Dispersion Modeling of Mercury Emissions from Coal-Fired Power Plants at Coshocton and Manchester, Ohio

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Abstract. Mercury emissions from coal-fired power plants are estimated to contribute to approximately 46% of the total U. S. anthropogenic mercury emissions and required to be regulated by maximum achievable control technology (MACT) standards. Dispersion modeling of mercury emissions using the AERMOD model and the Industrial Source Complex Short Term (ISCST3) model was conducted for two representative coal-fired power plants at Coshocton and Manchester, Ohio. Atmospheric mercury concentrations, dry mercury deposition rates, and wet mercury deposition rates were predicted in a 5 × 5 km area surrounding the Conesville and JM Stuart coal-fired power plants. In addition, the analysis results of meteorological parameters showed that wet mercury deposition is dependent on precipitation, but dry mercury deposition is influenced by various meteorological factors.

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INTRODUCTION

Due to the impacts of mercury on environment and human health, mercury has been assigned as one of the hazardous air pollutants (HAPs) in the 1990 Clean Air Act Amendments (Kilgroe and others 2002). In addition, in February 2008, the U.S. district court required Environmental Protection Agency (EPA) to regulate mercury emissions under section 112 of the Clean Air Act which requires the application of the maximum achievable control technology (MACT) (United States Court, 2008). Of several anthropogenic mercury emission sources, coal-fired boilers account for approximately 46% anthropogenic mercury emissions in the United States (Keating and others 1997). Three forms of mercury exist in coal combustion flue gas streams: elemental mercury (Hg^0), oxidized mercury (Hg^{2+}), and particulate mercury (Hg^p). The atmospheric mercury is deposited on the soil and waterbody in the absence of precipitation (dry deposition) and by cloud microphysics and precipitation (wet deposition). While most of Hg^{2+} and Hg^p are known to be deposited on a local and regional scale, Hg^0 may transport globally due to its insolubility to water (Rice and others 1997).

According to the National Energy Technology Laboratory (NETL)'s 2007 Coal Power Plant Database (http://www.netl.doe.gov/energy-analyses/technology.html), 33 coal-fired power plants have being operated in Ohio. Dispersion modeling was conducted for the top two mercury-emitting coal-fired power plants. Atmospheric mercury concentrations, dry mercury deposition rates, and wet mercury deposition rates were predicted on a 500 m Cartesian grid up to 5 km far from those power plants. Meteorological data used in the dispersion model were analyzed to examine meteorological influences on mercury deposition rates.

MATERIALS AND METHODS

The AERMOD model and the Industrial Source Complex Short Term (ISCST3) model were used for dispersion modeling of mercury emissions from the top two mercury-emitting coal-fired power plants in Ohio in 2005. AERMOD can be used to model the local atmospheric dispersion of mercury, while photochemical models such as community multi-scale air quality (CMAQ) are typically used to simulate long-range transport and deposition of pollutants. AERMOD has been promulgated by EPA as a preferred air dispersion model to replace the ISCST3. Dispersion modeling was conducted by both AERMOD and ISCST3 model systems, and the results were compared in this study. The features of stack flue gases and mercury emission rates of those power plants were obtained from the NETL's 2007 Coal Power Plant Database and EPA's Toxics Release Inventory (TRI) database (http://www.epa.gov/triexplorer), respectively, and summarized in Table 1. In addition, AERMOD and ISCST3 model parameters are summarized in Table 2. Meteorological data were obtained from the meteorological resource center (http://www.webmet.com). Due to limitations on availability, 1990 meteorological data were used for both AERMOD and ISCST3 modeling. Considering proximity to each coal-fired power plant, Columbus meteorological data were applied to the Conesville coal-fired power plant, and Dayton meteorological data were applied to the JM Stuart coal-fired power plant. As found in the EPA report to Congress (Rice and others 1997), the mercury species in all the stack flue gases were assumed to consist of 58% Hg^0, 40% Hg^{2+}, and 2% Hg^p. The atmospheric oxidized mercury is expected to be deposited more readily than the atmospheric elemental mercury. Several parameters such as diffusivity and Henry's law coefficient are used to apply a different deposition rate for different mercury species to the AERMOD model. The level of deposition rate is also expressed in terms of scavenging coefficient in the ISCST3 model. These parameters were obtained from the literature (Rice and others 1997, Wesely and others 2002, Sullivan and others 2003, Turner and Schulze 2007, Douglas and others 2008).

