



Using Physical Modeling to Refine Downwash Inputs to AERMOD

The authors advocate for the use of physical modeling practices to help refine and improve downwash inputs to the AERMOD modeling tool.

Achieving compliance in dispersion modeling can be quite challenging because of the tight National Ambient Air Quality Standards (NAAQS). In addition, the tool used to evaluate ambient impacts—AERMOD—has limitations that, in many cases, produce higher than normal concentrations due to the inherent assumptions and simplifications in its formulation. In the case of downwash, the theory used to estimate these effects was developed for a limited set of building types. However, these formulations are commonly used indiscriminately for all types of buildings. Furthermore, the downwash theory used in AERMOD is more than 15 years old and has yet to be updated based on our current scientific understanding of these effects.

Downwash Effects

Building downwash is the effect that is produced by airflow over and around structures. This effect forms localized cavity zones that can readily force pollutants down to ground level and result in an increase in concentrations. In dispersion modeling these effects are accounted for by mathematical algorithms developed from field and laboratory observations. These algorithms are based on a set of assumptions and generalizations that summarize the complexity of the physical phenomena. In the case of building downwash in AERMOD and other dispersion models (e.g., ISC, CALPUFF, SCICHEM), wind tunnel testing was used to develop a set of streamlines from a limited set of building types. This information was parametrized into the Plume Rise Model Enhancements (PRIME) algorithms that calculate downwash effects in AERMOD.

The input to PRIME comes from the Building Profile Input Program (BPIP), which is a preprocessor that uses the building

inputs from a facility and summarizes them into a single rectangular building for each of the 36 wind directions. This rectangular building is fed into PRIME to develop the downwash characteristics for a specific project. BPIP and PRIME assume that the structures are angular (i.e., have sharp edges) and solid. However, if the actual structure is not solid or has no sharp corners, the theory in the model is inaccurate. That is the case for porous and streamlined structures such as tanks and hyperbolic cooling towers.

Theory Limitations in BPIP/PRIME

There are three main issues that can produce unreasonably high concentrations due to downwash in AERMOD. The first one relates to wind coming at an angle for long and narrow structures. In this case, BPIP will create an artificially large building, as shown in Figure 1. This large building will significantly increase the wake height used to calculate downwash. As shown in Figure 2, the starting point for the wake growth moves farther upwind (location A vs. location B in Figure 2), which means that the height of the wake is much taller at the lee edge of the building than it should be if the wake growth started at location B. In addition, building wake turbulence enhancement should in reality start at location C while PRIME assumes it starts at location D. This results in an overstated wake height at location D and an overstated amount of turbulence enhancement. Both of these problems will likely lead to higher ground-level concentrations than in reality.

The second issue with the current formulation in PRIME is that it assigns turbulence enhancement effects up to the height of the wake boundary, which is significantly larger for long and narrow buildings when wind comes at an angle, as shown in Figure 2. In modeling evaluations, this condition

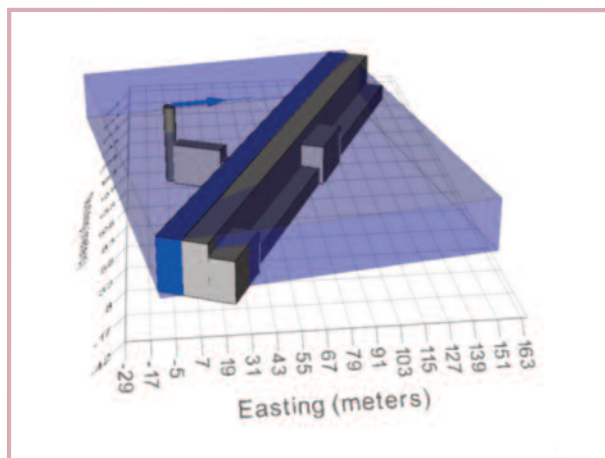


Figure 1. Artificial building (light blue) created by BPIP for a long/narrow structure when wind blows at an angle.

