55 to A-59 present the modeling results and design values. In summary:

- Overall, as observed for the case with one wall per link on the westbound links which had the wall downwind of the roadway links for winds from the south, modeled concentrations for runs with walls were higher than for the base case with no wall.
- The highest modeled concentrations for both the 24-hour and annual standards were observed for 20 ft walls for all three distances tested, with the highest overall for each standard occurring at the minimum distance tested of 20 ft.
- The margin with the NAAQS for the 24-hour $PM_{2.5}$ standard was substantial and ranged from 27.4% to 36.2%.
- For the annual standard, the margin was much tighter than for the 24-hour standard, reaching as low as 4.1% for a 20 ft wall at 20 ft.
  - The average margin for all wall heights ranged from 8.9% for 20 ft to 10.4% at 60 ft.
  - The average margin for all distances tested ranged from 4.8% for 20-ft high walls to 15% for 15-ft high walls.

Noise Wall				24 Hr* (µg/m3)	Index_24Hr	Annual (µg/m3)	Index_Annual
Links	Height (ft)	Distance (ft)	Receptor Offset				
EB1-EB2	0	0	na	2.2086	1.0000	0.9063	1.0000
EB1-EB2	15	20	1 m	3.0570	1.3842	1.4211	1.5680
EB1-EB2	20	20	1 m	5.5536	2.5146	2.6111	2.8811
EB1-EB2	25	20	1 m	4.2170	1.9094	2.0788	2.2937
EB1-EB2	15	40	1 m	2.5069	1.1351	1.2983	1.4326
EB1-EB2	20	40	1 m	5.4202	2.4542	2.5203	2.7809
EB1-EB2	25	40	1 m	4.1123	1.8620	2.0022	2.2092
EB1-EB2	15	60	1 m	2.3242	1.0524	1.1932	1.3166
EB1-EB2	20	60	1 m	5.2882	2.3944	2.4314	2.6828
EB1-EB2	25	60	1 m	3.9962	1.8094	1.9214	2.1201

** Eighth highest value*

Exhibit A-55: RLINEXT Maximum $PM_{2.5}$ Concentrations for Noise Wall on EB Links Only

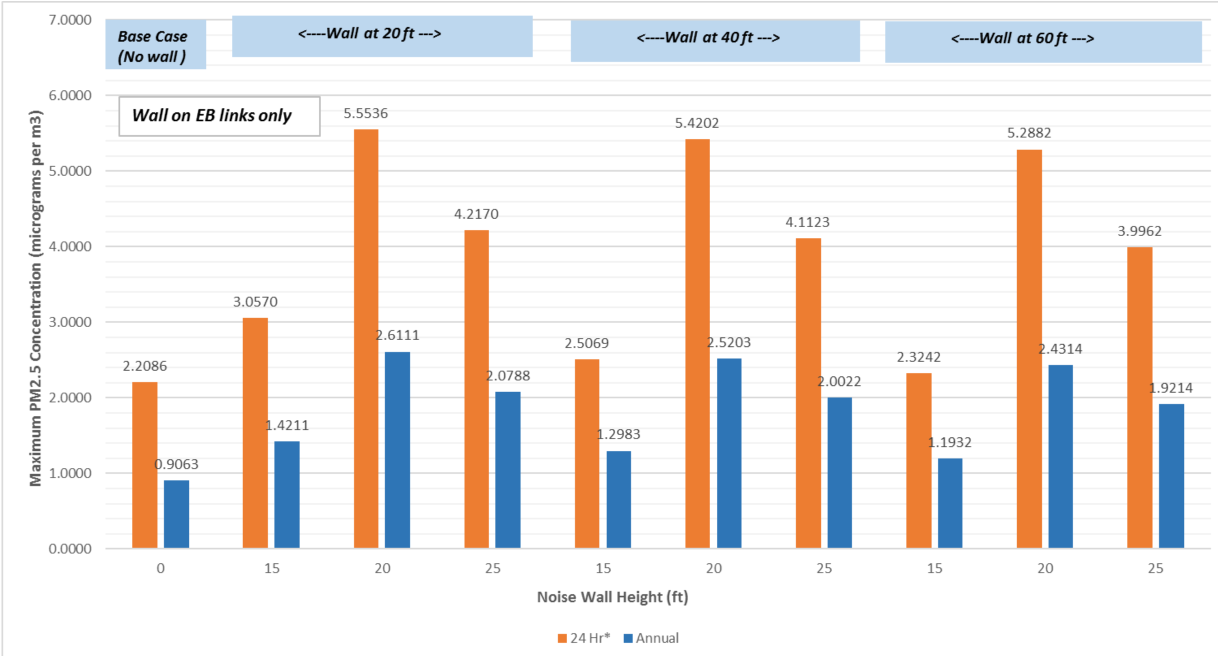

Exhibit A-56: RLINEXT Maximum $PM_{2.5}$ Concentrations for Noise Wall on EB Links Only

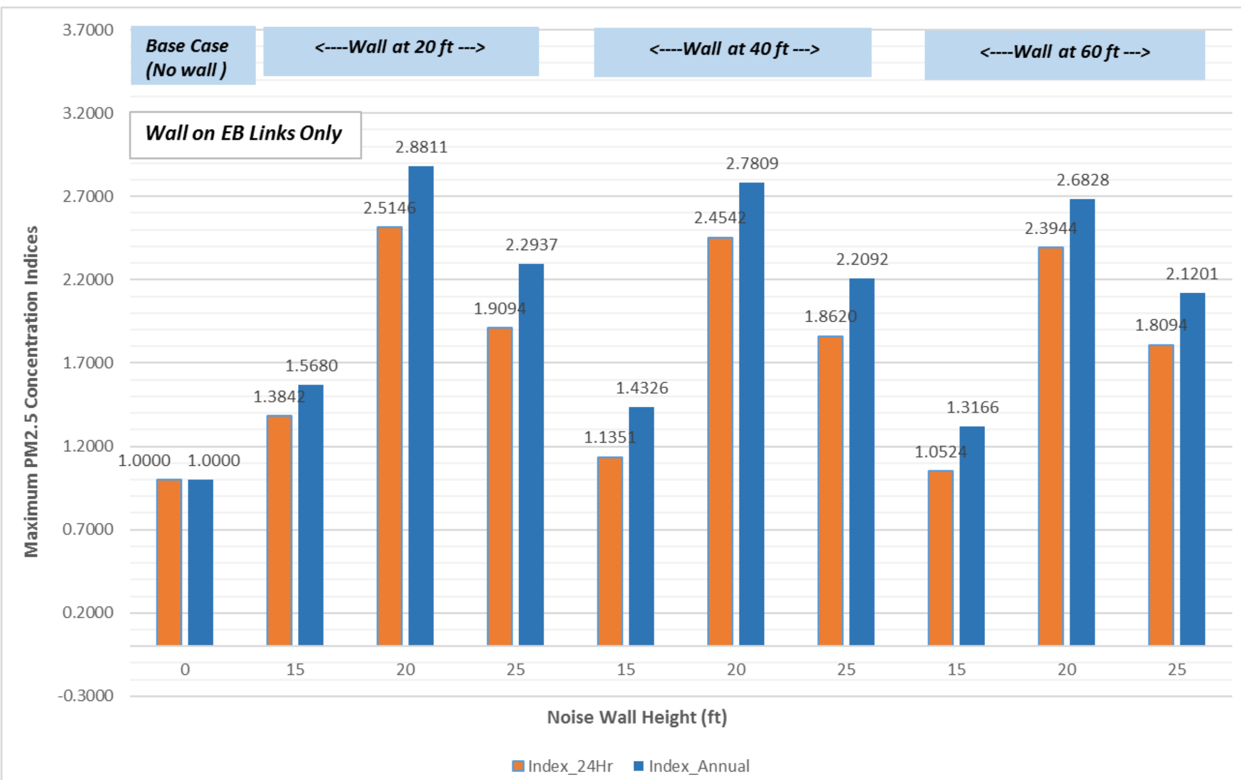

Exhibit A-57: RLINEXT Maximum $PM_{2.5}$ Concentrations for Noise Wall on EB Links Only, Indexed to the No-Wall Base Case

Noise Wall				24hr PM2.5 DV*	NAAQS Test	Margin		Annual PM2.5 DV	NAAQS Test	Margin	
Links	Height (ft)	Distance (ft)	Receptor Offset	(µg/m3)	(35)	(µg/m3)	% of NAAQS	(µg/m3)	(12)	(µg/m3)	% of NAAQS
EB1-EB2	0	0	na	22.2	PASS	12.8	36.5%	9.8	PASS	2.2	18.3%
EB1-EB2	15	20	1 m	23.1	PASS	11.9	34.1%	10.3	PASS	1.7	14.0%
EB1-EB2	20	20	1 m	25.6	PASS	9.4	27.0%	11.5	PASS	0.5	4.1%
EB1-EB2	25	20	1 m	24.2	PASS	10.8	30.8%	11.0	PASS	1.0	8.5%
EB1-EB2	15	40	1 m	22.5	PASS	12.5	35.7%	10.2	PASS	1.8	15.0%
EB1-EB2	20	40	1 m	25.4	PASS	9.6	27.4%	11.4	PASS	0.6	4.8%
EB1-EB2	25	40	1 m	24.1	PASS	10.9	31.1%	10.9	PASS	1.1	9.1%
EB1-EB2	15	60	1 m	22.3	PASS	12.7	36.2%	10.1	PASS	1.9	15.9%
EB1-EB2	20	60	1 m	25.3	PASS	9.7	27.7%	11.3	PASS	0.7	5.6%
EB1-EB2	25	60	1 m	24.0	PASS	11.0	31.4%	10.8	PASS	1.2	9.8%
Minimum Distance Tested			*Average*	24.3	*1.000*	10.7	30.6%	10.9	*1.000*	1.1	8.9%
Moderate Distance Tested			*Average*	24.0	*0.989*	11.0	31.4%	10.8	*0.991*	1.2	9.7%
Maximum Distance Tested			*Average*	23.9	*0.983*	11.1	31.8%	10.7	*0.983*	1.3	10.4%
Minimum Height Tested			*Average*	22.6	*1.000*	12.4	35.3%	10.2	*1.000*	1.8	15.0%
Moderate Height Tested			*Average*	25.4	*1.123*	9.6	27.4%	11.4	*1.119*	0.6	4.8%
Maximum Height Tested			*Average*	24.1	*1.065*	10.9	31.1%	10.9	*1.068*	1.1	9.2%

** Eighth highest value*

Exhibit A-58: RLINEXT $PM_{2.5}$ Design Values and Margins for Noise Wall on EB Links Only

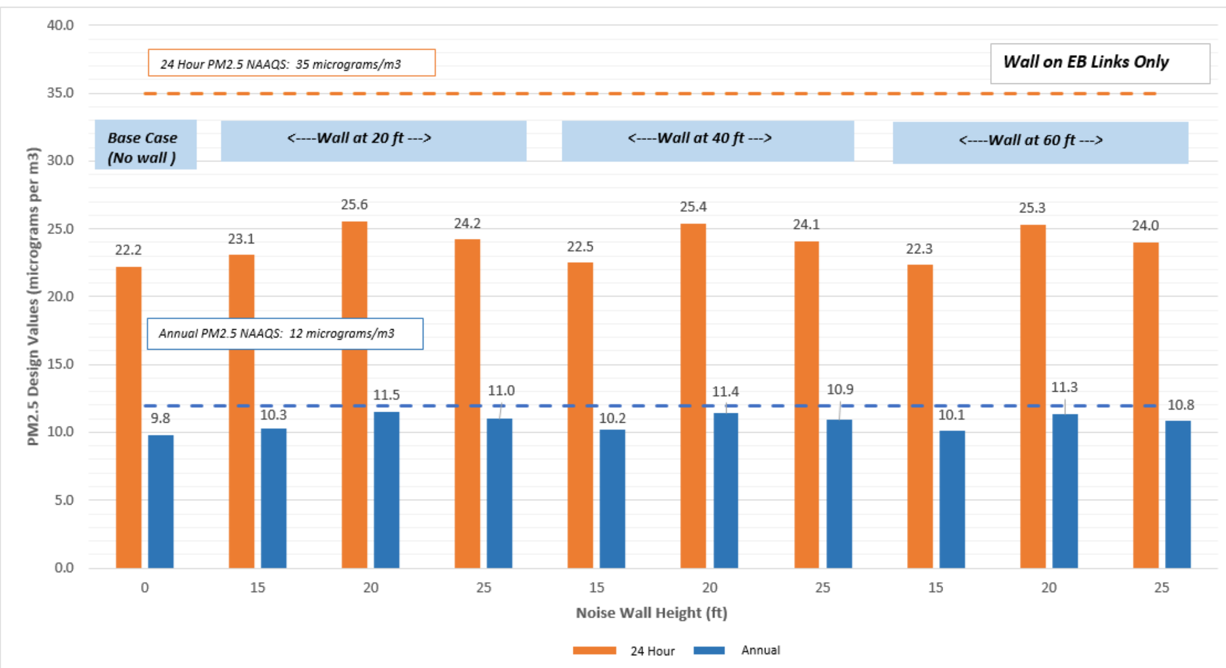

Exhibit A-59: RLINEXT $PM_{2.5}$ Design Values and Margins for Noise Wall on EB Links Only

3.5.7 Noise Wall on Northbound Links Only (SET G)

Testing was done for one noise wall per link on northbound links only, which puts the wall and roadway links parallel or nearly so to winds from the south. Comparisons of this run to the run with one noise wall per link in the southbound direction are presented in Section 3.7.3. Exhibits A-60 to A-64 present the modeling results and design values. In summary:

- Overall, as observed for the case with one wall per link on the southbound links, modeled concentrations were higher than for the base case with no wall.
- The highest modeled concentrations for both the 24-hour and annual standards were observed for walls of intermediate height (20 ft) for all three distances tested, with the highest overall for each standard occurring for the minimum distance tested (20 ft.)
- Design values were determined for each case.
  - The margin with the NAAQS for the 24-hour $PM_{2.5}$ standard was substantial and ranged from 30% to 35.5%.
  - For the annual standard, the margin was much tighter than for the 24-hour standard, reaching as low as 6.8% for a 20 ft wall at 20 ft.
    - The average margin for all wall heights ranged from 9.5% for 20 ft to 11.8% at 60 ft.
    - The average margin for all distances tested ranged from 8% for 20-ft high walls to 13.3% for 15-ft high walls.
    - Reflecting the trend for concentrations, the minimum margin for both standards was for the intermediate height of 20 ft for all distances tested, with the overall minimum occurring for each standard at the minimum distance tested of 20 ft.

Noise Wall				24 Hr*	Index_24Hr	Annual	Index_Annual
Links	Height (ft)	Distance (ft)	Receptor Offset	*(µg/m3)*		*(µg/m3)*	
NB1-NB2	0	0	na	2.3383	1.0000	1.1025	1.0000
NB1-NB2	15	20	1 m	3.1282	1.3378	1.6481	1.4948
NB1-NB2	20	20	1 m	4.6319	1.9809	2.2898	2.0769
NB1-NB2	25	20	1 m	3.7834	1.6180	1.9449	1.7641
NB1-NB2	15	40	1 m	2.8355	1.2126	1.4956	1.3565
NB1-NB2	20	40	1 m	4.5154	1.9310	2.1437	1.9444
NB1-NB2	25	40	1 m	3.5746	1.5287	1.8211	1.6517
NB1-NB2	15	60	1 m	2.5676	1.0980	1.3558	1.2297
NB1-NB2	20	60	1 m	4.3603	1.8647	2.0005	1.8145
NB1-NB2	25	60	1 m	3.4483	1.4747	1.6955	1.5379

** Eighth highest value*

Exhibit A-60: RLINEXT Maximum $PM_{2.5}$ Concentrations for Noise Wall on NB Links Only

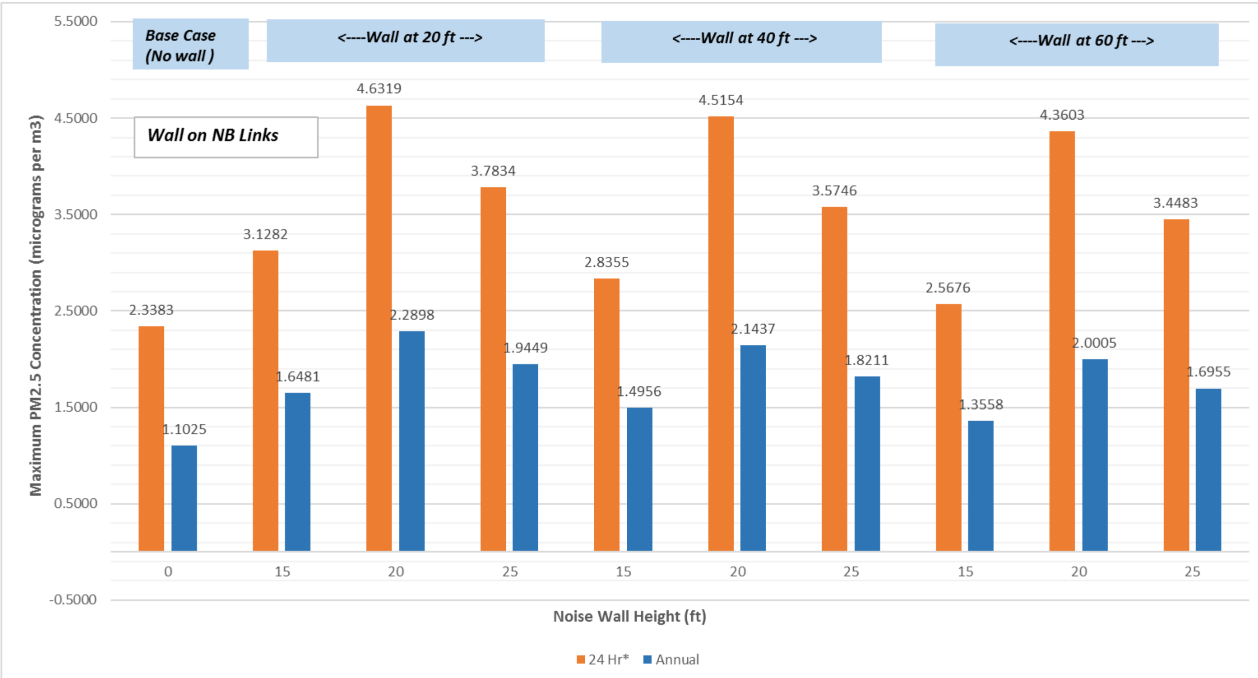

Exhibit A-61: RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall for NB Links Only

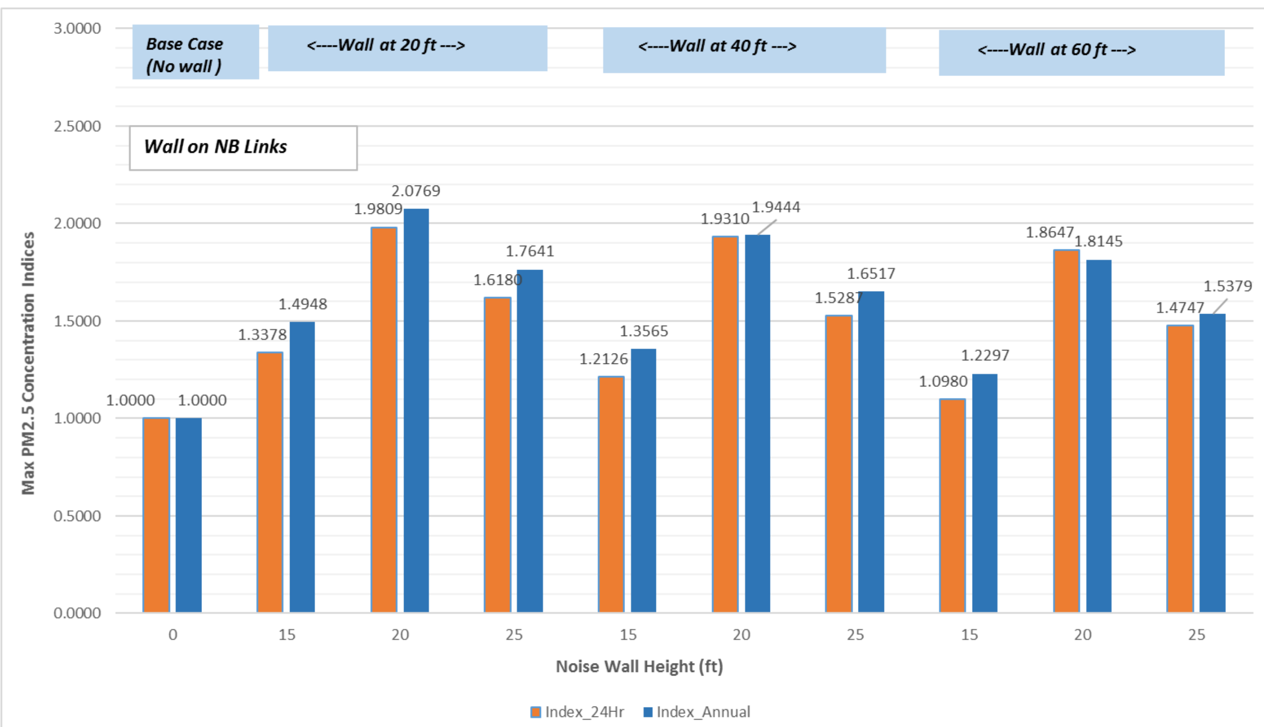

Exhibit A-62: RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall for NB Links Only, Indexed to the No-Wall Base Case

