



University Transportation Research Center - Region 2

Final Report



Modeling Emissions and Environmental Impacts of Transportation Activities Associated with High Volume Horizontal Hydraulic Fracturing Operations in the Marcellus Shale Formation



Performing Organization: Rochester Institute of Technology

May 2016



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The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the most responsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally. Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council, New York State Department of Transportation, and the New York State Energy and Research Development Authority and others, all while enhancing the center's theme.

Education and Workforce Development

The modern professional must combine the technical skills of engineering and planning with knowledge of economics, environmental science, management, finance, and law as well as negotiation skills, psychology and sociology. And, she/he must be computer literate, wired to the web, and knowledgeable about advances in information technology. UTRC's education and training efforts provide a multidisciplinary program of course work and experiential learning to train students and provide advanced training or retraining of practitioners to plan and manage regional transportation systems. UTRC must meet the need to educate the undergraduate and graduate student with a foundation of transportation fundamentals that allows for solving complex problems in a world much more dynamic than even a decade ago. Simultaneously, the demand for continuing education is growing – either because of professional license requirements or because the workplace demands it – and provides the opportunity to combine State of Practice education with tailored ways of delivering content.

Technology Transfer

UTRC's Technology Transfer Program goes beyond what might be considered "traditional" technology transfer activities. Its main objectives are (1) to increase the awareness and level of information concerning transportation issues facing Region 2; (2) to improve the knowledge base and approach to problem solving of the region's transportation workforce, from those operating the systems to those at the most senior level of managing the system; and by doing so, to improve the overall professional capability of the transportation workforce; (3) to stimulate discussion and debate concerning the integration of new technologies into our culture, our work and our transportation systems; (4) to provide the more traditional but extremely important job of disseminating research and project reports, studies, analysis and use of tools to the education, research and practicing community both nationally and internationally; and (5) to provide unbiased information and testimony to decision-makers concerning regional transportation issues consistent with the UTRC theme.

Project No(s):

UTRC/RF Grant No: 49997-29-26

Project Date: September 2015

Project Title: Modeling Emissions and Environmental Impacts of Transportation Activities Associated with High Volume Horizontal Hydraulic Fracturing Operations the Marcellus Shale Formation

Project's Website:

<http://www.utrc2.org/research/projects/horizontal-hydraulic-fracturing>

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1. Report No.		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Modelling Emissions and Environmental Impacts of Transportation Activities Associated with High Volume Horizontal Hydraulic Fracturing Operations In the Marcellus Shale Formation				5. Report Date September 18, 2015	
				6. Performing Organization Code	
7. Author(s) Dr. Karl Kortmacher (PI), Alyssa Mathews (Graduate Research Assistant) Katerijn Van Munster (Graduate Research Assistant)				8. Performing Organization Report No.	
9. Performing Organization Name and Address The Laboratory for Environmental Computing and Decision-Making Rochester Institute of Technology 65 Lomb Memorial Drive Rochester, NY 14623				10. Work Unit No.	
				11. Contract or Grant No. 49997-29-25	
12. Sponsoring Agency Name and Address University Transportation Center, Region 2 The City College of New York, Marshak 910 137th St. and Convent Avenue New York, NY 10031				13. Type of Report and Period Covered Final Report – March 1, 2014 to August 31, 2015	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract <p>Our initial UTRC research project identified routes and road segments with predicted high volumes of truck traffic related to natural gas extraction in the Marcellus Shale region. Results also generated annual estimates of pollution emissions per route and road segment related to these transportation activities. The road segment results identified areas of potentially elevated pollution emissions due to incremental truck traffic resulting from natural gas development. The current UTRC project uses these "hot spot" data as source inputs for the AERMOD pollution dispersion model to begin the assessment of potential health impacts on local populations due to increased truck traffic. Total truck traffic estimates from the PA Department of Transportation (PADOT) were also used to generate emission estimates and also input into AERMOD as a comparison dispersion analysis to help assess the relative impact of the natural gas truck activity. This report outlines the developed pollution dispersion methodology and provides results for 2011.</p> <p>Results indicate that the maximum average daily truck induced emission concentrations for PM₁₀ are 2.845 µg/m³ for the PADOT roads and 0.082 µg/m³ for the GIFT roads, the differences primarily due to overall truck counts. Subtracting the output files from the 2007 rate simulations from the 2008 rate simulations, if MY 2007 emission standards had been in place, pollution concentrations would have been reduced anywhere from 0.0625 - 0.00002 µg/m³ in the GIFT network analysis, and PADOT network reductions would have ranged from 2.1917 – 0.1165 µg/m³. Overall, however, model results suggest truck emissions are a small part of the average daily PM pollution, as determined by limited PADEP monitoring station data. In 2011, the average daily PM₁₀ emission concentrations ranged from 7.37 to 25.12 µg/m³, and 5.97 to 14.50 µg/m³ for PM_{2.5}.</p> <p>Results are considered to underestimate the true emission concentrations, however, due to temporal limitations of the truck count and total PM₁₀ emissions (both are annual values distributed evenly throughout the year as a model requirement). Despite the lower than expected concentrations, model results do highlight areas within the Marcellus Shale region that are predicted to have higher relative emission concentrations as a result of increased truck traffic related to hydraulic fracturing activities. These show where roads with higher truck counts may be impacting environmental and human health and may be used to help site monitoring stations. Using the AERMOD emission contour intervals to select 2010 US Census block data, model results suggest that over 1.2 million people are exposed at some level to elevated PM pollution due to trucks supporting gas extraction, although the vast majority of the population experiences low level exposure.</p>					
17. Key Words Hydraulic Fracturing, Marcellus Shale, Geographic Information Systems, Network Analyst, GIFT Model, Truck Transportation, Emissions, AERMOD			18. Distribution Statement		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 57	22. Price

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Executive Summary

Prior research using the GIFT model generated annual emission totals and truck count estimates for routes and road segments associated with the transport of materials and wastes from natural gas wells in the Marcellus Shale region (Korfmacher, et al., 2015 a,b). Road segments with the highest estimated truck counts (> 25,000) were identified and used to select 72 regions, represented by the boundaries of 72 USGS quad sheets, for further analysis using the emission dispersion model AERMOD. Four sets of simulations were generated for the year 2011, utilizing GIFT and PADOT road networks, modelling 2008 USEPA Average In-use Heavy Duty Diesel Engine emission rates and more stringent Model Year 2007 Heavy Duty Diesel Engine emission rates for PM₁₀. The project developed a detailed methodology for transferring shapefiles and associated emission attribute data into AERMOD compatible source files (excel format).

Results indicate that the maximum average daily truck induced emission concentrations for PM₁₀ are 2.845 µg/m³ for the PADOT roads and 0.082 µg/m³ for the GIFT roads, the differences primarily due to overall truck counts. Using the difference between the baseline 2008 rates and the target MY2007 rates, if MY 2007 emission standards had been met by the truck fleet, pollution concentrations would have been reduced anywhere from 0.0625 - 0.00002 µg/m³ in the GIFT network analysis, and PADOT network reductions would have ranged from 2.1917 – 0.1165 µg/m³. Overall, model results suggest truck emissions are a small part of the average daily PM pollution, as determined by monitoring station data (20 stations, based on PADEP records). In 2011, the average daily PM₁₀ emission concentrations ranged from 7.37 to 25.12 µg/m³, and 5.97 to 14.50 µg/m³ for PM_{2.5}.

In the PADOT analysis, the highest emissions for the AOI were seen around the major cities of Pittsburgh and Scranton and along major transportation corridors. This corresponds with the high volume of truck traffic along these corridors from both internal and out of state transportation. In the GIFT analysis, focusing on trucks supporting HVHF activities, the highest rates correspond to major roads, smaller towns such as Williamsport that act as transport hubs, and rural road segments situated around high concentrations of wells. Hotspots emerging from the two databases are useful in identifying differences in the two networks, such as small unmonitored rural roads with high truck counts, and comparative impacts, such as areas where much of the truck traffic is related to natural gas extraction activities.

Results are considered to underestimate the true emission concentrations, however, due to temporal limitations of the truck count (annual PADOT data) and total PM₁₀ emissions from the GIFT model. Both are annual totals converted to counts/emissions per second and distributed evenly throughout the year, in order to conform to AERMOD data format requirements. Thus seasonality and daily fluctuations are masked. Despite the damped concentrations, model results do highlight areas within the Marcellus Shale region that are predicted to have higher relative emission concentrations as a result of increased truck traffic related to hydraulic fracturing activities. These show where roads with higher truck counts may be impacting the environment and human health and may be used to help site monitoring stations in the future (there are very few rural air quality monitoring stations in the study area). Using the AERMOD emission contour intervals to select 2010 US Census block data, model results suggest that over 1.2 million people are exposed at some level to elevated PM pollution due to trucks supporting gas extraction, although the vast majority of the population experiences low level exposure.

The next phase of this research will use the AERMOD emission contours and population estimates as input for the computer model BENMAP CE to generate health impact and cost estimates.

Introduction

Our initial UTRC research project (Korfmacher, et al, 2015a,b) identified routes and road segments with predicted high volumes of truck traffic related to natural gas extraction in the Marcellus Shale region. Figure 1 illustrates truck counts for waste transport in 2011 and population density. The project results also generated annual estimates of pollution emissions per route and road segment related to these transportation activities. The road segment results identified areas of potentially elevated pollution emissions due to incremental truck traffic resulting from natural gas development. The current UTRC project uses these “hot spot” data as source inputs for the AERMOD pollution dispersion model (USEPA, 2013) to begin the assessment of potential health impacts on local populations due to increased truck traffic. Total truck traffic estimates from the PA Department of Transportation (PADOT) were also used to generate emission estimates and also input into AERMOD as a comparison dispersion analysis to help assess the relative impact of the natural gas truck activity.

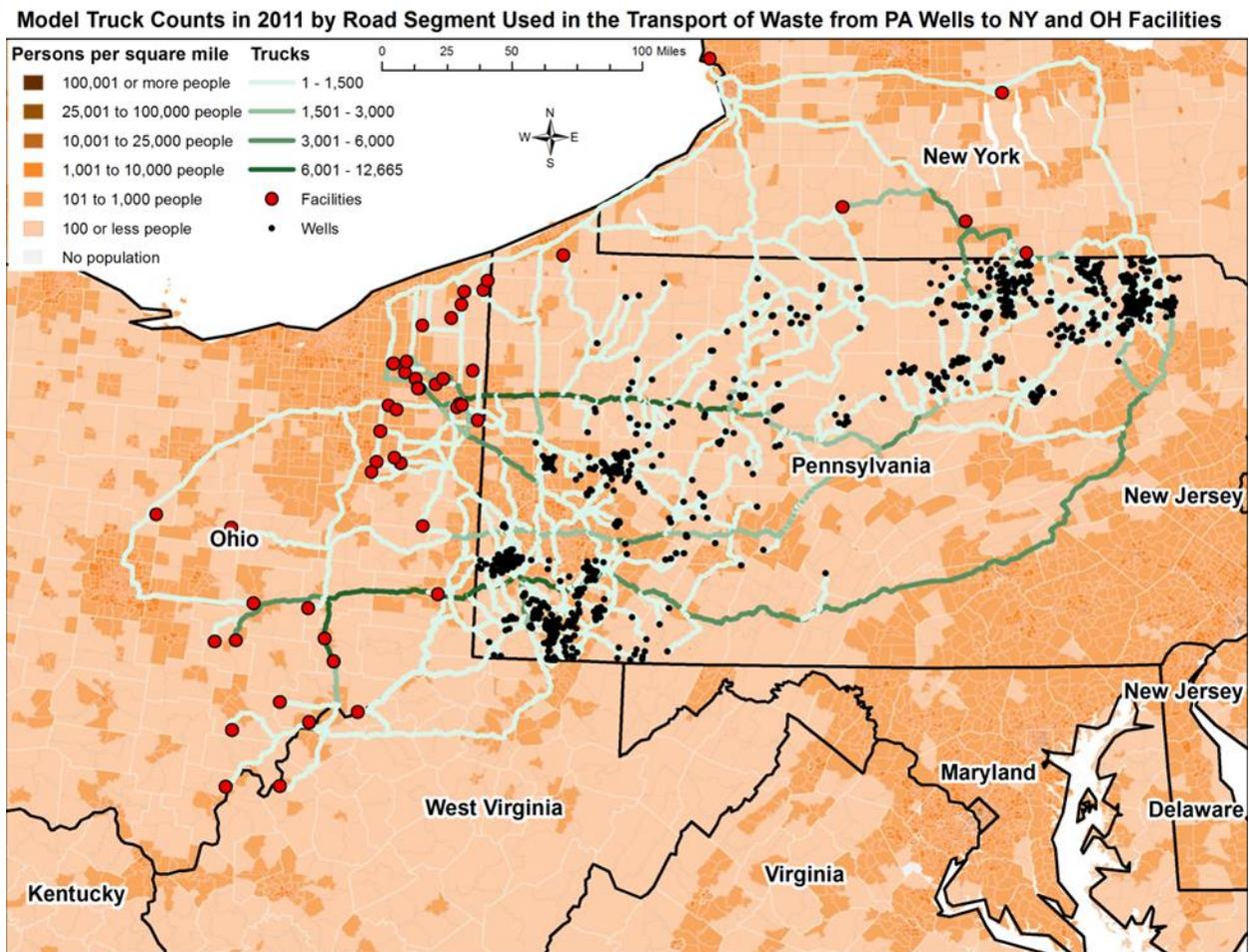


Figure 1. GIFT model results showing estimated truck counts from the delivery of waste materials from 2011 wells to disposal facilities. 2010 US Census tracts display population density surrounding these roads.

Developing and operating a HVHF natural gas well is resource and infrastructure intensive, primarily because the rural locations of the prime drilling sites require large numbers of trucks to transport materials, equipment, and wastes. Our previous research (Korfmacher, et al., 2015a,b) estimates nearly 1.7 million one-way truck trips were made delivering sand and water and removing wastes in 2011. These trips totaled over 30.2 million miles and generated over 6.6 Mg of PM₁₀, in addition to other pollutants. Table 1 summarizes the results of the 2011 emissions calculated by the Geospatial Intermodal Freight Transport (GIFT) model (Winebrake, et al., 2008). What the results of Figure 1 and Table 1 do not show is how these pollutants are dispersed over the landscape and potential exposure concentrations around road segments (based on topology and meteorological conditions). Knowing how far pollution spreads from the roadways and the concentrations of the pollution in the plumes will help researchers assess the impact on human health by linking these results to population data (2010 US Census data). This report outlines the developed pollution dispersion methodology and provides results for 2011.

With the number of gas wells expected to grow, particularly if New York eventually allows high volume horizontal hydraulic fracturing in the future, the transport of wastes and materials will also increase, along with diesel emissions. The emissions include CO₂, volatile organic compounds (VOCs), NO_x, SO_x, and particulate matter (PM₁₀ and PM_{2.5}). These emissions are linked to human health impacts, including premature deaths due to cardiovascular and respiratory issues, increased asthma rates, and lesser impacts such as eye, nose, and throat irritation (Pope, 2002; Ostro, 2004; Brook, et al., 2010; Laumbach, 2010; Gan, et al., 2011; Ristovski, et al., 2012; Fann, et al., 2013; Wierzbicka et al., 2014). Because of the truck transportation associated with HVHF, rural communities are likely facing greater exposure to these pollutants due to the high volume of truck traffic (McKenzie, et al., 2012; Finkel and Hays, 2013; Litovitz, et al., 2013). Utilizing pollution dispersion models such as AERMOD (USEPA, 2013) with the GIFT model results allows for a better spatial assessment of the potential risks these areas may experience (Heist, et al., 2013).

Table 1. 2011 pollution emissions from truck transport of PA well wastes and materials. The shaded columns represent a truck fleet meeting stricter 2007 Model Year emissions.

	TRUCKS	MILES	HOURS	ENERGY	CO	CO2	NOx	NOx	PM10	PM10	SOx	VOC
YEAR	(oneway)	(oneway)	(oneway)	(MBTU)	(Mg)	(Mg)	(Mg)	(Mg)	(Mg)	(Mg)	(Mg)	(Mg)
2011	1,698,309	30,205,955	743,656	652,449	70	52,558	260	22	6.6	1.1	0.4	13.5

METHODS

Much of the effort for this project focused on developing methodology for bringing large numbers of shapefiles and associated emission attribute data into AERMOD. At the time of this project, no versions of AERMOD contained a shapefile import option (although the model outputs shapefiles). AERMOD requires a specific data format for each type of pollution source, and the excel file format is somewhat complex. For a line volume source, which was used in this analysis, the Lakes Environmental version of AERMOD requires three lines for each record (Figure 2), complicating the development of excel macros. As a result, the research team developed a four step process for importing shapefiles and attribute data generated from the initial stage of this research project (Korfmacher, et al., 2015 a,b). A summary of the four steps is provided here, with a detailed manual provided as Appendix A.

ID	Desc	SourceID	Emission_Rate	Configuration	LineVolumeHeight [m]	PlumeWidth [m]	LineVolumeType	Num_Coords	X1 [m]	Y1 [m]	X2 [m]	Y2 [m]	X3 [m]	Y3 [m]
SLINE1		1001		1 Adjacent	8.228		11 Elevated	3	708230.86	3649734.86	708435.12	3649736.91	708447.38	3649732.53
SLINE1									Rel_Height_m	4.11	4.11	4.11	4.11	4.11
SLINE1									Base_Elev_m	0.00	0.00	0.00	0.00	0.00

Figure 2. Example of the format for a single Source Line Volume record (from the Lakes Environmental version of AERMOD). The first row of SLINE1 contains the XY Coordinates for each point in the line segment. The second row is the release height of the pollutant, and the third line is the elevation of each point in the line segment, assigned to the point by the subprogram AERMAP. The release height is a constant value. Pivot tables can easily generate the first row, but inserting the second and third rows was problematic, due to the variable number of points making up each line segment and the number of records in each shapefile. Appendix A presents a modified table for an initial import into AERMOD.

Step 1 – Creating Emission Attributes and Exporting Shapefiles Based on USGS Quadsheet Boundaries

Total truck trip counts were generated in the GIS attribute tables for each road segment of the GIFT model database (using TIGER roads) and the PADOT Road Database (using average daily truck estimates, multiplied by 365). Emission totals were calculated for each road segment (GIFT and PA) based on estimated truck counts multiplied by modeled fleet emission rates (2008 EPA Average In-use Fleet Emissions and target Model Year 2007 Emissions, both in g/mile) multiplied by the distance of the segment. This provides the total annual emissions (grams) from trucks for a given segment. GIFT truck counts were multiplied by 2 to roughly account for two way traffic, since there were no publicly available deadhead truck and trailer data for this study.

Emissions totals for PA and GIFT road segments were then converted to AERMOD emission rates (g/sec) for a given line segment by dividing totals by 31,536,000 (seconds in a year). These rate values are used by AERMOD in the line volume calculations. 2011 GIFT road segments with the highest estimated truck counts (>25,000) were selected by attribute query to identify and create a hotspot segment database. Because AERMOD is a computationally intensive program, the decision was made to limit each model run to the area of a US Geological Survey Quad. This is a modified version of the approach developed by Rowengould (2015) for the LA Basin in a separate AERMOD analysis. USGS Quad sheets containing the the GIFT hotspot segment data were selected using the Select by Location function in ArcGIS. Only PA quad sheets were retained, in order to match PA road segments (OH, NY, WV quad sheets were excluded). Individual hotspot PA quad sheets were subsequently used to select all GIFT road segments and all PA road segments intersecting the quad sheet boundaries, and the selected road segments were then exported into separate shapefiles for further processing. For 2011, the 72 PA USGS quad sheets resulted in 288 AERMOD simulations (72 GIFT 2007, GIFT 2008, PA 2007, and PA 2008 simulations).

Step 2 – Creating XY Coordinates for Each Point of a Line Feature While Retaining a Unique ID

Road shapefiles were imported into DNRGPS, a free GPS software developed by the Minnesota Department of Natural Resources (2015) (<http://www.dnr.state.mn.us/mis/gis/DNRGPS/DNRGPS.html>). Each road segment is converted into a track, using the road segment unique ID for each set of XY locations, derived from the line vertices. See pages 13-14 of Appendix A for more details and an example of the DNRGPS structure. Converting lines into a series of linked XY points is the required format for AERMOD line sources. DNRGPS files were saved as comma delimited text files.

Step 3 – Converting Text Files into AERMOD Compatible Excel Files Through Pivot Tables

Text files were imported into excel, where pivot tables are used to reformat XY coordinates and road IDs into individual row entries, similar to the first record shown in Figure 2. Detailed instructions for creating and formatting the attributes and pivot tables used in the excel files are included in Appendix A, pages 14-17. We are currently working on an excel macro to help automate these steps.

Emission rates are copied from the shapefile DBF files and added into the reformatted excel files. Unique IDs, emission rates, and XY point pairs are copied from the reformatted excel files to the Lakes Environmental AERMOD data template for GIFT and PA roadways, simulating 2007 and 2008 emission rates. Details for creating and formatting the template file as AERMOD input files for GIFT and PA 2007 and 2008 emission models are included in Appendix A, page 18. Each simulation used a plume height of 6.99 meters and a plume width of 8.6 meters, generated by the Haul Road calculator in AERMOD, using a truck height of 4.11 meters and a width of 2.6 meters.

NOTE: The format created in Step 3 is not the official format for a line volume source, as described by Lakes Environmental, but a simplified format used to import the positions and assigned emissions of each road segment. The official line volume format (Figure 2) requires three rows of input for each record (emissions, elevation, and release height), but the three rows per record format complicates the pre-processing of the shapefile data in excel. We correct for this format in Step 4.

Step 4 – Using AERMOD to Correctly Format the Source Files for Use in Excel

The simplified format AERMOD excel sheets are imported as sources into AERMOD, as outlined on page 21 of Appendix A. Once imported, the files are processed through the remaining project set up steps, as outlined in Appendix A. Loading the terrain data and running the AERMAP module will import the elevation data and update the source base elevations (the third row of the record in Figure 2) from the default value of 0.0 to a georeferenced elevation (Appendix A, pages 28-29). This step will also update the receptor elevations.

At this point, the AERMOD project is essentially complete, except for needing to update the source release height values from a default value of 0.0 to the calculated value of 3.49. Going back to the Sources window, the user needs to export the current sources to a new excel worksheet. AERMOD will automatically format the file to have three rows per record. Open the file in excel and highlight the columns showing a release height of 0.0. With only those columns highlighted, use **Replace All Values** to update 0.00 to the correct value of 3.49. It is critical to have the correct columns highlighted to limit the replace operation. Otherwise, any 0.00 within the database will be replaced with 3.49, including coordinates. Re-import the updated excel sheet through Sources in AERMOD to complete the project.