RESULTS

Annual atmospheric mercury concentrations, annual dry mercury deposition rates, and annual wet mercury deposition rates were predicted on a 500 m Cartesian grid of ground level positions in a 5 × 5 km area surrounding each coal-fired power plant using AERMOD and ISCST3. Table 3 summarizes these annual values averaged for the receptor area (5 × 5 km). As shown in the table, AERMOD predicted similar levels of atmospheric mercury concentrations and dry deposition rates as ISCST3 for both power plants, but significantly lower wet deposition rates than ISCST3.

In addition, dry and wet deposition rates were determined for each month by the AERMOD model to evaluate monthly variations and meteorological effects on mercury deposition. As shown in Figure 1, both power plants show similar trends of monthly

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Table 1

Description of coal-fired power plants considered in this study

Coal-fired Power Plant	Stack Height (m)	Stack Diameter (m)	Design Exit Velocity (m/sec)	Mercury Emission Rate (kg/yr)
Conesville	137	4.3	28	446
	244	7.9	25.3	
	137	5.3	12.2	
	244	7.9	24.1	
JM Stuart	244	5.8	32.3	358
	244	5.8	32.3	
	244	5.8	32.3	
	244	5.8	32.3	

Table 2

Modeling parameters

AERMOD Site Characteristic Parameters

Parameters	Spring, Summer, Fall	Winter
Surface Albedo	0.2	0.6
Bowen Ratio	1	2
Surface Roughness	1	0.5

AERMOD Deposition Parameters

Form of Mercury	Diffusivity in Air (cm^2/s)	Diffusivity in Water (cm^2/s)	Cuticular Resistance (s/cm)	Henry's Law Coefficient ($Pa\ m^3/mol$)
Hg^0	7.23×10^{-2}	6.30×10^{-6}	1.0×10^{5}	150
Hg^{2+}	6.0×10^{-2}	3.256×10^{-4}	1.0×10^{5}	6.0×10^{-6}

	Fine Mass Fraction	Mean Particle Diameter
Hg^P	0.8	0.4 μm

ISCST3 Deposition Parameters

Form of Mercury	Liquid Scavenging Coefficient (hr/s.mm)	Frozen Scavenging Coefficient (hr/s.mm)
Hg^0	3.3×10^{-7}	1.0×10^{-7}
Hg^{2+}	2.5×10^{-4}	5.0×10^{-5}
Hg^P 0.68 μm	7.0×10^{-5}	2.0×10^{-5}
Hg^P 3.5 μm	2.8×10^{-4}	5.0×10^{-5}

variations in mercury deposition. Since similar meteorological conditions were found to be applied to these power plants, this result indicates that the dry and wet mercury deposition rates may be influenced by meteorological factors. Therefore, the effects of meteorological parameters were analyzed with respect to the dry deposition rate and the wet deposition rate, respectively. Figure 2 shows correlation of each selected meteorological parameter with the dry deposition rate and the wet deposition rate for each coal-fired power plant. As shown in the figure, while rainfall parameters have a close relationship with wet mercury deposition rate, no significant meteorological factor is found for dry mercury deposition.

To further investigate meteorological effects on dry and wet deposition, the isopleths for atmospheric mercury concentrations, dry mercury deposition rates, and wet mercury deposition rates are illustrated for the Conesville coal-fired power plant during February in Figures 3, 4 and 5, respectively. As shown in these figures, while dry deposition has similar isopleths as atmospheric mercury concentration, wet deposition is mainly found in the center of the emission source.