Noise Wall				24hr PM2.5 DV*	NAAQS Test	Margin		Annual PM2.5 DV	NAAQS Test	Margin	
Links	Height (ft)	Distance (ft)	Receptor Offset	(µg/m3)	(35)	(NAAQS-DV)	% of NAAQS	(µg/m3)	(12)	(NAAQS-DV)	% of NAAQS
NB1-NB2	0	0	na	22.3	PASS	12.7	36.2%	10.0	PASS	2.0	16.6%
NB1-NB2	15	20	1 m	23.1	PASS	11.9	33.9%	10.5	PASS	1.5	12.1%
NB1-NB2	20	20	1 m	24.6	PASS	10.4	29.6%	11.2	PASS	0.8	6.8%
NB1-NB2	25	20	1 m	23.8	PASS	11.2	32.0%	10.8	PASS	1.2	9.6%
NB1-NB2	15	40	1 m	22.8	PASS	12.2	34.8%	10.4	PASS	1.6	13.4%
NB1-NB2	20	40	1 m	24.5	PASS	10.5	30.0%	11.0	PASS	1.0	8.0%
NB1-NB2	25	40	1 m	23.6	PASS	11.4	32.6%	10.7	PASS	1.3	10.7%
NB1-NB2	15	60	1 m	22.6	PASS	12.4	35.5%	10.3	PASS	1.7	14.5%
NB1-NB2	20	60	1 m	24.4	PASS	10.6	30.4%	10.9	PASS	1.1	9.2%
NB1-NB2	25	60	1 m	23.4	PASS	11.6	33.0%	10.6	PASS	1.4	11.7%
Minimum Distance Tested			*Average*	23.8	*1.000*	11.2	31.9%	10.9	*1.000*	1.1	9.5%
Moderate Distance Tested			*Average*	23.6	*0.991*	11.4	32.5%	10.7	*0.987*	1.3	10.7%
Maximum Distance Tested			*Average*	23.5	*0.984*	11.5	33.0%	10.6	*0.974*	1.4	11.8%
Minimum Height Tested			*Average*	22.8	*1.000*	12.2	34.7%	10.4	*1.000*	1.6	13.3%
Moderate Height Tested			*Average*	24.5	*1.073*	10.5	30.0%	11.0	*1.062*	1.0	8.0%
Maximum Height Tested			*Average*	23.6	*1.033*	11.4	32.6%	10.7	*1.031*	1.3	10.7%

** Eighth highest value*

Exhibit A-63: RLINEXT $PM_{2.5}$ Design Values and Margins for One Noise Wall for NB Links Only

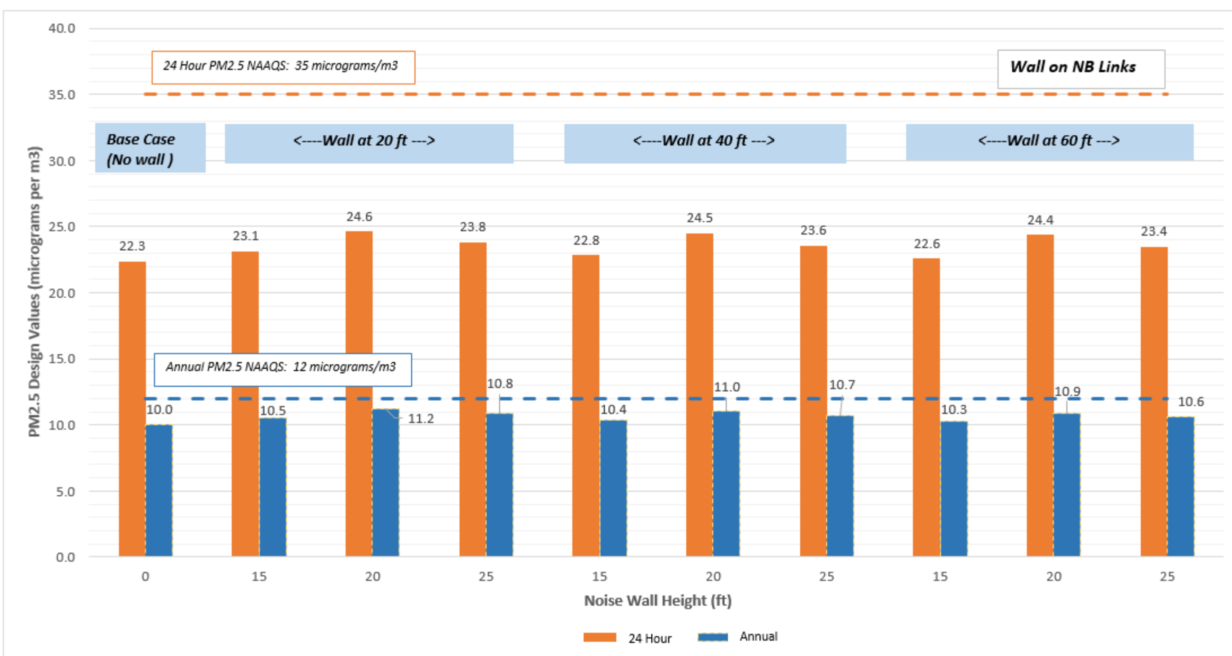

Exhibit A-64: RLINEXT $PM_{2.5}$ Design Values and Margins for One Noise Wall for NB Links Only

3.5.8 One Half-Length Wall (SET E)

Testing was done for one noise wall for one link only in each of the westbound and southbound directions, which corresponds to projects in practice that may have a noise wall for a portion of a freeway link but not its entire length. It addresses the question: would modeled design values be significantly affected if a wall ends within the project modeled area? Exhibits A-65 to A-69 preset the modeling results and design values. In summary:

- Overall, as observed for the corresponding cases with full length walls in each direction, modeled maximum concentrations for the runs with walls were higher than for the base case with no wall.
- The highest modeled concentrations for both the 24-hour and annual standards were observed for walls of intermediate height (20 ft).
    - For the west-east links, the increase over the no-wall base case was 113% for the 24-hour standard and 164% for the annual standard.
    - For the north-south links and wall, the increase over the base case was slightly less, 101% for the 24-hour standard and 139% for the annual standard.
- The margin between the design value and the NAAQS for the 24-hour $PM_{2.5}$ standard was substantial and ranged from 29.4% to 36.2%.
- For the annual standard:
    - The margin was much tighter than for the 24-hour standard, averaging 9.9% for all heights tested.
    - The average margin ranged from 4.9% for 20-ft walls to 12.8% at for 15-ft walls.
    - The minimum margin was 3.9%, which was for a wall of intermediate height (20 ft) and minimum distance (20 ft) on the SB links.

Link Direction	Noise Wall				24 Hr* (µg/m3)	Index_24hr	Annual (µg/m3)	Index_Annual
	Links	Height (ft)	Distance (ft)	Receptor Offset				
West-East	WB1	No Wall	No Wall	na	2.2086	1.00	0.9063	1.00
West-East	WB1	15	20	1 m	2.7428	1.24	1.4763	1.63
West-East	WB1	20	20	1 m	4.7014	2.13	2.3888	2.64
West-East	WB1	25	20	1 m	3.7170	1.68	1.9604	2.16
North-South	SB1	No Wall	No Wall	na	2.3383	1.00	1.1025	1.00
North-South	SB1	15	20	1 m	3.0401	1.30	1.6487	1.50
North-South	SB1	20	20	1 m	4.7036	2.01	2.6321	2.39
North-South	SB1	25	20	1 m	3.7815	1.62	2.1681	1.97

** Eighth highest value*

Exhibit A-65: RLINEXT Maximum $PM_{2.5}$ Concentrations for One Half-Length Noise Wall (WB/SB Links)

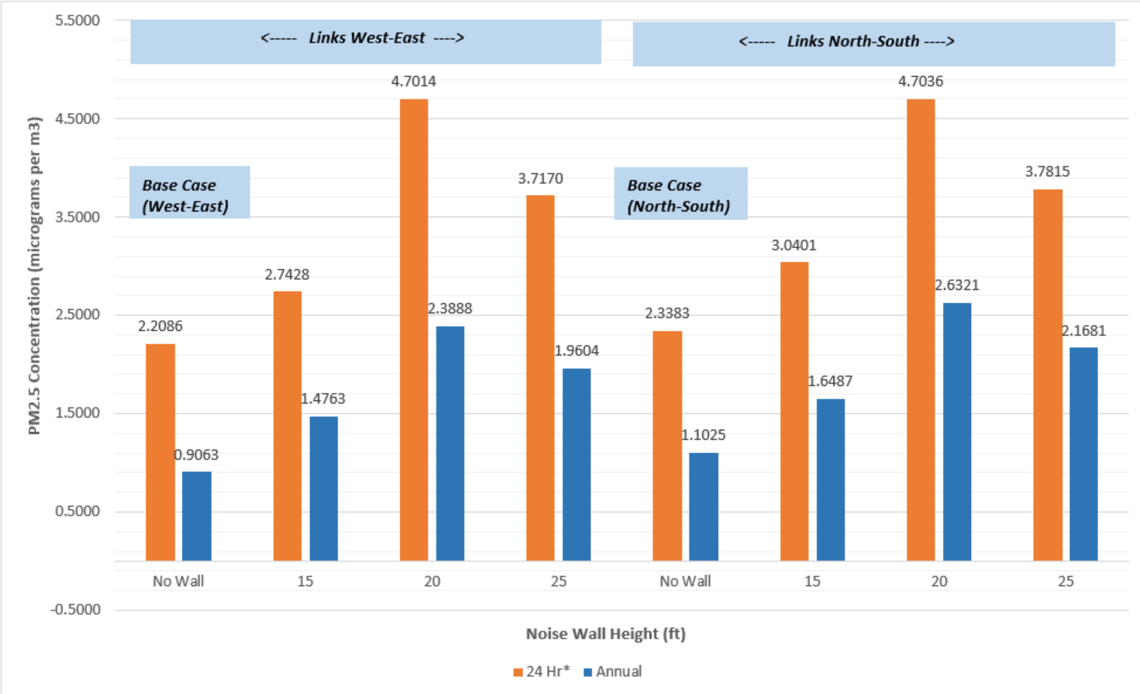

Exhibit A-66: RLINEXT Maximum $PM_{2.5}$ Concentrations for a Half-Length Noise Wall (WB/SB Links)

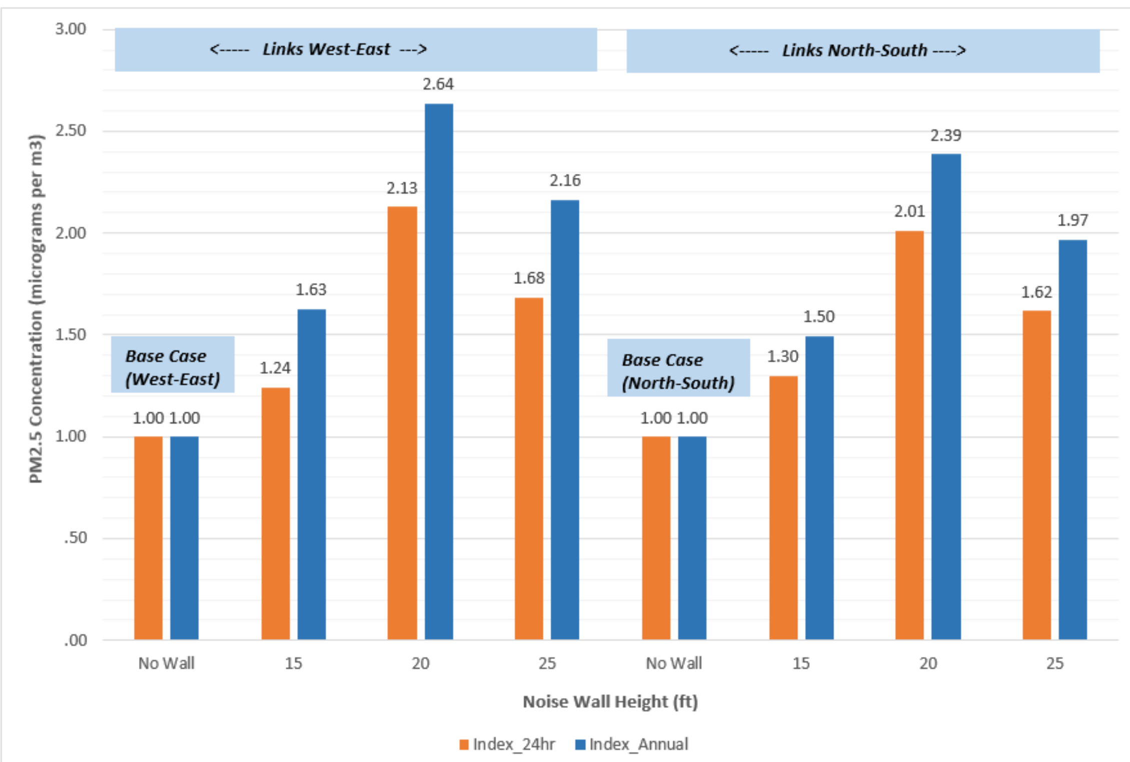

Exhibit A-67: RLINEXT Maximum $PM_{2.5}$ Concentrations for a Half-Length Noise Wall (WB/SB Links), Indexed to the No-Wall Base Case

Noise Wall				24hr PM2.5 DV*	NAAQS Test	Margin		Annual PM2.5 DV	NAAQS Test	Margin	
Links	Height	Distance	Receptor	*(µg/m3)*	*(35)*	*(µg/m3)*	% of NAAQS	*(µg/m3)*	*(12)*	*(µg/m3)*	% of NAAQS
WB1	No Wall	No Wall	na	22.2	PASS	12.8	36.5%	9.8	PASS	2.2	18.3%
WB1	15	20	1 m	22.7	PASS	12.3	35.0%	10.4	PASS	1.6	13.5%
WB1	20	20	1 m	24.7	PASS	10.3	29.4%	11.3	PASS	0.7	5.9%
WB1	25	20	1 m	23.7	PASS	11.3	32.2%	10.9	PASS	1.1	9.5%
SB1	No Wall	No Wall	na	22.3	PASS	12.7	36.2%	10.0	PASS	2.0	16.6%
SB1	15	20	1 m	23.0	PASS	12.0	34.2%	10.5	PASS	1.5	12.1%
SB1	20	20	1 m	24.7	PASS	10.3	29.4%	11.5	PASS	0.5	3.9%
SB1	25	20	1 m	23.8	PASS	11.2	32.1%	11.1	PASS	0.9	7.8%
Overall:			*Minimum*	22.3		10.3	29.4%	10.0		0.5	3.9%
			Maximum	24.7		12.7	36.2%	11.5		2.0	16.6%
			Average	23.6		11.4	32.6%	10.8		1.2	9.9%
Minimum Height Tested			*Average*	22.9	*1.000*	12.1	34.6%	10.5	*1.000*	1.5	12.8%
Moderate Height Tested			*Average*	24.7	*1.079*	10.3	29.4%	11.4	*1.091*	0.6	4.9%
Maximum Height Tested			*Average*	23.7	*1.037*	11.3	32.1%	11.0	*1.048*	1.0	8.6%

** Eighth highest value*

Exhibit A-68: RLINEXT Design Values for a Half-Length Noise Wall (WB/SB Links)

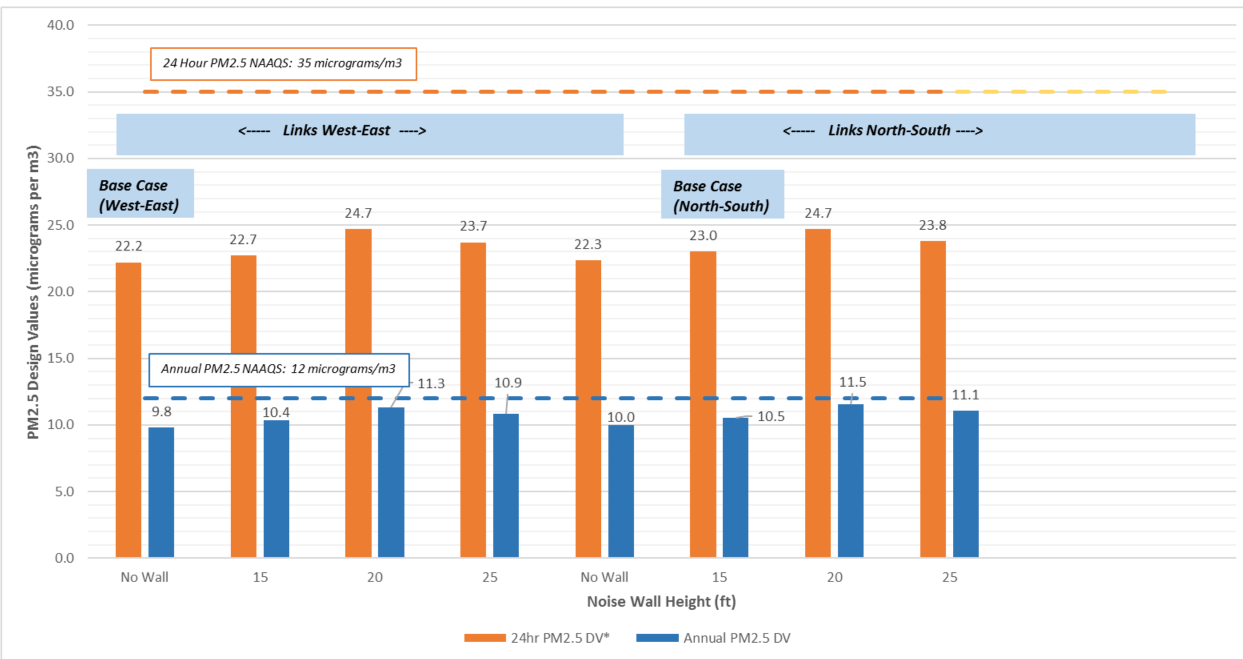

Exhibit A-69: RLINEXT Design Values for a Half-Length Noise Wall (WB/SB Links), Indexed to the No-Wall Base Case

3.6 Sensitivity Testing - Depressed Section with and without a Wall (SET F)

A depressed section with and without a noise wall for both urban and non-urban settings was tested for both west-east and north-south links. The depressed section modeled was based on design specifications in the AASHTO Green Book as referenced previously and had a minimum depth (16 feet) and vertical walls with shoulder lanes. The noise wall selected for testing with the depressed section was one (20 ft high wall at 20 feet) for which high modeled maximum $PM_{2.5}$ concentrations were observed in testing for at-grade links. Exhibits A-70 to A-72 present the modeled concentrations and indices relative to the at-grade no-wall base case. Exhibits A-73 and A-74 present the corresponding design values. In summary:

Overall, in contrast to RLINEXT with noise walls, RLINEXT with a depressed section resulted in maximum 24-hour and annual $PM_{2.5}$ concentrations *less* than modeled for the at-grade no-wall base case. This is curious as both walls and depressed sections present a vertical barrier to dispersion of pollutants from the roadway links, but one (with walls) resulted in substantially *increased* maximum concentrations while the other (depressed with a vertical section/wall but no at-grade walls) resulted in substantially *reduced* maximum concentrations.

- For the 24-hour standard:
    - Non-urban (rural) maximum concentrations were 13% less than the base case for both the west-east links and north-south links.
    - The urban case was 43% lower than the base case for the west-east links and 45% lower for the north-south links.
    - In contrast, the combination of a noise wall with a depressed section resulted in modeled maximum concentrations 127% higher than the base case for west-east links and 105% higher for north-south links.
- For the annual standard:
    - Non-urban (rural) maximum concentrations were 11% less than the base case for both the west-east links and north-south links.
    - The urban case was lower than the base case by 28% for the west-east links, and 29% for the north-south links.
    - In contrast, the combination of a noise wall with a depressed section resulted in modeled maximum concentrations 158% higher than the base case for west-east links and 133% higher for north-south links.
- Design value margins were high for the depressed section case, and similar to other test results for the case with the noise wall.
    - For the 24-hour standard, margins ranged from 37.2% for a depressed section in a non-urban setting to 39.2% for an urban setting. With a noise wall present (in a non-urban setting), the margin was reduced to 28.8%, which is still substantial.
    - For the annual standard, margins ranged from 18.4% to 19.9% for the depressed section on-urban and urban settings respectively. With a wall (non-urban), the margin was reduced to only 5.4%.