Creating Shapefiles and Rasters of Emissions for use with Population Data

AERMOD projects based on the 72 quad sheets were run in batch mode using the Lakes Environmental Batchter program, optimized for eight cores. Each project took 3-26 hours to run, depending on the terrain and road complexity. Once complete, the generated emission dispersion contours are displayed in common concentration increments set to a standard legend and palette (0.001, 0.01, 0.05, 0.1, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 $\mu\text{g}/\text{m}^3$) and then exported to shapefiles. Surfer format grid files were also exported.

The individual shapefiles from the four simulations (GIFT 2007, GIFT 2008, PA 2007, PA 2008) were clipped to the boundaries of their primary quad sheet and then merged to form four emission dispersion files at 1:24,000 scale (the resolution of the DEMs). Surfer files (raster format) were merged using a mosaic command in ArcGIS. Because vector shapefiles are more compatible with census polygon data, the shapefile output was ultimately used in the final analysis. Raster output from AERMOD was also limited to a 200x200 pixel resolution in this version of the Lakes Environmental software (each pixel is roughly 300 x 300 meters) creating overly generalized output from the USGS quad sheet extents. The raster images were used to calculate emission reductions between the EPA Average In-Use Fleet baseline (2008) and the target MY 2007 fleet (control) emission rate simulations.

Final shapefiles were used to select US Census TIGER Block data and summarize population counts within each contour interval. Blocks were assigned to a contour if their centroid intersected with a given contour. This avoided double counting blocks that intersected multiple emission contours and assigned a polygon's population to the dominant emission contour. Splitting block polygons by the emission contours and weighting population counts by area was considered, but ultimately rejected, due to uncertainty about population distributions within census polygons.

RESULTS AND DISCUSSION

Figures 3 and 4 illustrate the estimated annual truck counts of the GIFT and PADOT databases used in this analysis. Figures 5-8 show the results of the four AERMOD simulations for the 2011 truck traffic analyses. AOI regions 1-3 were identified by quad sheets containing GIFT network road segments with annual truck counts greater than 25,000. The AERMOD results show the usefulness of this type of modelling approach to identifying emission impacts, even with the temporal limitations due to the use of annual traffic and pollution databases.

Overall, the MY 2007 results for both the GIFT and the PADOT databases (Figures 5 and 7) illustrate the potential pollution reductions of PM₁₀ emissions if all trucks in 2011 met the more stringent emission standards set by EPA. This contrasts with the calculated emissions using EPA estimates of the truck fleet's average in-use emission rates from 2008 (Figures 6 and 8), which simulates an older, mixed age fleet (EPA, 2010). The difference between the 2008 baseline and the MY 2007 control emission rates show GIFT reduction ranges from 0.0625 - 0.00002 µg/m³, and PADOT reduction ranges from 2.1917 – 0.1165 µg/m³ for the 2011 analyses. In the PADOT analysis, the highest emissions for the AOI were seen around the major cities of Pittsburgh and Scranton and along major transportation corridors. This corresponds with the high volume of truck traffic along these corridors from both internal and out of state transportation (Figure 4). In the GIFT analysis, focusing on trucks supporting HVHF activities, the highest rates correspond to not only major roads, but smaller towns such as Williamsport that act as transport hubs and rural road segments situated around high concentrations of wells (Figure 3).

From an environmental health perspective, none of the simulations seem to indicate significant risks due to elevated PM₁₀ concentrations from truck traffic. From the emission contour shapefiles, the highest average daily simulated emission concentration was 2.845 µg/m³ for the PADOT roads and 0.082 µg/m³ for the GIFT roads. Using the 2008 EPA emission rates as a guide (USEPA, 2008), 92% of PM₁₀ is PM_{2.5}, so calculated average daily maximum PM_{2.5} concentrations are 2.617 µg/m³ for PADOT and 0.076 µg/m³ for GIFT. Figure 9 shows average daily background PM₁₀ and PM_{2.5} levels from PADEP monitoring stations in 2011, indicating that the average daily PM₁₀ emission concentrations ranged from 7.37 to 25.12 µg/m³, and 5.97 to 14.50 µg/m³ for PM_{2.5}. Model results therefore indicate that the majority of the PM pollution, as reported by the PADEP monitoring network in 2011, originates from sources other than trucks. The contour areas generated by AERMOD associated with the highest emission impacts were also quite small, 75.50 ha or 0.29 mi² for the GIFT network (Figure 6) and 7.54 ha or 0.03 mi² for the PADOT network (Figure 8).

Figures 9-18 highlight differences between the two transportation databases. While overall emissions from the GIFT simulations are lower due to lower truck counts, areas of relatively higher emissions due to HVHF truck traffic are identified in this analysis. Often, they coincide strongly with higher emission areas shown in the PADOT comparison image (see Figures 11, 12, 17-19), suggesting higher proportions of the PADOT counts and associated emissions are due to HVHF truck traffic. In areas where the GIFT network differs from the PADOT network, such as the western part of Blossburg (Figure 10), higher emissions are linked to HVHF traffic alone. These can be used to help locate potential air quality monitoring sites for more in depth analyses of HVHF trucking emission impacts, relative to overall truck and vehicle traffic. Figures 13-16 show overall truck traffic emissions dwarfing HVHF traffic impacts.

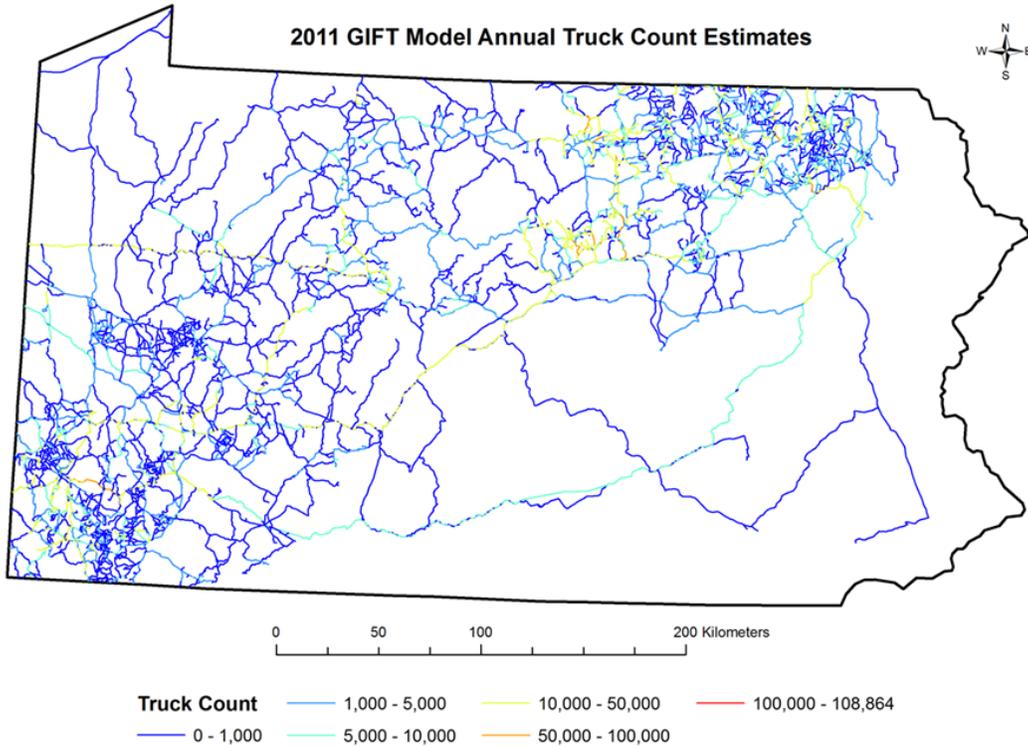


Figure 3. 2011 GIFT transportation network with annual truck count estimates for trucks transporting sand, water, and waste related to HVHF activities.

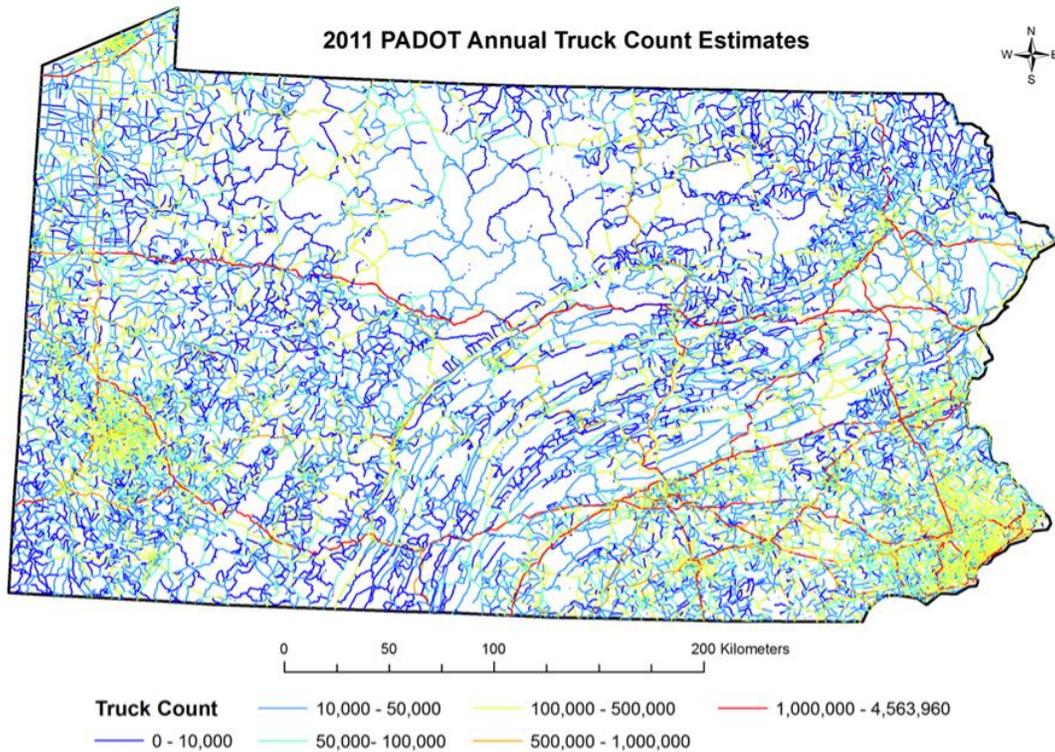


Figure 4. 2011 PADOT transportation network with annual truck count estimates for all truck activities.

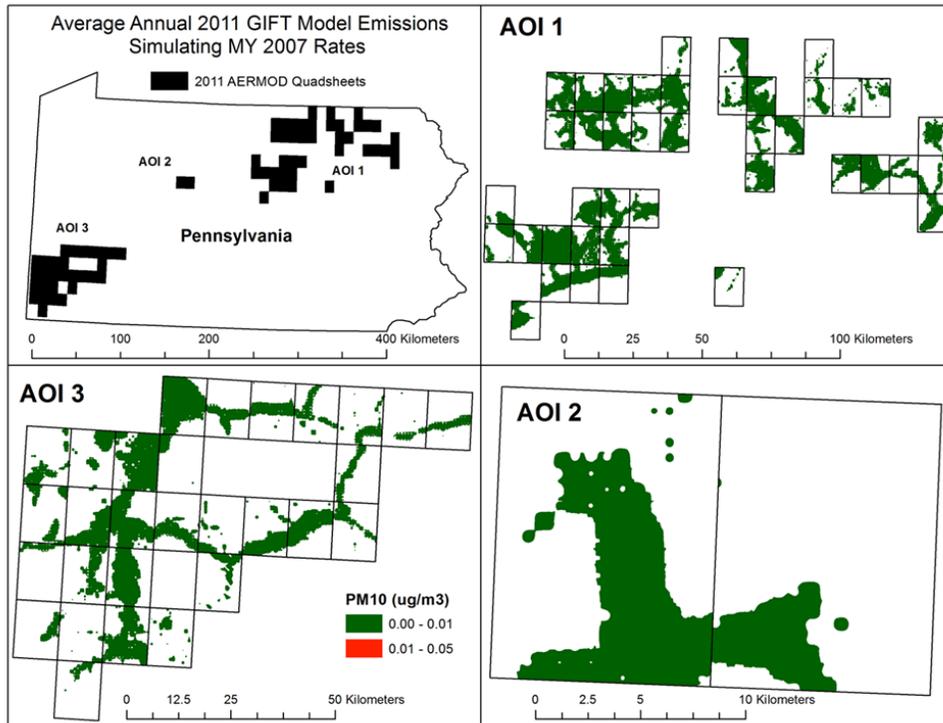


Figure 5. 2011 GIFT average daily emission concentrations of PM₁₀ (µg/m³) from HVHF truck traffic generating Model Year 2007 emission rates (0.036 g/mile).

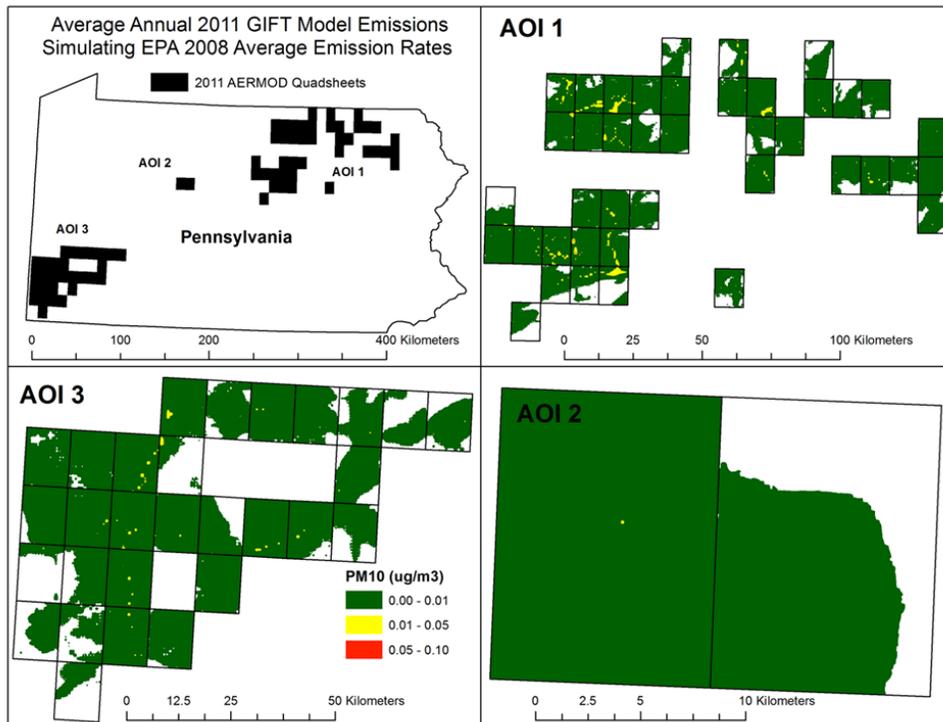


Figure 6. 2011 GIFT average daily emission concentrations of PM₁₀ (µg/m³) from HVHF truck traffic generating 2008 USEPA Average In-use Heavy Duty Diesel Emission Rates (0.219 g/mile).

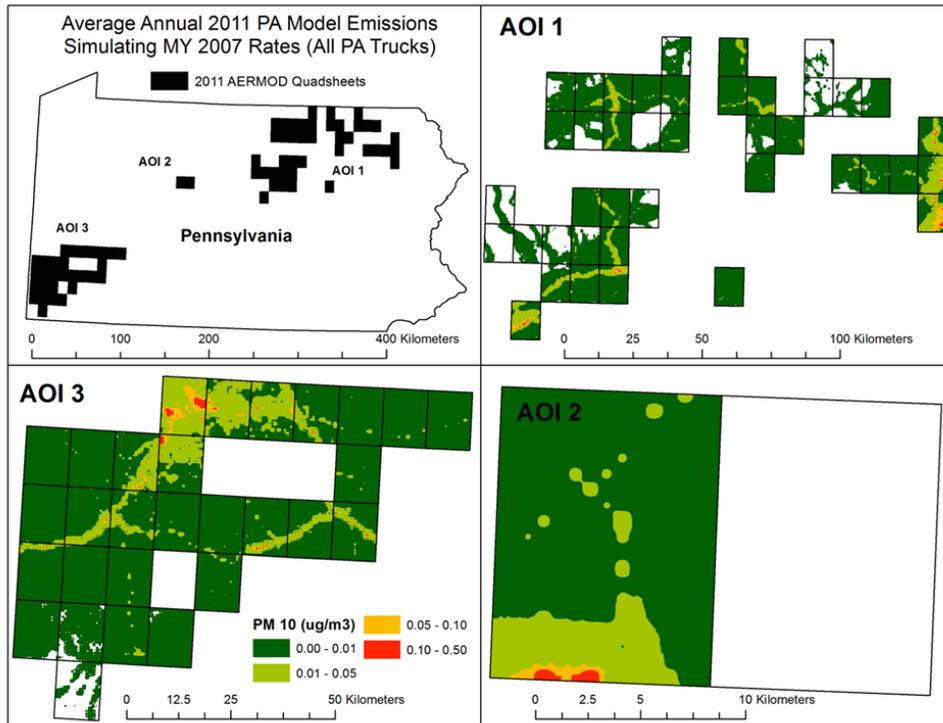


Figure 7. 2011 PADOT average daily emission concentrations of PM_{10} ($\mu g/m^3$) from HVHF truck traffic generating Model Year 2007 emission rates (0.036 g/mile).

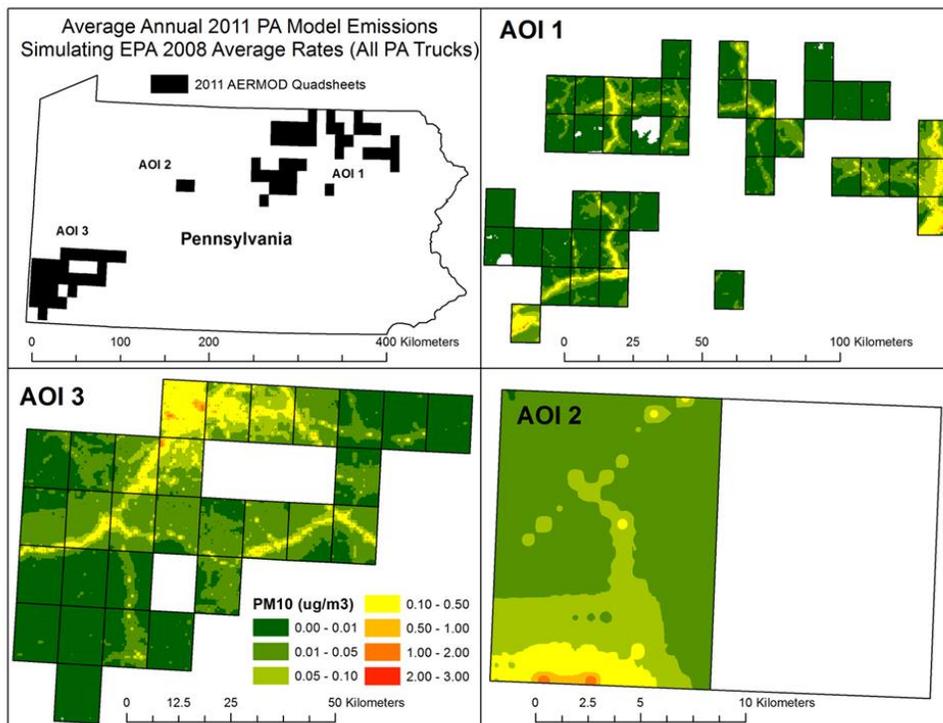
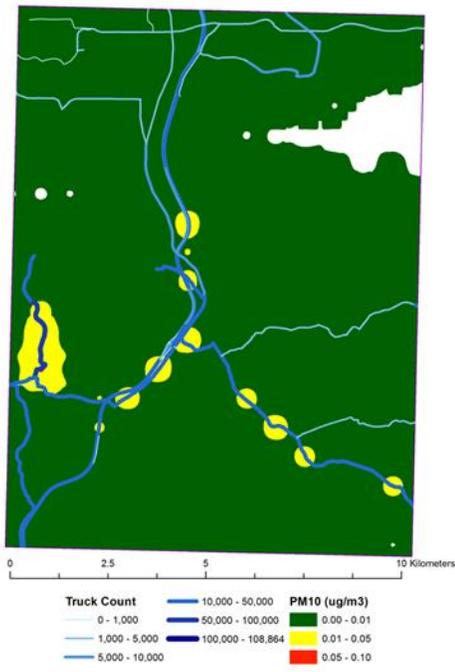


Figure 8. 2011 PADOT average daily emission concentrations of PM_{10} ($\mu g/m^3$) from HVHF truck traffic generating 2008 USEPA Average In-use Heavy Duty Diesel Emission Rates (0.219 g/mile).

2011 GIFT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Blossburg



2011 PADOT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Blossburg

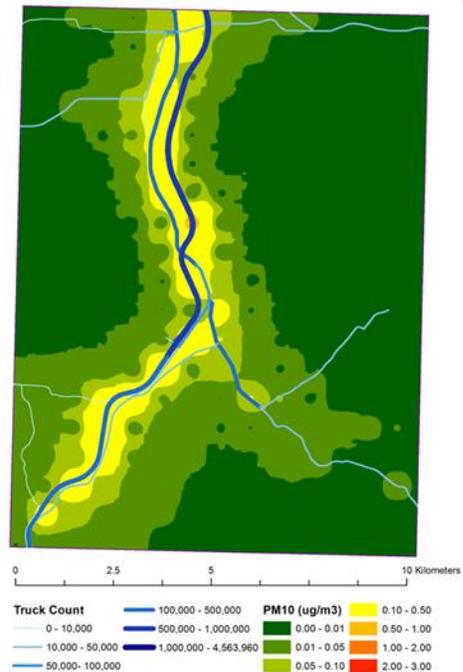
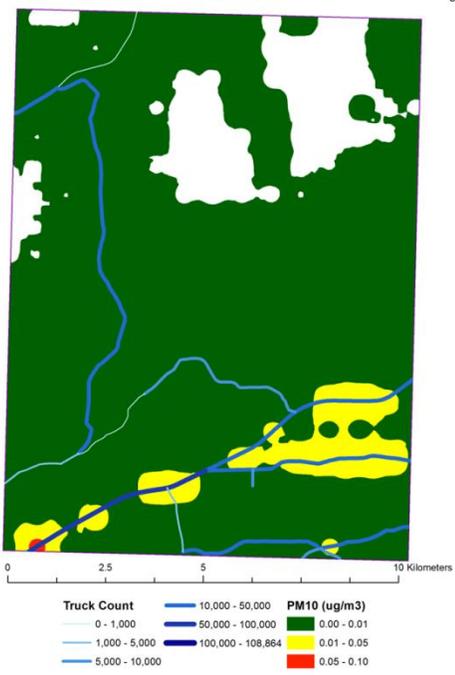


Figure 9. Blossburg AERMOD PM₁₀ results for GIFT and PADOT road networks and truck counts.