DISCUSSION

The average dry and wet deposition rates during each month were predicted for two representative Ohio coal-fired power plants using the AERMOD model. While similar trends of monthly variations in mercury deposition were found between two coal-fired power plants, the dry deposition rate showed a different trend of monthly variation from the wet deposition rate. These results indicate that the dry and wet mercury deposition rates may be influenced by meteorological conditions, but have different meteorological factors each other. As a result of correlation analysis with meteorological data, wet mercury deposition was found to be dependent on rainfall parameters. Hence the isopleths showed that wet mercury deposition is centered in the mercury emission source. On the other hand, a critical meteorological factor was not found for dry mercury deposition. However, the isopleths drawn for dry mercury deposition were consistent with the isopleths for atmospheric mercury concentrations. Therefore, wet mercury deposition is dependent on precipitation near the emission source, but dry mercury deposition is related to the dispersion and transport of atmospheric mercury which are influenced by various meteorological factors.

Table 3

Summary of average annual atmospheric concentration, dry deposition, and wet deposition in a 5 x 5 km area surrounding each coal-fired power plant predicted by AERMOD and ISCST3

Coal-fired Power Plant	Conesville		JM Stuart	
Model	AERMOD	ISCST3	AERMOD	ISCST3
Average annual atmospheric mercury concentration (ng/m^3)	0.036	0.085	0.014	0.041
Average annual dry mercury deposition ($\mu g/m^2$)	6.25	3.62	4.34	4.4
Average annual wet mercury deposition ($\mu g/m^2$)	0.47	5.01	0.35	13.73