URBAN* Option	Source	Features	Links	24 Hr** (µg/m3)	Index_24Hr	Annual (µg/m3)	Index_ Annual
Rural	RLINEXT	At-Grade, No Wall	West-East	2.2086	1.00	0.9063	1.00
Rural	RLINEXT	Depressed (Vert.Cut, Min.Depth, No Wall)	West-East	1.9196	0.87	0.8048	0.89
Urban	RLINEXT	Depressed (Vert.Cut, Min.Depth, No Wall)	West-East	1.2686	0.57	0.6503	0.72
Rural	RLINEXT	Depressed, Wall (20ft ht & distance)	West-East	5.0233	2.27	2.3365	2.58
Rural	RLINEXT	At-Grade, No Wall	North-South	2.3383	1.00	1.1025	1.00
Rural	RLINEXT	Depressed (Vert.Cut, Min.Depth, No Wall)	North-South	2.0352	0.87	0.9822	0.89
Urban	RLINEXT	Depressed (Vert.Cut, Min.Depth, No Wall)	North-South	1.2788	0.55	0.7820	0.71
Rural	RLINEXT	Depressed, Wall (20ft ht & distance)	North-South	4.7904	2.05	2.5675	2.33

** Urban population: 6.2m* *** Eighth highest value*

Exhibit A-70: RLINEXT Maximum $PM_{2.5}$ Concentrations for a Depressed Freeway, With and Without a Wall

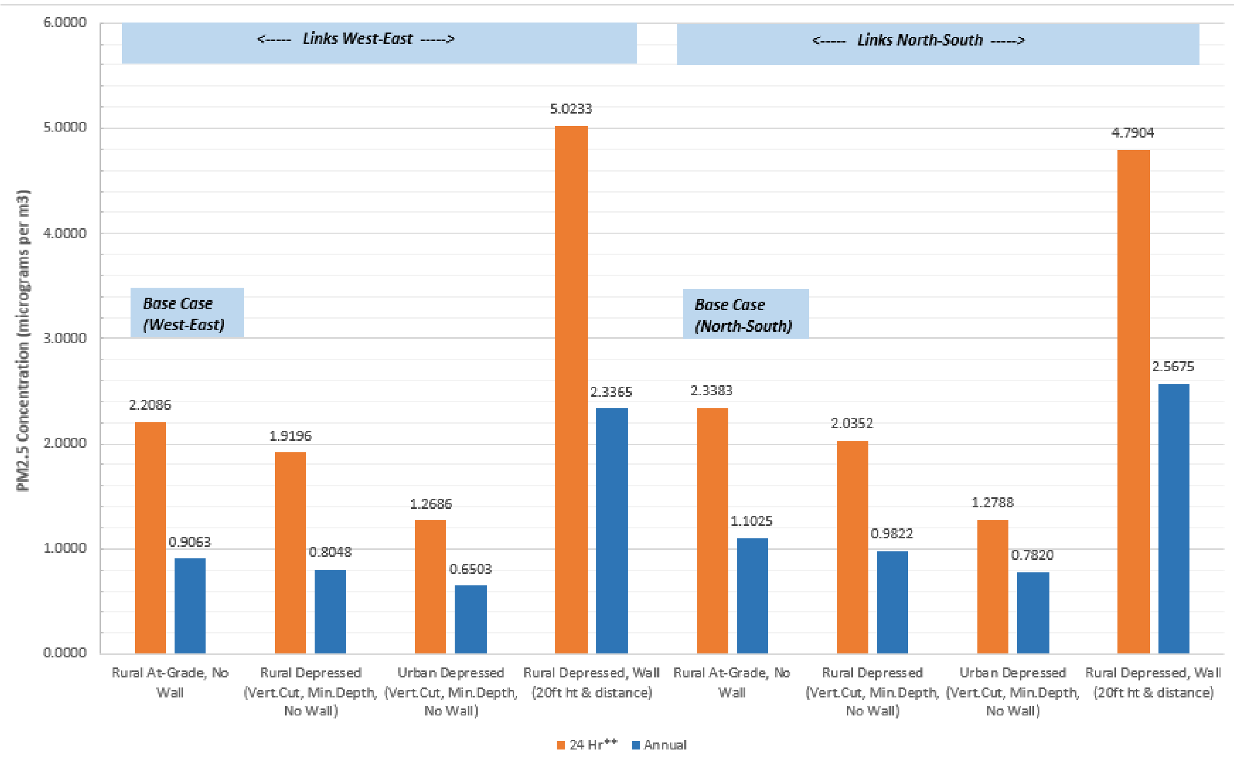

Exhibit A-71: RLINEXT Maximum $PM_{2.5}$ Concentrations for a Depressed Freeway, With and Without a Wall

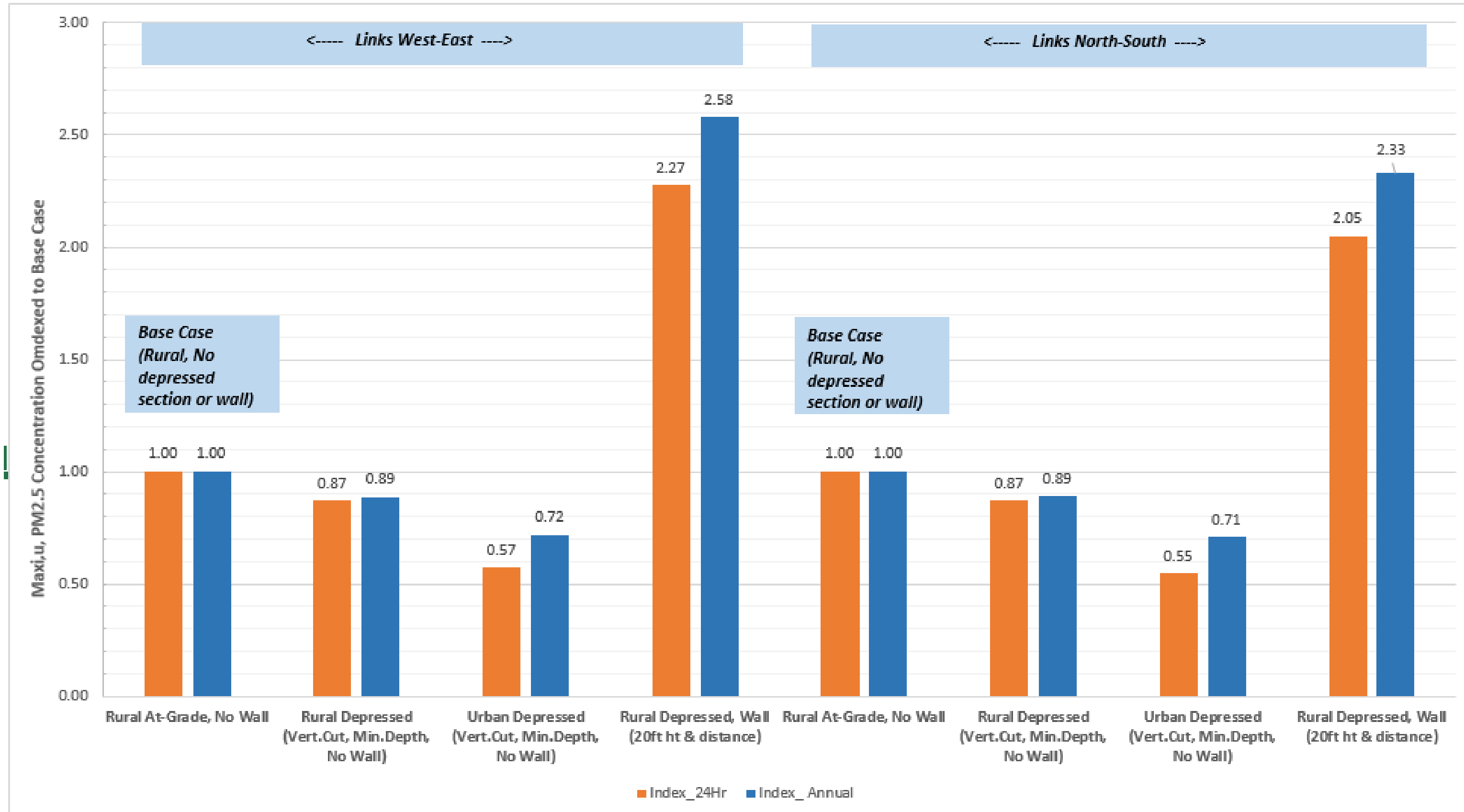

Exhibit A-72: RLINEXT Maximum $PM_{2.5}$ Concentrations for a Depressed Freeway, With and Without a Wall, Indexed to Base Cases

URBAN Option*	Source	Case	Links	24hr PM2.5 DV** (µg/m3)	NAAQS Test (35)	Margin (µg/m3)	Margin % of NAAQS	Annual PM2.5 DV (µg/m3)	NAAQS Test (12)	Margin (µg/m3)	Margin % of NAAQS
Rural	RLINEXT	At-Grade, No Wall	West-East	22.2	PASS	12.8	36.5%	9.8	PASS	2.2	18.3%
Rural	RLINEXT	Depressed (Vert.Cut, Min.Depth, No Wall)	West-East	21.9	PASS	13.1	37.4%	9.7	PASS	2.3	19.1%
Urban	RLINEXT	Depressed (Vert.Cut, Min.Depth, No Wall)	West-East	21.3	PASS	13.7	39.2%	9.6	PASS	2.4	20.4%
Rural	RLINEXT	Depressed, Wall (20ft ht & distance)	West-East	25.0	PASS	10.0	28.5%	11.2	PASS	0.8	6.4%
Rural	RLINEXT	At-Grade, No Wall	North-South	22.3	PASS	12.7	36.2%	10.0	PASS	2.0	16.6%
Rural	RLINEXT	Depressed (Vert.Cut, Min.Depth, No Wall)	North-South	22.0	PASS	13.0	37.0%	9.9	PASS	2.1	17.6%
Urban	RLINEXT	Depressed (Vert.Cut, Min.Depth, No Wall)	North-South	21.3	PASS	13.7	39.2%	9.7	PASS	2.3	19.3%
Rural	RLINEXT	Depressed, Wall (20ft ht & distance)	North-South	24.8	PASS	10.2	29.2%	11.5	PASS	0.5	4.4%
RUR At-Grade, No Wall		Average of Directional Results		22.3	*1.000*	12.7	36.4%	9.9		2.1	17.5%
RUR DEP No Wall		Average of Directional Results		22.0	*0.987*	13.0	37.2%	9.8		2.2	18.4%
URB DEP No Wall		Average of Directional Results		21.3	*0.955*	13.7	39.2%	9.6		2.4	19.9%
RUR DEP & Wall		Average of Directional Results		24.9	*1.118*	10.1	28.8%	11.4		0.6	5.4%

** Urban population: 6.2m* *** Eighth highest value*

Exhibit A-73: RLINEXT $PM_{2.5}$ Design Values and Margins for a Depressed Freeway, With and Without a Wall

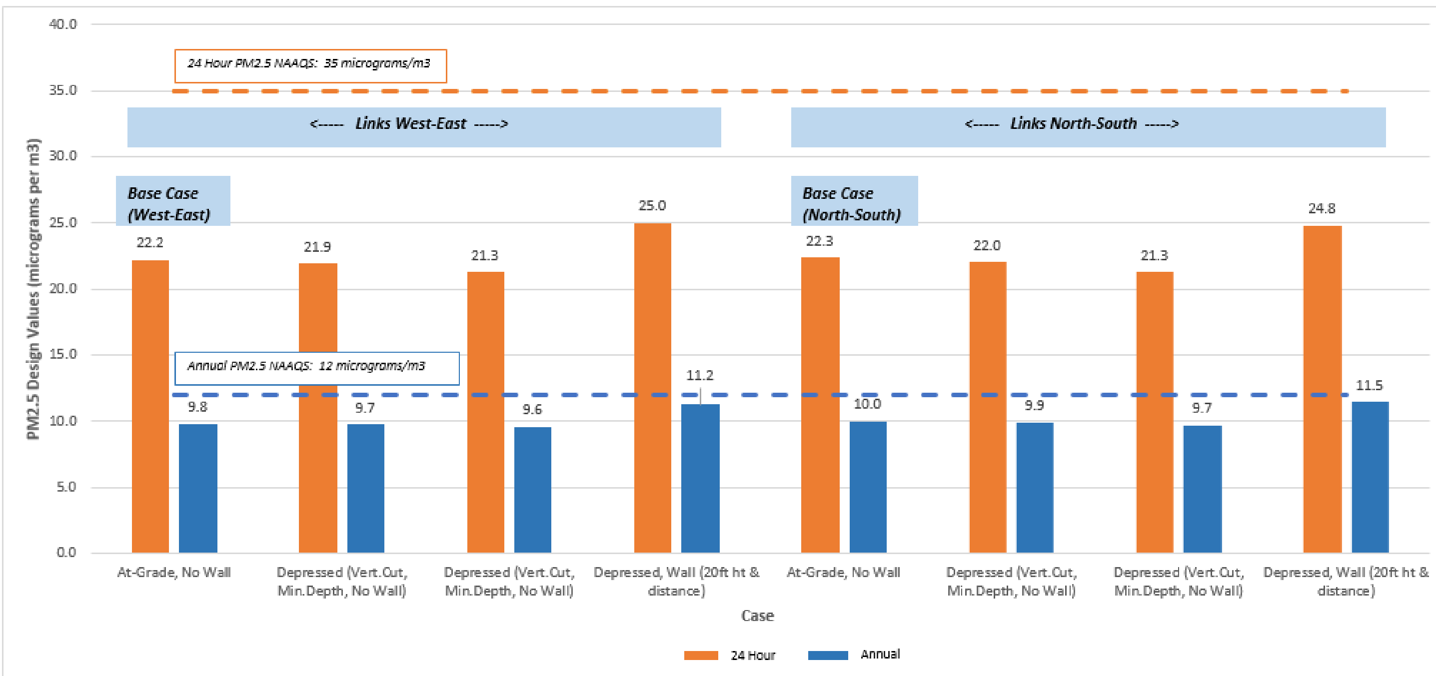

Exhibit A-74: RLINEXT $PM_{2.5}$ Design Values and Margins for a Depressed Freeway, With and Without a Wall

3.7 Comparisons

3.7.1 Comparison of One Noise Wall for Westbound and Southbound Links (Perpendicular v. Parallel Wind Components)

Exhibits A-75 to A-77 compare differences (SB minus WB) and percent differences (relative to SB) for modeled maximum $PM_{2.5}$ concentrations for one noise wall on SB links to one on WB links, for the full range of typical noise wall heights and distances in Virginia. The SB links and walls are parallel to winds from the south, while the WB links are upwind of the wall and perpendicular to winds from the south.

- Overall, the percent differences in concentrations were greatest for 15 ft walls at 20 ft (maximum concentrations were higher for the SB case than the WB) and decreased with increasing distance for both the 24-hour and annual standards.
    - For the 24-hour standard, while the percent differences were positive for walls at 20 ft, they were negative (i.e., WB concentrations were higher than SB) for walls at 40- and 60 ft.
    - For the annual standard, the relative differences in maximum concentrations for the southbound case exceeded those for westbound for all heights and distances.

Noise Wall				Diff_24 Hr*	%_Diff_24Hr	Diff_Annual	%_Diff_Annual
Links	**Height (ft)**	**Distance (ft)**	**Receptor Offset**	*(µg/m3) (SB-WB)*	*(Diff/WB)*	*(µg/m3) (SB-WB)*	*(Diff/WB)*
SB1-SB2, WB1-WB2	0	0	na	0.1298	5.88%	0.1962	21.65%
SB1-SB2, WB1-WB2	15	20	1 m	0.3057	11.18%	0.1748	11.86%
SB1-SB2, WB1-WB2	20	20	1 m	0.0022	0.05%	0.2457	10.29%
SB1-SB2, WB1-WB2	25	20	1 m	0.0646	1.74%	0.2100	10.73%
SB1-SB2, WB1-WB2	15	40	1 m	0.1845	7.17%	0.1275	9.33%
SB1-SB2, WB1-WB2	20	40	1 m	-0.1036	-2.26%	0.1858	8.09%
SB1-SB2, WB1-WB2	25	40	1 m	-0.0221	-0.61%	0.1605	8.53%
SB1-SB2, WB1-WB2	15	60	1 m	0.0924	3.82%	0.0800	6.26%
SB1-SB2, WB1-WB2	20	60	1 m	-0.1812	-4.05%	0.1233	5.57%
SB1-SB2, WB1-WB2	25	60	1 m	-0.0910	-2.60%	0.1030	5.69%

** Eighth highest value. Differences calculated as concentrations for SB minus WB.*

Exhibit A-75: Differences in RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall on SB Links v. WB

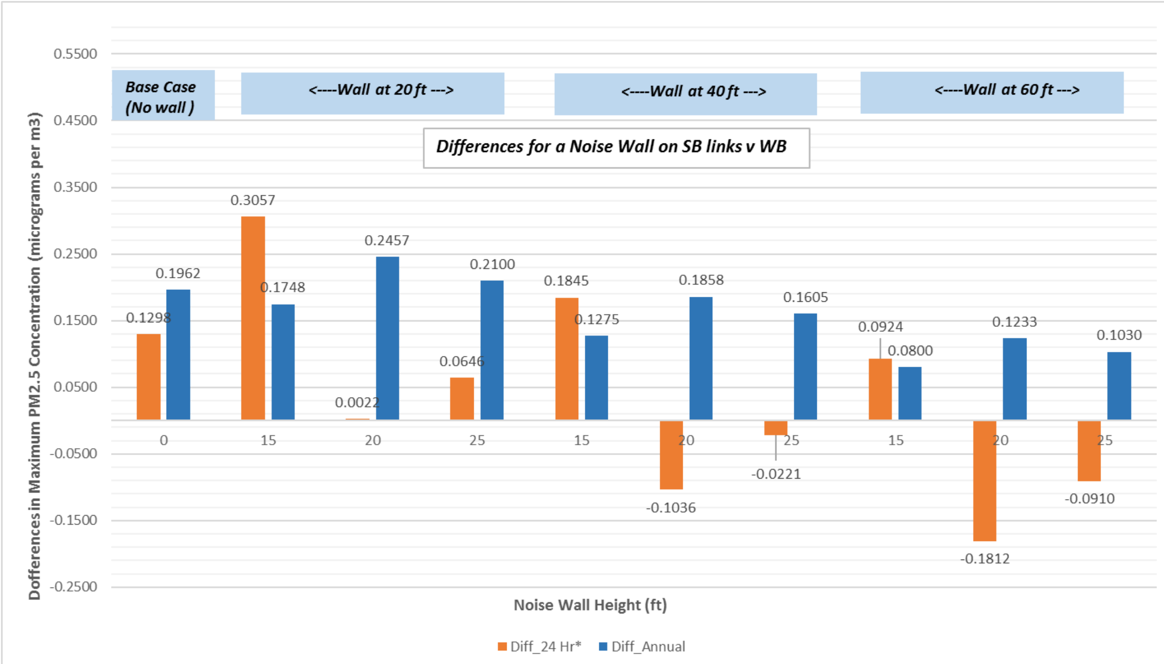

Exhibit A-76: Differences in RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall on SB v. WB Links

Exhibit A-77: Percent Differences in RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall on SB Links v. WB

3.7.2 Comparison for Noise Walls on Westbound and Eastbound Links (Noise Wall Downwind v. Upwind of Sources for Winds from the South)

Exhibits A-78 to A-80 present modeling results for a noise wall on westbound links (downwind of the links for winds from the south) versus one on eastbound links (upwind of freeway links for winds from the south). In summary:

- Overall, for both the 24-hour and annual standards, the differences (WB minus EB) are negative, i.e., the maximum concentrations for the EB case (upwind) are higher than for the WB case (downwind), for wall heights of 20 and 25 ft for all distances tested.
- For 15 ft walls:
  - The results were reversed for the annual standard for all distances, i.e., the results were positive as the max concentrations for the WB cases (wall downwind of winds from the south) were higher than the corresponding EB (upwind) cases.
  - For the 24-hr standard, the differences were positive for distances of 40 and 60 ft, and negative for 20 ft.

	Noise Wall			Diff_24 Hr*	%_Diff_24Hr	Diff_Annual	%_Diff_Annual
Links	Height (ft)	Distance (ft)	Receptor Offset	*(µg/m3) (WB-EB)*	*(Diff/EBl)*	*(µg/m3) (WB-EB)*	*(Diff/EB)*
WB & EB	0	0	na	0.0000	0.00%	0.0000	0.00%
WB & EB	15	20	1 m	-0.3226	-10.55%	0.0528	3.71%
WB & EB	20	20	1 m	-0.8522	-15.34%	-0.2246	-8.60%
WB & EB	25	20	1 m	-0.5001	-11.86%	-0.1208	-5.81%
WB & EB	15	40	1 m	0.0653	2.61%	0.0692	5.33%
WB & EB	20	40	1 m	-0.8364	-15.43%	-0.2239	-8.88%
WB & EB	25	40	1 m	-0.4998	-12.15%	-0.1201	-6.00%
WB & EB	15	60	1 m	0.0935	4.02%	0.0842	7.05%
WB & EB	20	60	1 m	-0.8146	-15.40%	-0.2191	-9.01%
WB & EB	25	60	1 m	-0.4942	-12.37%	-0.1122	-5.84%

** Eighth highest value. Differences calculated as WB concentrations minus EB.*

Exhibit A-78: Differences in RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall (WB minus EB)

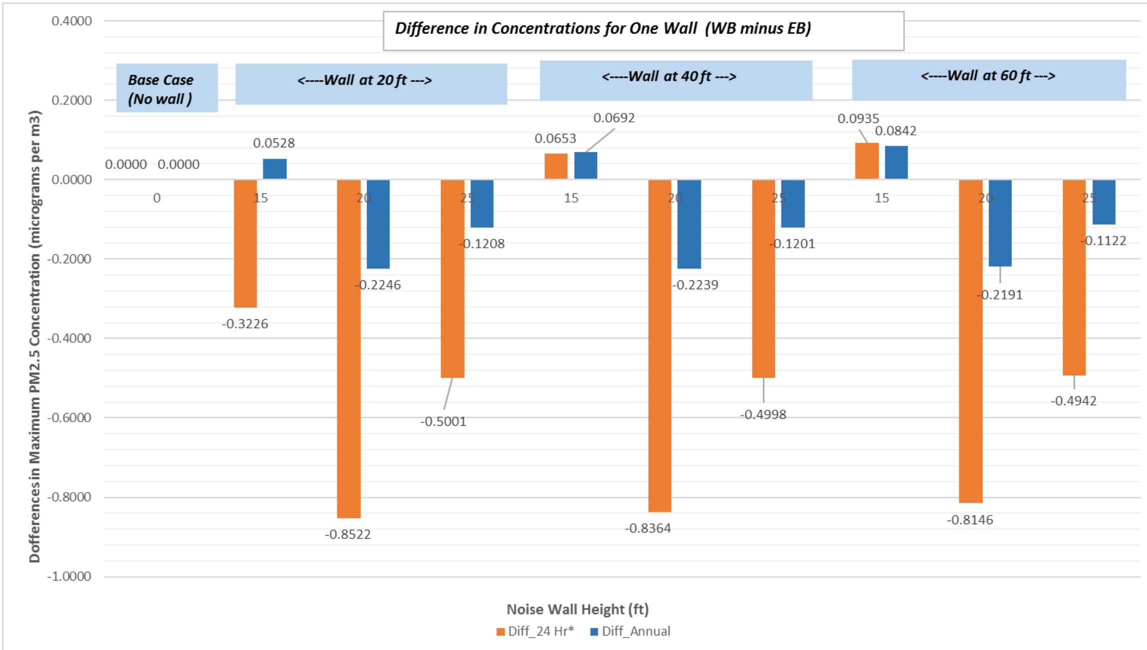

Exhibit A-79: Differences in RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall WB v. One Noise Wall EB

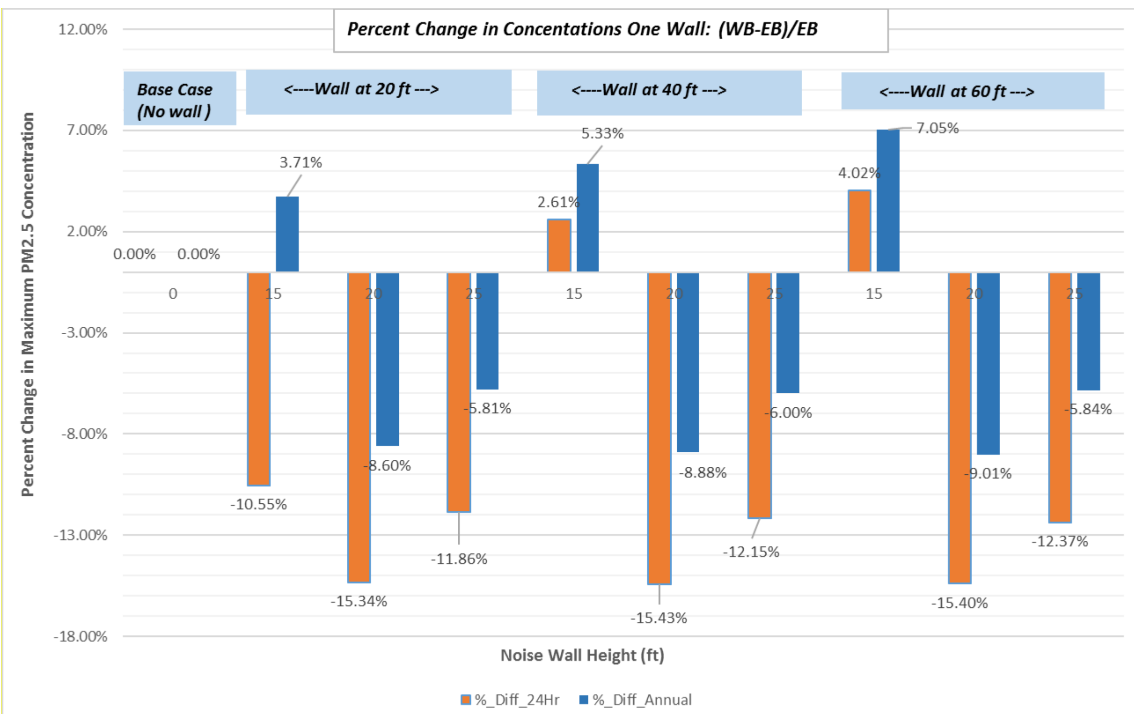

Exhibit A-80: Percent Changes in RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall WB v. One Noise Wall EB

3.7.3 Comparison for Noise Wall on Southbound and Northbound Links (Noise Wall Downwind v. Upwind of Winds from Northwest)

Exhibits A-81 to A-83 present differences in maximum concentrations for a noise wall on southbound links versus (minus) one on northbound links. In both cases the links and walls are parallel or nearly so to winds from the south, but the southbound links are downwind of the wall for winds from the northwest and the northbound links upwind. Overall:

- Relative differences in concentrations are smaller for the 24-hour standard than the annual standard, reaching at most -2.9%, which, rounding, occurred for a 15-ft wall at both 20 ft and 40 ft from the road.
- Relative differences were more substantial for the annual standard for wall heights of 20 and 25 ft, ranging from 10.29% to 14.35% (increasing with distance). In contrast, differences were negligible for wall heights of 15 ft, ranging from -0.03% to 0.11% with the minimum at the intermediate distance of 40 ft.