2011 GIFT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Crooked Creek

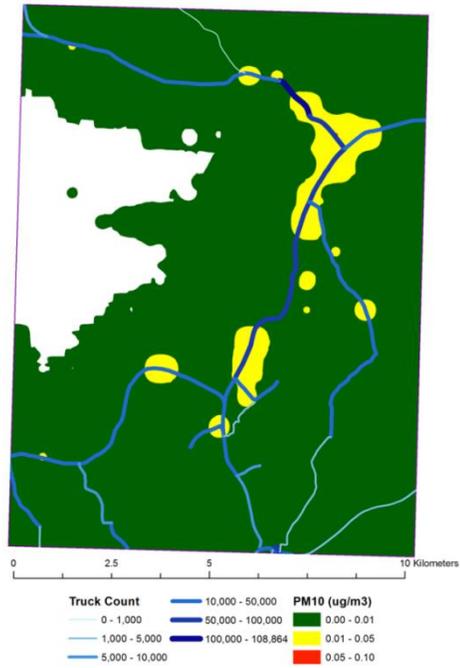


2011 PADOT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Crooked Creek



Figure 10. Crooked Creek AERMOD PM₁₀ results for GIFT and PADOT road networks and truck counts.

2011 GIFT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Keeneyville



2011 PADOT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Keeneyville

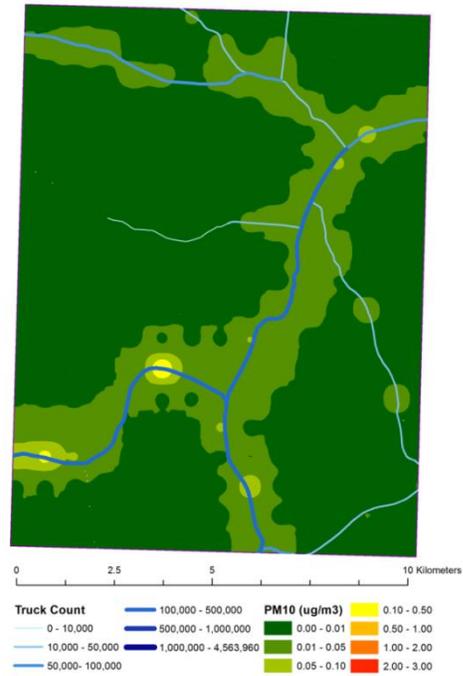
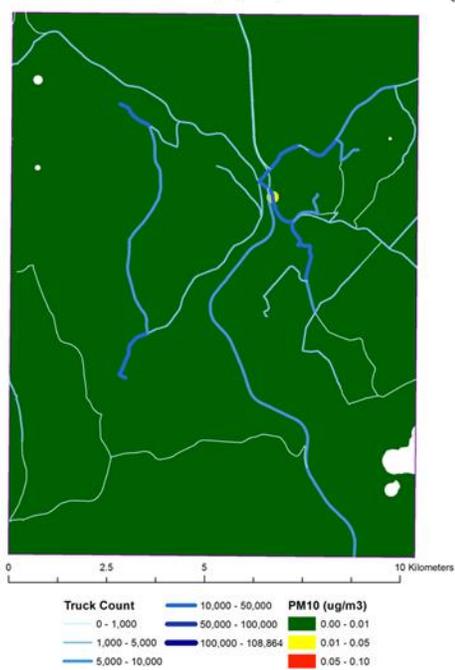


Figure 11. Keeneyville AERMOD PM₁₀ results for GIFT and PADOT road networks and truck counts.

2011 GIFT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Lenoxville



2011 PADOT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Lenoxville

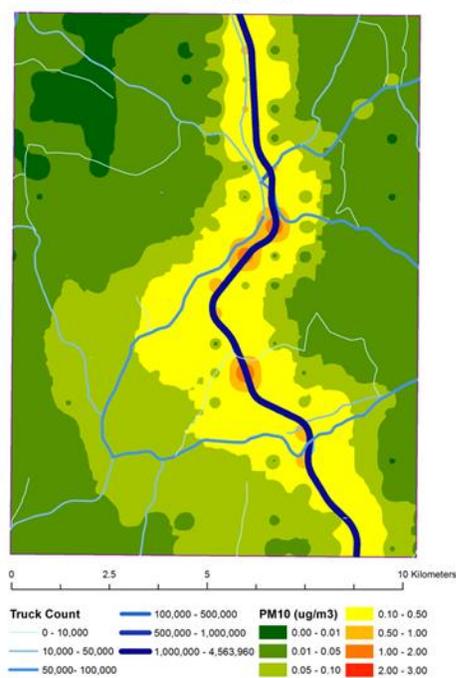
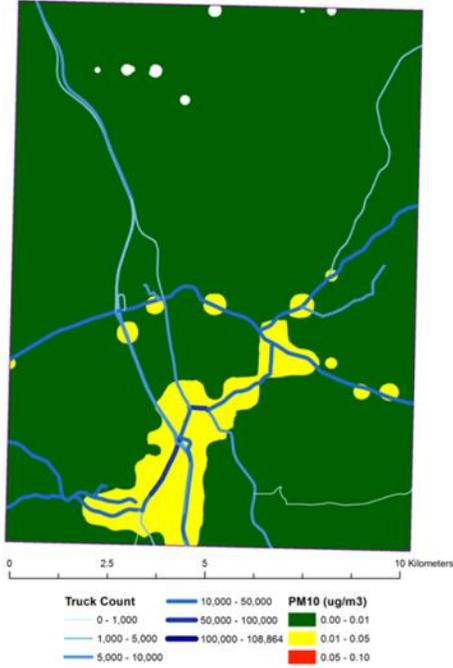


Figure 12. Lenoxville AERMOD PM₁₀ results for GIFT and PADOT road networks and truck counts.

2011 GIFT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Mansfield



2011 PADOT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Mansfield

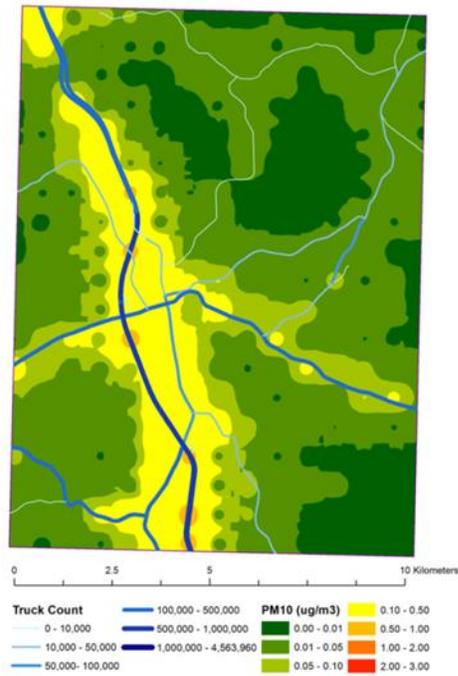
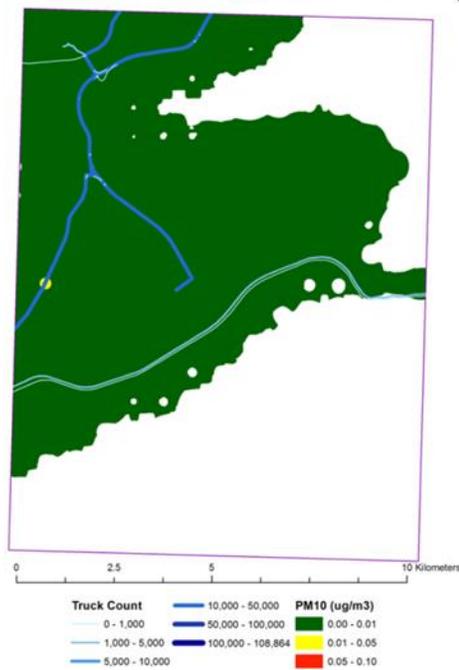


Figure 13. Mansfield AERMOD PM₁₀ results for GIFT and PADOT road networks and truck counts.

2011 GIFT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Mill Hall



2011 PADOT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Mill Hall

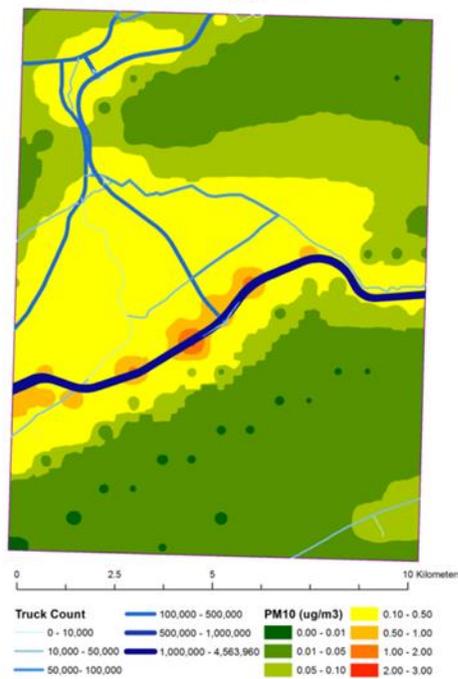
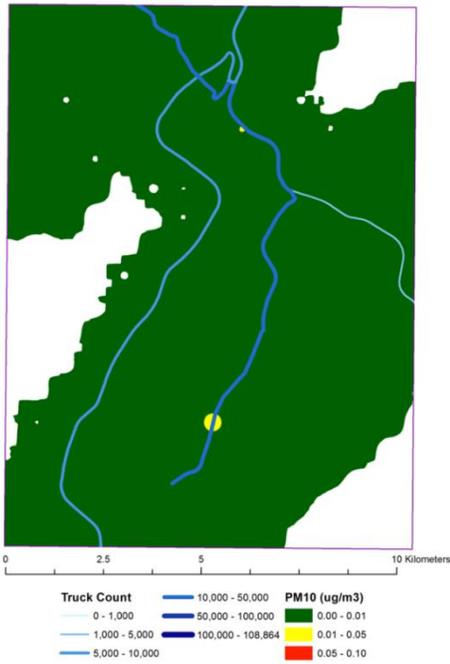


Figure 14. Mill Hall AERMOD PM₁₀ results for GIFT and PADOT road networks and truck counts.

2011 GIFT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Scranton



2011 PADOT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Scranton

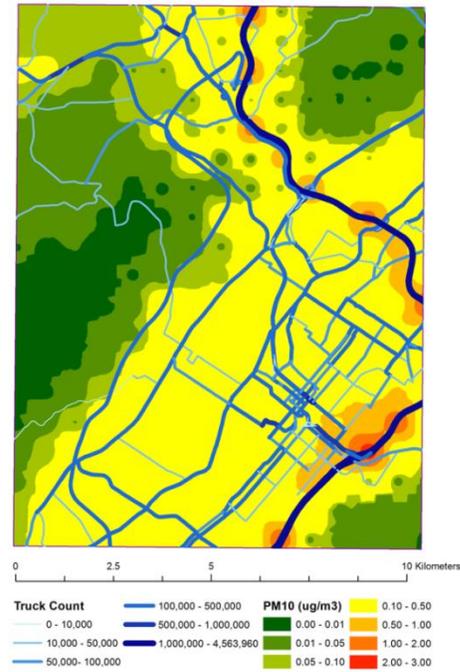
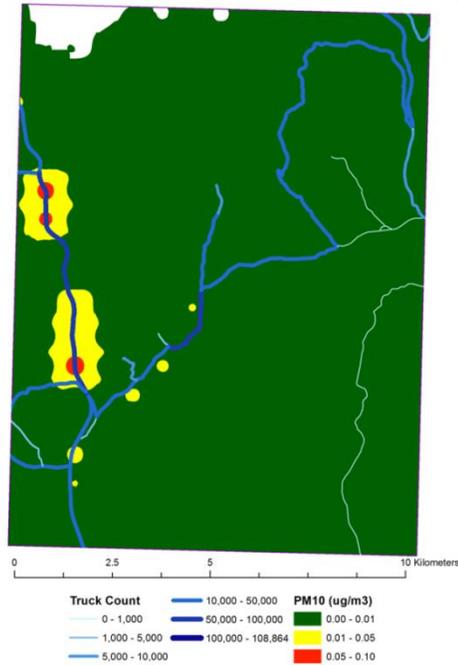


Figure 15. Scranton AERMOD PM₁₀ results for GIFT and PADOT road networks and truck counts.

2011 GIFT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Salladasburg



2011 PADOT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Salladasburg

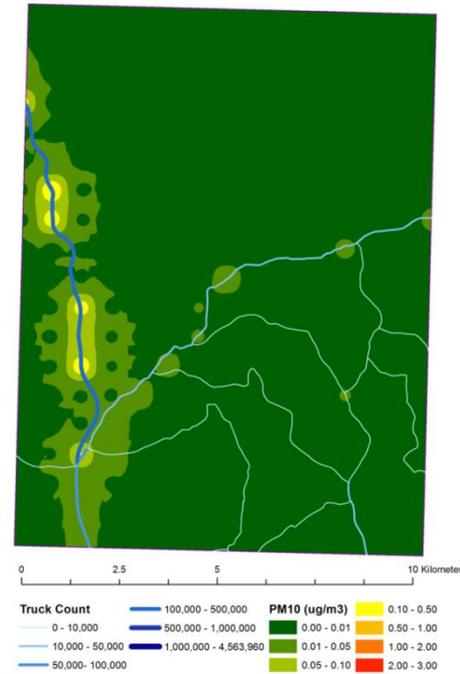
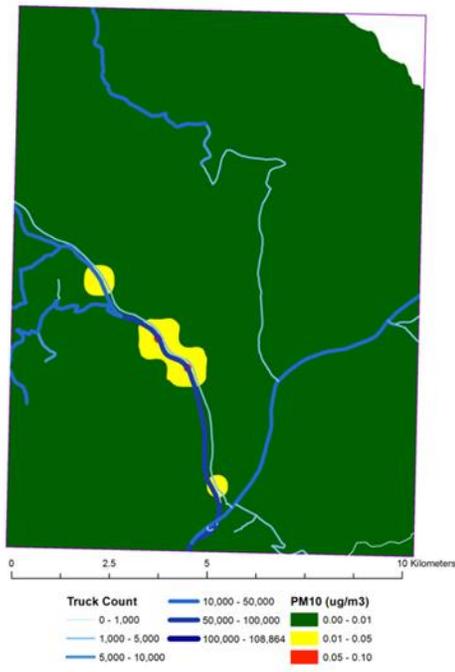


Figure 16. Salladasburg AERMOD PM₁₀ results for GIFT and PADOT road networks and truck counts.

2011 GIFT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Trout Run



2011 PADOT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Trout Run

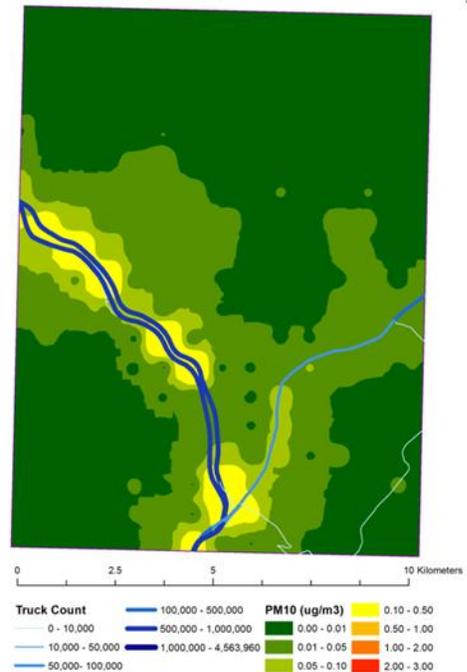
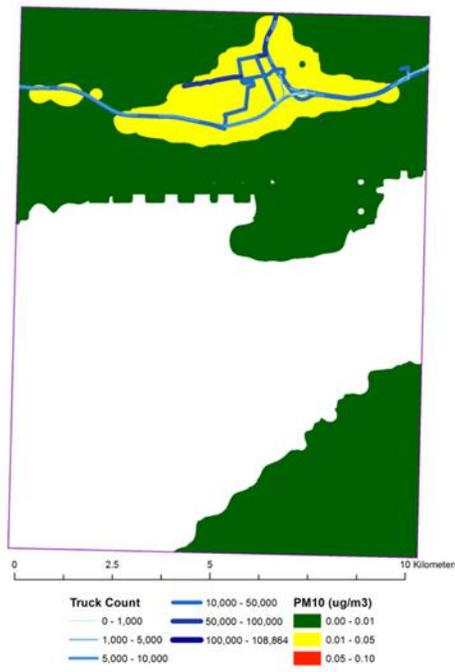


Figure 17. Trout Run AERMOD PM₁₀ results for GIFT and PADOT road networks and truck counts.

2011 GIFT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Williamsport



2011 PADOT Roads and Annual Truck Counts and PM10 Concentrations (ug/m3) in Williamsport

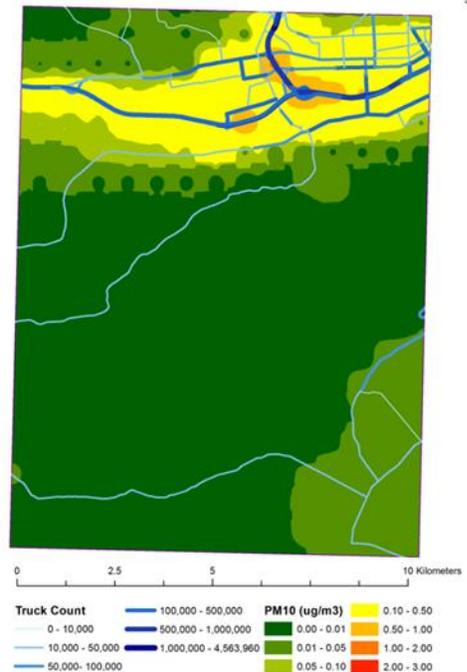


Figure 18. Williamsport AERMOD PM₁₀ results for GIFT and PADOT road networks and truck counts.

Table 2 shows the 2010 population based on census block totals with their centroid contained in an emission contour polygon (select by location in ArcGIS). While the PADOT simulations had similar total estimates of impacted populations (1.43 million), the number of individuals exposed to an additional average daily concentration of at least 1 $\mu\text{g PM}_{10}/\text{m}^3$ dropped by over 17,500 people if trucks had met MY 2007 standards. Because the GIFT simulations started with lower truck counts (and therefore lower overall annual emissions), many areas with low emission impacts (0-0.01 $\mu\text{g}/\text{m}^3$) at 2008 rates zeroed out using MY 2007 emission rates, so fewer people were impacted. But a similar reduction in the most impacted population was seen in the GIFT model (14,949 fewer people were impacted by the highest concentrations if control measures are accounted for). These results will become part of the next phase of this research, using the computer model BENMAP CE to assess human health impacts and costs.

Table 2. Estimated PA population totals exposed to specified average daily PM_{10} levels associated with total truck traffic (PADOT Network Models) and fracking truck traffic (GIFT Network Models) using AERMOD simulations on roadways with the highest estimated fracking truck traffic in 2011. 2008 columns refer to models using USEPA 2008 Average In use Heavy Duty Diesel emission rates, while 2007 columns reflect potential reduced emissions from Model Year 2007 engines if all trucks met those emission rate standards. Daily emission ranges are low, due to the use of annual emission totals (Mg) to derive emission rates for line volumes ($\mu\text{g}/\text{sec}$), which spreads traffic volume evenly throughout the year, eliminating hourly, daily, and seasonal peaks. Although the methodology homogenizes emission rates, these results suggest that nearly 15,000 people are exposed to the highest particulate concentrations due to truck traffic generated by HVHF activities, and over 1 million people are exposed to some level of elevated particulate pollution. Model results also indicate implementing 2007 MY emission standards would significantly reduce the number of individuals exposed to the highest concentrations.

PM10 ug/m3	PA 2008 RATES		PA 2007 RATES		GIFT 2008 RATES		GIFT 2007 RATES		PERCENT
	POPULATION	PERCENT	POPULATION	PERCENT	POPULATION	PERCENT	POPULATION	PERCENT	
0.00-0.01	13,180	0.92	72,392	5.08	834,201	67.26	519,533	91.95	
0.01-0.05	111,811	7.81	514,646	36.08	391,071	31.53	45,472	8.05	
0.05-0.10	383,624	26.78	711,418	49.88	14,949	1.21	11	0.00	
0.10-0.50	382,118	26.68	112,801	7.91	11	0.00	0	0.00	
0.50-1.00	524,121	36.59	15,131	1.06	0	0.00	0	0.00	
1.00-1.50	15,649	1.09	0	0.00	0	0.00	0	0.00	
1.50-2.00	1,916	0.13	0	0.00	0	0.00	0	0.00	
2.00-2.50	0	0.00	0	0.00	0	0.00	0	0.00	
2.50-3.00	3	0.00	0	0.00	0	0.00	0	0.00	
TOTAL	1,432,422		1,426,388		1,240,232		565,016		

Issues/limitations with this emission dispersion analysis stem from the use of annual totals for truck counts and emission totals. Daily, hourly, and seasonal variability due to shifting traffic patterns (congestion) and weather conditions are suppressed in this annualized analysis. Both GIFT and PADOT truck counts were total **annual** estimates, with corresponding total **annual** emissions. PADOT data do have average daily vehicle traffic estimates/distributions, but the GIFT model output does not, so all analyses were performed at the annual level. For AERMOD to run, the total emissions generated by truck traffic along a given road segment (Mg of PM_{10}) were converted into an emission rate (grams/second). Total annual truck counts and emissions were therefore evenly spread, by second, over the course of a year. This distribution generates constant truck traffic, minimizing congestion impacts and ignoring the timing of the major truck traffic activity surrounding the development of a well or series of wells (a truck intensive 2-3 week period). Those traffic data were not publically available for this analysis. The influence of daily, short term, and seasonal weather impacts are also muted.