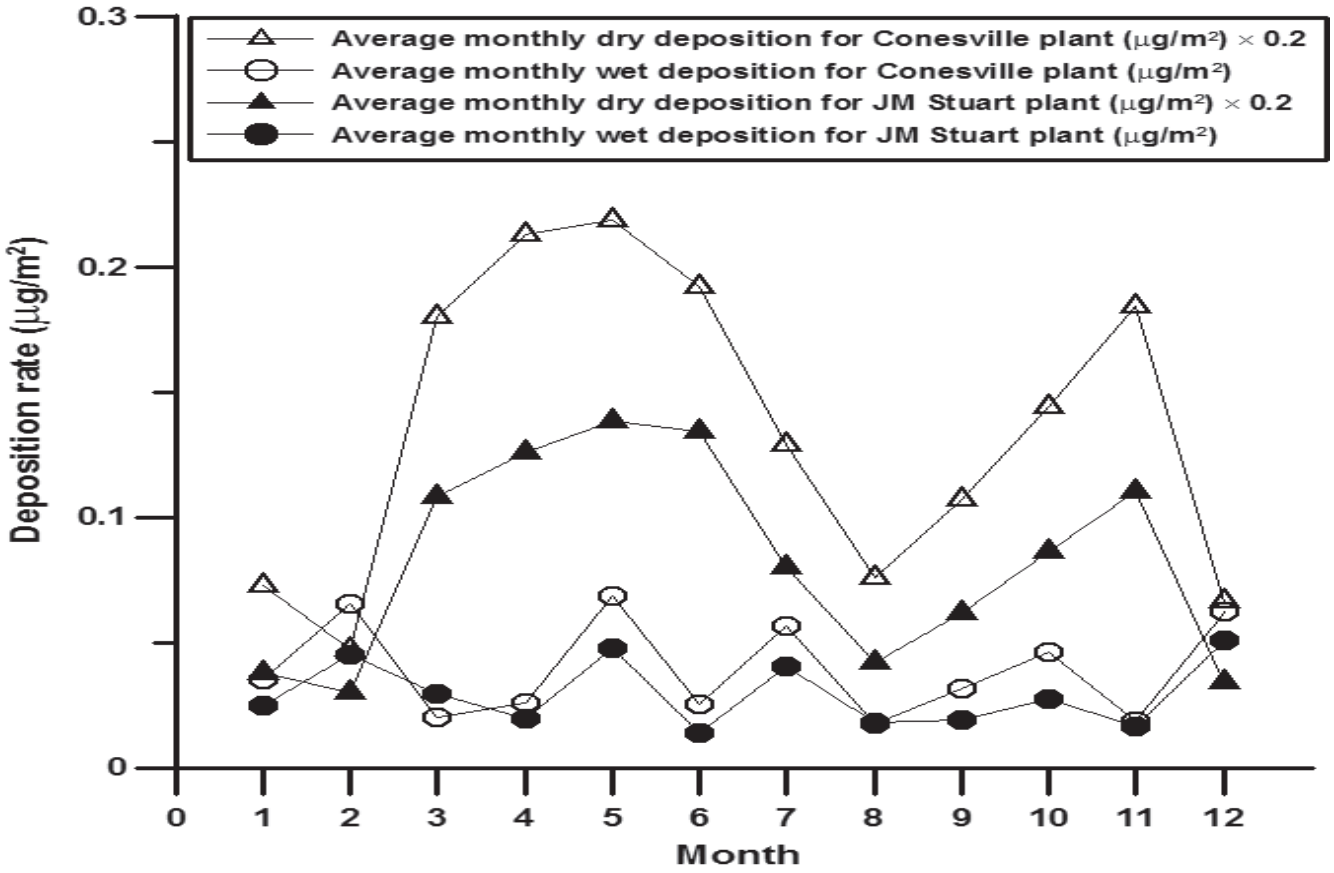

FIGURE 1. Average monthly dry mercury deposition rates (μg/m², scaled by 0.2) and average monthly wet mercury deposition rates (μg/m²) predicted for the Conesville and JM Stuart coal-fired power plants by the AERMOD model for year 2005.