Noise Wall				Diff_24 Hr*	%_Diff_24Hr	Diff_Annual	%_Diff_Annual
Links	Height (ft)	Distance (ft)	Receptor Offset	*(µg/m3) (SB-NB)*	*(Diff/SB)*	*(µg/m3) (SB-NB)*	*(Diff/SB)*
SB & NB	0	0	na	0.0000	0.00%	0.0000	0.00%
SB & NB	15	20	1 m	-0.0881	-2.90%	0.0006	0.04%
SB & NB	20	20	1 m	0.0716	1.52%	0.3423	13.01%
SB & NB	25	20	1 m	-0.0018	-0.05%	0.2231	10.29%
SB & NB	15	40	1 m	-0.0788	-2.86%	-0.0005	-0.03%
SB & NB	20	40	1 m	-0.0351	-0.78%	0.3385	13.64%
SB & NB	25	40	1 m	0.0158	0.44%	0.2216	10.85%
SB & NB	15	60	1 m	-0.0575	-2.29%	0.0016	0.11%
SB & NB	20	60	1 m	-0.0680	-1.58%	0.3351	14.35%
SB & NB	25	60	1 m	-0.0373	-1.09%	0.2167	11.33%

** Eighth highest value. Differences calculated as SB concentration minus NB.*

Exhibit A-81: Differences in RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall SB v. One Noise Wall NB

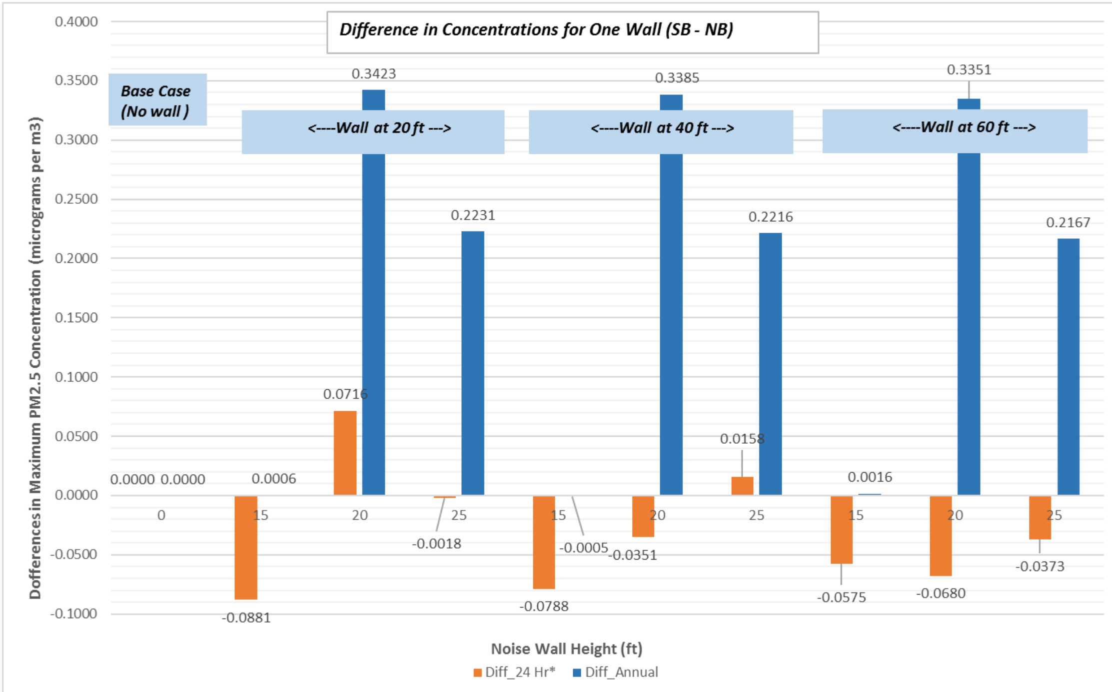

Exhibit A-82: Differences in RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall SB v. One Noise Wall NB

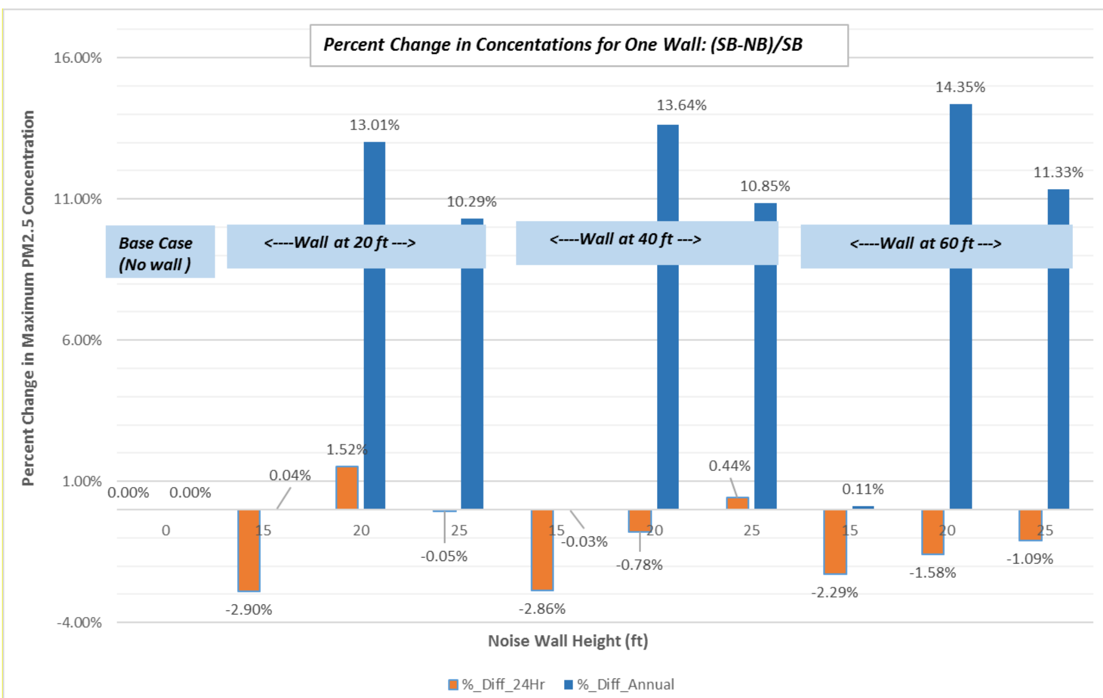

Exhibit A-83: Percent Changes in RLINEXT Maximum $PM_{2.5}$ Concentrations for One Noise Wall SB v. One Noise Wall NB

3.7.4 Comparison of One to Two Noise Walls (One Wall Each for Southbound v. Southbound and Northbound Links)

Exhibits A-84 to A-86 present differences between modeling one wall per link for the southbound direction and one wall per link for both the southbound and northbound directions. In both cases the links and walls are parallel or nearly so to winds from the south, but the southbound links are downwind of the wall for winds from the northwest and the northbound links upwind. In summary:

- Overall, the modeled concentrations were higher for the one SB wall than for the case with walls both SB and NB, for both the 24-hour and annual standards and for all combinations of wall height and distances.
- The percent differences increased with distance for both the 24-hr and annual standards in all cases except for a 25-ft wall (the highest tested) at the maximum distance tested of 60 ft.
- The highest percent difference overall was 7.8%, which was for the annual standard for a 15-ft wall at 60 ft. The highest percent difference for the 24-hr standard was 6.35%, which was for a 25 ft wall at 40 ft.

	Noise Wall			Diff(1-2)_24 Hr*	%_Diff_24Hr	Diff(1-2)_Annual	%_Diff_Annual
Links	Height (ft)	Distance (ft)	Receptor Offset	*(µg/m3)* *(SB - NB&SB)*	*(Diff/SB)*	*(µg/m3)* *(SB - NB&SB)*	*(Diff/SB)*
SB v SB & NB	0	0	na	0.0000	0.00%	0.0000	0.00%
SB v SB & NB	15	20	1 m	0.0711	2.34%	0.0605	3.67%
SB v SB & NB	20	20	1 m	0.2170	4.61%	0.1104	4.19%
SB v SB & NB	25	20	1 m	0.2281	6.03%	0.1038	4.79%
SB v SB & NB	15	40	1 m	0.1012	3.67%	0.0890	5.95%
SB v SB & NB	20	40	1 m	0.2335	5.21%	0.1276	5.14%
SB v SB & NB	25	40	1 m	0.2279	6.35%	0.1120	5.49%
SB v SB & NB	15	60	1 m	0.1422	5.67%	0.1059	7.80%
SB v SB & NB	20	60	1 m	0.2346	5.47%	0.1330	5.69%
SB v SB & NB	25	60	1 m	0.2096	6.14%	0.1152	6.02%

** Eighth highest value. Differences calculated as concentrations for one wall SB minus those for one both SB & NB..*

Exhibit A-84: Differences in RLINEXT Maximum $PM_{2.5}$ Concentrations for One versus Two Noise Walls: SB-NB&SB

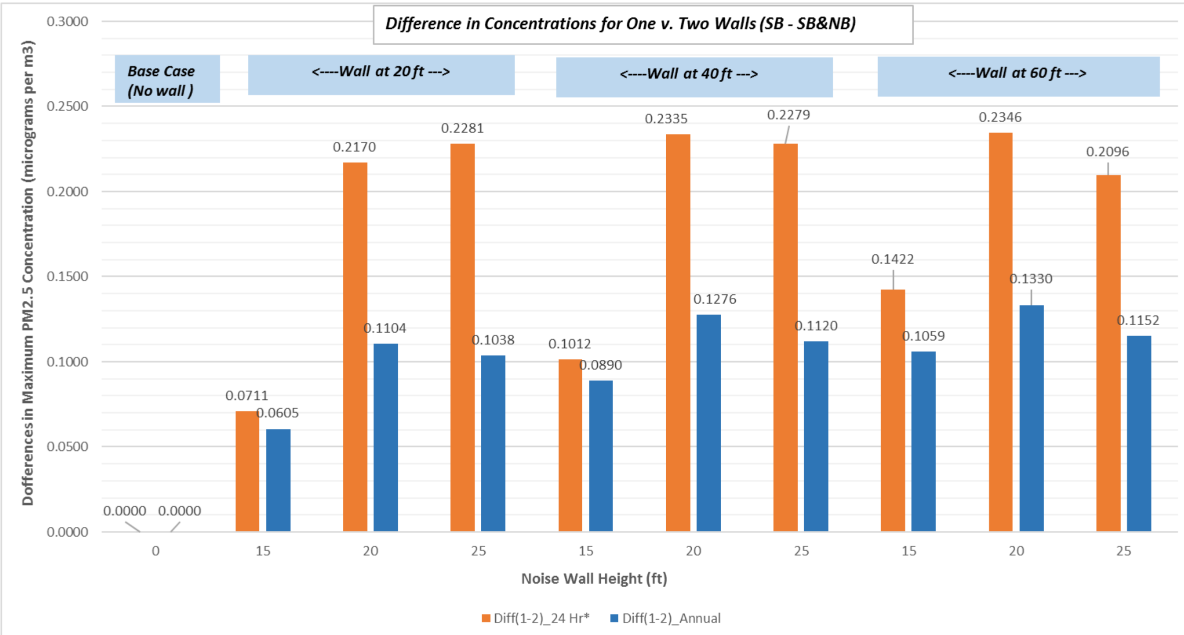

Exhibit A-85: Differences in RLINEXT Maximum $PM_{2.5}$ *Concentrations for One versus Two Noise Walls: SB-NB&SB*

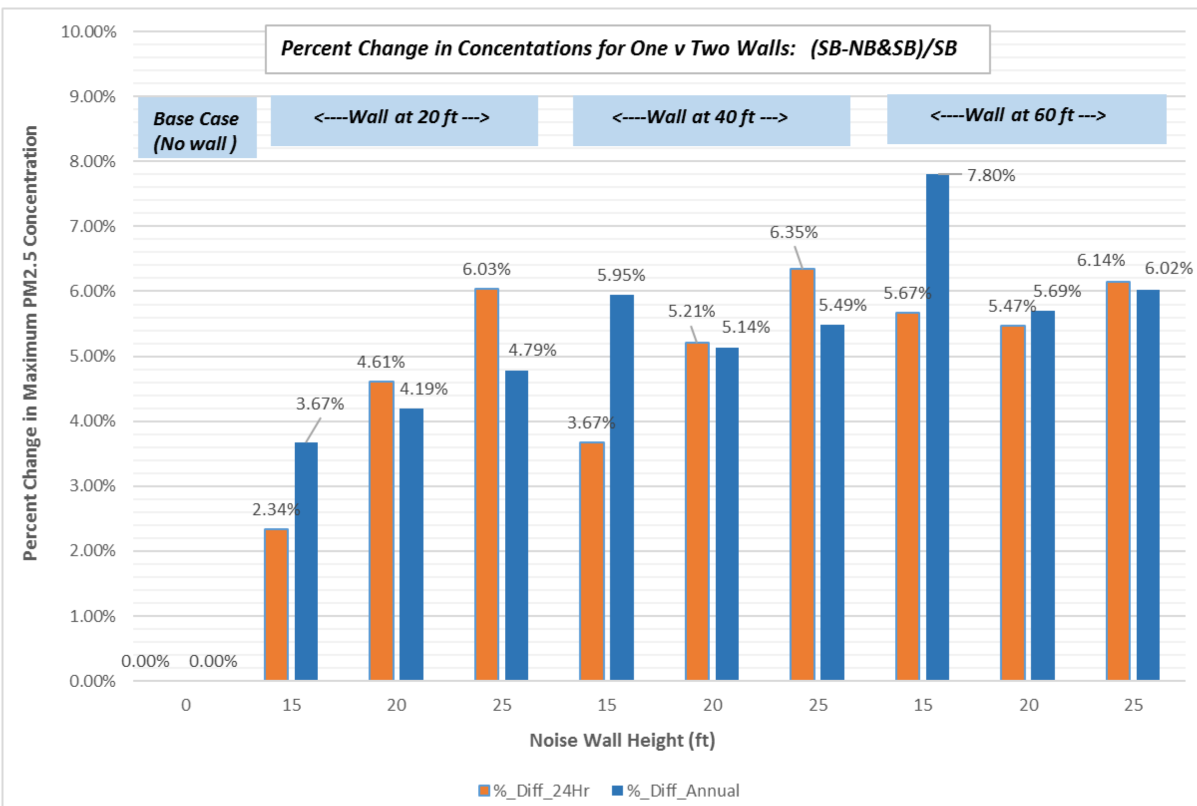

Exhibit A-86: Percent Changes in RLINEXT Maximum $PM_{2.5}$ *Concentrations for One versus Two Noise Walls: (SB-NB&SB)/SB*

3.8 Worst-Case Margins between Design Values and the NAAQS

Of all of the runs modeled using RLINEXT for this study, Exhibit A-87 presents the top fifteen with the smallest (worst) margins for design values for the annual $PM_{2.5}$ NAAQS, which is the limiting case (versus the 24-hour standard) for showing compliance with the NAAQS. That is, the annual $PM_{2.5}$ NAAQS would be the more challenging to meet based on the modeling results presented here than the 24-hr NAAQS, at least for projects in Virginia.

Exhibit A-88 shows the margins for design values versus the ratio of the modeled concentrations for cases with walls and/or a depressed section to the corresponding base cases with no walls or depressed section. The relationship is linear for each category tested for link orientation and the inclusion of a depressed section, and generally shows that increasing modeled concentrations result as expected in corresponding decreases in the margins with the applicable NAAQS. It also shows the relative order by margin for all cases. Overall, the results show that:

- Thirteen of the fifteen cases with the smallest (worst) margins involved noise walls at the intermediate height of 20 feet. The remaining two cases were for noise walls 15 feet in height, and those were also the only two cases included in the list that had a depressed section with a wall.
- The smallest margins (3.9%) were observed for a wall on the southbound links, whether full- or half-length, for which winds from the south were parallel or nearly so. The wall was also upwind of the links for winds from the northwest.
- The margins were consistently smaller for links and walls oriented north-south than west-east, although the slopes of the margin versus concentration lines are nearly the same.
- For links-oriented west-east, the smallest margins and greatest index for concentration were for walls for the eastbound lanes, for which the wall was upwind of the roadway links for winds from the south. The effect decreases with increasing distance of the wall from the road.
- For links oriented north-south, the margin was lower for walls closer to the road both for cases with a wall on the SB links only and walls on both southbound and northbound links. In these cases, winds from the south were generally parallel to the roadway links and noise walls.

Case	Noise Wall			Annual PM2.5 *(µg/m3)*	Index_Annual	Annual PM2.5 DV** *(µg/m3)*	Index_Annual *DV*	Margin		Index_Annual Margin
	Height (ft)	Distance (ft)	Receptor Offset					*(µg/m3)*	% of NAAQS	
Base Case XT W-E No Wall	na	na	na	0.9063	1.000	9.8	1.000	2.2	18.3%	1.000
Wall WB1-WB2	20	20	1 m	2.3865	2.633	11.3	1.151	0.7	5.9%	0.325
Wall WB1-WB2	20	40	1 m	2.2964	2.534	11.2	1.142	0.8	6.7%	0.366
Wall WB1 Only	20	20	1 m	2.3888	2.636	11.3	1.151	0.7	5.9%	0.324
Wall EB1-EB2	20	20	1 m	2.6111	2.881	11.5	1.174	0.5	4.1%	0.223
Wall EB1-EB2	20	40	1 m	2.5203	2.781	11.4	1.165	0.6	4.8%	0.264
Wall EB1-EB2	20	60	1 m	2.4314	2.683	11.3	1.156	0.7	5.6%	0.305
Base Case XT N-S No Wall	na	na	na	1.1025	1.000	10.0	1.000	2.0	16.6%	1.000
Wall SB1-SB2	20	20	1 m	2.6321	2.387	11.5	1.153	0.5	3.9%	0.234
Wall SB1-SB2	20	40	1 m	2.4822	2.251	11.4	1.138	0.6	5.1%	0.309
Wall SB1-SB2	20	60	1 m	2.3356	2.118	11.2	1.123	0.8	6.4%	0.383
Wall SB1 Only	20	20	1 m	2.6321	2.387	11.5	1.153	0.5	3.9%	0.234
Wall NB1-NB2	20	20	1 m	2.2898	2.077	11.2	1.119	0.8	6.8%	0.406
Walls SB1-SB2, NB1-NB2	20	20	1 m	2.5217	2.287	11.4	1.142	0.6	4.8%	0.290
Walls SB1-SB2, NB1-NB2	20	40	1 m	2.3546	2.136	11.3	1.125	0.7	6.2%	0.373
Base Case XT W-E No Wall or Depressed	na	na	na	0.9352	1.000	9.8	1.000	2.2	18.0%	1.000
Depressed with wall WB1-WB2	20	20	1 m	2.3365	2.498	11.2	1.142	0.8	6.4%	0.353
Base Case XT N-S No Wall or Depressed	na	na	na	1.1507	1.000	10.1	1.000	1.9	16.2%	1.000
Depressed wth wall SB1-SB2	20	20	1 m	2.5675	2.231	11.5	1.141	0.5	4.4%	0.273
Minimum with Wall or Depressed Section:				2.2898	2.077	11.2	1.119	0.5	3.9%	0.223
Maximum with Wall or Depressed Section:				2.6321	2.881	11.5	1.174	0.8	6.8%	0.406
Average with Wall or Depressed Section:				2.4524	2.435	11.4	1.145	0.6	5.4%	0.311