If many wells were developed over a short period of time in a specific area, roads in that area would be expected to see extremely high truck counts for a brief period during the year, with smaller truck counts associated with well maintenance once the well went into production. These detailed data on truck counts and movement times don't exist in the public domain, so the analysis is currently limited to an annual, distributed simulation. This is akin to taking annual total rainfall estimates for a region and creating an average daily rainfall database – you imply that it rains every day, but only a little. Batterman, Cook, and Justin (2015) address this issue by applying annual, monthly, daily, and hourly temporal allocation factors (TAFs) in urban settings using hourly traffic data from continuous counting stations. A similar approach may be possible for this rural region if suitable PA traffic monitoring stations can be identified, but many of the smaller rural roads appear to be unmonitored.

Another approach to refining the temporal aspect of this analysis would be to re-distribute GIFT model truck counts based on the spud date information of the wells. If the most intense truck activity occurs during the development of a well, then water, sand, and waste movements could be modelled over a 2-3 week period starting with the spud date of each well. Wells with the same spud date would be part of the same 2-3 week analysis, and a series of separate 2-3 week spud date analyses could be combined within ArcGIS using merge and dissolve to create a time series estimate of daily truck counts for GIFT road segments. These data could then be uploaded into AERMOD and run at different time intervals, corresponding to the valid periods of the source segments. We have begun preliminary analyses of this approach on areas around Williamsport to see if it is feasible.

These simulations do, however, identify potential emission and health impact hotspots due to truck traffic associated with HVHF activities and compare them to total truck traffic emission hotspots. AERMOD accounts for terrain and weather influences on emission dispersion and concentrations, so even with the calculated lower distributed emission rates input into the model, generated areas of relatively higher emission concentrations are areas of potential concern and can be considered as target areas for future monitoring. Similarly, identified areas with higher populations along the predicted road segments servicing HVHF truck traffic could be monitored as a comparison. Establishing monitoring stations in these areas would help determine times and duration of high truck traffic and provide more detailed emission rates for modelling analyses. As Figure 19 illustrates, very few PM monitoring stations were active in 2011 in rural areas where the vast majority of the wells are located.

PADEP has begun to modify established monitoring stations and add new ones to try and assess the emissions impacts from various sectors of natural gas development in the Marcellus Shale. The 2015 Annual Ambient Air Monitoring Network Plan (PADEP, 2015) documents the establishment of targeted hazardous air pollution (HAP) monitoring stations in Susquehanna County in late 2013, Wyoming County in early 2014, and the planned establishment of a new site in Fayette County. The first two will be especially useful for analyzing GIFT model results in later years for AO11 (Figures 5-8). Within the Marcellus Shale region, additional PM_{2.5} monitors were added to stations in Tioga County specifically to address shale gas activities (again, benefiting modelling activities in AO11). Results from this project may be useful in locating potential near-road monitoring sites to supplement these existing monitoring systems.

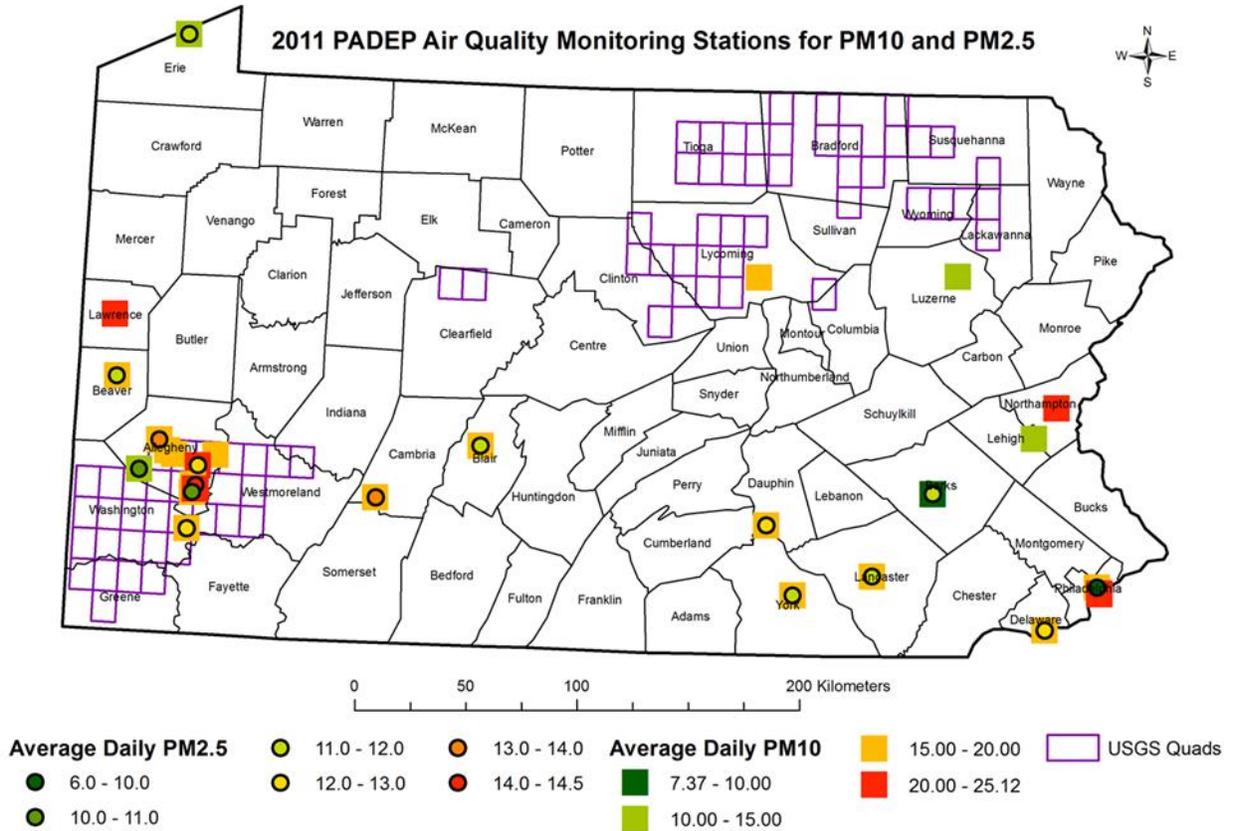


Figure 19. Average daily PM₁₀ (squares) and PM_{2.5} (circles) concentrations ($\mu\text{g}/\text{m}^3$) as reported by PADEP monitoring stations in 2011. Comparing AERMOD model results to these values indicate that trucks are minor contributors to average daily particulate matter emissions, although the truck emission are likely underestimated due to the use of total annual emissions data in AERMOD. Very little monitoring data are available for AOIs 1 and 2, highlighting the need for additional monitoring in rural areas with high levels of HVHF activities. PADEP has begun to address this issue in 2014-2015 with the establishment of additional monitoring stations in Susquehanna, Wyoming, and Tioga Counties (PADEP, 2015).

Conclusions and Future Analyses

While the actual concentrations may be underestimated due to limitations associated with the use of annual truck counts and total pollution emissions, we believe the spatial component of this project helps to identify areas subject to higher pollution concentrations and associated impacts from truck emissions. Linked to population data, this provides a potentially powerful tool to help identify at risk populations. This project helps support the growing literature of probable health impacts and the need for more monitoring data for more rigorous modelling activities (Werner, et al., 2015). In addition to investigating methods of redistributing the timing of the truck traffic, the research team is continuing the dispersion model runs to generating pollution contours for transport activities in 2012 and 2013. We are also interested in comparing our population results to findings reported by Ogneva-Himmelberger and Huang (2015), who compared well density to US Census tract population factors such as age and income to investigate social justice issues in the Marcellus Shale Region. There is a strong possibility that the populations identified in our project share some of the socioeconomic attributes identified by Ogneva-Himmelberger and Huang.

The emission dispersion model activities outlined in this project represent the second phase of a planned three part project. The final phase involves using hotspot pollution concentrations from AERMOD in the EPA health risk model BenMAP-CE (Benefits Mapping and Analysis Program- Community Edition) to assess human health and economic impacts associated with emissions from HVHF truck traffic. Shapefiles of emission plumes from AERMOD will be imported into BenMAP-CE to generate localized health risk estimates and health related economic impact assessments. Simulations will include 1) ambient conditions, 2) estimated HVHF truck traffic, 3) all estimated truck traffic (from PA DOT), and 4) on-site waste recycling to help determine how transportation emissions related to hydraulic fracturing impact human health. This final phase of the research will enhance previous research on regional impacts of HVHF transportation emissions by providing localized assessments over a period of years (2007-2015). Katie Van Munster, an Environmental Science graduate student at RIT, is currently working on adding the 2011 contour data to BenMAP CE as the basis of her Masters thesis.

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Appendix A – Steps for setting up an AERMOD Simulation (version 8.8.9)

AERMET

AERMET is the meteorological preprocessor for AERMOD. It prepares the meteorological data and produces both a surface file and a sounding file (vertical atmospheric profile).

Preprocessing:

Follow the steps outlined in the San Joaquin Valley APCD (2013) PDF to help with the downloading and preprocessing of the data for AERMET.

http://www.valleyair.org/busind/pto/Tox_Resources/MeteorologicalDataProcessing4-11-13.pdf

Follow the steps in Section 1 to get the appropriate surface air data. For FracGIFT, use ISH data (AKA TD-3505 data). It's from the National Climactic Data Center (<ftp://ftp.ncdc.noaa.gov/pub/data/noaa/>).

- Click on the desired year
- Find the appropriate file for the desired location by using the ISD History link below

<ftp://ftp.ncdc.noaa.gov/pub/data/noaa/isd-history.txt> ← USE THIS LINK

(<ftp://ftp.ncdc.noaa.gov/pub/data/inventories/>) ← This is the legacy site

- Use **Ctrl F** to bring up a search window in the web page and search for the place of interest (example, Williamsport) and record the associated WBAN number in the second column (example, 14778 for the Williamsport Regional Airport). Use this number to get desired file from the ISH data link above and unzip the file if necessary.

Other WBAN file numbers of potential interest for the 2011 FracGIFT analysis (linked to the location of the high truck count road segments identified in the GIS analysis):

- Washington County Airport, PA, 725117 (2006-2014) **4827**
- Wheeling Ohio County Airport, WV, 724275 (1973-2015) **14894**
- Allegheny County Airport, PA, 725205 (1973-2015) **14762**
- Pittsburg International Airport, PA 725200 (1945-2015) **94823**
- Arnold Palmer Regional Airport, PA 725207 (2006-2015) **54735**
- Du Bois-Jefferson County Airport, PA 725125 (1973-2015) **4787**
- Clearfield-Lawrence Airport, PA 725119 (2006-2015) **54792**
- University Park Airport, PA 725128 (2005-2015) **54739**
- Penn Valley Airport, PA 725105 (1999-2015) **14770**
- Williamsport Regional Airport, PA 725140 (1973-2015) **14778**
- Wilkes-Barre/Scranton Airport, PA 725130 (1973-2015) **14777**
- Greater Binghamton Airport, NY 725150 (1973-2015) **4725**
- Elmira/Corning Regional Airport, NY 725156 (1973-2015) **14748**

Figure 1 displays these stations, mapped using the coordinates provided with the WBAN records.

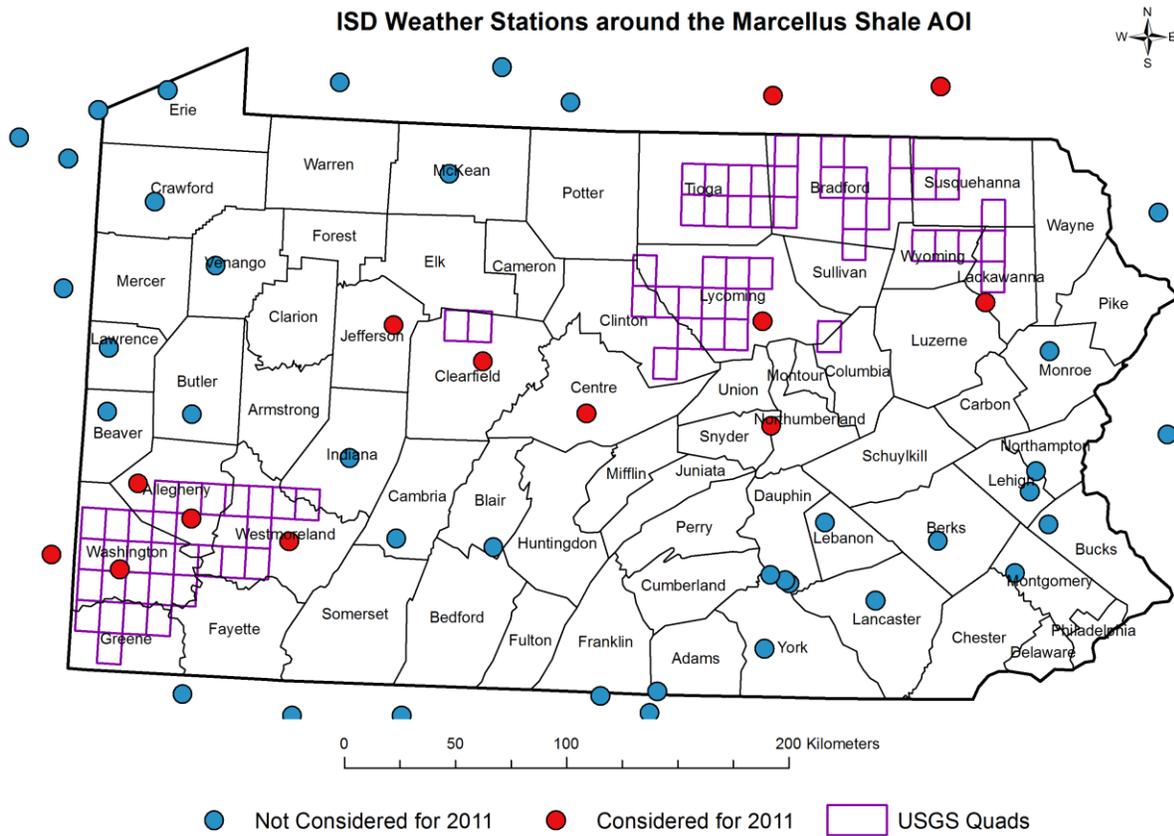


Figure 1. Map of ISD Stations available for the Marcellus Shale AOI. Not all of the considered stations were ultimately used, due to data quality issues and/o missing data for the period January 1, 2011 to December 31, 2011. AERMOD provided warning messages when a station’s record exceeds a quality assurance threshold, as assigned by the user.

Start AERMET

Surface Module

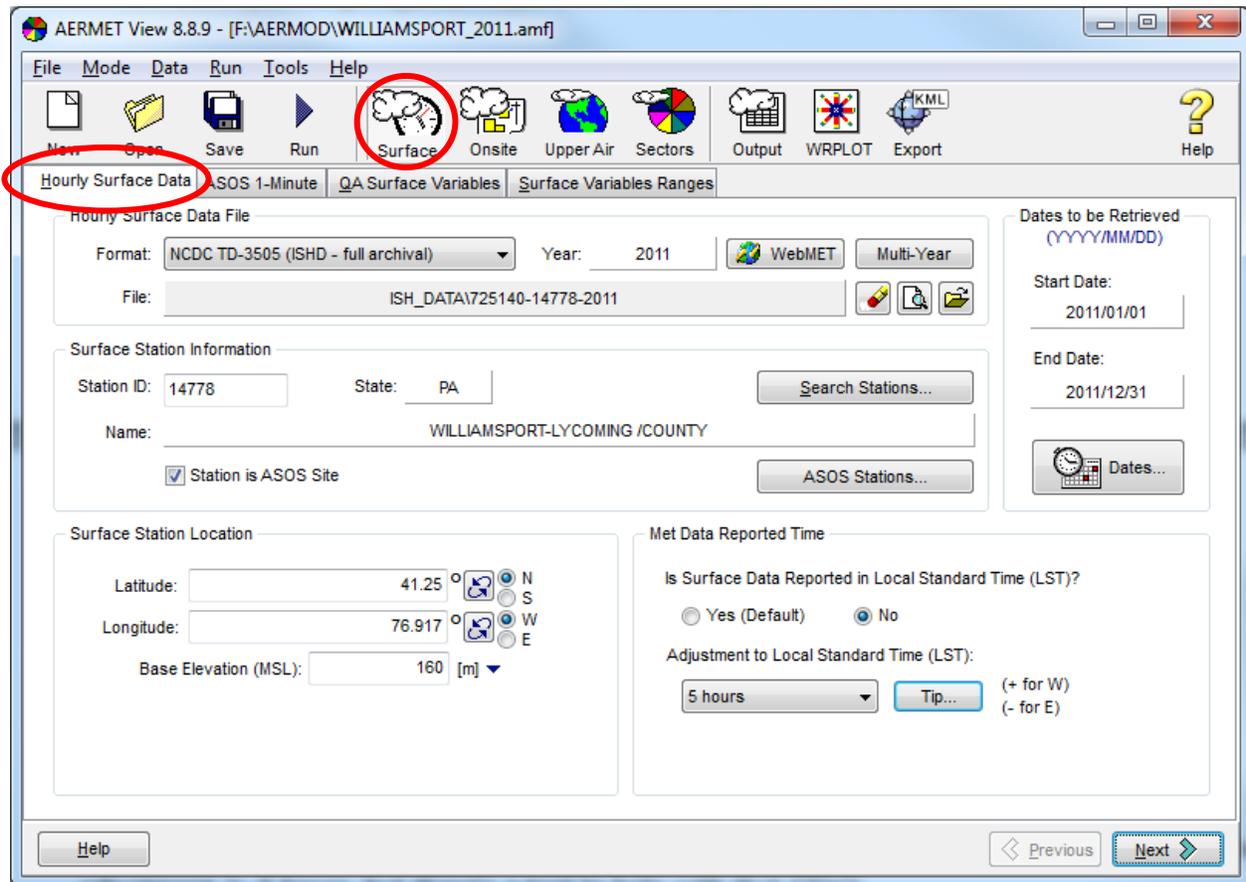
Hourly Surface Data Tab

Under the **Hourly Surface Data** tab, load the ISH Data downloaded from above

The ISH file will not be reported in local standard time (LST), so that needs to be changed. For EST the adjustment is -5 hours, but there's a tool to help with that ('Tip').

Make sure that the dates to be retrieved line up with the desired dates.

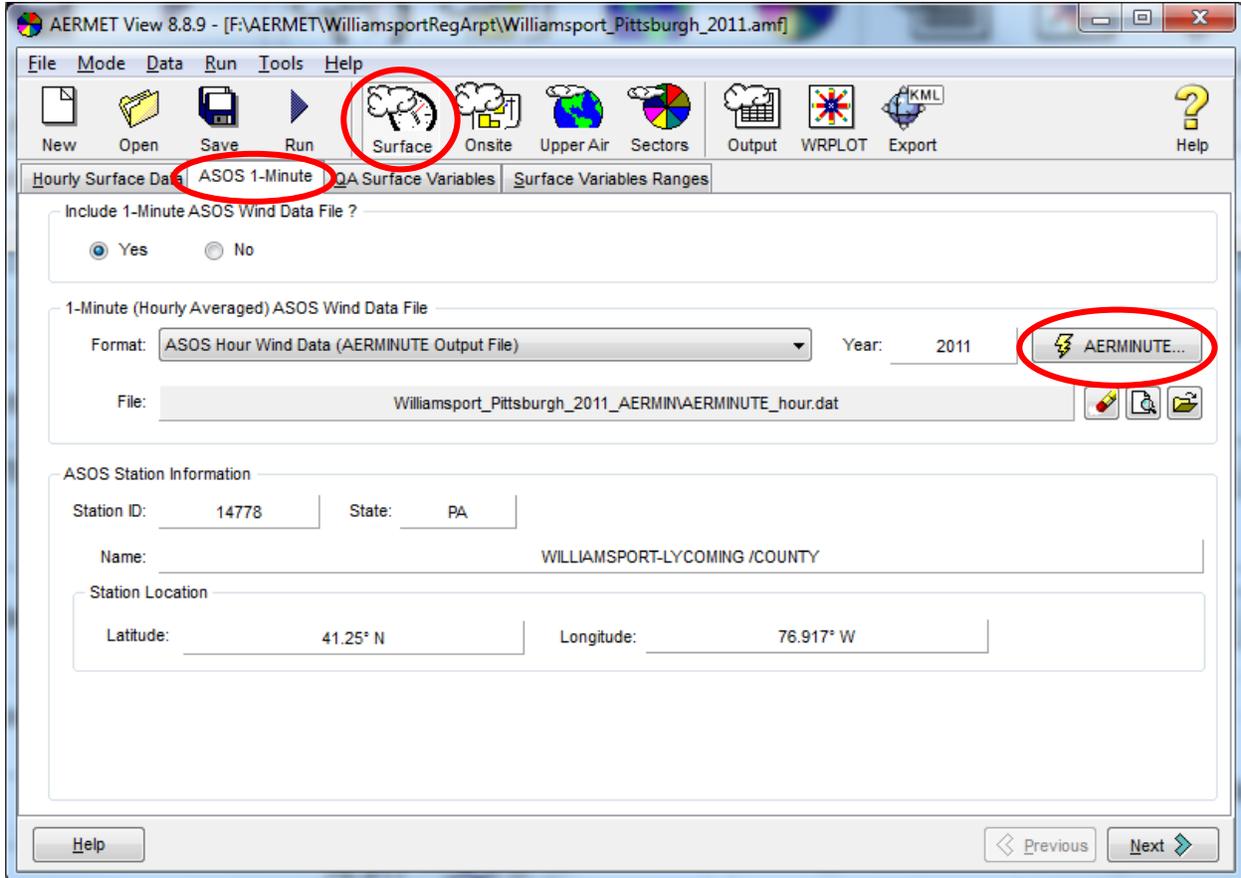
Hit Next



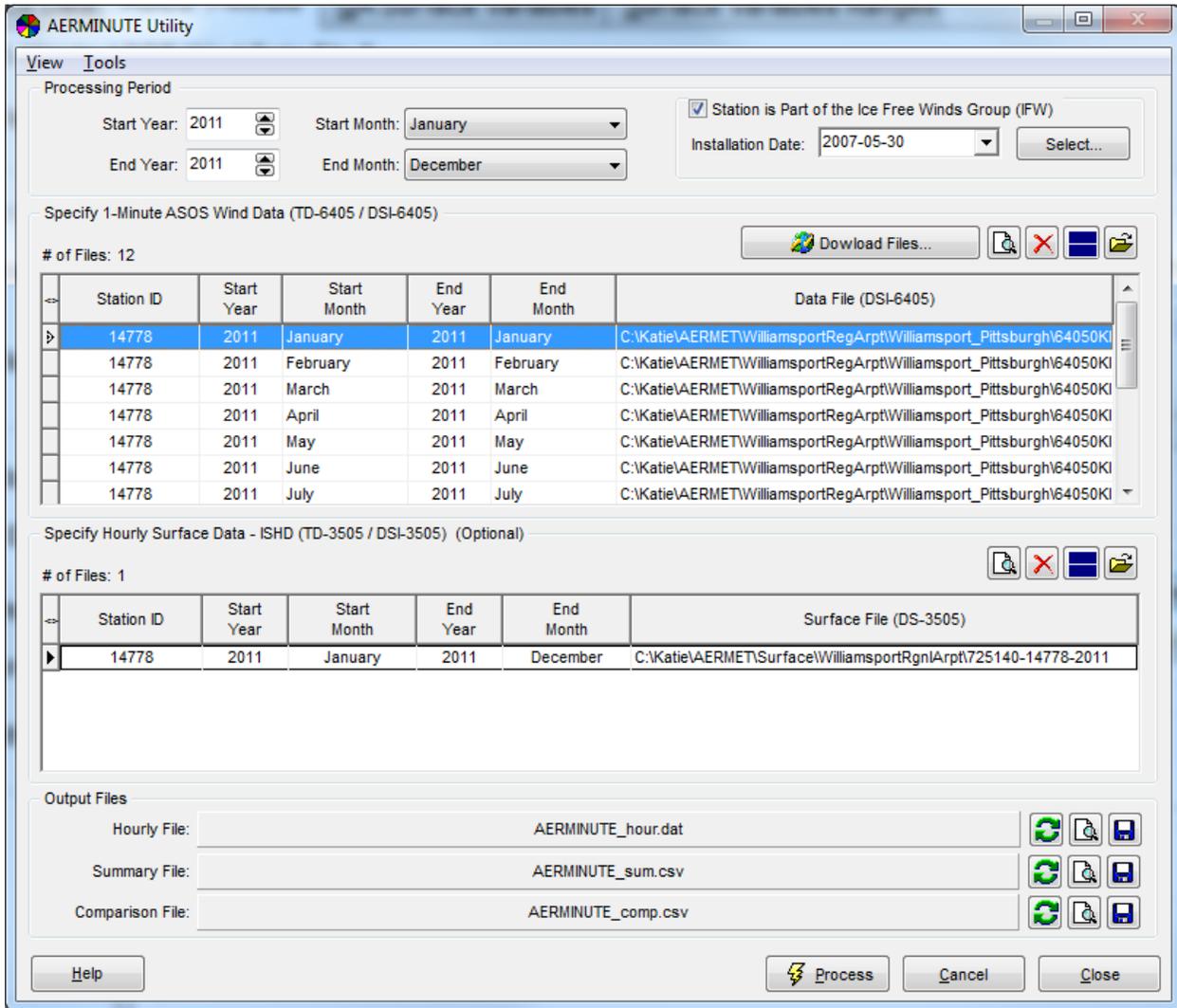
ASOS 1-minute Wind Data Tab

Include the 1-minute ASOS Wind Data files, which provide more accurate data later on.