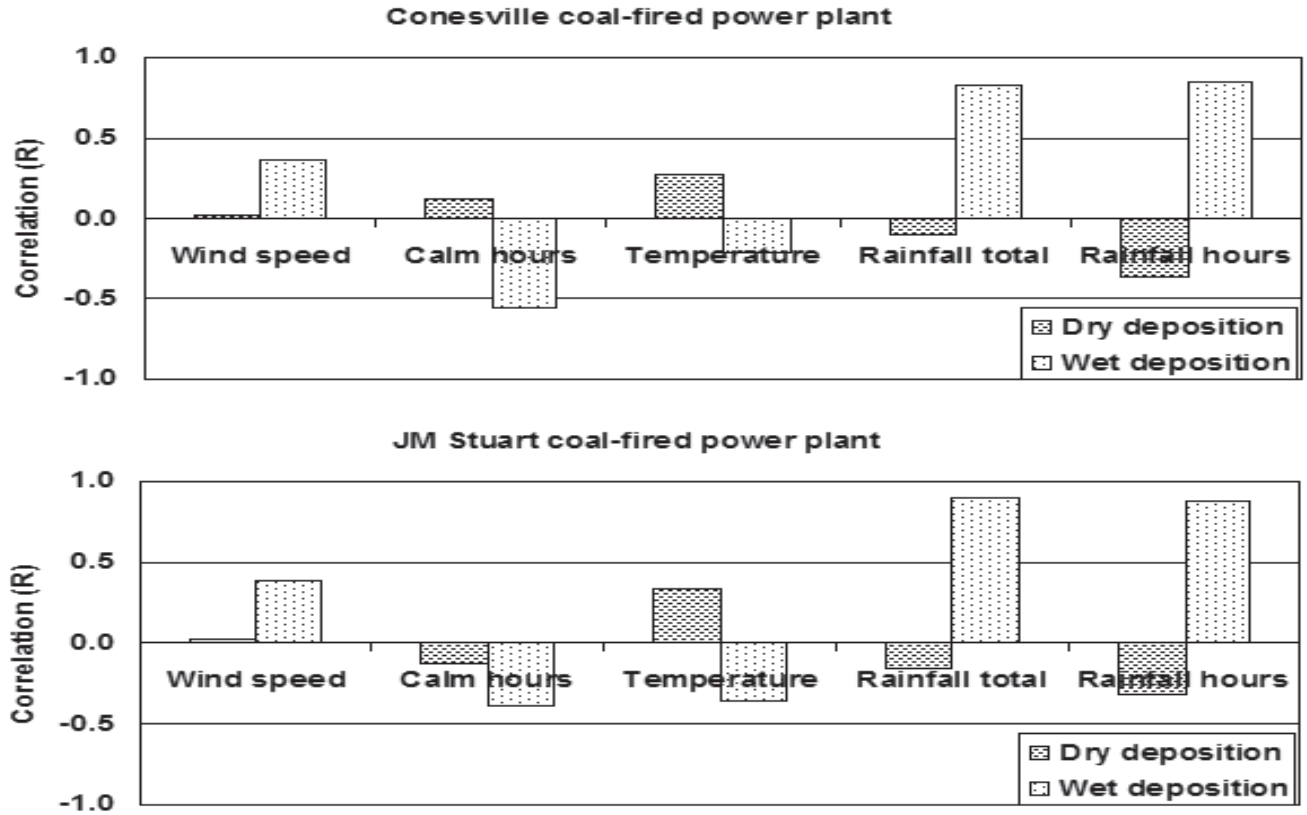

FIGURE 2. Correlation of the selected meteorological parameters with dry deposition and wet deposition for the Conesville (top) and JM Stuart (bottom) coal-fired power plants.