** Eighth highest value* *** Background concentration:* *8.9* *micrograms per cubic meter*

Exhibit A-87: Cases with Minimum Margins with the NAAQS

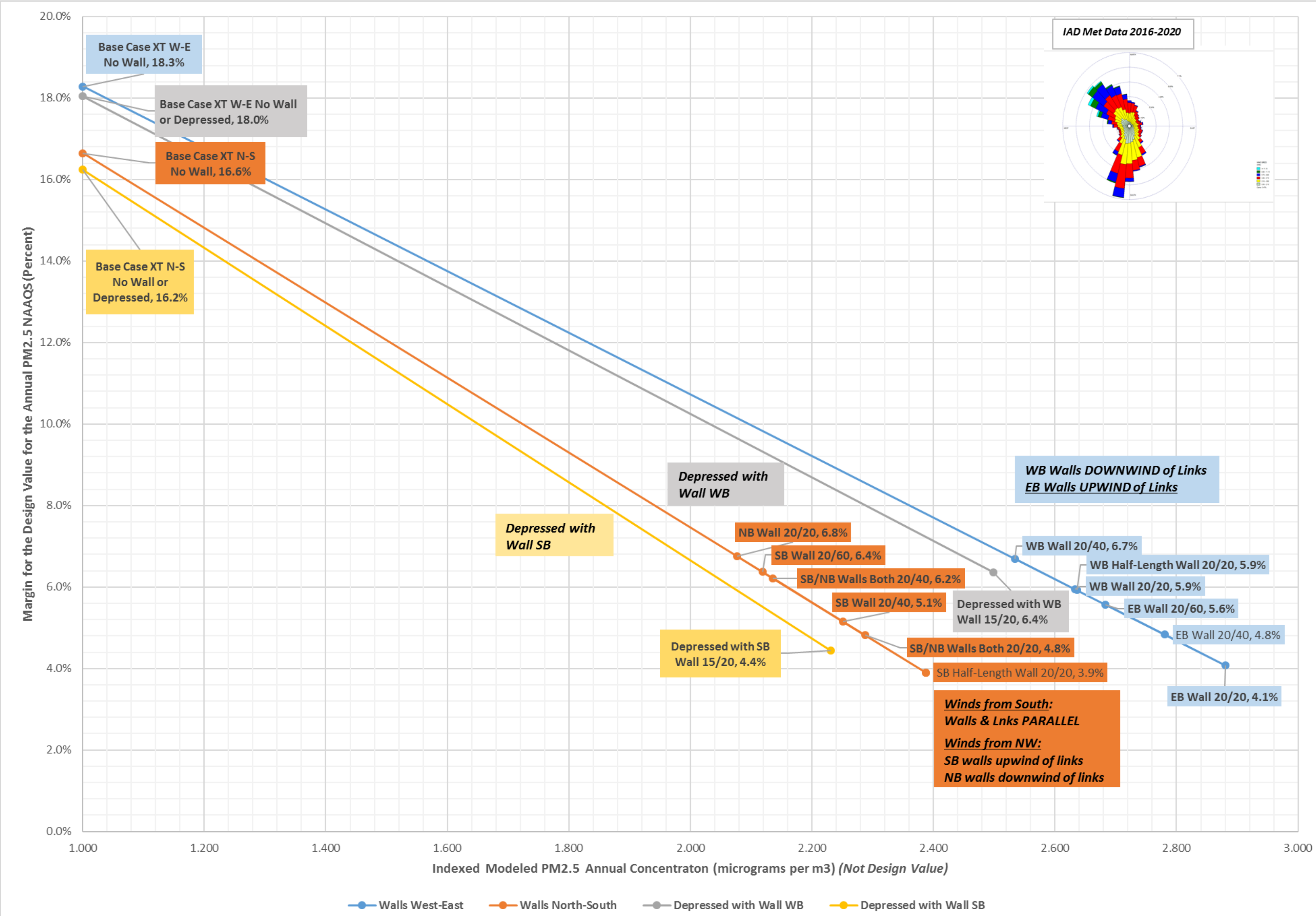

Exhibit A-88: Cases with Minimum Margins with the NAAQS

4. Conclusions and Recommendations

Priority conclusions and recommendations from the perspective of a state DOT are summarized below. More detailed conclusions and recommendations are presented in the main report with the documentation for each option and sensitivity test. Note, if other project types, configurations etc. were to be tested than those addressed here, the detailed conclusions and recommendations may differ to some extent, but the priority items would be expected to remain.

All modeling was conducted following EPA and FHWA guidance for projects subject to conformity requirements. Virginia-specific inputs were applied for MOVES (3.0.1) and AERMOD (v.21112,) including five years of meteorological data from Dulles International Airport (IAD).

Overall, for a near-term project opening year of 2025, a 0.2 mile long hypothetical ten-lane freeway at-grade segment with a median would meet current 24-hour and annual $PM_{2.5}$ NAAQS for all combinations of noise wall heights and distances typically implemented in Virginia and for a depressed section with or without a barrier. In some cases, however - all involving noise walls - the margin by which the hypothetical project would meet the annual $PM_{2.5}$ NAAQS was very small, e.g., as low as 3.9%.

A common theme among the conclusions and recommendations for the different highway and noise wall configurations and scenarios tested is the need for enhanced model validation against field data to verify modeling results for regulatory applications for the full range of typical transportation projects (project types, configurations, etc.) For this reason, it is presented as the highest priority recommendation.

4.1 Model Validation against Field Data for Typical Transportation Applications

The need for an enhanced model validation process for transportation is summarized below, followed by specific recommendations.

4.1.1 Need for Enhanced Model Validation for Transportation Applications

Based on the modeling results presented here as well as the factors summarized below, it is time to develop and implement an *enhanced* model validation or evaluation process for dispersion models to be applied in regulatory air quality analyses of transportation projects conducted to meet federal transportation conformity requirements and for purposes of NEPA. By enhanced is meant a process involving all transportation stakeholders that commits more resources and is of broader scope than the historical model validation process. The recommended approach includes a continuing, comprehensive, and cooperative (3C) consultation process (or its equivalent) with transportation agencies, and otherwise involve complete transparency in support of NEPA decision-making processes. Key reasons supporting the need for such an enhanced model validation process from a state DOT perspective include but are not limited to the following:

- Questions have arisen about the accuracy of regulatory dispersion models (including AERMOD) for the full range of transportation applications, as outlined below, due in large part to the fact that they have not been validated against field data for the full range of transportation applications for which the models are required to be applied by regulation, which in turn is due to the lack of suitable field data (including tracer studies,) which involve substantial costs to acquire. The validation for AERMOD as reported in the current EPA *Guideline on Air Quality Models (Appendix W)*[33] as a result references two field studies for transportation applications, only one of which included a transportation facility and that for a low volume roadway with no walls. The continued improvement of regulatory dispersion models for transportation applications therefore depends on enhancing the current model validation or evaluation process to cover the full range of typical transportation applications (project types, configurations, operating conditions, setting etc.), including specifically high volume facilities with and without noise walls, which requires more field data than is currently available.

  That said, new field data for model validation have or may become available in the near-future for high volume highways with and without noise walls (CalTrans/UC Riverside and NCHRP 25-55[34]), which would make model validation against field data feasible for those specific applications. NCHRP 25-55 has co-located sites for tracer and near-road monitoring data, as well as background concentration data, so can be used both to assess performance of the dispersion model against tracer data as well as the full traffic, emissions, and dispersion modeling chain against near-road monitoring data. The validation against near-road monitoring data is critically needed to be able to evaluate the project-level modeling chain for its intended regulatory purpose of showing compliance with the applicable regulatory tests (NAAQS and Build/No-Build).
- In addition to concerns with the current lack of *coverage* of all typical transportation applications, there are concerns with *accuracy* for transportation applications. Recently published model evaluation (model-to-monitor) case studies report modeled near-road concentration estimates significantly exceeded near-road monitoring data[35] for high volume freeway facilities, based on facility-specific modeling including use of detailed local traffic data as well as emission and dispersion modeling using AERMOD, Rigorous and systematic model validation against field data is therefore needed to resolve questions about accuracy

[33] See: https://www.epa.gov/scram/2017-appendix-w-final-rule
Direct links: https://www.epa.gov/sites/default/files/2020-09/documents/appw_17.pdf
https://www.govinfo.gov/content/pkg/CFR-2017-title40-vol2/xml/CFR-2017-title40-vol2-part51-appW.xml

[34] See: https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4383

[35] For example, the Transportation Pooled Fund for Near-Road Air Quality (http://nearroadaqpf.com/) conducted model-to-monitor comparisons and provided the following conclusions for two sites evaluated in its final summary paper (D. Eisinger et al., "Near-Road Air Quality Insights from a U.S. DOT Five-Year Transportation Pooled Fund Study", TR News March-April 2021, p.26): "*For Indianapolis, AERMOD was run for 152 analysis days in 2016. The average modeled* $PM_{2.5}$ *near-road increments for these days were compared to the monitored near-road* $PM_{2.5}$ *increments. The modeled increment (3.7 µg/m3) was three to four times larger than the measured increments obtained from Federal Reference Method (FRM) or Federal Equivalent Method (FEM) monitoring instruments (1.2 µg/m3 for FRM and 0.9 µg/m3 for FEM). EPA allows the use of either FRM or FEM monitors; FRM measurements usually are more accurate. AERMOD modeling results for Providence for 2015–2016 were compared with measured increments for 382 analysis days. The AERMOD-based analysis for Providence also significantly overpredicted the average measured near-road* $PM_{2.5}$ *increment. The average modeled* $PM_{2.5}$ *increment (8.8 µg/m3) was more than six times, or 530 percent, greater than the average measured increment (1.4 µg/m3)*."

More detail on the model-to-monitor comparisons conducted for the pooled fund for near-road air quality is provided in:
Kenneth J. Craig, Lynn M. Baringer, Shih-Ying Chang, Michael C. McCarthy, Song Bai, Annie F. Seagram, Vikram Rav, Karin Landsberg, Douglas S. Eisinger, "Modeled and measured near-road $PM_{2.5}$ concentrations: Indianapolis and Providence cases," Atmospheric Environment, Volume 240, 1 November 2020, 117775. Modeled and measured near-road $PM_{2.5}$ concentrations: Indianapolis and Providence cases - ScienceDirect

for the full range of transportation applications, including specifically (as tested here) high volume freeways with noise walls. Modeling results for this study also highlight a need for more information on accuracy:

- Differences, some substantial, were found in this study for modeled maximum 24-hour and annual $PM_{2.5}$ maximum concentrations for different sources (LINE, VOLUME, RLINE, and RLINEXT without noise walls or a depressed section,) setting (URBAN or not) and value for Szinit.
    - The decision on which source to use requires information on model accuracy in regulatory applications for each source, which may vary by transportation application (project type, configuration, etc.) and related parameters (setting and Szinit).
    - Conversely, in the absence of a comprehensive model validation for each source against field data for each transportation application, a decision cannot reliably be made on which source to recommend for use and which, if any, to exclude for a given application.
- Surprisingly high modeled concentrations were modeled for RLINEXT with a noise wall for receptors close to the wall, whether upwind or downwind of the roadway links, and for near-parallel wind conditions, which makes model validation against field data for noise walls for a full range of typical heights and distances a critical need. The modeled high maximum concentrations varied primarily with wall height (with maximum concentrations peaking for an intermediate height wall of 20 ft) and to a lesser extent with distance of the wall from the roadway link.
    - The modeled high maximum concentrations near the wall appear to exceed those reported in the literature for field or wind tunnel studies.[36]
    - A range of offset distances for receptor placement outside of the noise wall was tested, with the results (testing a 20-ft wall only) showing a receptor offset distance of about three wall heights was needed for modeled maximum concentrations for cases with the wall to fall back to the levels for cases without a wall. This is for one simple configuration (a short freeway segment), so the result may well vary with different transportation project types and configurations including different wall heights.
    - Guidance for receptor placement near the wall is needed, especially if the model is found to overestimate maximum concentrations near the wall compared to field data. The guidance in this case may specify a receptor exclusion zone near the wall.
    - Modeled concentrations maximum concentrations decreased for a depressed section without a wall relative to a base case at-grade section. This raises the following question: why would RLINEXT predict a *reduction* in modeled maximum concentrations for a vertical cut depressed section 16 ft in depth (for which the vertical cut effectively acts as a wall) but predict *major increases* in concentrations for at-grade walls with heights of 15, 20 and 25 ft?

[36] See for example: Chris Owen, Dianna Francisco, David Heist, Steve Perry (ret.), Akula Venkatram, Lydia Brouwer, "RLINE Updates/ Mobile Source Modeling", presentation to the EPA Regional/State/Local Dispersion Modelers' Workshop, June 21. 2021. https://gaftp.epa.gov/Air/aqmg/SCRAM/workshops/2021_RSL_Modelers_Workshop/Presentations/2021%20RSL%20-%20Day%201%20-%20RLINE%20Updates.pdf

- Current consultation processes with transportation stakeholders are inadequate, and therefore enhanced (3C) consultation with transportation stakeholders is needed. As documented in this report and summarized above, the modeling results for the ALPHA version of RLINEXT showing marked increases in modeled concentrations near (one meter away from) barriers relative to a no-wall base case raise serious concern from the state DOT perspective. The concern stems from not only the modeling results themselves but also from the surprise in discovering them in testing and not having been given any advance notice in the guidance or otherwise that the model would exhibit such behavior. Note modeling receptors near the barrier as done here may be needed for example for projects involving a bicycle/pedestrian path (or other sensitive receptors) adjacent to the noise wall.

  For context, a recent presentation[37] by EPA introducing the new RLINEXT capability to model noise walls, charts showed wind tunnel data and model results with low concentrations relative to a no-wall base case but do not include data or results for receptors as near the wall as modeled in this study. As it did not address field data or model results near (immediately adjacent to) the barrier, it missed the opportunity to give transportation stakeholders advance notice of high modeled concentrations in that area.

  Releasing an update to AERMOD in a way that fails to highlight potentially concerning model behavior such as this in the model is not good transparency, which is a significant concern. On the positive side, it can be easily remedied with an enhanced model validation process as recommended below.
- Considerable resource requirements are needed for field data collection and analysis for the full range of transportation applications, and well as for the subsequent model validation process including comparative analyses. A pooled fund involving EPA, FHWA and state DOTs could meet this need and at the same time provide a good forum for a 3C consultation process with DOTs and other transportation stakeholders. FTA and state and regional transit agencies may also be interested in participating in such an effort if it also covered transit applications.
- The 2007 National Research Council (NRC) report, "*Models in Environmental Regulatory Decision-Making*,"[38] made important recommendations that should be followed for all regulatory environmental models, including dispersion models to be applied for transportation applications. Based on the NRC report, recommendations presented here for a model validation plan, peer review processes, multiple evaluation criteria including model parsimony, and ensuring that a model is adequate for its intended regulatory purpose are of particular interest and strongly supported.

  Consistent with the recommendations of the 2007 NRC report, model validation for the intended regulatory purpose for transportation therefore includes the need for showing compliance with statistical confidence with the applicable regulatory tests (NAAQS and build/no-build.) for the full range of transportation applications, or otherwise limiting use of the model to only those transportation applications for which it has been proven through

[37] See Chris Owen, Dianna Francisco, David Heist, Steve Perry (ret.), Akula Venkatram, Lydia Brouwer, "RLINE Updates/ Mobile Source Modeling", presentation to the EPA Regional/State/Local Dispersion Modelers' Workshop, June 21. 2021. https://gaftp.epa.gov/Air/aqmg/SCRAM/workshops/2021_RSL_Modelers_Workshop/Presentations/2021%20RSL%20-%20Day%201%20-%20RLINE%20Updates.pdf

[38] See: *https://www.nap.edu/catalog/11972/models-in-environmental-regulatory-decision-making*

model validation against representative field data to be adequate for its intended regulatory purposes.

For transportation, this also means that assessments of the performance of the entire project-level analysis modeling chain (traffic, emissions, and dispersion) as well as the determination of representative background concentrations are needed to be able to assess the regulatory application of comparing design values to the applicable NAAQS. That is, in addition to assessing the performance of dispersion modeling with tracer studies, assessing the performance of the project-level modeling chain including the determination of background concentrations against near-road monitoring data is needed.

- The 2018 EPA Inspector General (IG) report on air quality dispersion models[39] effectively echoed the recommendation of the 2007 NRC report that regulatory models be adequate for their intended (regulatory) use. It also included findings related to documentation of model revisions, which supports transparency.
- Finally, it bears keeping in mind that AERMOD was introduced for transportation applications in the relatively recent past and, given anecdotal estimates that less than about thirty project-level analyses for particulate matter using AERMOD have been completed to date across the entire nation, is still effectively a relatively new and unfamiliar application for many transportation agencies. Development and implementation of an enhanced model validation process for transportation applications that involves 3C consultation with state DOTs would significantly help improve their familiarity and capabilities with the model.

4.1.2 Key Principles for Enhanced Model Validation for Transportation Applications

Based on the findings and recommendations of the 2007 NRC report and 2018 EPA IG report, and comments from state DOTs in the past, certain key principles apply for an enhanced model validation program for transportation. Additionally, NCHRP 25-55 is expected to provide detailed recommendations for model validation and provide a good basis for the design of an enhanced model validation process for transportation applications.[40] Overall, the following key elements are needed for an enhanced model validation process relative to the current process for transportation applications.

Comprehensive Coverage of Regulatory Applications for Transportation: The enhanced model validation process must cover all transportation applications for which the model is required for use by regulation, including all facility types, configurations, operating conditions, settings (urban/rural), pollutant etc. for which modeled near-road concentrations and design values may reasonably be expected to vary to the extent that it would affect the determination of compliance with statistical confidence of the applicable regulatory tests (NAAQS and B/NB.) This should be done in priority order, i.e., in the order in which the regulatory need is greatest.

[39] See: "EPA Can Strengthen Its Process for Revising Air Quality Dispersion Models that Predict Impact of Pollutant Emissions", Report No.18-P-0241, September 2018. https://www.epa.gov/sites/default/files/2018-09/documents/_epaoig_20180905-18-p-0241.pdf

[40] The outline of key principles recommended here is based in part on or otherwise is consistent with comments provided by the author to NCHRP 24-55, which is still in progress.

Budget estimates are needed for each prioritized application for planning purposes. Transportation applications include but are not limited to the following:

- Project types (freeways, interchanges with and without adjacent congested intersections, truck, and bus terminals with a high proportion of diesel vehicles etc.),
- Configurations (with and without noise walls, depressed/elevated sections, skewed intersections and interchanges, roadways with high road grades etc.)
    - A range of typical noise wall heights and distances should be included, as well as a range of typical widths and depths for depressed sections. Consideration should be given to setting up barriers on a temporary basis at varying heights and distances, to minimize the number of sites that need to be selected and the associated costs, to provide more direct comparisons of the roadways with noise walls.
    - The configurations tested should also include ones with high road grades to test the emission modeling portion of the regulatory project-level analysis modeling chain. This is particularly needed as MOVES is known to exhibit anomalous behavior at high road grades, which varies by pollutant, fuel type, facility type etc., as reported to the MOVES Review Workgroup[41] of the EPA Mobile Source Technical Review Subcommittee (MSTRS) in 2019. One possible configuration to test is a highway with truck climbing lanes with a high diesel truck percentage, with and without noise walls.
    - Onboard portable emission monitoring systems may be used to provide simultaneous emission data for assessing performance of the emission model, which will be useful at all road grades but particularly so for high road grades where there are known issues with MOVES emission factors.
    - Temporary near-road air quality monitors may be deployed to enable testing at roadways sites without near-road monitors but are otherwise ideal for testing. The monitors should still meet EPA requirements for federal reference or equivalent monitors.
- Operating conditions (high and low volume; and congested versus uncongested, as one roadway may have more stop-and-go traffic while another may have higher operating speeds and more traffic-induced turbulence; high diesel truck and bus percentages, etc.)
- Settings (urban and non-urban, urban canyons)
- Pollutants for which project-level analyses are required by regulation, to the extent that model performance in determining design values for compliance with the NAAQS and B/NB tests with statistical confidence may be significantly affected.

Field Data Collection and Analysis: A detailed plan for field data collection and analysis on a prioritized basis for transportation applications is needed. Minimum requirements include:

- Co-located tracer studies and near-road monitors, as they allow both testing of the dispersion model against the tracer data and the project-level (hotspot) analysis modeling chain of traffic, emissions and dispersion against the near-road monitoring data. The latter is needed to assess the performance of the models in regulatory application, i.e., whether

[41] See: https://www.epa.gov/sites/default/files/2019-12/documents/03-moves-project-level-analyses-2019-10-09.pdf

the models may be applied with statistical confidence for their intended regulatory purpose with the NAAQS and B/NB tests, or whether limitations would need to apply.
  - Multiple tracers may be used, e.g., different tracers for LDVs and HDVs.
  - Background concentrations must be well characterized for each pollutant

- Database or other documentation of sites that may be considered for use in model validation
  - Identify data that are currently available, e.g., building from the NCHRP 25-55 summary of available field study data.
  - Identify data that meet criteria for model validation and so can be applied in the near-term for model validation.
  - In support of long-term efforts, identify additional data collection that would be needed to cover the transportation applications identified below.
- Note, multiple field data sets are needed to ensure that the results are reproducible and to check model validation and avoid bias, i.e., by validating the model against one data set and checking model performance against another data set. The field data collection plan should address this need.

Multiple Criteria: Consistent with the 2007 NRC report recommendations, the model validation process should be based on multiple criteria appropriate for a regulatory application. That is, the criteria would include accuracy, which is already assessed in model validations completed to date, as well as other relevant criteria for *regulatory* applications such as proportionality or model parsimony (limiting the time and resource requirements to run the model to just that needed to meet the regulatory purpose), ease-of-use (especially for screening applications), quality assurance and control features etc.

- Estimates of accuracy and uncertainty are needed for both the modeled near-road concentrations and the background concentrations used in the regulatory modeling chain, to be able to assess the confidence level for the model for showing compliance with the NAAQS as well as the B/NB test. Note accuracy for the regulatory tests is different from overall accuracy, i.e., matching maximum concentrations versus all receptors, though both are needed to be able to show that the model generates accurate results for the right reasons, i.e., its underlying science and formulation.
- For regulatory applications, the proportionality criterion concerns whether the time and costs for applying the model are proportionate to the regulatory need. In other words, a regulatory model should not be more complex to apply or require more accuracy than is demonstrably needed for its intended regulatory application. The need for proportionality distinguishes regulatory models from models used in cutting-edge research, which may seek to be more accurate than needed for regulatory applications, with that added accuracy coming however at the cost of more time, resources and/or expertise to apply the models.
- Different criteria may apply for screening applications versus refined. For example, a more stringent requirement for accuracy for refined modeling for the annual $PM_{2.5}$standard would be expected than for screening CO, given the typical relatively small margins between background concentrations and the NAAQS for the annual $PM_{2.5}$ standard and the

relatively large margins for the CO eight-hour standard. Conversely, screening models would place a relatively greater weight on criteria related to ease-of-use and streamlining the modeling process than refined models.