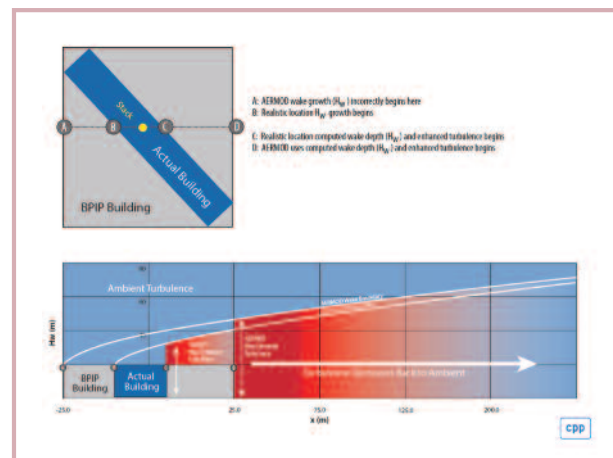


Figure 2. Wake characteristics for a long/narrow building with wind blowing at an angle based on BPIP assumptions.

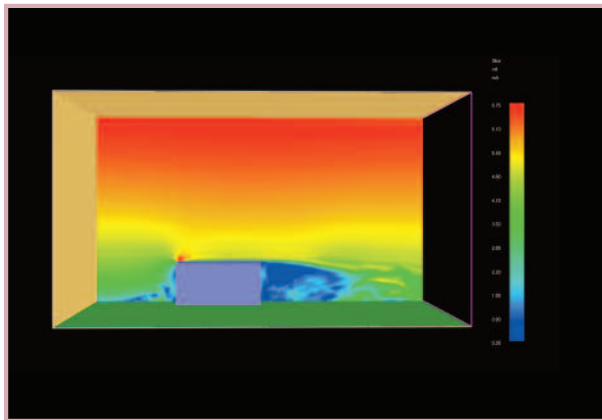


Figure 3. CFD Simulation showing mean velocities for a 1:1:2 (H:W:L) building.

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requires a much higher stack to clear that turbulent zone that will force the plume down to the ground faster than in reality. Computational Fluid Dynamics (CFD) simulations, such as the one in Figure 3, confirm the results obtained from wind tunnel testing where downwash effects extend barely above the height of the building.

The third issue relates to streamlined and porous structures which the model treats as solid rectangles. In reality, the downwash characteristics of these structures are significantly different than those for the BPIP-assumed rectangular building. For example, a building about half the height of the original structure can usually cause the same downwash effects as the porous building shown in Figure 4. These and other issues have been documented by the U.S. Environmental Protection

Agency (EPA) and others.¹ This is relevant because research performed by Petersen² and Petersen and Beyer-Lout³ has shown that AERMOD concentrations can be two to eight times higher than reality, based upon the building configuration (e.g., when the building width and/or length are greater than about 3.5 times the height).

How to Diagnose Building Inputs to AERMOD?

Among the different inputs to the model, the one that is most commonly ignored relates to building downwash. However, as described above, downwash effects can cause significant overprediction of concentrations in AERMOD. To diagnose whether downwash may be overestimating concentrations, a simple evaluation may be performed for all stacks and wind directions. The output from BPIP includes the dimensions and location of the single rectangular building that describes the downwash characteristics for each wind direction. This output can be further analyzed by calculating the ratios of BPIP-derived building width and/or length to building height. When these ratios are above 3.5, overestimations of downwash effects are commonly observed. These calculations can be done in a spreadsheet, however, there is also a free web tool (<http://www.cppwind.com/what-we-do/air-permitting/bpip-diagnostic-tool#/>) available to diagnose the magnitude of these overpredictions due to downwash. This tool generates a report indicating areas that may not accurately represent downwash effects.

Use of Wind Tunnel Testing to Correct Building Dimensions

Wind tunnel modeling remains the best available scientific tool for studying fluid dynamics in complex environments, including wind flow patterns around buildings and structures.