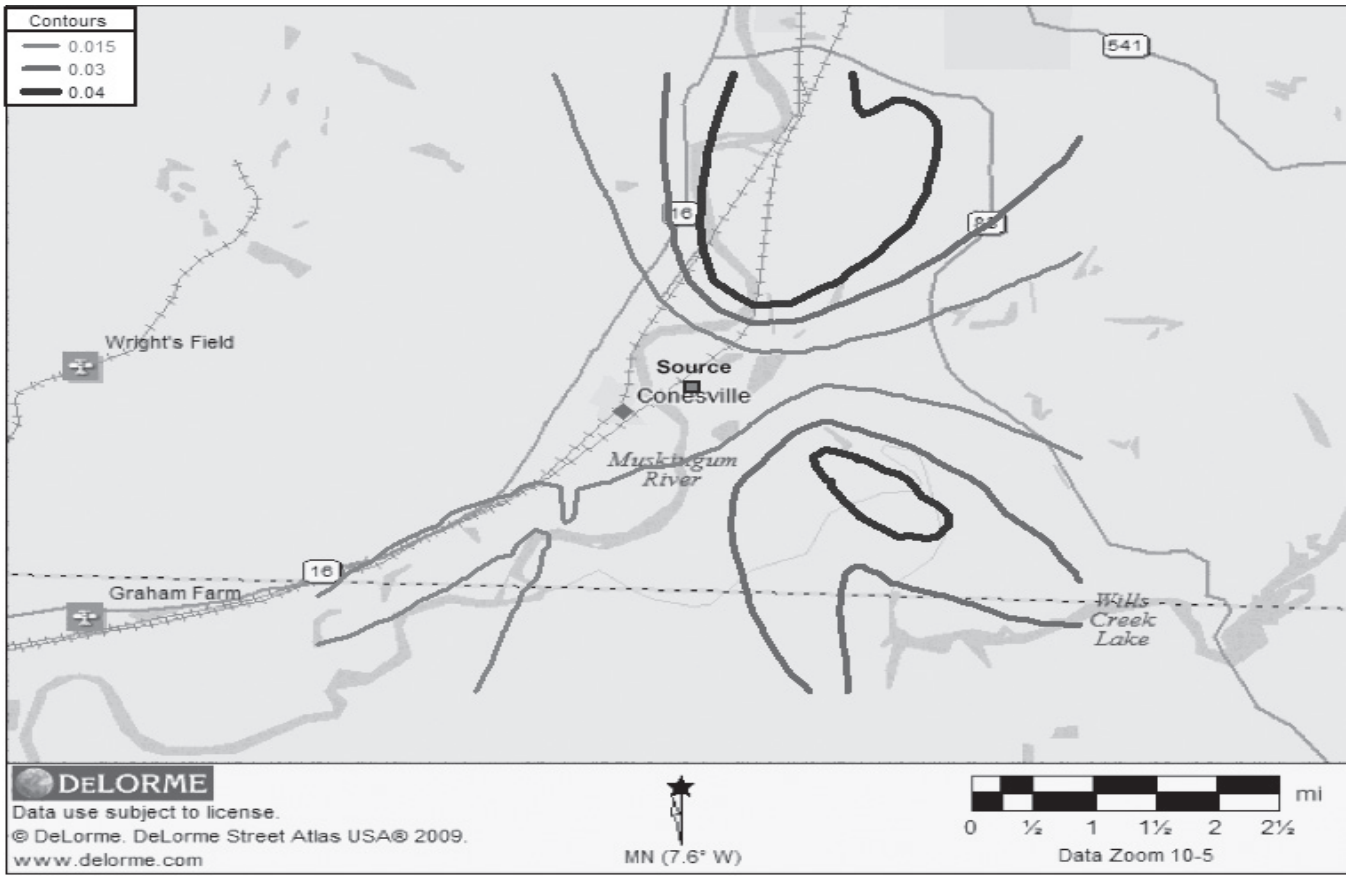

FIGURE 3. Isopleths for average monthly atmospheric mercury concentrations (ng/m^3/month) predicted for the Conesville coal-fired power plant in February using AERMOD.