Click on the AERMINUTE button, then download the files

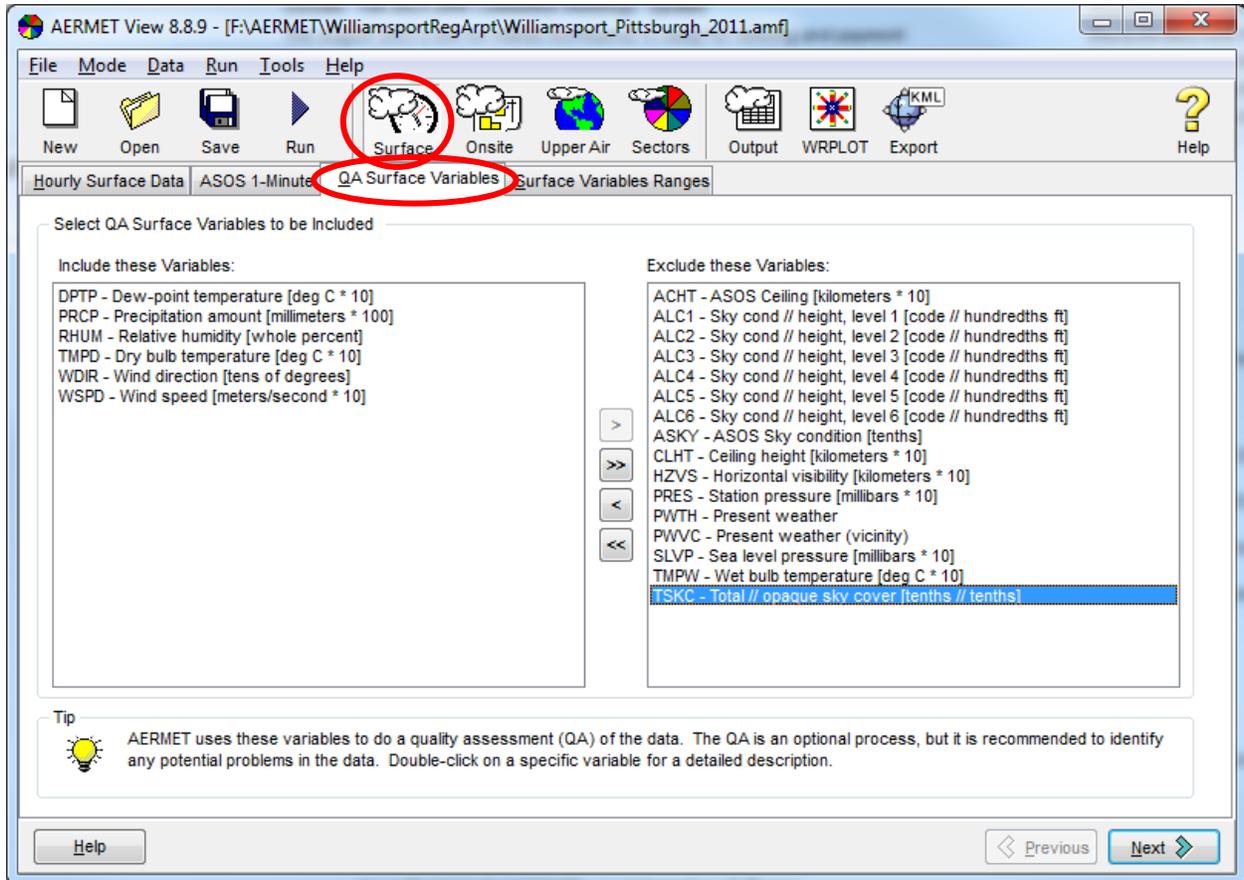


Select Process, then Next back on the ASOS 1-Minute tab



QA Surface Variables Tab

Load **TMPD**, **WDIR**, **WSPD**, **RHUM**, **PRCP**, **DPTP** (these differ slightly from the QA common parameters identified in the 2013 San Joaquin Valley APCD AERMET guide).



Surface Variable Ranges Tab

Check **modify ranges**, select **Default**, and **All** (then **Next**)

The screenshot shows the AERMET View 8.8.9 software interface. The 'Surface' menu item in the toolbar is circled in red. Below the toolbar, the 'Surface Variables Ranges' tab is selected and also circled in red. The 'Modify Ranges' checkbox is checked, and the 'Default' button is highlighted. The main area contains a table with the following data:

Description	Units	Variable Name	Boundary Type	Lower Bound	Upper Bound	Missing Indicator	Missing Message
Dew-point temperature	deg C * 10	DPTP	Exclude (<)	-650	350	999	✓
Precipitation amount	millimeters * 100	PRCP	Include (<=)	0	25400	-9	✓
Relative humidity	whole percent	RHUM	Include (<=)	0	100	999	✓
Dry bulb temperature	deg C * 10	TMPD	Exclude (<)	-300	360	999	✓
Wind direction	tens of degrees	WDIR	Include (<=)	0	36	999	✓
Wind speed	meters/second * 10	WSPD	Include (<=)	0	500	999	✓

Tip: You may also change the default upper and lower bounds for the QA and missing value indicator for each variable.

Onsite Module

Did not include this step because no local data for 2011 were found (seems more appropriate for stationary sources).

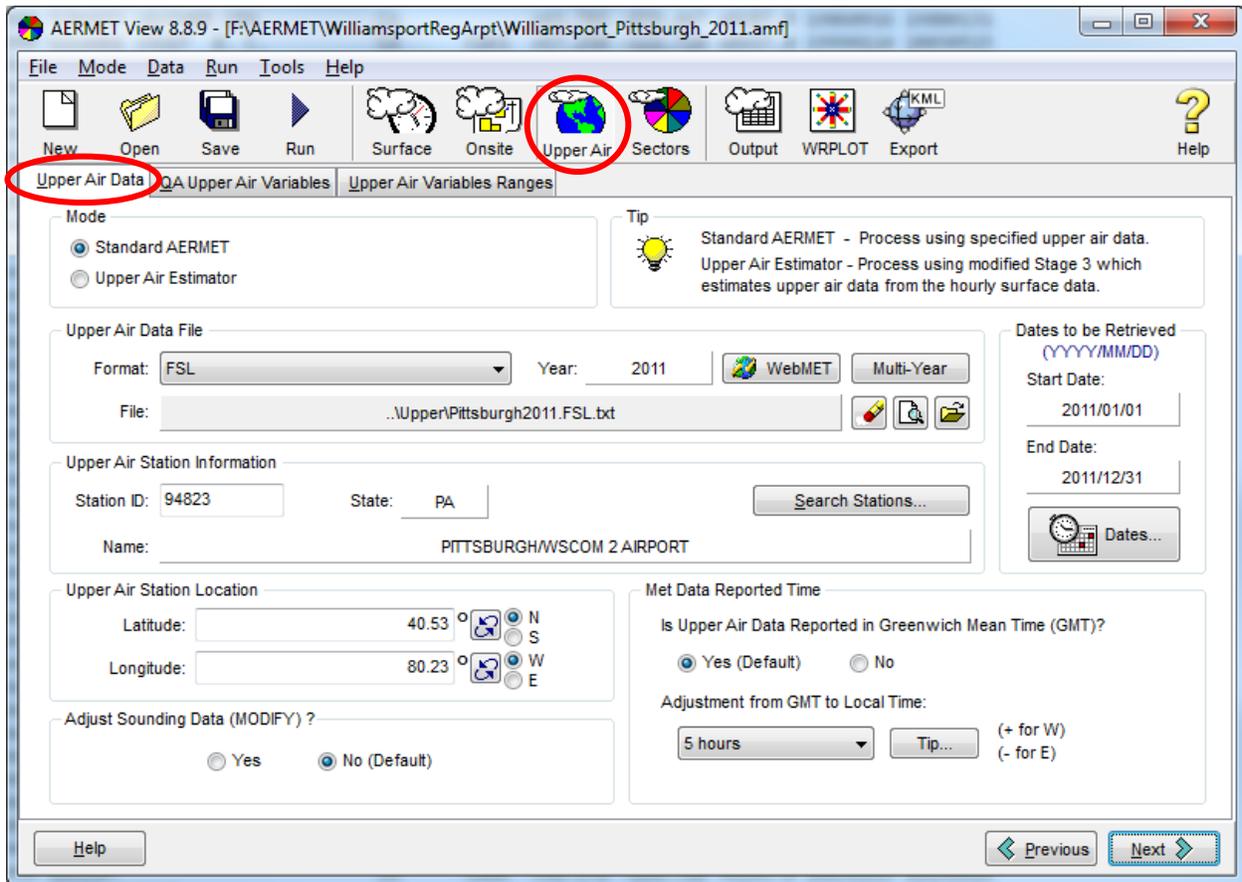
Upper Air Module

Upper Air Data Tab

Use Standard AERMET

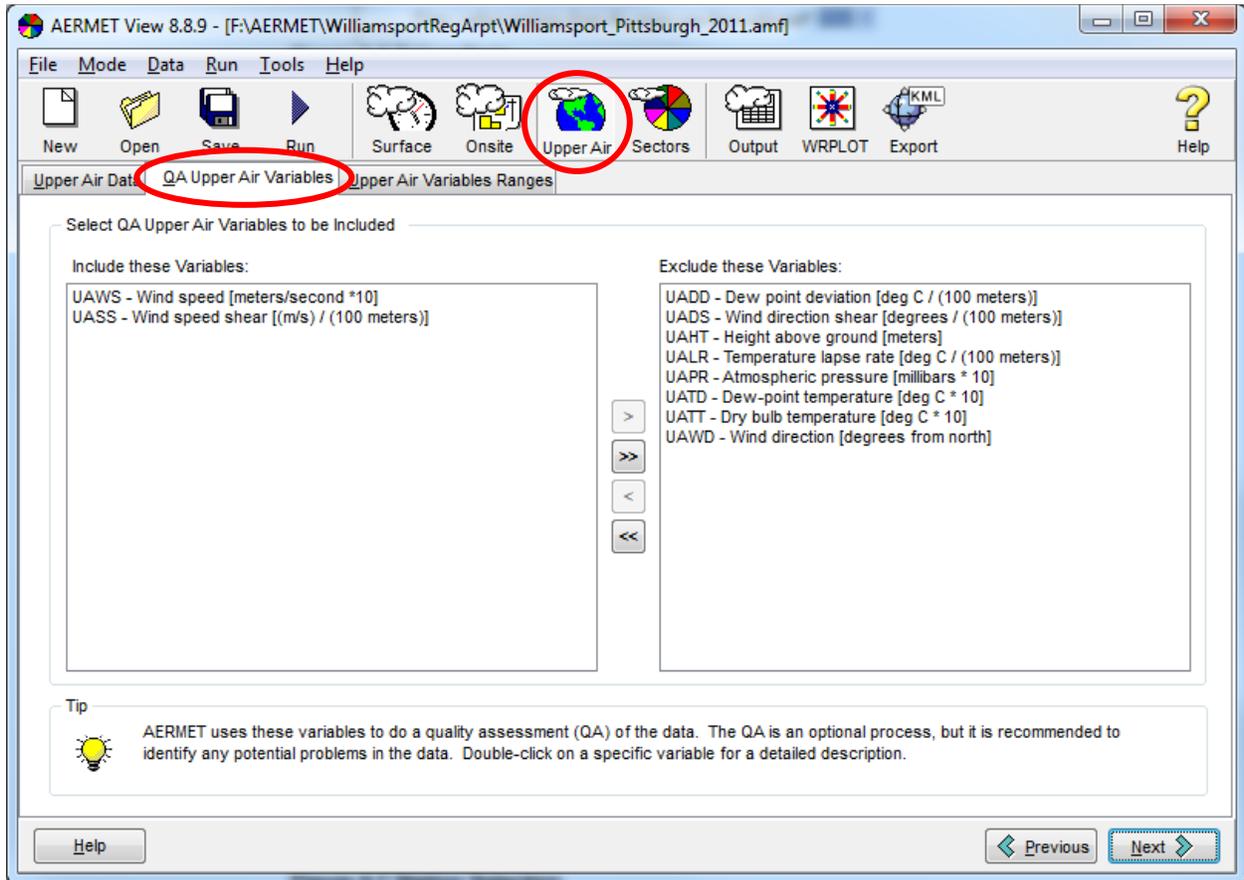
Possible station data include Buffalo, Pittsburg, or Albany, but Pittsburgh was used for the 2011 analysis due to prevailing winds. Follow the directions in Section 5 of the 2013 San Joaquin Valley APCD manual to download Upper Air data from the NOAA/ESRL Radiosonde Database (<http://esrl.noaa.gov/raobs/>). Search for stations by STATE to identify available data.

Upper Air Data will be in FSL format and should be reported in GMT, so adjust to EST (5 hours)



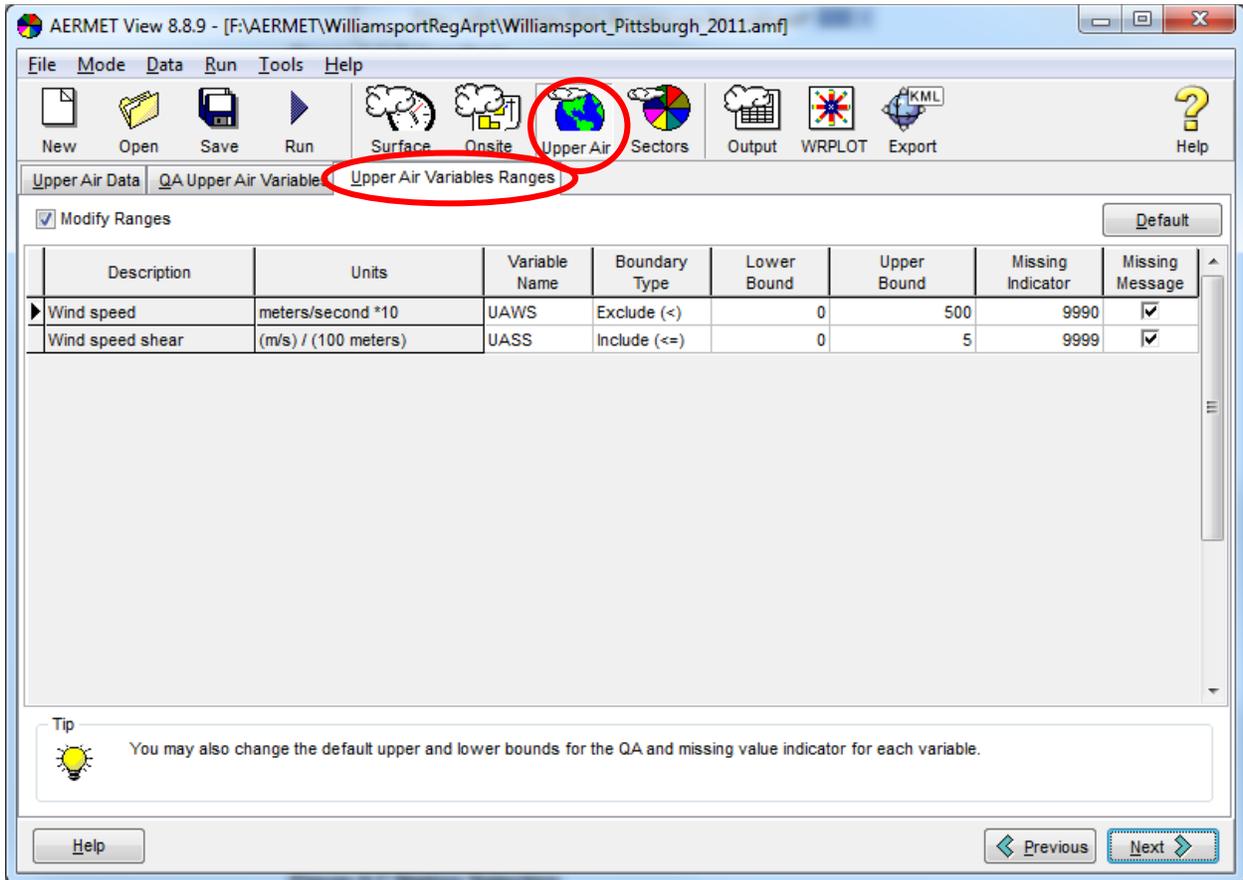
QA Upper Air Variables Tab

Choose **UAWS** and **UASS** for QA for Upper Air Data (Next)



Upper Air Variable Ranges Tab

On the ranges tab, check Modify Ranges – Default – All (Next)



The screenshot shows the AERMET View 8.8.9 software interface. The title bar indicates the file path: [F:\AERMET\WilliamsportRegArpt\Williamsport_Pittsburgh_2011.amf]. The menu bar includes File, Mode, Data, Run, Tools, and Help. The toolbar contains icons for New, Open, Save, Run, Surface, Onsite, Upper Air (circled in red), Sectors, Output, WRPLOT, Export, and Help. The 'Upper Air Variables Ranges' tab is active, showing a 'Modify Ranges' checkbox that is checked. A 'Default' button is located to the right of the checkbox. Below the checkbox is a table with the following data:

Description	Units	Variable Name	Boundary Type	Lower Bound	Upper Bound	Missing Indicator	Missing Message
Wind speed	meters/second *10	UAWS	Exclude (<)	0	500	9990	<input checked="" type="checkbox"/>
Wind speed shear	(m/s) / (100 meters)	UAAS	Include (<=)	0	5	9999	<input checked="" type="checkbox"/>

At the bottom of the window, there is a 'Tip' section with a lightbulb icon and the text: 'You may also change the default upper and lower bounds for the QA and missing value indicator for each variable.' Navigation buttons for 'Previous' and 'Next' are located at the bottom right, along with a 'Help' button on the bottom left.