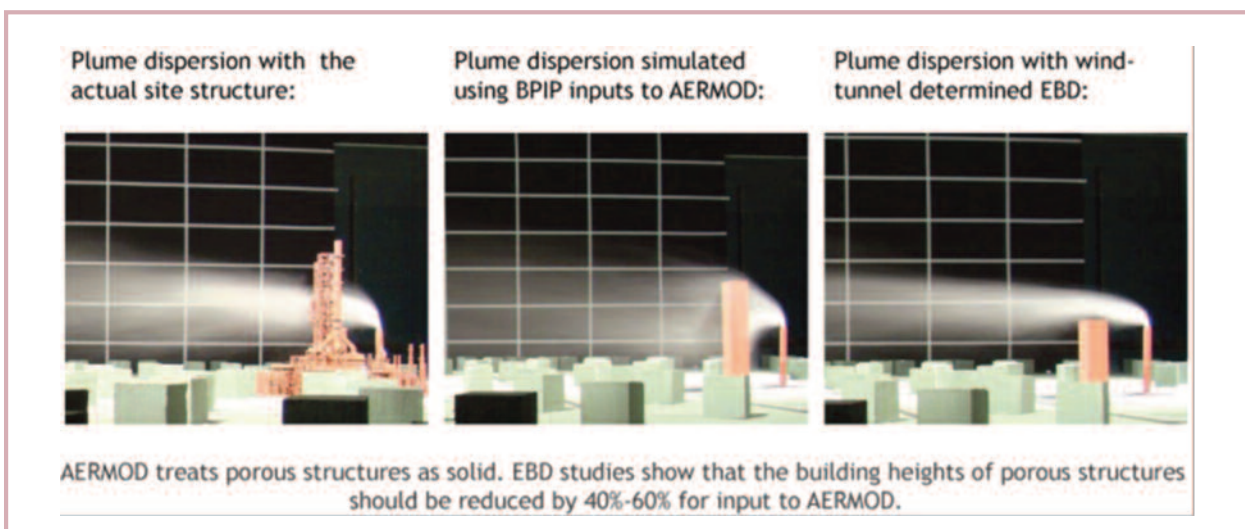


Figure 4. Downwash effects for a porous structure based on traditional and EBD methods.

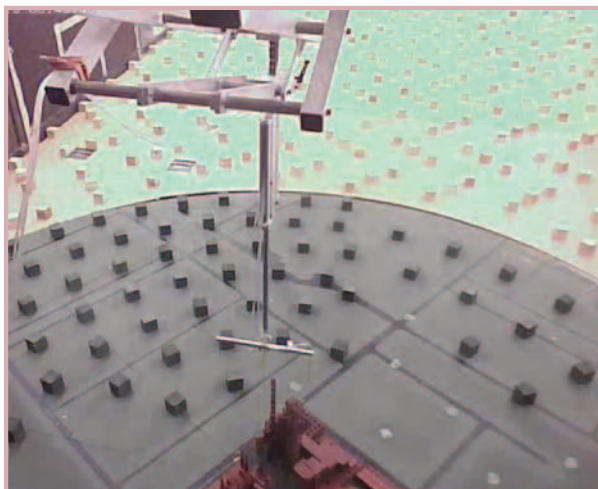


Figure 5. Automatic traverse used to measure maximum ground-level concentration profiles at different distances from the stack.

Watch the video at:

<https://www.youtube.com/watch?v=1e26mUSWdtc&list=PLn0drSQFO5tbuweUvuLXfLTmiACogUS1a&index=4>

Wind tunnel testing⁴ was used in the development of the PRIME algorithms we now use to assign downwash effects in AERMOD. This same method can also be used to determine the building dimensions that best characterize the building environment at a site. This process is more accurate because

it relies in the actual physical makeup of a site to determine downwash characteristics. In contrast, BPIP relies on a set of numerical assumptions used to average tier heights and merge buildings to determine a single rectangular building that describes each wind direction at a site.

Equivalent building dimension (EBD) studies are currently performed by first characterizing the dispersion profile characteristics at a site for each wind direction of concern. This is done by releasing a tracer from a stack, as shown in Figure 5, and measuring the maximum ground-level (MGL) concentrations downwind from each stack with an automated traverse, as shown in Figure 6. Then, the site structure is replaced by a rectangular building and its MGL concentrations are compared to those from the original site case (Figure 7). This process is repeated with buildings of various dimensions placed at different locations until acceptable agreement with the original site case is achieved.