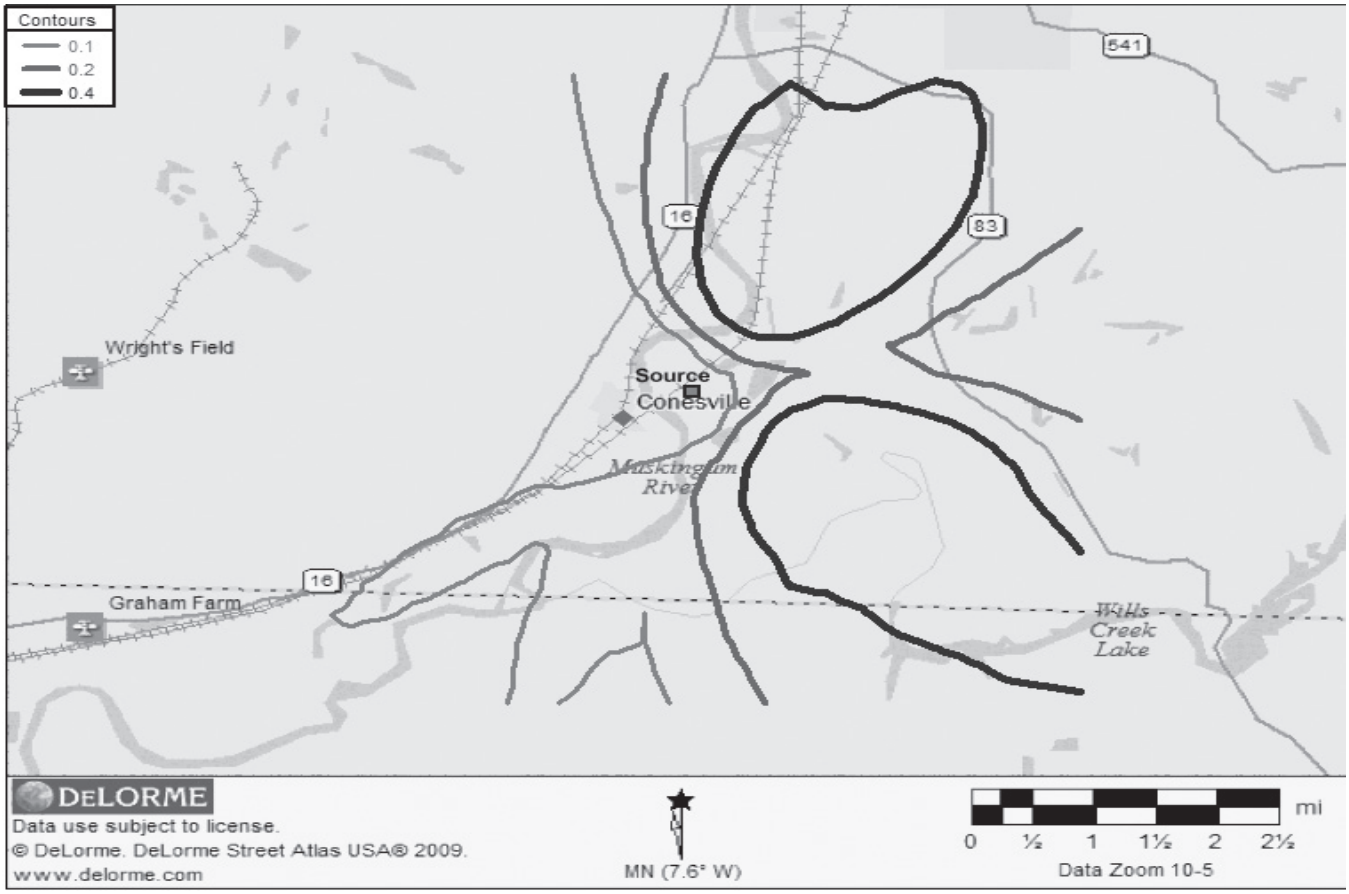

FIGURE 4. Isopleths for average monthly dry mercury deposition rates (μg/m^2/month) predicted for the Conesville coal-fired power plant in February using AERMOD.