Comparative Analyses: Comparative analyses are a critical element of an enhanced model validation process for transportation. They are needed to assess why one model formulation performs better than another based on a detailed understanding of the science and how the model is formulated or coded. They are critical in identifying and prioritizing needed model improvements. For regulatory applications, the model(s) must not only generate the right answers for the right reasons (as for research models) but be designed to do so efficiently and reliably (including QA/QC) by the regulated community (who generally would not have the expertise of the model developers) following applicable EPA and FHWA guidance. Comparative analyses serve to assess performance against all criteria.

Creative approaches for conducting comparative analyses may be employed to further enhance the model validation process. For example, in the interest of generating greater insights and better recommendations for model improvements, multiple consultants and agencies with expertise in project-level modeling using AERMOD might be engaged to develop <u>independent</u> assessments. After the findings and recommendations of each independent assessment are subjected to review and comment, a consensus or hybrid set of findings and recommendations for future model improvements could be developed. e.g., at a workshop or peer exchange. Matters for which consensus is not obtained could be noted, with recommendations for future research made to resolve those questions as appropriate.

Alternative models for testing generally include ones that may potentially have superior performance over the preferred model on one or more criteria (accuracy, ease-of-use etc.) for model validation. The model validation exercise therefore also serves to:

- Determine which model formulations works better for each transportation application (project type, configuration etc.) This information may then inform recommendations for the development and implementation of future model improvements for both the preferred and alternative models.
- Validate alternative models as appropriate along with the preferred model.

Stakeholder Involvement: The model validation process should be open and transparent and include extensive (3C or equivalent) consultation with all transportation stakeholders including state DOTs in addition to peer review. All stakeholders must be provided complete and timely access to all data and information (documents, procedures etc.) used in the model validation process, e.g., via a web site established for this purpose.

Determination of Model Adequacy for the Intended Regulatory Application: Consistent with the recommendations and findings of the 2007 NRC study and the 2018 EPA IG report, the model validation should include a determination of model adequacy for all regulatory applications, i.e., all typical transportation facility types, configurations, operating conditions, settings, etc.

The determination should be whether the model as applied following EPA and DOT guidance is adequate for the regulatory purpose of showing compliance with statistical confidence with the NAAQS and B/NB regulatory tests or, perhaps more commonly, whether the model may only be applied with statistical confidence with specified limitations, e.g., for one project type but not another; one test type but not another; with a receptor exclusion zone near noise walls or other barriers; with a minimum margin (in percentage and/or absolute terms) between the NAAQS and the background concentration; etc.

4.1.3 Recommendations for Enhanced Model Validation for Transportation Applications

- Develop a model validation plan (MVP) for transportation applications, generally following the principles for enhanced model validation for transportation as outlined above including field data collection and extensive (3C or equivalent) consultation with state DOTs.
  - A pooled fund approach involving EPA, FHWA/FTA, the Volpe Center, and state DOTs is recommended, e.g., following the example of the recently completed pooled fund for near-road air quality.[42]
  - The pooled fund may be carried forward to the pilot testing phase (see below) and then continue for future model validation efforts on an ongoing basis.
  - Other parties may also be interested in joining the pooled fund, for example, Lawrence Berkeley National Lab, which provided expertise and resources in field data collection for NCHRP 25-55, and/or other research institutions that have expertise in project-level air quality analyses.
- Initiate a pilot model validation study using field data for criteria pollutants as well as tracer data, based on the MVP. Field data that are currently (or soon will be) available, e.g., CalTrans/UCR and NCHRP 25-55, may be used and/or new field data may be collected for this purpose. Update the MVP as needed, informed by the results of the pilot study.
- Implement the MVP and conduct comprehensive model validation against field data for all transportation applications for which the dispersion model(s) are required for use by regulation. A pooled fund as noted above is recommended for this purpose.
  - The critical objective is to assess the model(s) for their intended regulatory purpose, which in this case is to show compliance (with statistical confidence) with the applicable regulatory tests (NAAQS and B/NB) for each NAAQS for each transportation application.
  - Update the validation periodically as appropriate, e.g., for each major update to the model for at least the specific applications affected by the update.

4.2 RLINEXT with Noise Walls

For a receptor offset distance of one meter outside the noise wall, which corresponds for example to concentrations along a bicycle/pedestrian path adjacent to the wall, modeled maximum 24-hour and annual $PM_{2.5}$ concentrations for freeway segments with noise walls for both at-grade and depressed sections are very high relative to no-wall base cases. More specifically, for certain combinations of noise wall height and distance, the modeled maximum

[42] See: http://nearroadaqpf.com/

concentrations are more than double the base case no-wall concentration. These high modeled concentrations lead to relatively small margins between the modeled design values and the NAAQS and particularly for the annual $PM_{2.5}$ NAAQS.

The modeling results therefore for both the 24-hour and annual $PM_{2.5}$ standards give rise to concern that the use of RLINEXT in regulatory applications may pose significant challenges for meeting the NAAQS for receptors near a barrier.[43] For example, margins for the annual $PM_{2.5}$ NAAQS were as low as 3.9% for cases involving a wall, which warrants serious concern particularly given that the hypothetical freeway segment was not a worst-case scenario. Other project types (not modeled here given time constraints) may be considered more worst-case, e.g., interchanges with adjacent congested intersections with high diesel truck and bus volumes, or simply a freeway segment carrying volumes higher than the 200k tested here and/or higher diesel truck volumes and may reasonably be expected to have design values that could well exceed the annual NAAQS. Further testing is needed to assess the potential for modeled exceedances for different project types and configurations. In contrast, margins for the 24-hour $PM_{2.5}$ standard were relatively high and not a cause for concern for compliance with the existing NAAQS; this observation may differ however for different project types and/or locations.

Noise Wall Height Effect on Model Maximum Concentrations

For receptors only one meter from the wall, the modeled maximum concentrations (and smallest margins) vary strongly with wall height for the three wall heights tested (15, 20 and 25 ft) for all three distances from the roadway (20, 40 and 60 ft.)

- For each distance tested, the highest maximum concentration was observed for the *intermediate* wall height of 20 ft, and the overall highest concentrations observed were for the 20 ft wall at the minimum distance tested of 20 ft. The lowest concentration was for the lowest wall height tested of 15 ft, with an intermediate concentration for the highest wall height tested of 25 ft. Further, the effect was consistent for all configurations tested, i.e., walls for one direction of links only (WB, EB, NB, and SB) and walls for both NB and SB links.
    - This observation is made in the context that the five-year wind field data set applied here include substantial components from both the south and the northwest, and receptors were placed only outside of noise walls, i.e., not between the roadway links and the wall. More investigation is needed to test the role meteorology plays in these modeled high concentrations near the wall.
- Correspondingly, the lowest margin with the NAAQS for all runs was modeled for a wall height of 20 ft for a wall located 20 ft from the roadway (travelled lanes) edge.

[43] The results presented here are for modeling one noise wall per link only, and not the new option of associating two walls with the same link provided in AERMOD v21112. The reason for this limitation is that the new option for RLINEXT with two noise walls did not work in initial testing for certain days in the five-year meteorological data set. Contradictory warning messages were received to the effect that the modeled configuration had two noise walls on the same side of the roadway link, even though the specified distances to the centerline (DCLs) for the respective walls had opposite signs in the input file.

- As only three wall heights were tested, the maximum concentrations and smallest margins may occur at a height between 15 and 25 ft and not necessarily specifically at the intermediate height of 20 ft tested here. Further testing is needed to identify the wall height for peak maximum concentrations, which may differ by project type and configuration.

Noise Wall Receptor Placement (Offset Distances): Receptor proximity to the wall had a major effect on modeled concentrations, as expected.

- For receptors only one meter from the wall, the modeled maximum concentrations were the highest and the associated margins between the design values and the applicable NAAQS the smallest.
- Receptors further offset from the wall (e.g., by more than three wall heights) resulted in lower design values and higher margins for all wall heights tested that generally correspond with modeling results for cases without a wall.

NAAQS Revisions and Trends in Background Concentrations: If updated background concentrations for both the 24-hour and annual $PM_{2.5}$ NAAQS for Virginia were applied, a wider margin between modeled design values and the applicable NAAQS would be obtained than presented here.

- However, future revisions to the $PM_{2.5}$ NAAQS could offset in whole or in part the reduced background concentrations.
- Additionally, other states have higher background concentrations and therefore would have more of a challenge in meeting the NAAQS.

For these reasons, the recent trend to lower background concentrations in Virginia specifically does not alleviate concerns with accuracy for a model for noise walls that may be applied in states across the nation.

Depressed Sections: Limited modeling was done for a depressed section, and the results were mixed:

- For a minimum depth vertical cut depressed section (following 2011 AASHTO Green Book design standards) *without* an adjacent wall, marked *decreases* in maximum concentrations relative to the no-wall base case were observed.
- In contrast, for the same depressed section *with* a nearby wall, marked *increases* in maximum concentrations were observed near the wall.
- These observations lead to the question of why the model generates high concentrations for a wall but not a depressed section, which also presents a vertical barrier to emissions from highway sources.

Recommendations:

- *Model Validation*:
  - Model validation against field data (including data "near" the wall) for AERMOD RLINEXT for a full range of typical noise wall heights and distances near highways is needed. Until this is done:
    - AERMOD RLINEXT should not be required for use in any regulatory application for transportation involving noise walls.
    - AERMOD guidance should include appropriate warnings for the use of RLINEXT for walls in non-regulatory applications, including specifically for receptors near walls.
  - Model validation against field data for depressed sections against field data is similarly needed, and particularly for cases in which there is an associated noise wall or other barrier.
- *Receptor Placement Guidance for Noise Walls and Depressed Sections*: The establishment of guidance for receptor placement near a barrier including a "receptor exclusion zone" may serve as an interim solution until the model is validated against field data. Based on the results of the model validation against field data, it may still be needed on an ongoing basis if the model is shown to overestimate maximum concentrations near barriers and that overestimation is not resolved through improvements to the model.
  - Different typical project types and configurations with a range wall heights and distances would need to be assessed to develop comprehensive guidance for receptor placement (i.e., a receptor exclusion zone) for barriers that would cover all cases.
  - Similar guidance may be needed for depressed sections with walls.
- *Depressed Sections:* Further sensitivity testing of depressed sections covering a full range of typical depths and widths should be conducted.

4.3 Source Selection (LINE, VOLUME, RLINE and RLINEXT), URBAN Setting and Szinit

LINE, VOLUME, RLINE, and RLINEXT sources were compared for an at-grade freeway segment with no barriers. Comparisons were made using the following categories for URBAN setting and Szinit: I- Non-urban with an Szinit of zero, II - Non-urban with an Szinit of 2.55, III – URBAN with an Szinit of zero, and IV - URBAN with an Szinit of 2.55. Key conclusions include:

- Modeled maximum $PM_{2.5}$ concentrations vary substantially by source, URBAN setting and Szinit, with differing but greater effect for URBAN setting and Szinit than for source.
- Key conclusions for each category include:
  - Category I (non-urban with zero Szinit):
    - This category is only included for comparison to runs with non-zero Szinit values. The use of a zero value for Szinit is *not* recommended for use by state DOTs in regulatory applications, as the potentially substantial benefit in terms of reduced estimates for near-road modeled concentrations from the use of a non-zero value would be lost.
    - Note, as use of a zero value for Szinit is not recommended, few if any projects should fall in this category.

    - For projects (if any) that do fall in this category, the use of VOLUME sources over LINE, RLINE and RLINEXT may be preferred over model validation exercises against field data to confirm its accuracy for on-road vehicles.
  - Category II (non-urban with an Szinit of 2.55):
    - Projects implemented by state DOTs may fall much more in this category than in Category I.
    - Based on the results obtained here, the use of a non-zero value for Szinit is *strongly* recommended for use by state DOTs for *all* sources in regulatory applications as the benefit in terms of reduced estimates for near-road modeled concentrations from the use of a non-zero value are potentially substantial depending on the specific value applied for Szinit.
    - The use of VOLUME sources for motor vehicles may be preferred projects in areas that have small margins with the annual $PM_{2.5}$ NAAQS, while the use of RLINE once it is made regulatory (as it is beta at present) may be preferred for areas needing to show compliance with the 24-hour $PM_{2.5}$ standard.
    - For projects in areas (if any) needing to show compliance with both the 25-hour and annual $PM_{2.5}$ standards, either may be preferred depending on the relative margins with the two standards.
    - These recommendations are made with the caveat that each source is shown in model validation against field data for transportation applications to meet criteria for accuracy.
  - Category III (URBAN setting with a zero value for Szinit):
    - As with Category I, this category is only included for comparison to runs with non-zero Szinit values. Again, the use of a zero value for Szinit is *not* recommended for use by state DOTs in regulatory applications, as the potentially substantial benefit in terms of reduced estimates for near-road modeled concentrations from the use of a non-zero value would be lost. For this reason, few if any projects should fall in this category.
    - In that context, the modeling results presented here support a *strong* recommendation for use of the URBAN setting where applicable (i.e., EPA criteria are met) for all projects for all sources.
  - Category IV (Combined use of the URBAN setting and an Szinit of 2.55):
    - Many projects in non-attainment and maintenance areas may fall in this category.
    - For projects in this category, use of the combined settings are *strongly* recommended for all sources for all projects.
    - The preferred source may differ depending on the NAAQS. For areas needing to show compliance with the 24-hour $PM_{2.5}$ standard, VOLUME, RLINE and RLINEXT (without walls) may be preferred to LINE sources. For the annual standard, RLINE may be preferred.
    - These recommendations are made with the caveat that each source is shown in model validation against field data for transportation applications to meet criteria for accuracy.

- Overall:
  - In the absence of noise walls or depressed sections, the hypothetical project would pass the current 24-hour and annual NAAQS in all scenarios tested. However, if the NAAQS were to be revised and made more stringent in the future, then this conclusion might change.
  - The results in terms of meeting the NAAQS may differ substantially for other typical transportation project types (interchanges, intersections etc.), configurations (with or without noise walls, skew angles etc.) and/or operating conditions (higher volume/ congestion and/or higher truck diesel truck and bus percentages.)
  - For both the 24-hour and annual standards, the selection of source has a relatively small effect on the margin between the design value and the applicable NAAQS compared to the effects for URBAN setting and input value for Szinit.
    - The URBAN setting should be selected wherever applicable (i.e., EPA criteria are met.)
    - The use of a non-zero value for Szinit is strongly recommended for all projects. LINE and RLINE sources both allow the optional value of zero for Szinit to be used, which results in less initial dispersion and higher resulting modeled concentrations than if a non-zero value was used. All sources (LINE, VOLUME, RLINE and RLINEXT without a wall) generate significantly lower modeled maximum concentrations for both the 24-hour and annual standards when an Szinit of 2.55 meters is specified compared to an Szinit of zero.
  - The preferred source may depend on the applicable NAAQS:
    - For the 24-hour $PM_{2.5}$ standard, VOLUME, RLINE and RLINEXT (without walls) may be preferred over LINE sources, although the effect on margins between the design values and the NAAQS were relatively small for Category IV, only about two percentage points. As VOLUME sources are the only one of these three that may be used in regulatory applications at present (as RLINE is beta and RLINEXT alpha), the use of VOLUME sources may be preferred at present.
    - For the annual standard, LINE and VOLUME sources are comparable in terms of modeled design values. RLINE and RLINEXT (without walls) are very marginally lower, i.e., by about one-fifth of one percentage point (for Category IV.) Given the increased pre-processing and run times for VOLUME sources, LINE sources may be preferred as the regulatory option at present. RLINE or RLINEXT without walls may be preferred in the future, if and when, they are made regulatory (as they are respectively beta and alpha at present.)
    - These recommendations are made with the caveat that each source is shown in model validation against field data for transportation applications to meet criteria for accuracy.

Given the differences in modeled maximum concentrations for each scenario tested here, model validation against field data is needed for all sources for the full range of typical transportation applications (project type, configuration including noise walls and depressed or elevated sections, operating condition, setting and pollutants) for which the model is required to be used in regulatory clearances. A comprehensive model validation would best support conclusions on which source is the best to use for transportation projects, which may vary by application (project type etc.)

Recommendations:

- All sources (including VOLUME sources) should be retained as options for state DOTs and other modelers to apply until model validation against field data for the full range of transportation applications has been completed.
  - For VOLUME sources, improvements in efficiency are needed for both pre-processing (as it takes significantly longer to set up VOLUME source runs than it does the other sources) and run times, which are very long compared to the other sources.
- Modelers should specify a non-zero value for Szinit following EPA and FHWA guidance as appropriate for all sources, even when it is optional (with a default of zero,) as the resulting modeled maximum concentrations for both the 24-hr and annual standards for $PM_{2.5}$ are substantially lower.
- Modelers should apply the URBAN setting for regulatory modeling where applicable (i.e., where EPA Appendix W criteria are met) for LINE and VOLUME sources, as it has a substantial effect (reducing) modeled maximum concentrations for both standards. The reduction in modeled maximum concentrations showed a relatively weak dependence on population over the range of 100 thousand to 6.2 million, for LINE sources. It should also be provided as a regulatory option (where EPA criteria are met) for RLINE and RLINEXT sources as soon as practicable.
- Based on the results of comparative analyses (see model validation recommendations below):
  - Identify advantages for each source that improve model accuracy, considering both the underlying science as well as the model algorithms or formulations, and recommend model improvements.
  - In particular, assess and implement options to improve run speeds for volume sources and RLINEXT, particularly when a barrier is specified. Run speeds for depressed sections should also be improved.

4.4 AERMOD Scenario Testing Features

Software improvements to implement features that would facilitate scenario testing with AERMOD are needed to minimize the tedious pre- and post-processing now required to conduct comparisons of modeling results between a series of runs. As AERMOD undergoes periodic updates and associated testing, such scenario testing features would significantly streamline the process and improve quality assurance and control in modeling results and comparisons.

For example, one feature that may significantly help reduce post-processing time is to designate a common output file for summary results that could be specified in the input files for individual runs, similar to what is already done for plot files.

- A run summary file could be written for each run that would contain only the results of interest, e.g., run number (or title), maximum annual $PM_{2.5}$ concentration and location (receptor ID/x-y-z coordinates), 24-hour maximum (eighth-highest), receptor ID/x-y-z coordinates, etc.
- The modeler can be provided the option of selecting which specific outputs to write to this summary output file.
- The summary file should be in comma-separated-value (csv) format to facilitate usage of spreadsheets for post-processing.
- Provision by the model of such a run summary file would eliminate the tedious manual process for modelers of looking for the maxima and their locations in existing large output files and the potential for error in that manual process. It would facilitate sensitivity studies and model evaluation efforts that involve comparisons of results from a large number of modeling runs.

A second feature would be to provide an input option to conduct scenario testing for one parameter with all other parameter inputs held the same, e.g., with user input for the parameter values or range to be tested and automatic running of the model with output to multiple output files. As a simple example, an optional SCENARIO keyword could be provided in which the user could specify the URBAN parameter to be subjected to sensitivity testing, with the range of population values and a prefix to be added to corresponding output file names specified on the same line or in a separate user-specified file, as follows:

*** Keyword*	*Parameter*	*Parameter values to be tested*	*Output file prefix, where "N" corresponds to the parameter values tested*
SCENARIO	*URBAN*	*100000 500000 1000000 … N*	*Urban_N_*

A third feature would be to include an estimated and actual run times. The estimated run time may be included with the output for runs specified as "RUNORNOT NOT" and actual run time with the output when the model is run. The run time estimate could be based on the source, inclusion of a barrier or not, number of receptors, and whatever other inputs to which run time is particularly sensitive, and be for a typical or minimum-recommended PC configuration for AERMOD modeling. For example, run times could be estimated using average RPPM values by source and configuration. This would help modelers plan runs by having at least a first-order approximation of the time needed before the run is initiated. Including actual run times with output would help with performance tracking, such as may be done in beta testing.

Recommendation: Develop and implement features to facilitate scenario testing and comparisons of modeling results between runs.

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ATTACHMENT A: Three-Dimensional Charts of Near-Road Concentrations for a Freeway Segment with a Noise Wall in Fairfax County, VA

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Three-Dimensional Charts of Near-Road Concentrations for a Freeway Segment with a Noise Wall in Fairfax County, VA

Modeling results are presented for a three-dimensional receptor grid for links oriented west-east. The 3D run was conducted for the 2D run that had the maximum modeled concentrations, which had a 20-ft wall at a distance of 20 feet from the roadway. Output for the 3D run was generated for both the annual $PM_{2.5}$ standard and the maximum eighth-highest 24-hour PM 2.5 standard. The modeling and 3D charts were generated using Trinity Breeze software for AERMOD v21112.