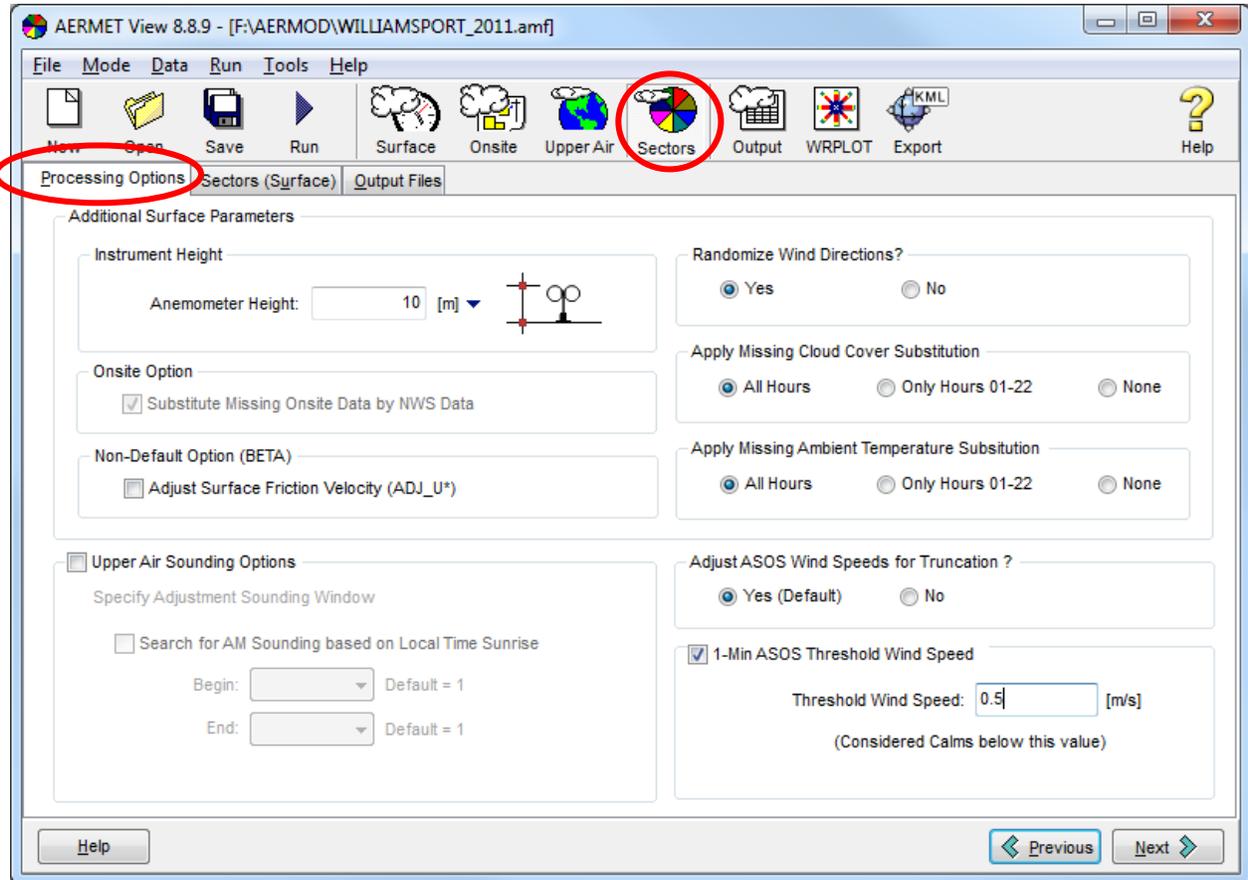
Sectors Module

Processing Options Tab

Get Anemometer Height from Weather Underground (www.wunderground.com). Look up the station of interest and use 'station height' OR use 10 meters as the suggested default from Section 8.2.6 of the 2013 San Joaquin Valley APCD manual.

Leave most defaults, but change 1-min ASOS Threshold Wind Speed to 0.5 m/s

Click Next

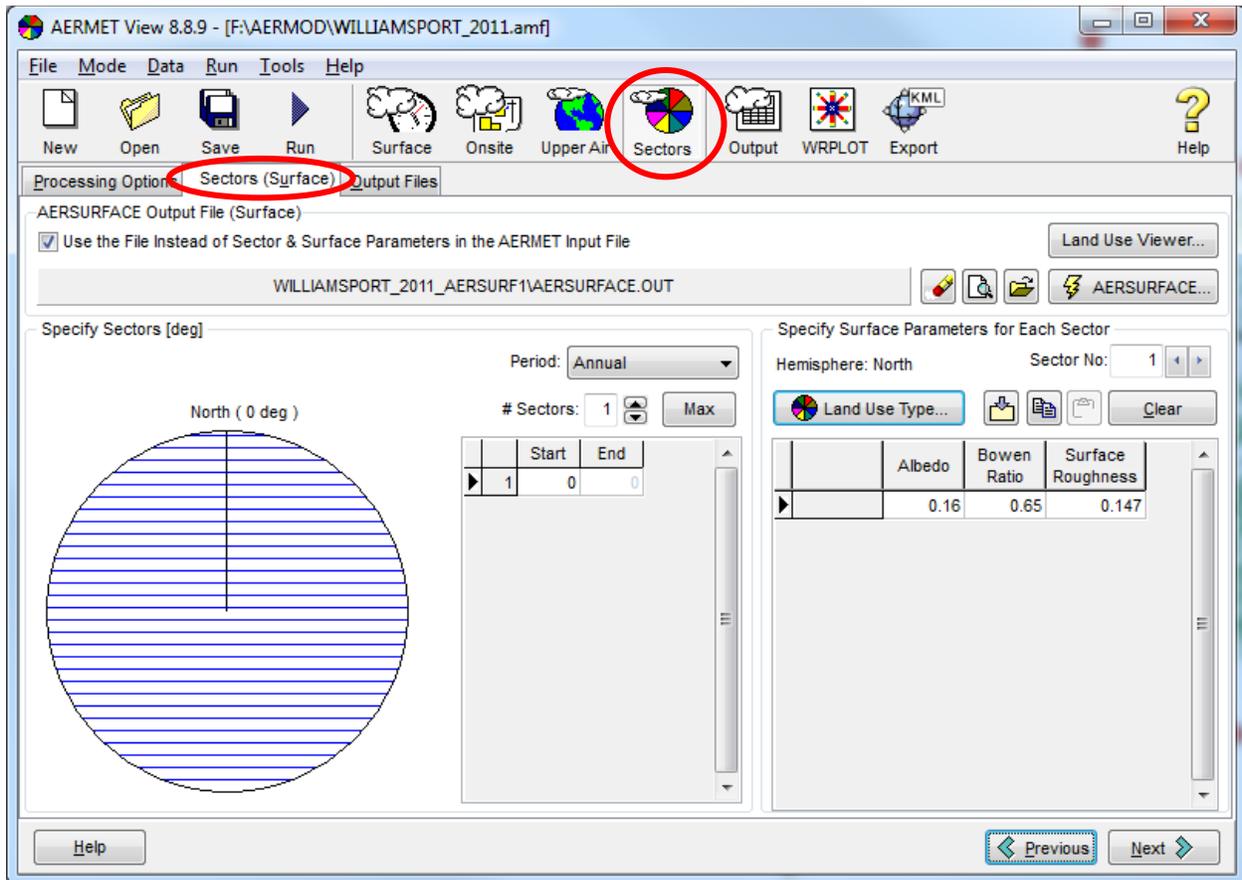


Sectors (Surface) Tab

Use the AERSURFACE Output file (check box)

Click on AERSURFACE

Use default file format, download the files and process



Hit Next

Review the Output files and modify if necessary

Run the AERMET model! The model will tell you if your project is complete or not.

PREPROCESSING ESRI SHAPEFILES AND ATTRIBUTE DATA INTO AERMOD EXCEL SHEETS FOR IMPORT

AERMOD does not have a shapefile import module, so the location (XY) and emission data for each point in the GIFT and PADOT road networks needs to be converted from shapefile format to a text file. These text files can then be converted into an excel file and modified through pivot tables for use in the Lakes Environmental AERMOD excel import template. The following steps outline this process. In the coming year, the research team hopes to create a macro enhanced excel template to automate much of the import and conversion process. Manually working through these steps for the 2011 data took the research team over two months to create the four simulations using the 78 PA quad sheet sections.

Setting up the Attribute Table in the ArcGIS shapefiles

ArcGIS

The emissions totals for each PADOT and GIFT road segment are converted to emission rates (g/sec) for a given line segment by dividing the emission totals by 31,536,000 (seconds in a year). These emission rate (g/sec) values are used by AERMOD in the line volume calculations. From the earlier FracGIFT analysis (Korfmacher, et al., 2015), four sets of total emissions by road segment were generated by multiplying estimated truck counts from the GIFT and PADOT networks by EPA average 2008 in-use emission rates (g/mile) for heavy duty diesel trucks (USEPA, 2008) and emission rates (g/mile) for cleaner trucks meeting the stricter 2007 Model Year standards. These emission totals were then multiplied by the length of the road segment (miles) and then divided by 31,536,000 to convert annual totals to grams/second, the emission rate format needed by AERMOD.

Because AERMOD simulations are memory and time intensive, the project focused on areas around roadways with the highest predicted truck traffic from the 2011 GIFT analysis. Road segments from the GIFT network analysis with more than 25,000 trucks were selected by attribute query to create a smaller hotspot segment database. These hotspot segments were used to select USGS quad sheet polygons using the **Select by Location** function in ArcGIS. The selected USGS quad sheets were in turn used to select all GIFT and PADOT road segments that intersected the quad sheet boundaries. The selected road segments were then exported, by quad sheet, to quad sheet specific road shapefiles (72 GIFT road shapefiles and 72 PADOT road shapefiles). Only quad sheets entirely within PA were used in this analysis.

DNRGPS

Each road shapefile was imported as a tracks file into DNRGPS, a free Minnesota Department of Natural Resources GPS data processing program (<http://www.dnr.state.mn.us/mis/gis/DNRGPS/DNRGPS.html>). Using the road segment unique ID as the track identifier (TIDENT), each road segment is converted into a track and assigned a track ID (IDENT), with line vertices used to create a series of two point line segments. Each track is made up of one or more two-point line segments, and each of these two-point line segments is assigned a sequential XY ID (Figure 2). This segmented track format is needed for input into the AERMOD excel template for pollution sources. Tracks were then saved as comma delimited text files (TXT) and imported at text into Excel (Figure 3).

	type	tident	ident	Latitude	Longitude	y_proj	x_proj	new_trk	new_seg
-	TRACK	2242196	T1	40.0242769657139	-80.174434112823	4443295.07589848	58364.0441047763	True	True
	TRACK	2242196	T1	40.0240133295554	-80.1744304764148	4443265.77596904	58362.6492605418	False	False
-	TRACK	2242197	T3	40.0207860559772	-80.1746813857906	4442908.57323189	58320.3478807407	True	True
	TRACK	2242197	T3	40.0219860564167	-80.1743322943466	4443040.12020883	58357.9199871584	False	False
	TRACK	2242197	T3	40.0223824197839	-80.1742413853087	4443083.69187069	58368.2466690856	False	False
	TRACK	2242197	T3	40.023109692737	-80.174135021697	4443163.94053112	58382.0333177001	False	False
	TRACK	2242197	T3	40.0237215108434	-80.1740913852123	4443231.67765136	58389.7167760346	False	False
	TRACK	2242197	T3	40.0242160562595	-80.174082294578	4443286.56118222	58393.6918167576	False	False
-	TRACK	2242198	T9	40.0198115107691	-80.1749550216826	4442801.6921993	58290.6768843337	True	True
	TRACK	2242198	T9	40.0207860559772	-80.1746813857906	4442908.57323189	58320.3478807407	False	False
-	TRACK	2242199	T11	40.0188596919724	-80.1752241132968	4442697.3128282	58261.5404234576	True	True
	TRACK	2242199	T11	40.0198115107691	-80.1749550216826	4442801.6921993	58290.6768843337	False	False
-	TRACK	2242200	T13	40.0179742374171	-80.1754850219768	4442600.26383479	58233.5315592809	True	True

Projection: NAD_1983_UTM_Zone_18N

Figure 2. Shapefile imported into DNRGPS. TIDENT represents the feature SourceOID attribute from the shapefile database. IDENT represents unique tracks, with the number representing the cumulative number of preceding points plus one. In the example, T1 is a two-point road segment, while T3 contains six vertices. For use in AERMOD, sequential XY identifiers are assigned to the X_PROJ and Y_PROJ values, so that T1 would show X1 Y1, X2 Y2, while T3 would show X1 Y1, X2 Y2, ..., X6 Y6. See Figure 3 for details.

EXCEL

TXT files imported into excel require manipulation (using concatenation) to generate the sequential XY pairs for each point in a given tract (Figure 3). Once complete, these records are selected and inserted into a pivot table (Figure 4). Using SourceOID as the Row Label and the Count of X and Count of Y as Column Labels, sequential ordered pairs of points are generated by calculating the average value of the X and Y coordinates. This returns the actual XY UTM coordinate of each point.

A second pivot table is needed to compress the SourceOID and IDENT data into single record pairs (Figure 5), as AERMOD requires input files to contain all road segment points for a given track to be in a single record. The number of points in a road segment is provided as a count of the ordered pairs of vertices. Combining the results of the two pivot table analyses produces much of the data for AERMOD, shown in Figure 6. POINTS is simply a count of the XY ordered pairs by record, and the PM10_RATE_2008 and PM10_RATE_2007 data are copied from the shapefile DBF. Since the shapefile and the text file both contain the unique SourceOID attributes, the data can be sorted by SourceOID to ensure a 1:1 record match. This is akin to an attribute JOIN operation in ArcGIS.

The screenshot shows a Microsoft Excel spreadsheet titled "GIFT_AMITY_2011.xlsx". The spreadsheet contains a table with 12 rows of data. The columns are labeled as follows: A (Source_OID), B (ident), C (x_proj), D (y_proj), E (ID), F (ID2), G (X), H (Y), I (X_COUNT), J (Y_COUNT), K (X_PAIR), and L (Y_PAIR). The data is as follows:

	A	B	C	D	E	F	G	H	I	J	K	L
1	Source_OID	ident	x_proj	y_proj	ID	ID2	X	Y	X_COUNT	Y_COUNT	X_PAIR	Y_PAIR
2	2242196	T1	58364.0441	4443295.076	1	1	X	Y	1	1	X1	Y1
3	2242196	T1	58362.64926	4443265.776	1	1	X	Y	2	2	X2	Y2
4	2242197	T3	58320.34788	4442908.573	2	2	X	Y	1	1	X1	Y1
5	2242197	T3	58357.91999	4443040.12	2	2	X	Y	2	2	X2	Y2
6	2242197	T3	58368.24667	4443083.692	2	2	X	Y	3	3	X3	Y3
7	2242197	T3	58382.03332	4443163.941	2	2	X	Y	4	4	X4	Y4
8	2242197	T3	58389.71678	4443231.678	2	2	X	Y	5	5	X5	Y5
9	2242197	T3	58393.69182	4443286.561	2	2	X	Y	6	6	X6	Y6
10	2242198	T9	58290.67688	4442801.692	3	3	X	Y	1	1	X1	Y1
11	2242198	T9	58320.34788	4442908.573	3	3	X	Y	2	2	X2	Y2
12	2242199	T11	58261.54042	4442697.313	4	4	X	Y	1	1	X1	Y1

Figure 3. CSV imported file with additional fields added for pivot table analysis. After adding in the initial row of data in row 2, columns E-L, **ID** and **ID2** are calculated by the formula **=IF(B3=B2,E2,E2+1)**. **X_COUNT** and **Y_COUNT** are calculated by the formula **=IF(E3=E2,I2+1,1)**. **X_PAIR** and **Y_PAIR** are calculated by the formula **=CONCATENATE(G3,I3)**. These data are inserted into a pivot table for further analysis.

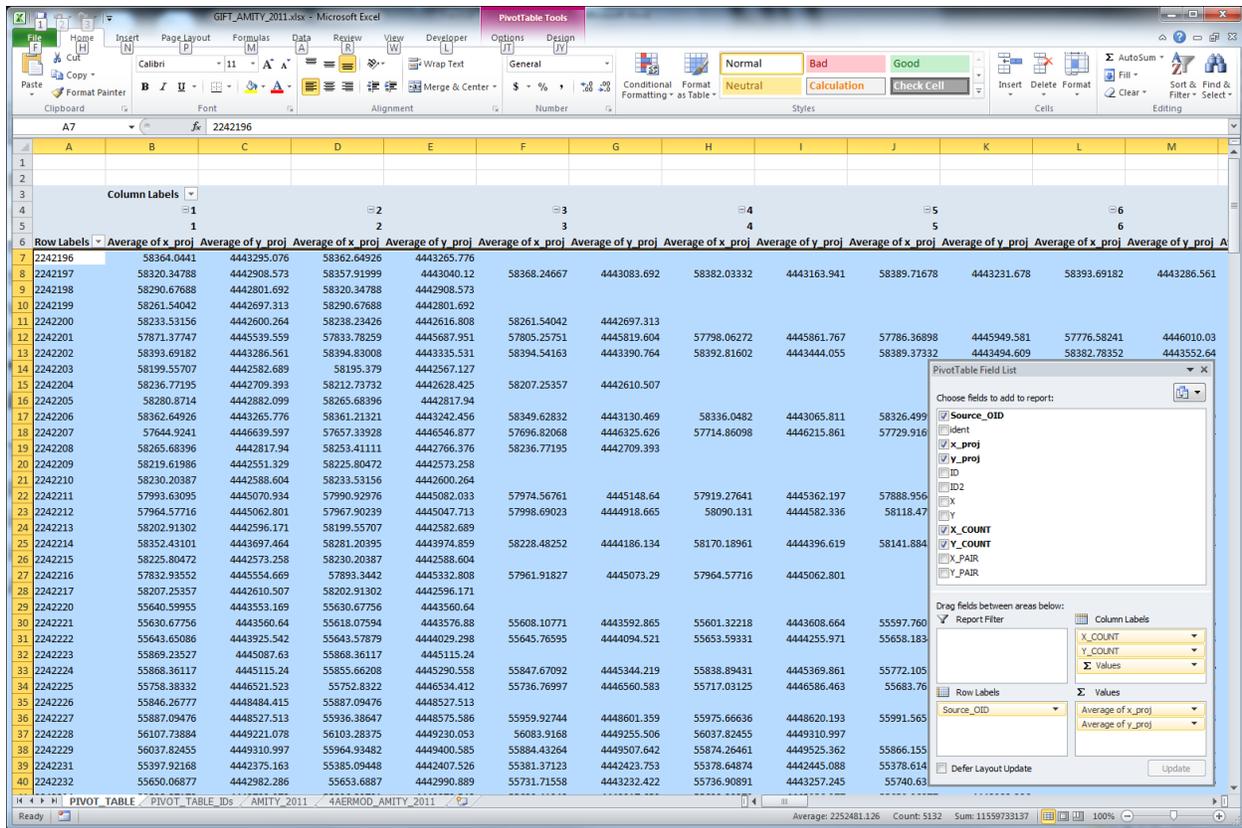


Figure 4. Main pivot table set up and format. Data from initial import are re-organized to display as rows, based on the road segment unique ID (**SourceOID**). Column labels are set up to create ordered XY pairs of road segment vertices, and the Column Label header values indicate the maximum number of ordered pairs. These data are copied and pasted as values into a new worksheet called AERMOD for further formatting.

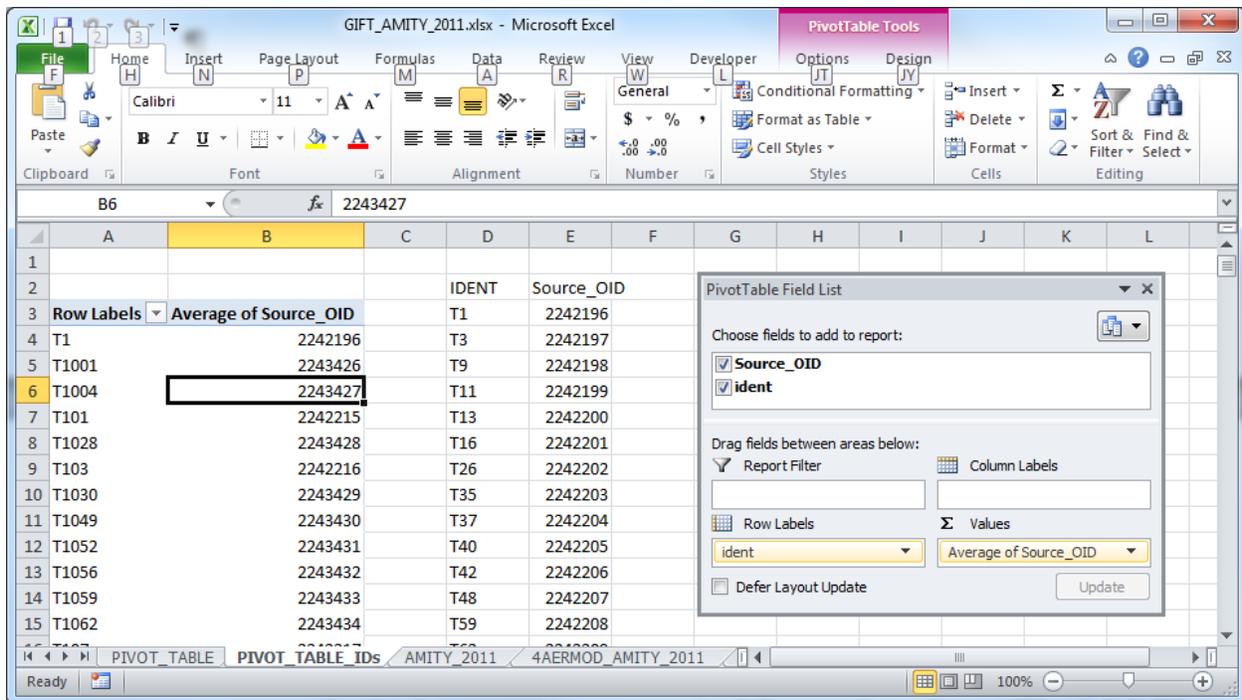


Figure 5. ID Pivot Table setup, used to collapse initial records into pairs of primary (**SourceOID**) and secondary (**ident**) road segment identifiers. **Ident** is cumulative N+1 record of point counts from sequential road segments, determined by **SourceOID**. These data are copied pasted into columns D and E and then sorted by SourceOID (column E). **IDENT** (column D) is then copied and pasted into the AERMOD Worksheet, following the template structure required for input into AERMOD as sources.

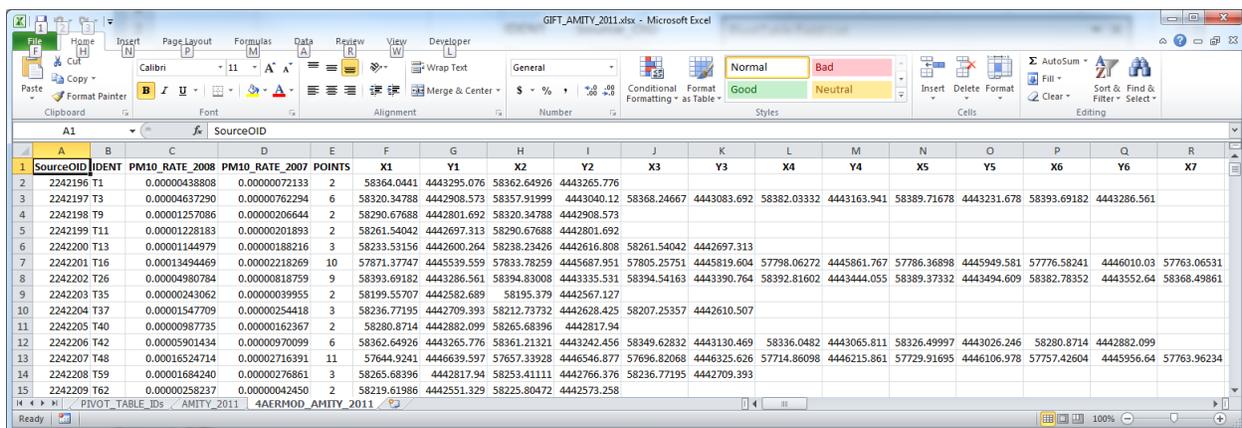


Figure 6. The AERMOD worksheet includes the original CVS import data transformed and consolidated from columns to single record row data. **PM10_RATE_2008** and **PM10_RATE_2007** are inserted and the data from the ArcGIS shapefile DBF tables are copied and pasted into this worksheet. Care must be taken to ensure that both the DBF file and the AERMOD worksheet are sorted by **SourceOID** to ensure emission rates are assigned to the correct road segments. **POINTS** is calculated by the formula $=COUNT(F2:X2)/2$, where X2 represents the column and row of the largest XY ordered pair.