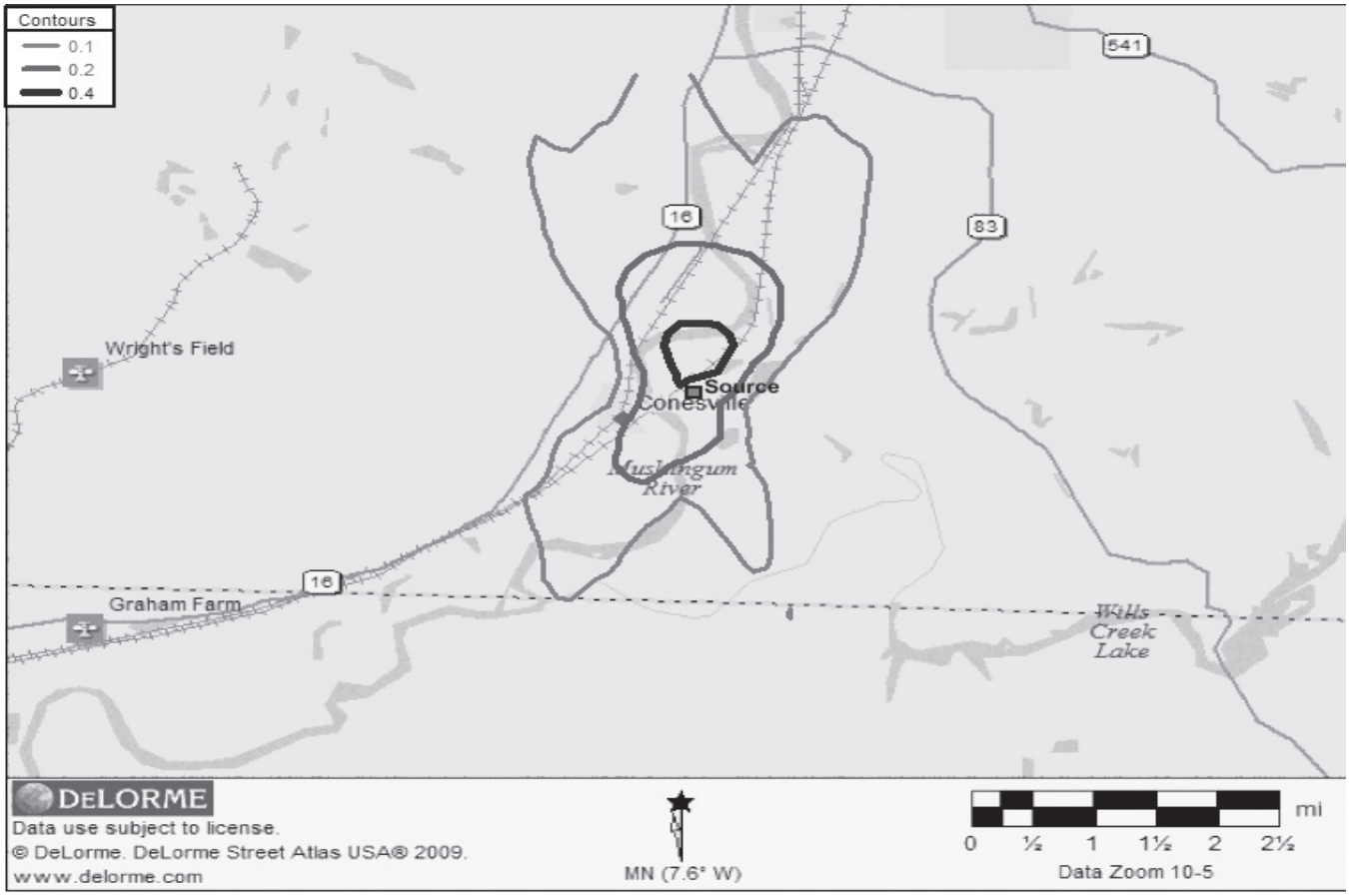

FIGURE 5. Isopleths for average monthly wet mercury deposition rates (μg/m^2/month) predicted for the Conesville coal-fired power plant in February using AERMOD.

LITERATURE CITED

Douglas S, Haney J, Wei Y, Myers T, Hudischewskyj B. 2008. Mercury deposition modeling for the Virginia mercury study. Available from http://www.deq.state.va.us/export/sites/default/regulations/documents/App_A-VDEQ_Hg_Modeling_Report_FINAL_10-20-08.pdf

Keating MH, Beauregard D, Benjey WG, Driver L, Maxwell WH, Peters WD, Pope AA. 1997. Mercury study report to congress volume II: An inventory of anthropogenic mercury emissions in the United States. Washington (DC): U.S. Environmental Protection Agency. EPA-452/R-97-004.

Kilgroe JD, Sedman CB, Srivastava RK, Ryan JV, Lee CW. Thorneloe SA. 2002. Control of mercury emissions from coal-fired electric utility boilers: interim report. Research Triangle Park (NC): U.S. Environmental Protection Agency. EPA-600/R-01/109.

Rice GE, Ambrose Jr RB, Bullock Jr OR, Swartout J. 1997. Mercury study report to congress volume III: Fate and Transport of Mercury in the Environment. Washington (DC): U.S. Environmental Protection Agency. EPA-452/R-97-004.

Sullivan TM, Lipfert FD, Morris SM, Renninger S. 2003. Assessing the mercury health risks associated with coal-fired power plants: impacts of local depositions. Proceedings of Air Quality IV Conference; 2003 Sep; Arlington (VA). Available from http://204.154.137.14/technologies/coalpower/ewr/air_quality_research/health_effects/pdfs/PRH-2_AQIV_Sullivan.pdf

Turner DB, Schulze RH. 2007. Atmospheric dispersion modeling. Dallas: Trinity Consultant, Inc. and Air & Waste Management Association. Chapter 9.

United States Court of Appeal for the District of Columbia Circuit. 2008. Available from http://pacer.cadc.uscourts.gov/docs/common/opinions/20082/05-1097a.pdf

Wesely ML, Doskey PV, Shannon JD. 2002. Deposition parameterizations for the industrial source complex (ISC3) model. Argonne (IL): Argonne National Laboratory. ANL/ER/TR-01/003.