The criteria for defining whether or not two concentration profiles are similar is to determine the smallest building which: (1) produces an overall maximum concentration exceeding 90 percent of the overall maximum concentration observed with all site structures in place; and (2) at all longitudinal distances, produces ground level concentrations that exceed the ground-level concentration observed with all site structures in place less 20 percent of the overall MGL concentration with all site structures in place. These criteria have been

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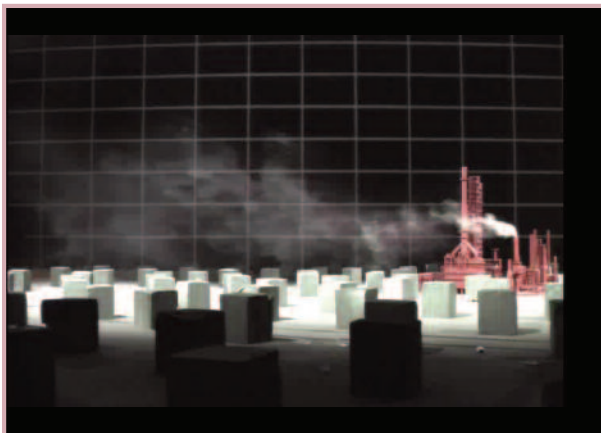


Figure 6. Smoke visualization illustrating the downwash characteristics for a site with porous structures.

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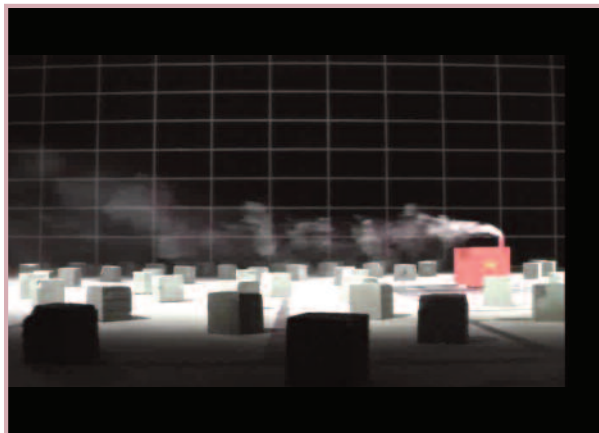


Figure 7. Smoke visualization illustrating the downwash characteristics for a test rectangular building.

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accepted on past EPA approved EBD studies⁵⁻⁸ and is a suggested approach in the Tikvart memorandum.⁹ Once these criteria have been achieved, the building dimensions from the wind tunnel analysis that best match with the original site are then used in AERMOD in place of the ones generated by BPIP for the wind direction(s) of concern. In Figure 8, the building that met the two criteria and best matched the original site case was a building of 29 m in height, 58 m in width, and 29 m in length placed upwind of the stack.

As noted in past model clearinghouse guidance⁹ on the use of EBDs in dispersion models, wind tunnel demonstrations have been used to develop appropriate building dimensions for input to the dispersion model. These simulations are not intended to replace the ambient air quality modeling based on AERMOD but rather to refine the inputs to the model. Therefore, these analyses have been classified as source characterization studies not subject to the requirements under Section 3.2 Alternative Models in the Guideline on Air Quality Models.¹⁰

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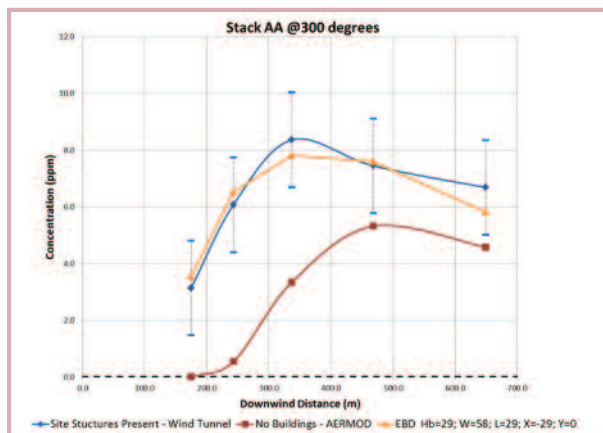


Figure 8. Sample wind tunnel results comparing the site structure, EBD, and no building profiles.

Summary

Ambient air quality standards are difficult to meet with traditional dispersion modeling techniques. Therefore, it is important to diagnose all inputs to AERMOD to better determine whether overestimations are due to limitations in the model's theory. When it comes to downwash effects, the BPIP output can be analyzed to determine whether overestimations of downwash are likely. This information can be useful in determining whether refinements on these parameters may be helpful in mitigating overestimation of concentrations. In the case of building dimensions, the use of wind tunnel testing can be a great option to determine more accurate dimensions to mitigate over-predictions in downwash. This method has been used for over two decades in regulatory modeling yielding significant savings in time and money. **em**

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