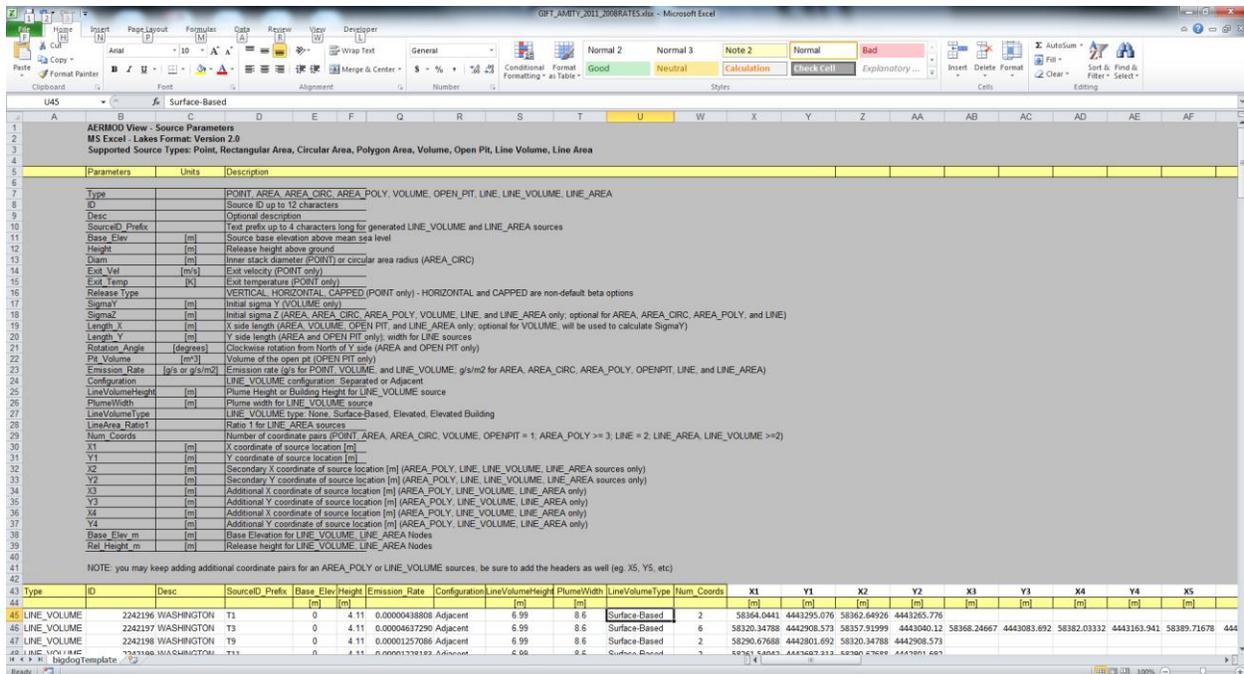


Figure 7. Lakes Environmental AERMOD Excel Template, set up to import in SOURCES as a “modified” emissions from Line Volume. Data from the AERMOD worksheet (Figure 6) are copied and pasted into this template. These include Unique IDs, emission rates, and XY point pairs. Four sets of files are created for each topo sheet, simulating 2007 and 2008 emission rates for GIFT and PA roadways. **Type** is set to **Line_Volume**. Values for **Plume Height** (6.99) and **Plume Width** (8.6) are calculated within AERMOD using the **Haul Roads Calculator** and are standard values in this analysis for each road segment. **Base Elevation** is set to zero and will be updated in AERMOD from terrain data (AERMAP). **Height** is set to represent the emission release height from the truck (3.49m for a 4.11m truck).

NOTE: The format shown in Figure 7 is not the official format for a line volume source, as described by Lakes: you may keep adding additional coordinate pairs for an AREA_POLY or LINE_VOLUME sources, be sure to add the headers as well (eg X5, Y5, etc).

The official line volume format (Figure 8) requires three rows of input for each record (emissions, elevation, and release height), but the three row format complicates the pre-processing of the shapefile data in excel. The final steps to creating a properly formatted Line Volume input file are detailed on page 22 of this manual.

ID	Desc	SourceID	Emission_Rate	Configuration	LineVolumeHeight	PlumeWidth	LineVolumeType	Num_Coords	X1	Y1	X2	Y2	X3	Y3
			[m]		[m]	[m]			[m]	[m]	[m]	[m]	[m]	[m]
SLINE1		1001		1 Adjacent	8.228	11	Elevated	3	708230.86	3649734.86	708435.12	3649736.91	708447.38	3649732.53
SLINE1								Rel_Height_m	4.11	4.11	4.11	4.11	4.11	4.11
SLINE1								Base_Elev_m	0.00	0.00	0.00	0.00	0.00	0.00

Figure 8. Example of the format for a single Source Line Volume record (from the Lakes Environmental version of AERMOD). The first row of SLINE1 contains the XY Coordinates for each point in the line segment. The second row is the release height of the pollutant, and the third line is the elevation of each point in the line segment, assigned to the point by the subprogram AERMAP. The release height is a constant value. Pivot tables can easily generate the first row, but inserting the second and third rows was problematic, due to the variable number of points making up each line segment and the number of records in each shapefile.

AERMOD

This is the actual atmospheric dispersion model used in the annual analyses. To help standardize file names and paths, create a series of folders named for the topographic sheets used in the annual analyses, with four additional folders under each topo folder specifying road network and emission dataset used.

Example

```
AERMOD/2011/AMITY/GIFT_AMITY_2011_2007
AERMOD/2011/AMITY/GIFT_AMITY_2011_2008
AERMOD/2011/AMITY/PADOT_AMITY_2011_2007
AERMOD/2011/AMITY/PADOT_AMITY_2011_2008
```

The final folder indicates a simulation using the GIFT road network within the Amity PA topographic quad sheet boundary for the year 2011 using the Model Year 2007 emissions set by the US EPA.

Start AERMOD and select New Project

- Specify project name and set the project location to the previously created folder
 - Remove check from Create Project Folder (created beforehand – see above)

Select Coordinate System

- UTM Universal Transverse Mercator
- Datum is NAD83
- UTM Zone is 18 North (keep this standard across PA)

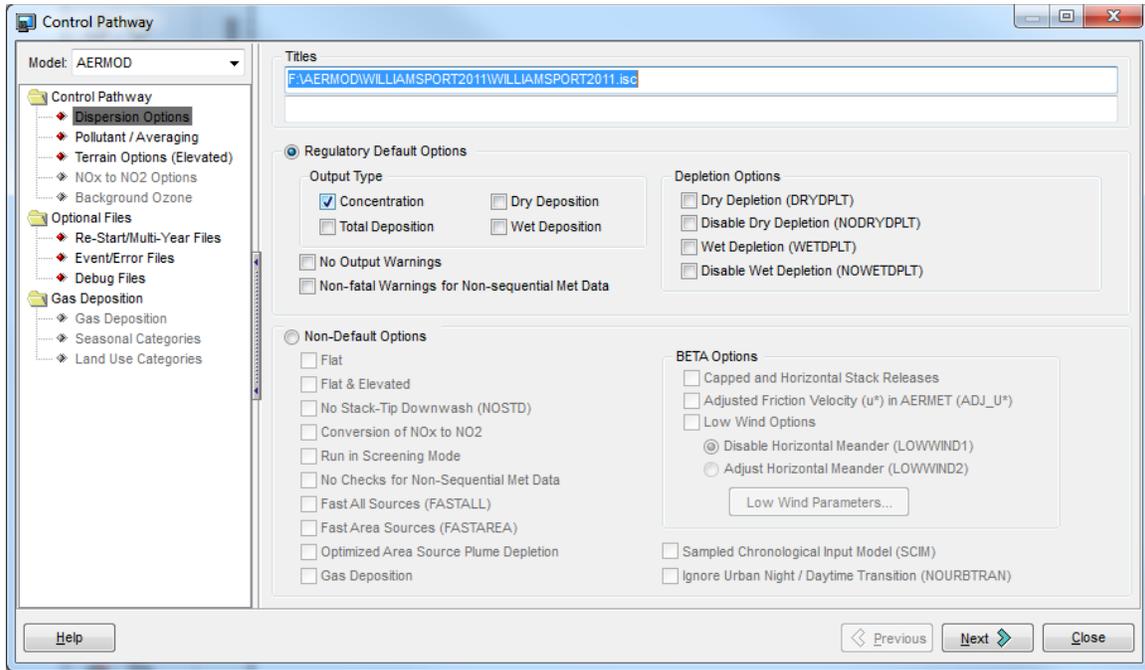
Enter a reference point to make sure your project is in the correct location, obtained from the center point of the specific topographic quad sheet polygon (calculated in ArcGIS)

- Choose UTM
- Choose 'center' for the reference point
- Enter the X and Y coordinates from the Attribute Table in ArcGIS for the specific quad sheet
- Specify the radius of the modeling area 7.5 km (this will encompass the boundaries of the quad sheet)
- Check the point against Google Earth.
 - The 1:24,000 AOI topographic quad sheet boundaries can be converted from shapefile to KML format and imported into Google Earth. Reference point should be in the center of a quad sheet boundary.

Hit Finish to open the project

Control Module

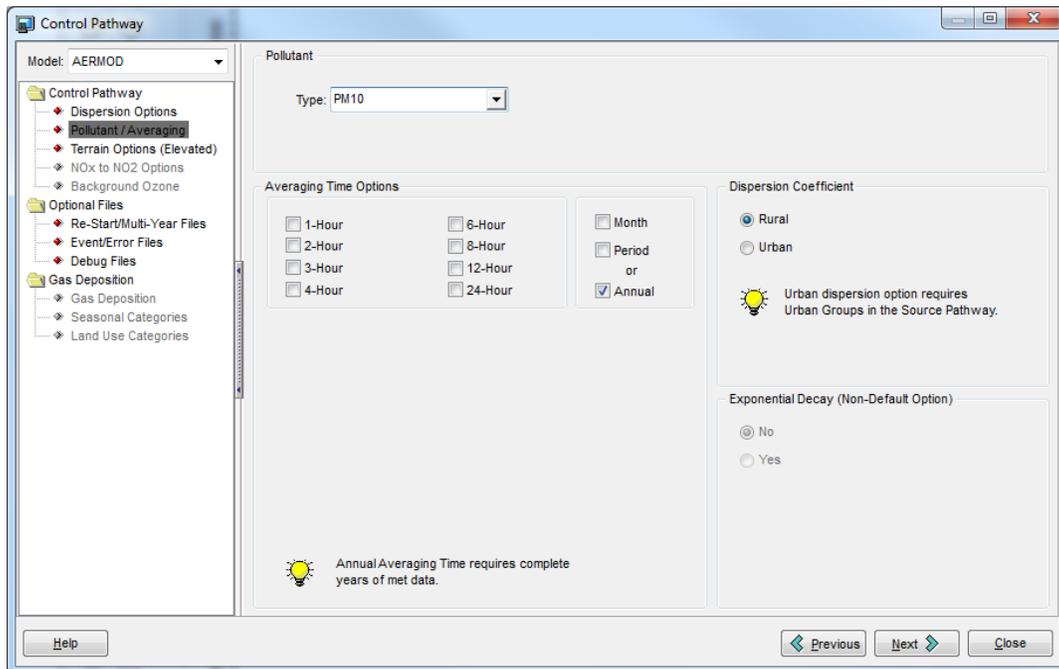
Under the Dispersion Options, Select Concentration, then Next



Select the Pollutant to be modelled (PM10) and the averaging time options.

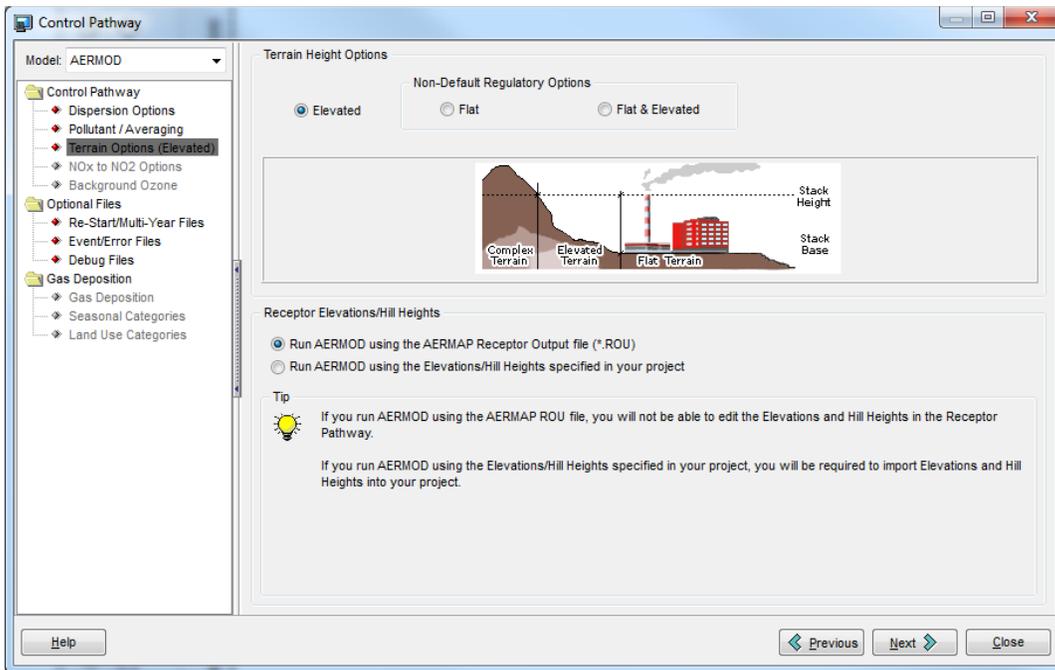
- For this analysis, **annual** was the only time period selected for averaging

Hit Next

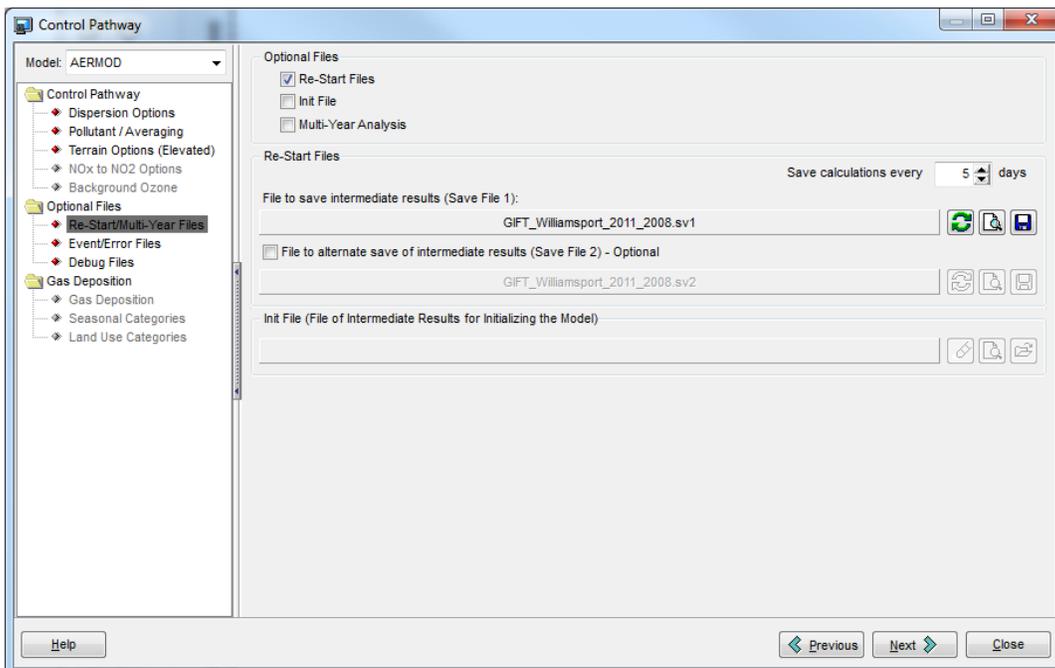


Under Terrain Option, select **Flat & Elevated** to simulate mountains and flood plains.

Hit Next



Select Re-Start Files. This ensures that if something goes wrong while the model is running, the files and project will be saved. The default setting says that these files will be saved every 5 days, but most model runs take hours, not days, using the extents of the topographic quad sheets in this analysis.



Everything else under **Control** can default, so close the Control Module.

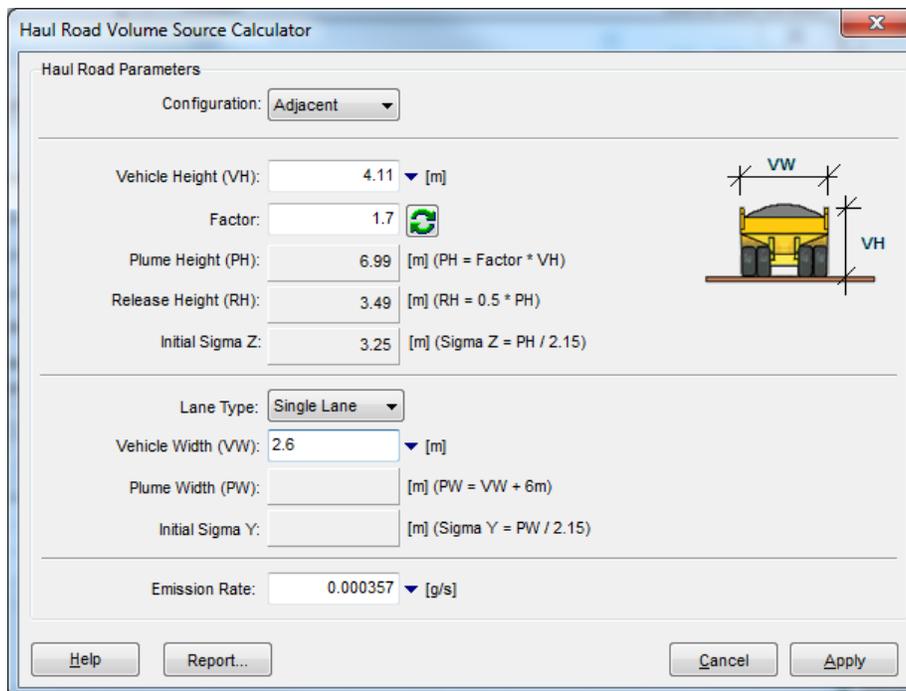
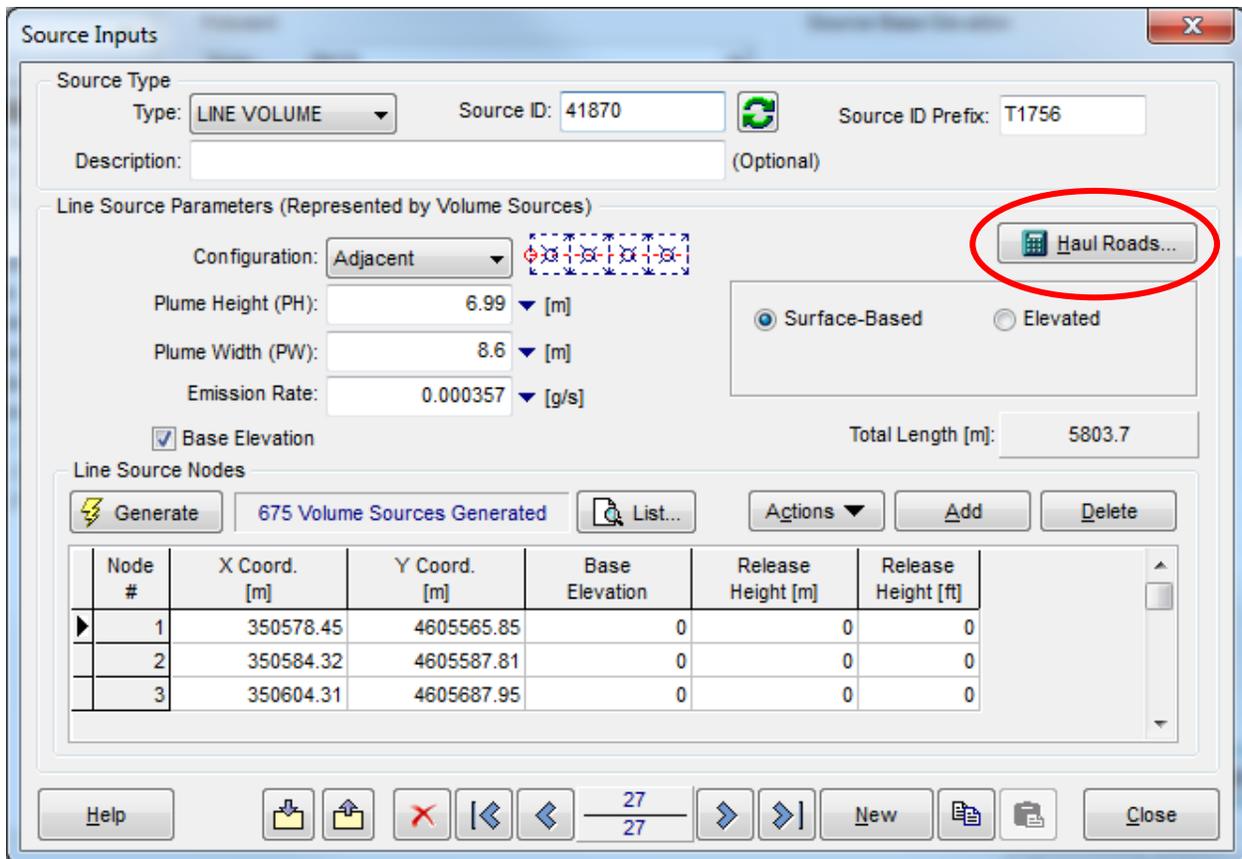
Source Module

The sources are the road segments that are emitting pollution, based on the truck counts. This step requires the modified Line Volume Source excel sheet created on Page 18 of this manual (Figure 7). Make sure the correct Pollutant is selected at the top (PM10)