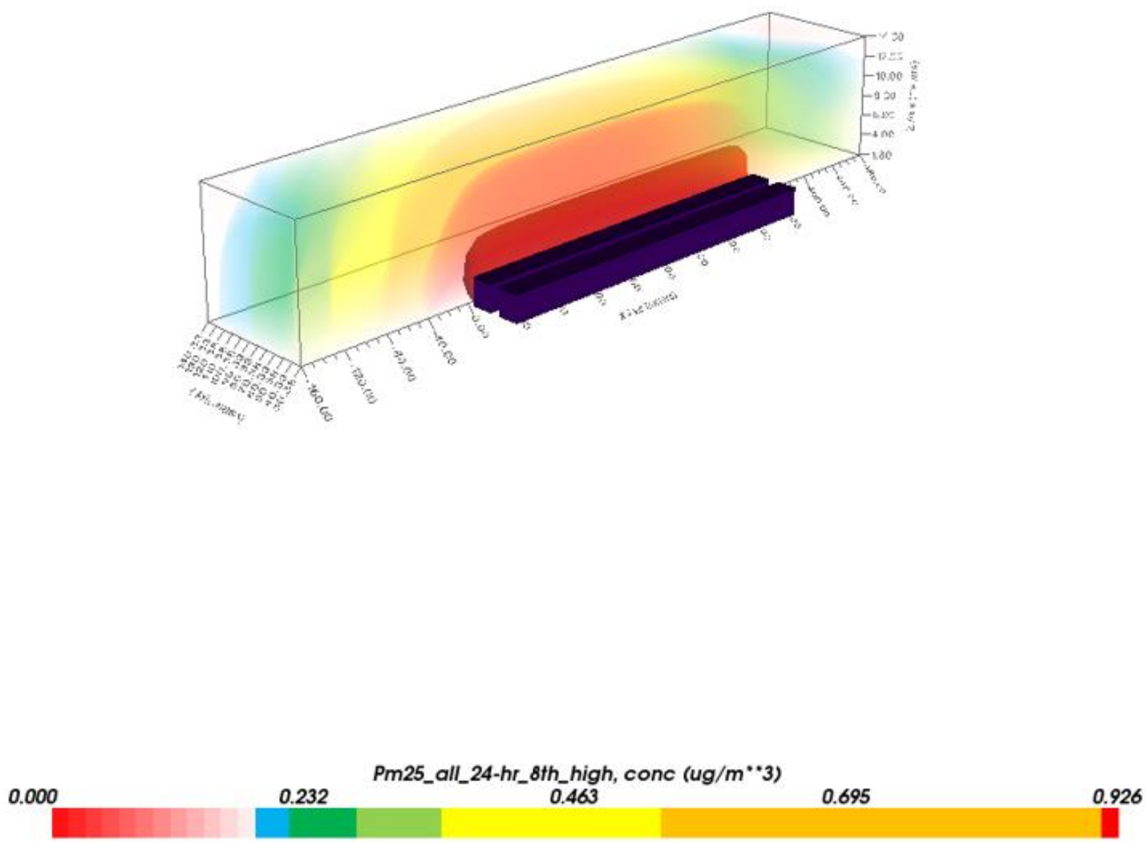

Exhibit A-89: RLINEXT 3D/Isosurface for a 20 Ft Wall @ 20 ft from the Roadway – Maximum 24 Hour $PM_{2.5}$

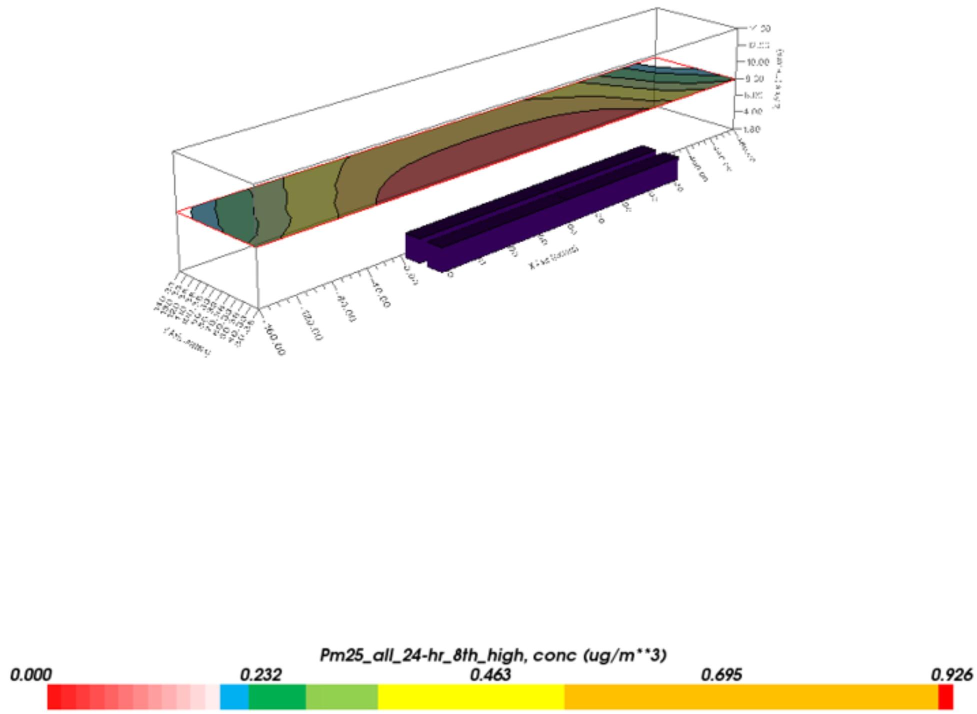

Exhibit A-90: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Maximum 24 Hour $PM_{2.5}$ *(XY Contours)*

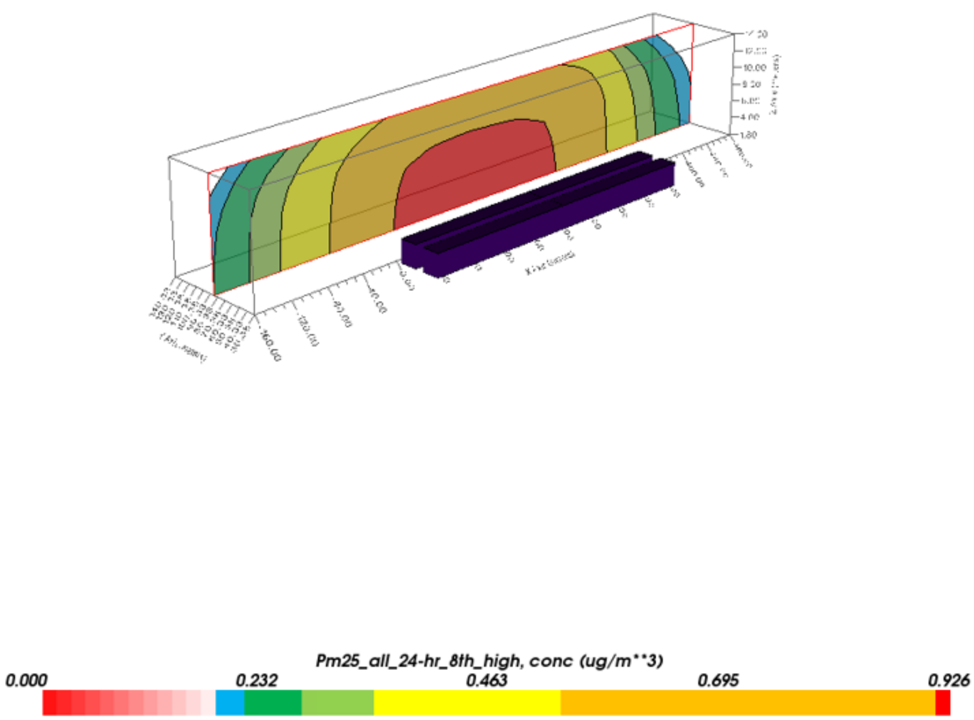

Exhibit A-91: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Maximum 24 Hour $PM_{2.5}$ *(XZ Contours)*

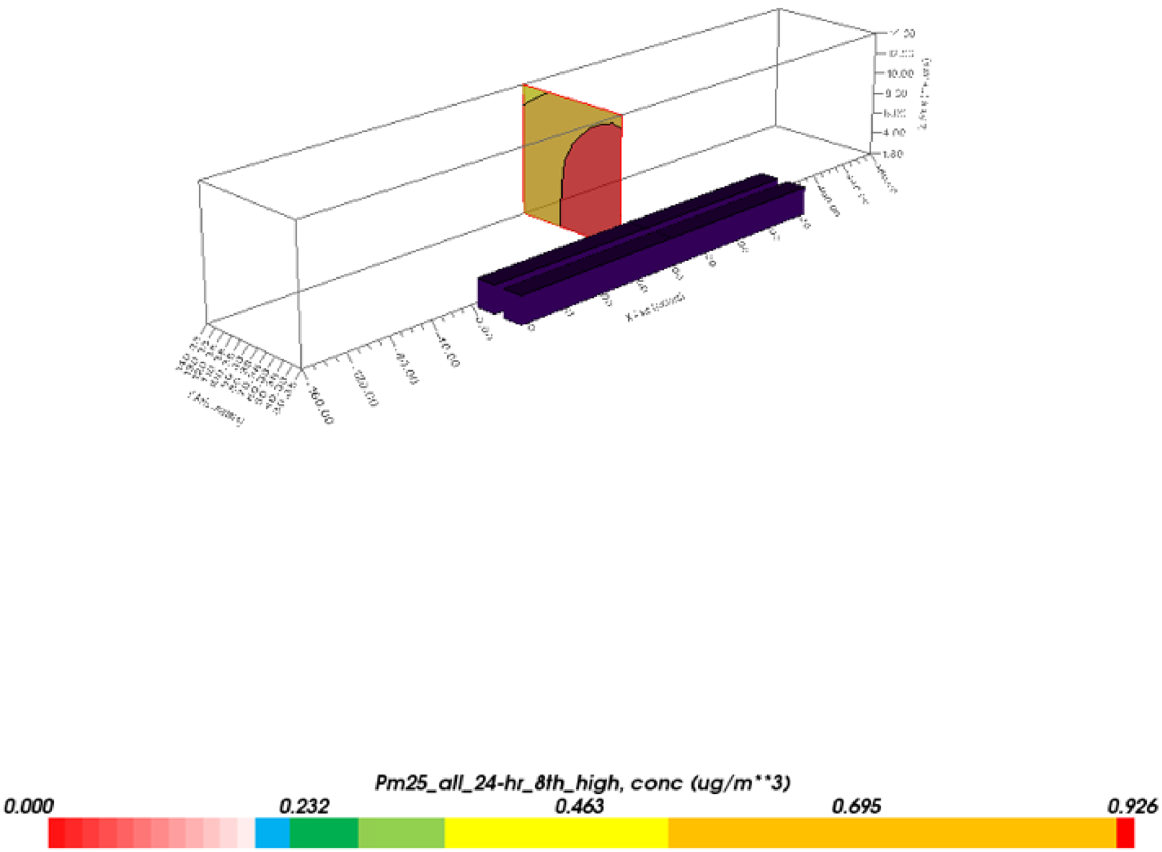

Exhibit A-92: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Maximum 24 Hour $PM_{2.5}$ *(*YZ Contours)

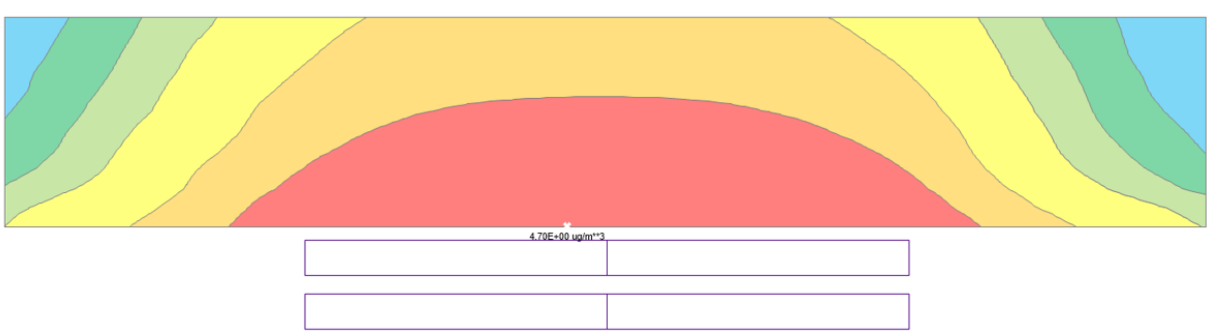

Exhibit A-93: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Maximum 24 Hour $PM_{2.5}$ *(XY Plane at Height: 1.8 m)*

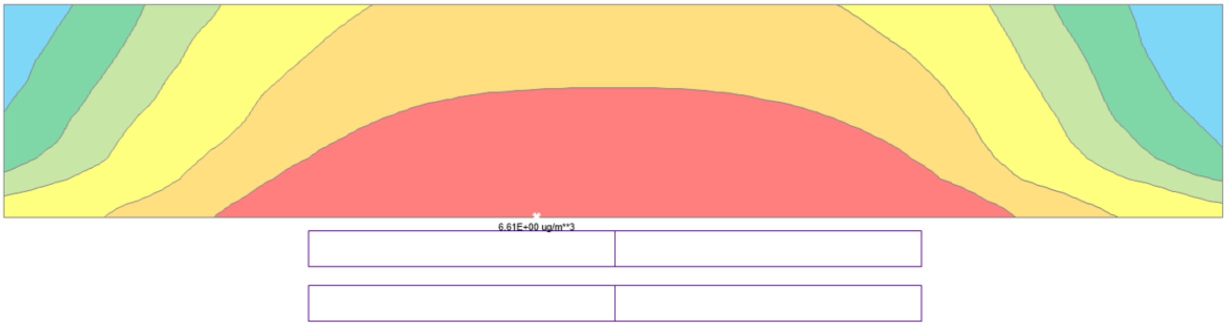

Exhibit A-94: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Maximum 24 Hour $PM_{2.5}$
*(*XY Plane at Height: 4 m)

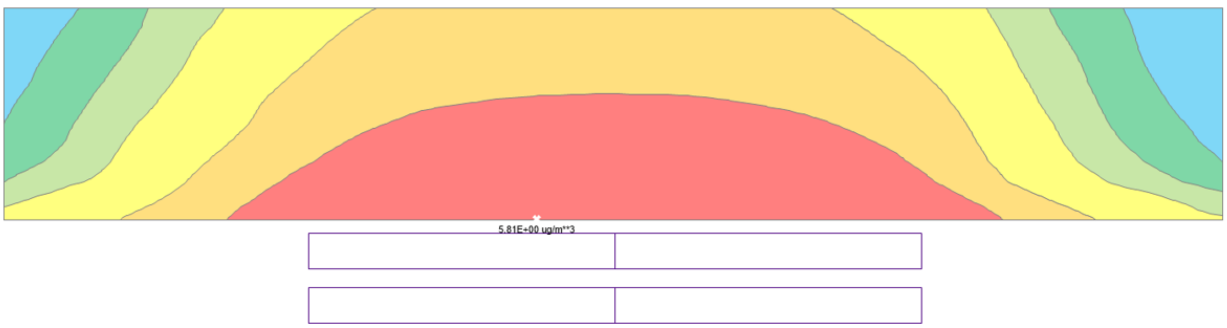

Exhibit A-95: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Maximum 24 Hour $PM_{2.5}$
*(*XY Plane at Height: 6 m)

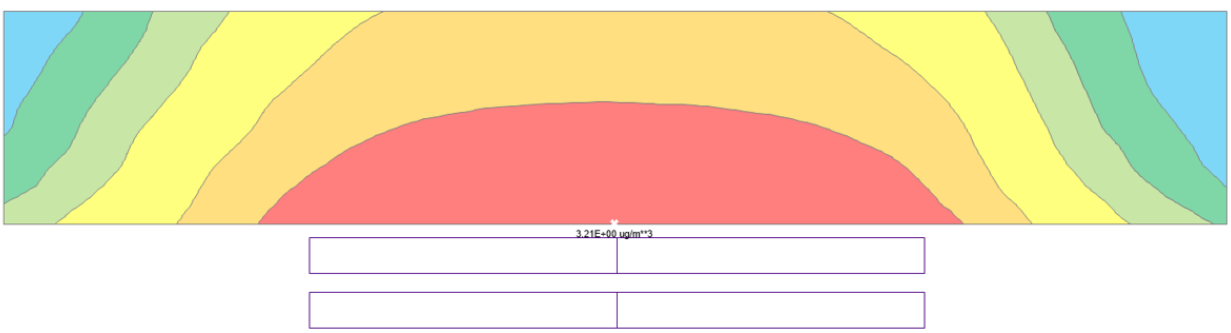

Exhibit A-96: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Maximum 24 Hour $PM_{2.5}$
*(*XY Plane at Height: 8 m)

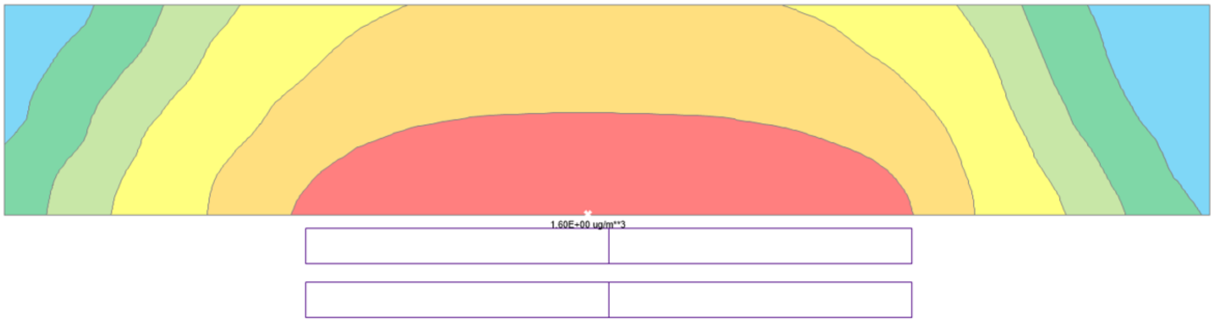

Exhibit A-97: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Maximum 24 Hour $PM_{2.5}$ *(*XY Plane at Height: 10 m)

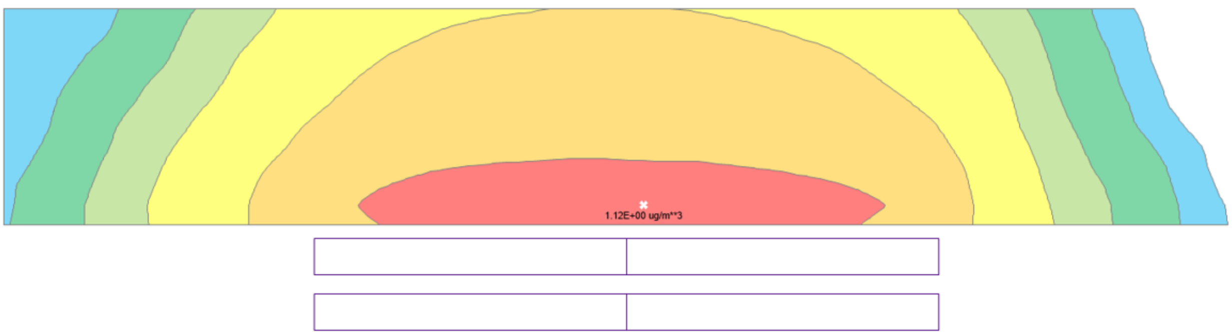

Exhibit A-98: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Maximum 24 Hour $PM_{2.5}$ *(*XY Plane at Height: 12 m)

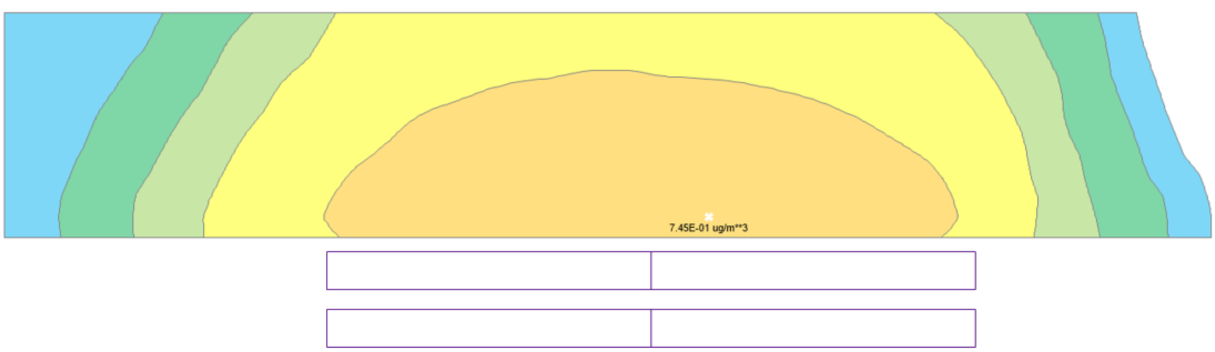

Exhibit A-99: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Maximum 24 Hour $PM_{2.5}$ *(*XY Plane at Height: 14 m)

Annual PM2.5

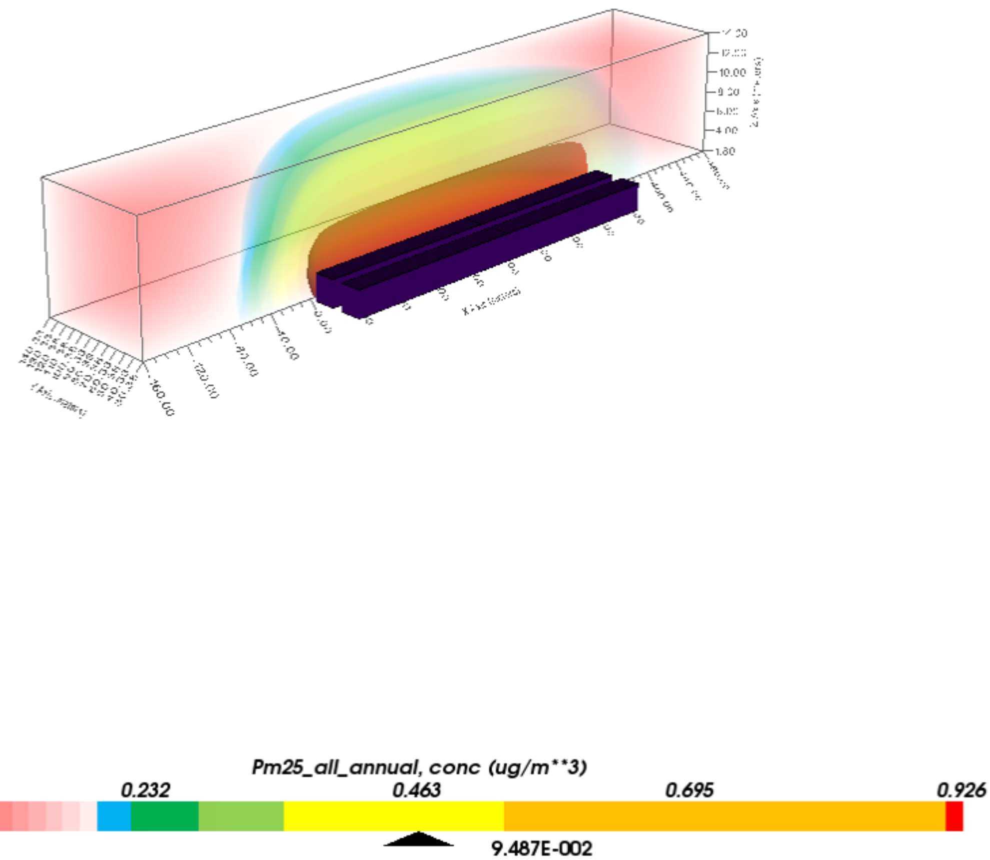

Exhibit A-100: RLINEXT 3D/Isosurface for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$

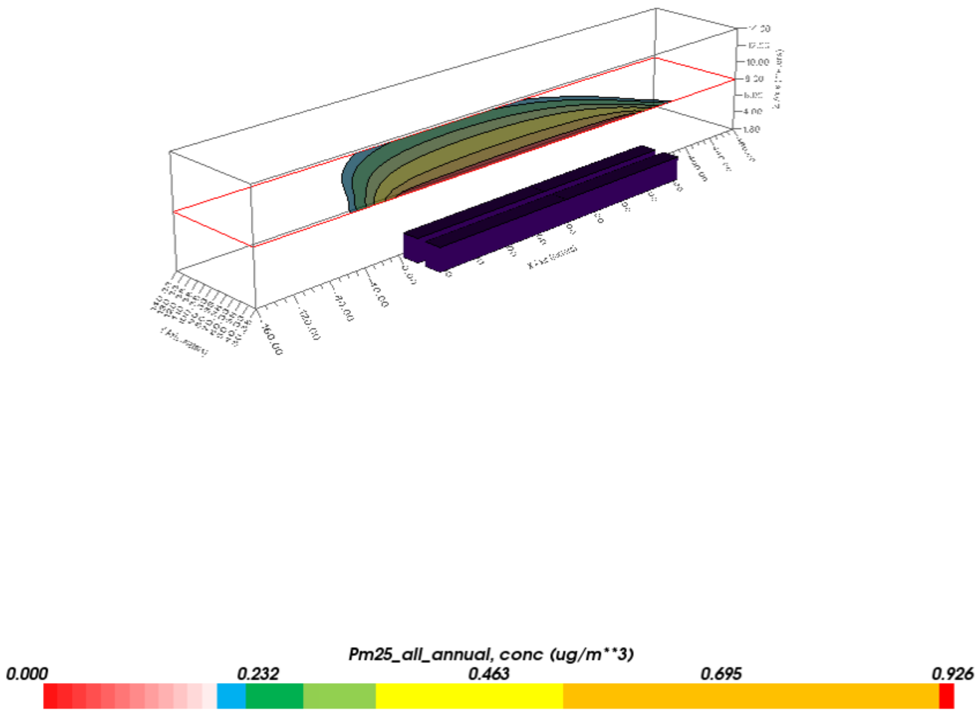

Exhibit A-101: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$ *(XY Contours)*

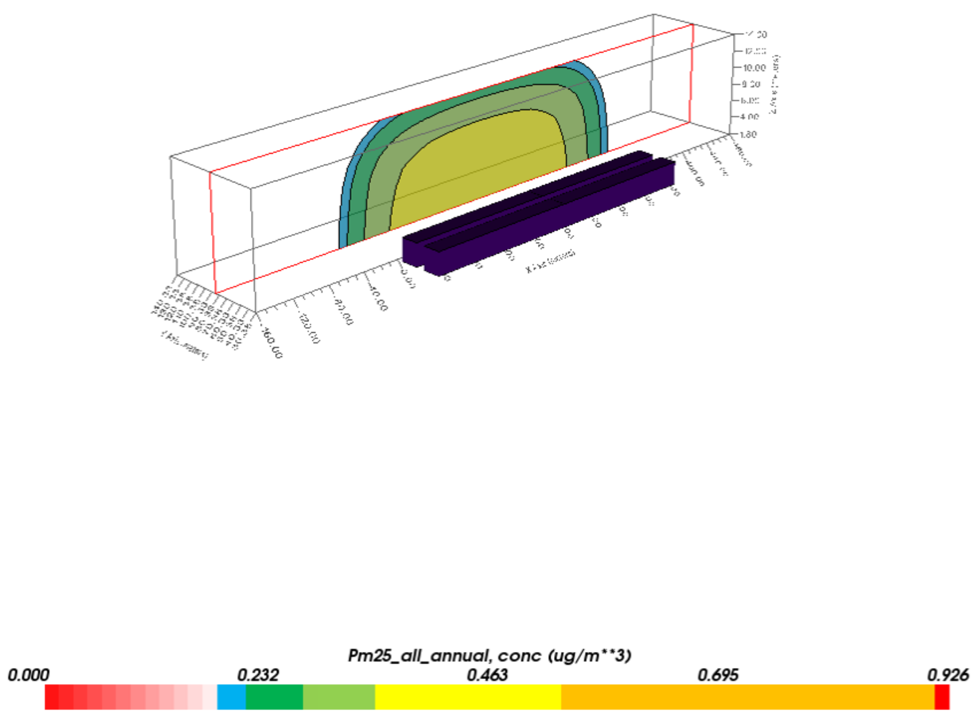

Exhibit A-102: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$ *(XZ Contours)*

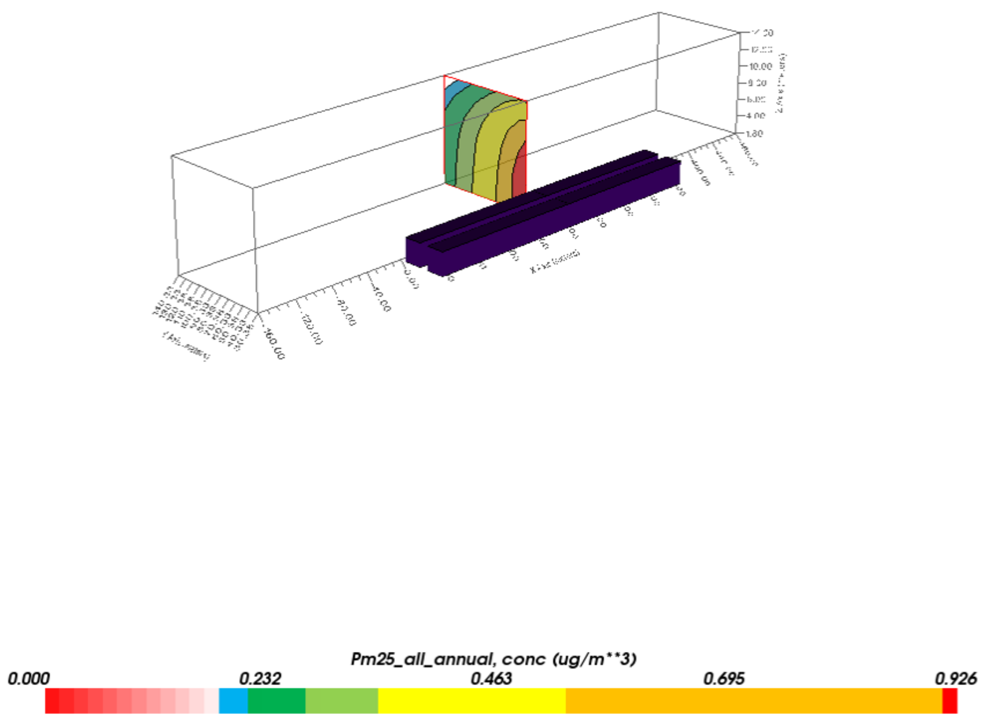

Exhibit A-103: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual PM$_{2.5}$ (YZ Contours)

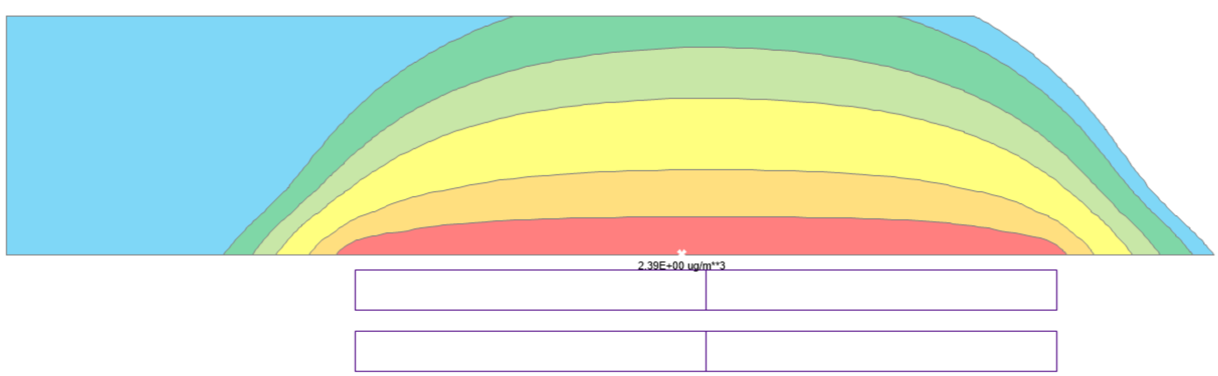

Exhibit A-104: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual PM$_{2.5}$ (XY Plane at Height: 1.8 m)

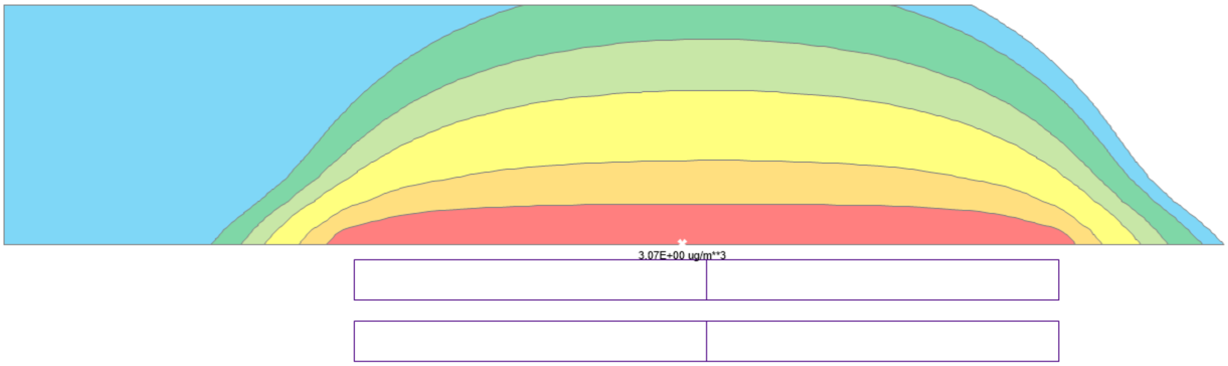

Exhibit A-105: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$ *(XY Plane at Height: 4 m)*

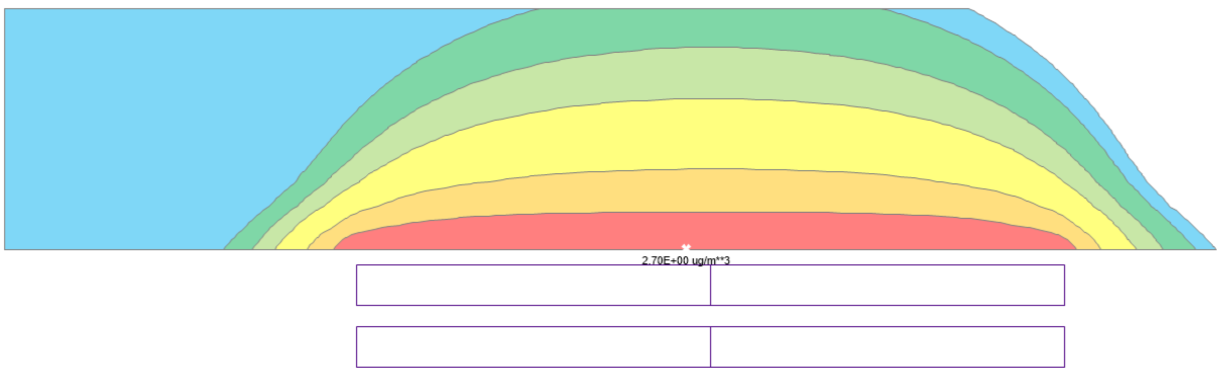

Exhibit A-106: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$ *(XY Plane at Height: 6 m)*

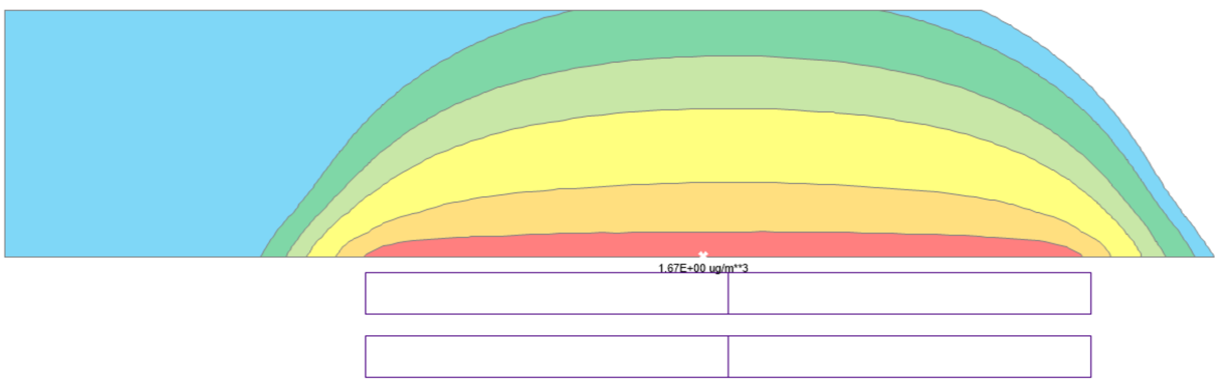

Exhibit A-107: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$ *(XY Plane at Height: 8 m)*

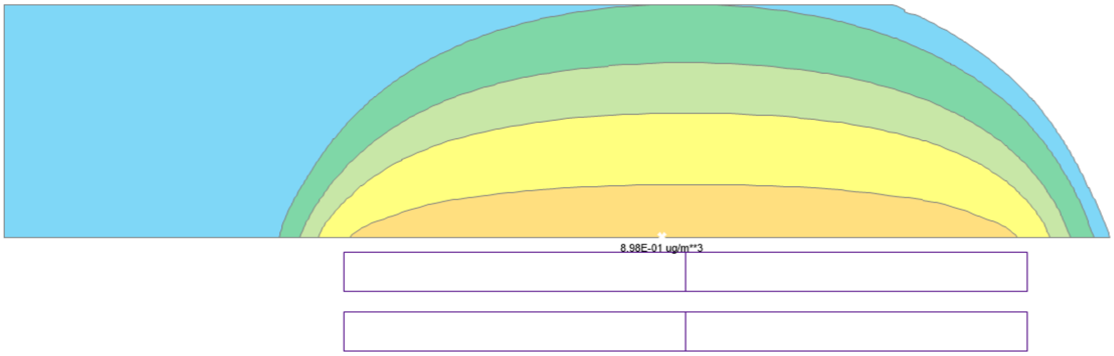

Exhibit A-108: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$ *(XY Plane at Height: 10 m)*

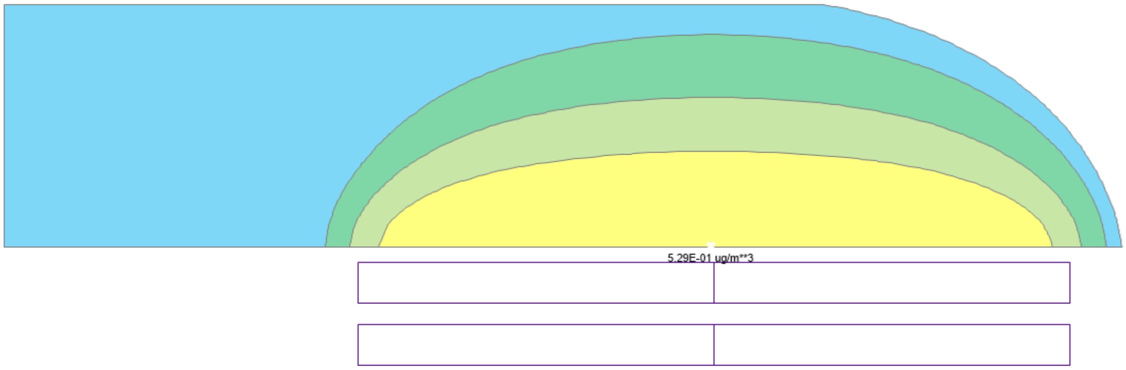

Exhibit A-109: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$ *(XY Plane at Height: 12 m)*

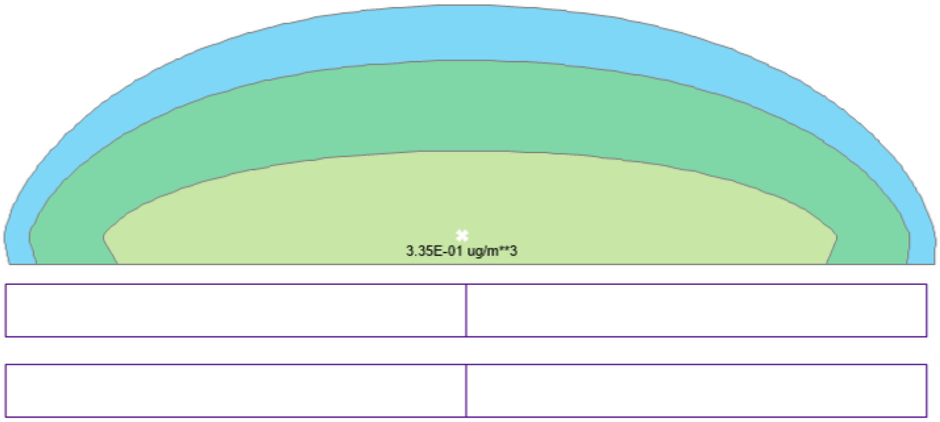

Exhibit A-110: RLINEXT 3D for a 20 Ft Wall @ 20 ft from the Roadway – Annual $PM_{2.5}$ *(XY Plane at Height: 14 m)*

ATTACHMENT B: Updated Background Concentrations

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Updated Background Concentrations

The VDOT Resource Document indicates ambient air quality monitoring data for $PM_{2.5}$ for the Loudoun County site are to be used for projects in northern Virginia outside of Arlington County or the City of Alexandria. Loudoun County data would therefore be applied for the hypothetical project for this study, which is located in Fairfax County. The exhibits below show the most recent data for Loudoun County for the 24-hour and $PM_{2.5}$ NAAQS respectively, which were taken from the most recent report on ambient air quality from VDEQ[44].

2017-2019 $PM_{2.5}$ 24-hour Averages, 98th Percentile Values ($\mu g/m^3$, LC)				
Site	**2017**	**2018**	**2019**	**3-Year Average**
(101-E) **Bristol**	16.2	14.3	13.4	15
(26-F) **Rockingham Co.**	14.6	18.4	17.8	17
(28-J) **Frederick Co.**	17.1	22.6	22.8	21
(33-A) **Albemarle Co.**	13.6	13.8	13.3	14
(19-A6) **Roanoke Co.**	14.2	15.6*	12.9	14
(110-C) **Salem**	14.0	15.3	13.2	14
(155-Q) **Lynchburg**	14.6	13.5	11.6	13
(71-H) **Chesterfield Co.**	14.6	14.1	12.4	14
(72-M) **Henrico Co.**	14.5	16.2	14.4	15
(72-N) **Henrico Co.**	14.7	14.5	13.2	14
(75-B) **Charles City Co.**	13.2	13.7	13.8	14
(158-X) **Richmond**	17.0*	19.4	19.7	19
(179-K) **Hampton**	15.5	13.4	13.8	14
(181-A1) **Norfolk**	12.7	13.8	16.9	14
(184-J) **Va. Beach**	13.5*	14.6*	17.5	15
(38-I) **Loudoun Co.**	14.2	16.6	19.8	17
(47-T) **Arlington Co.**	16.2	15.9	19.2	17
(46-B9) **Franconia, Fairfax Co.**	15.1	16.5	20.3	17
(46-C2) **Springfield, Fairfax Co.**	19.2*	19.7	25.2	21

* Annual value did not meet completeness criteria

Exhibit A-111: Background Concentrations –24-hour $PM_{2.5}$ NAAQS (Loudoun County site)

[44] Excerpted from the Virginia Ambient Air Monitoring 2019 Annual Report, VDEQ, 2020, pp.12-13. See: https://www.deq.virginia.gov/air/air-quality-monitoring-assessments/air-quality-reports

2017-2019 $PM_{2.5}$ Weighted Annual Arithmetic Means (μg/m³, LC)				
Site	**2017**	**2018**	**2019**	**3-Year Average**
(101-E) **Bristol**	7.2	6.7	6.4	6.8
(26-F) **Rockingham Co.**	6.9	6.8	7.1	6.9
(28-J) **Frederick Co.**	7.5	7.3	7.6	7.4
(33-A) **Albemarle Co.**	6.7	6.0	6.4	6.4
(19-A6) **Roanoke Co.**	6.6	6.6*	6.3	6.5
(110-C) **Salem**	7.0	7.0	6.6	6.9
(155-Q) **Lynchburg**	6.5	6.4	6.2	6.4
(71-H) **Chesterfield Co.**	7.1	6.5	6.7	6.8
(72-M) **Henrico Co.**	7.5	6.9	6.9	7.1
(72-N) **Henrico Co.**	7.2	6.7	6.8	6.9
(75-B) **Charles City Co.**	6.9	6.4	6.7	6.7
(158-X) **Richmond**	8.4*	8.2	8.4	8.3
(179-K) **Hampton**	6.6	6.0	6.3	6.3
(181-A1) **Norfolk**	6.9	6.6	7.1	6.9
(184-J) **Va. Beach**	6.8*	6.7*	6.8	6.8
(38-I) **Loudoun Co.**	7.3	7.0	7.2	7.2
(47-T) **Arlington Co.**	7.6	7.4	8.0	7.7
(46-B9) **Franconia, Fairfax Co.**	6.9	6.9	7.2	7.0
(46-C2) **Springfield, Fairfax Co.**	9.0*	8.9	9.1	9.0

* Annual value did not meet completeness criteria.

Exhibit A-112: Background Concentrations – Annual $PM_{2.5}$ NAAQS (Loudoun County site)