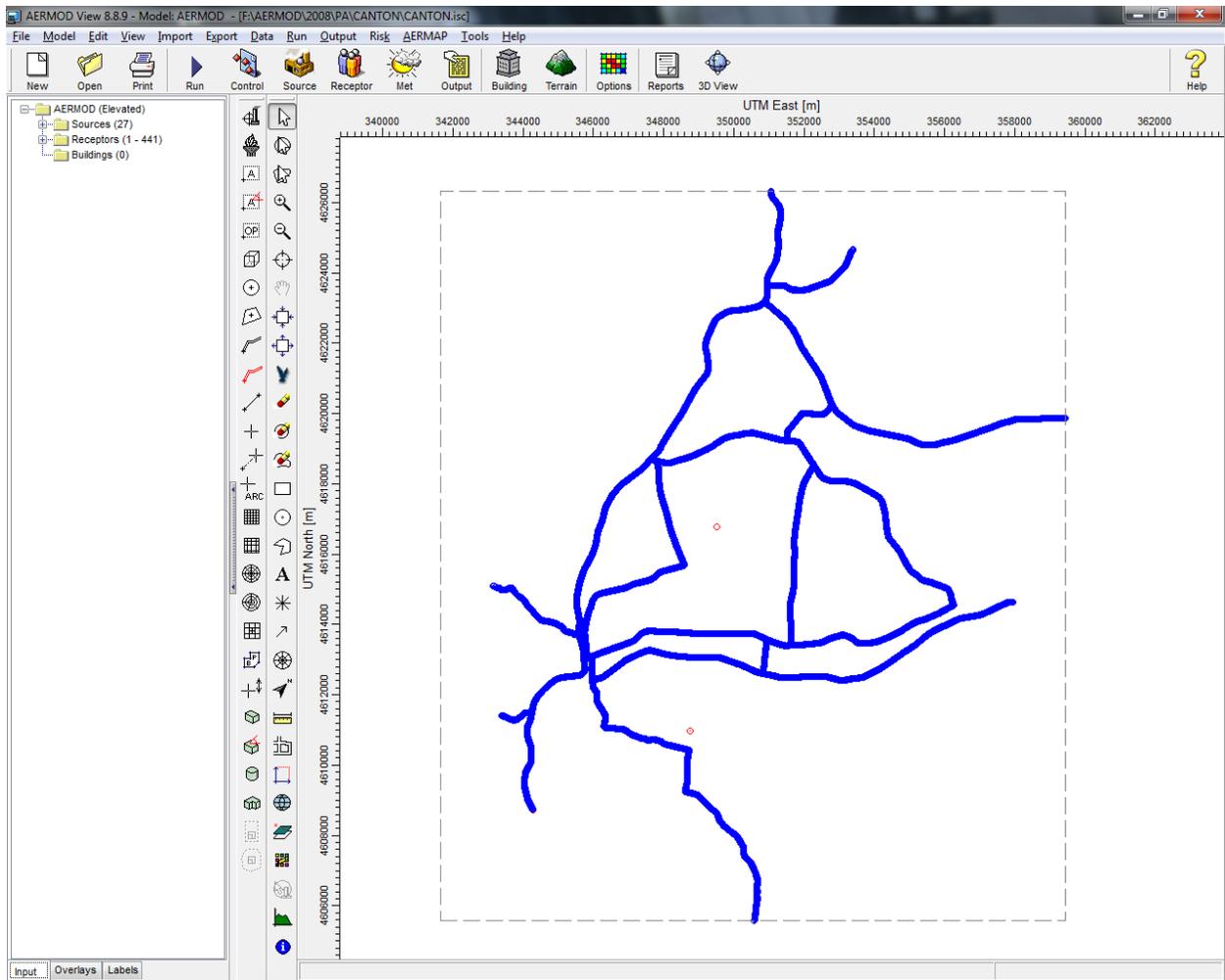
- Import the desired excel file – this creates a complex database of IDs, node locations, and emission for each segment.
- Note that Base Elevation and Release Height initially display zeros due to the modified format. This will be fixed in excel, once the project has been set up.
- To access the Haul Road Calculator, click on View Edit Source to access the Source Inputs screen.
- On the Source Input Screen, click on the Haul Roads Calculator icon.
- In the Haul Roads Volume Source Calculator window, provide the vehicle height and vehicle width. For this project, vehicle height was set to 4.11 meters and vehicle width to 2.6 meters. This generates a plume height of 6.99 meters, a plume width of 8.6 meters, and a release height of 3.49 meters. The release height value (3.49) needs to replace the current default release height value of 0.0, but to do this in AERMOD requires going through each source individually. At the end of this manual, we provide an alternative approach using excel. Base elevations will be updated later in the project using the AERMAP module when terrain is added to the project.

The screenshot shows the 'Source Pathway' software interface. On the left is a tree view with categories like 'Source Parameters', 'Source Options', and 'NOx to NO2 Options'. The main area displays a 'Source Summary' table with columns for #, Source ID, Source Type, X Coord. [m], Y Coord. [m], Base Elevation, Release Height [m], and Description. The table lists 27 sources, all of type 'LINE VOLUME'. At the top right, there are fields for 'Pollutant Type' (set to PM10) and 'Source Base Elevation' (Unit: Meters). Below the table is a control bar with buttons for 'List', 'Delete All', navigation arrows, a page indicator '27/27', 'New', and 'View / Edit Source' (which is circled in red). At the bottom are 'Help', 'Previous', 'Next', and 'Close' buttons.

#	Source ID	Source Type	X Coord. [m]	Y Coord. [m]	Base Elevation	Release Height [m]	Description
14	30134	LINE VOLUME	347634.47	4618698.09	0	0	
15	30309	LINE VOLUME	348726.05	4610426.61	0	0	
16	31039	LINE VOLUME	351630.37	4613404.23	0	0	
17	31232	LINE VOLUME	350942.66	4623638.31	0	0	
18	33401	LINE VOLUME	345957.99	4612419.13	0	0	
19	34287	LINE VOLUME	350833.26	4612601.15	0	0	
20	36170	LINE VOLUME	345578.88	4613726.37	0	0	
21	36383	LINE VOLUME	344243.57	4611475.82	0	0	
22	38924	LINE VOLUME	352769.67	4620292.89	0	0	
23	39132	LINE VOLUME	350940.18	4613572.62	0	0	
24	39180	LINE VOLUME	344281.08	4608732.30	0	0	
25	40273	LINE VOLUME	345819.40	4614171.53	0	0	
26	40349	LINE VOLUME	356254.49	4614549.60	0	0	
27	41870	LINE VOLUME	350578.45	4605565.85	0	0	

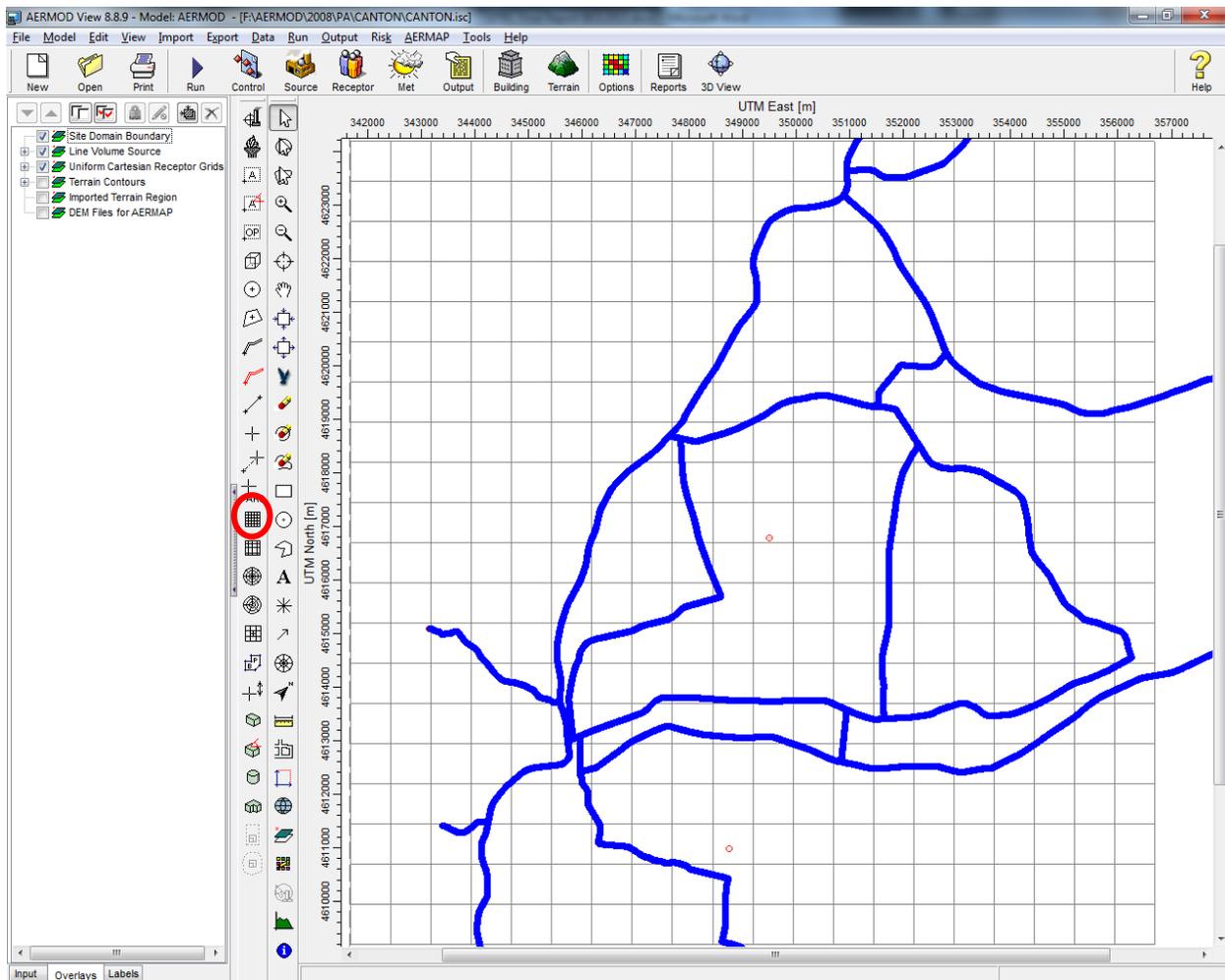


Close the Source Window (all other pages/options are default). Sources should show up as line segments, as seen in the following screenshot.

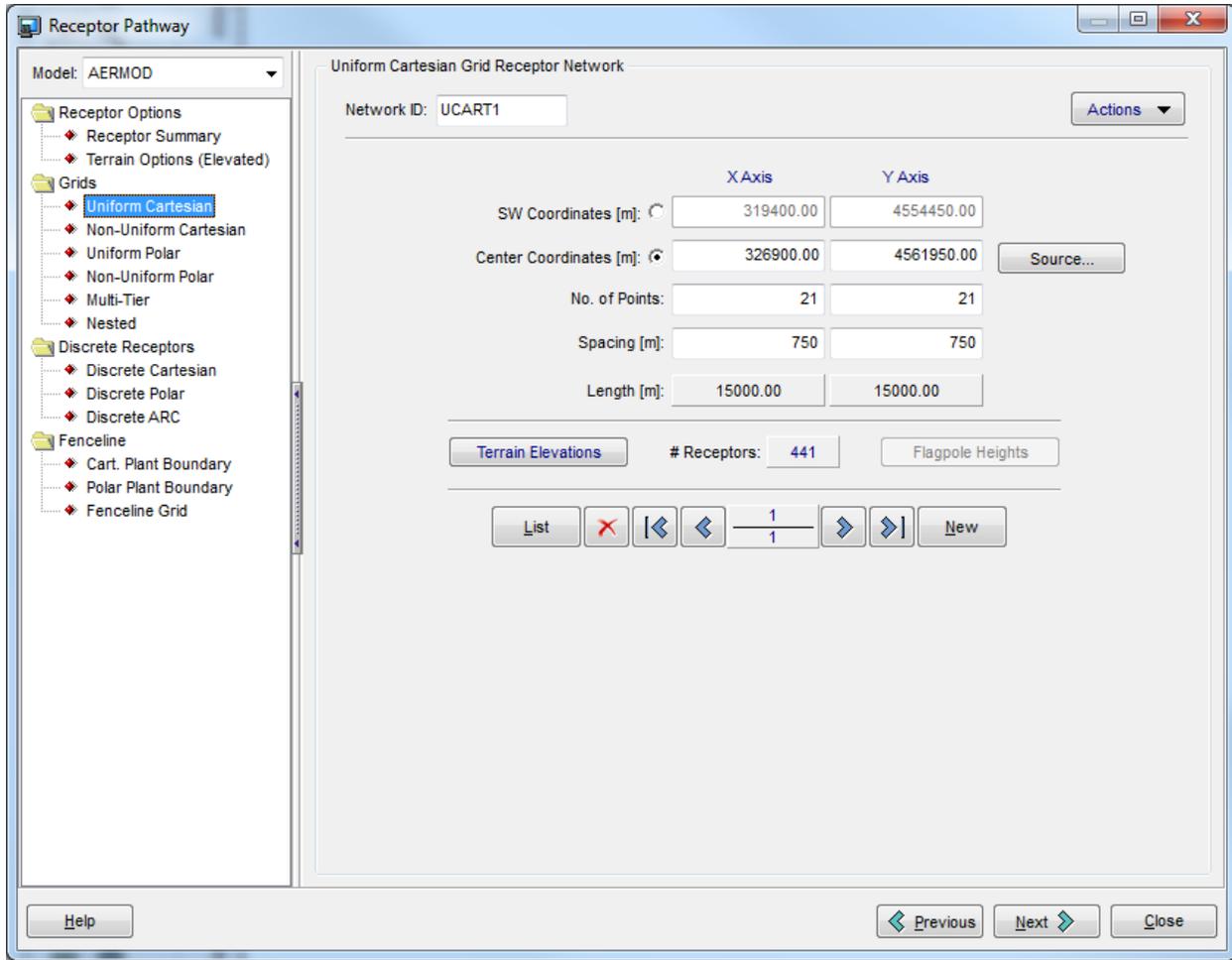


Receptor Module

Once all of your sources are input, receptors need to be added. Receptors are locations that will track and read the data during the modelling analysis. All of the dispersion data between the receptors are interpolated. Use the **Uniform Cartesian Grid** tool on the sidebar (Under the plus sign that says ARC – see red circle). Using the 7500 x 7500 meter box as a guide, stretch the grid from the NW corner to the SE corner to cover the modelling extents. It is OK for sources to fall outside of the receptor grid – these will be ignored in the analysis. The receptor grid determines the geographic bounds of your results, and the 7500 x 7500 area is slightly larger than a single USGS Quadsheet, allowing for some data analyses beyond the quadsheet boundaries. This can be trimmed off using an overlay operation, or used to mosaic and blend adjacent quad sheets when combining the separate quad sheet analyses.



Once the receptor grid network is in place, it can be modified on the next screen to ensure the proper spacing (750 x 750) and position.



This is the only part of the Receptor Module used in the current FracGIFT analysis. If additional monitoring data were available, or if center points of US Census Blocks were generated, these could be added as Non-Uniform Cartesian Coordinates. These are modifications planned for future simulations.

Meteorological Module

The Meteorological Module reads in the files from the earlier AERMET analysis. Just load in the results from AERMET here, input the base elevation of the anemometer, and make sure that the data period is still ok.

Model: AERMOD

Met File Options

- Met Input Data
- Data Period
- Wind Options
- Wind Speed Categories
- Non-Default Options
- SCIM Sampling

Surface Met Data

Start Date: 11 01 01 01 End Date: 11 12 31 24 Multi-Year

File: F:\AERMET\WilliamsportRegArpt\Williamsport_Pittsburgh_2011.SFC

Version: 14134 THRESH_1MIN = 0.50 m/s; CCVR_Sub TEMP_Sub

Profile Met Data

Start Date: 11 01 01 01 End Date: 11 12 31 24 Multi-Year

File: F:\AERMET\WilliamsportRegArpt\Williamsport_Pittsburgh_2011.PFL

Wind Speed

Wind Speeds are Vector Mean (Not Scalar Means)

Wind Direction

Rotation Adjustment: [] [deg]

Surface Station Primary Met Tower (Anemometer)

Base Elevation (MSL): 10.0 [m]

MAXDCONT (Max = 5 Years)

MAXDCONT (Max = 5 Years)

Met Years: []

Met Stations

Surface Station Upper Air Station Using On-Site Data

Station No.: 14778 Year: 2011

Station Name: WILLIAMSPORT-LYCOMING /COUNTY (Optional)

X Coord. [m]: (Optional) Y Coord. [m]: (Optional)

Help Previous Next Close

Output:

Once the AERMOD project has been run, the contours are set to a standard legend and palette (0.001, 0.01, 0.05, 0.1, 0.5, 1, 1.5, 2, 2.5, 3). The contours are then exported to shapefiles.

To generate raster output files, set the resolution to 200 and export into a Surfer format grid files. At this point, formatting restrictions prevent the 7500 x 7500 meter file from having a raster resolution less than 200 meters. Future releases will address this limitation, with a goal of 30 meters resolution to match the terrain data resolution.

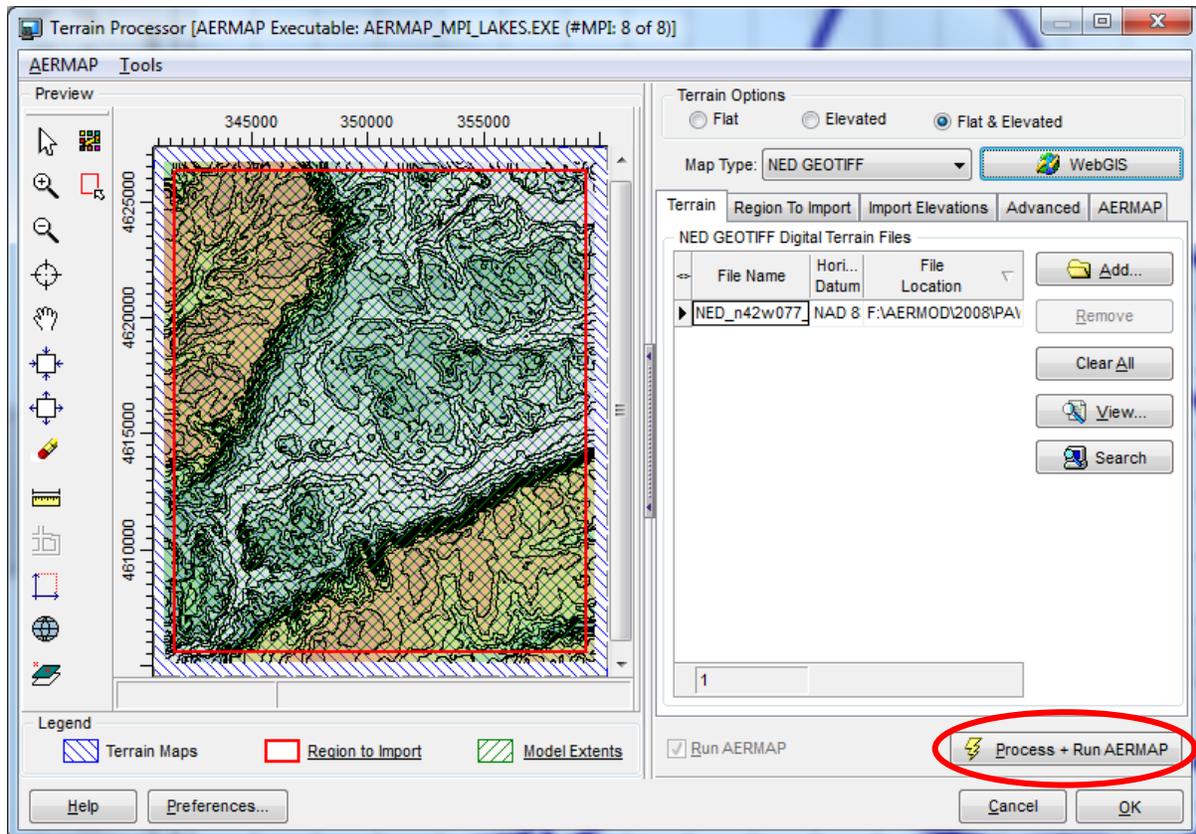
Close the Output window

Terrain Module

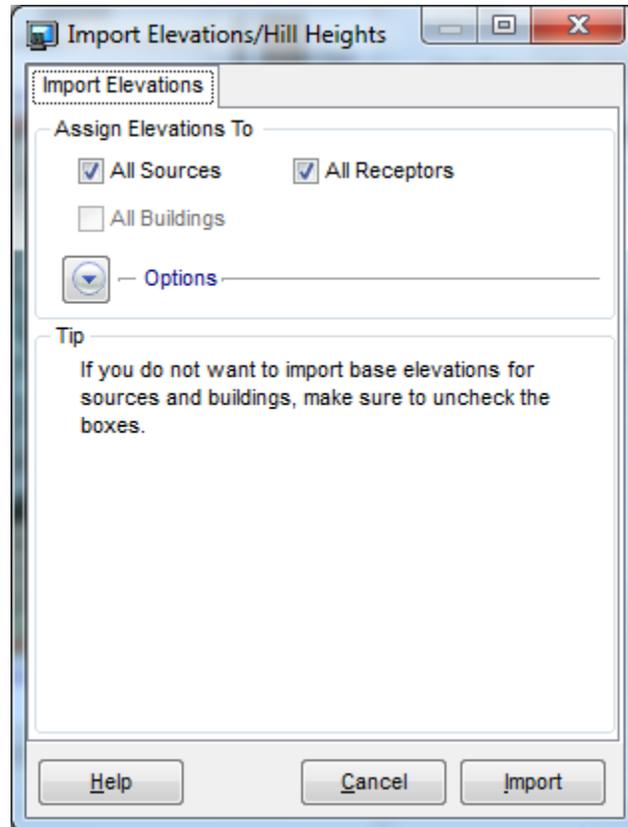
Once the main AERMOD inputs are set, receptors and line source nodes need to extract their elevation from a digital elevation dataset. AERMOD has an on-line repository and will load the files you need, based on the simulation extents.

- Select Load data, and select the 1 degree NED data (30-meter resolution) and go to WebGIS. This searches the on-line repository. There are higher spatial resolutions available (10 meter NED data, for example), but they take longer to process and are farther from the resolution of the road and census data used in this analysis.

Once the elevation data are loaded, the map should trim to the receptor extents. Select the 'Process with AERMAP' button. The AERMAP model will now run.

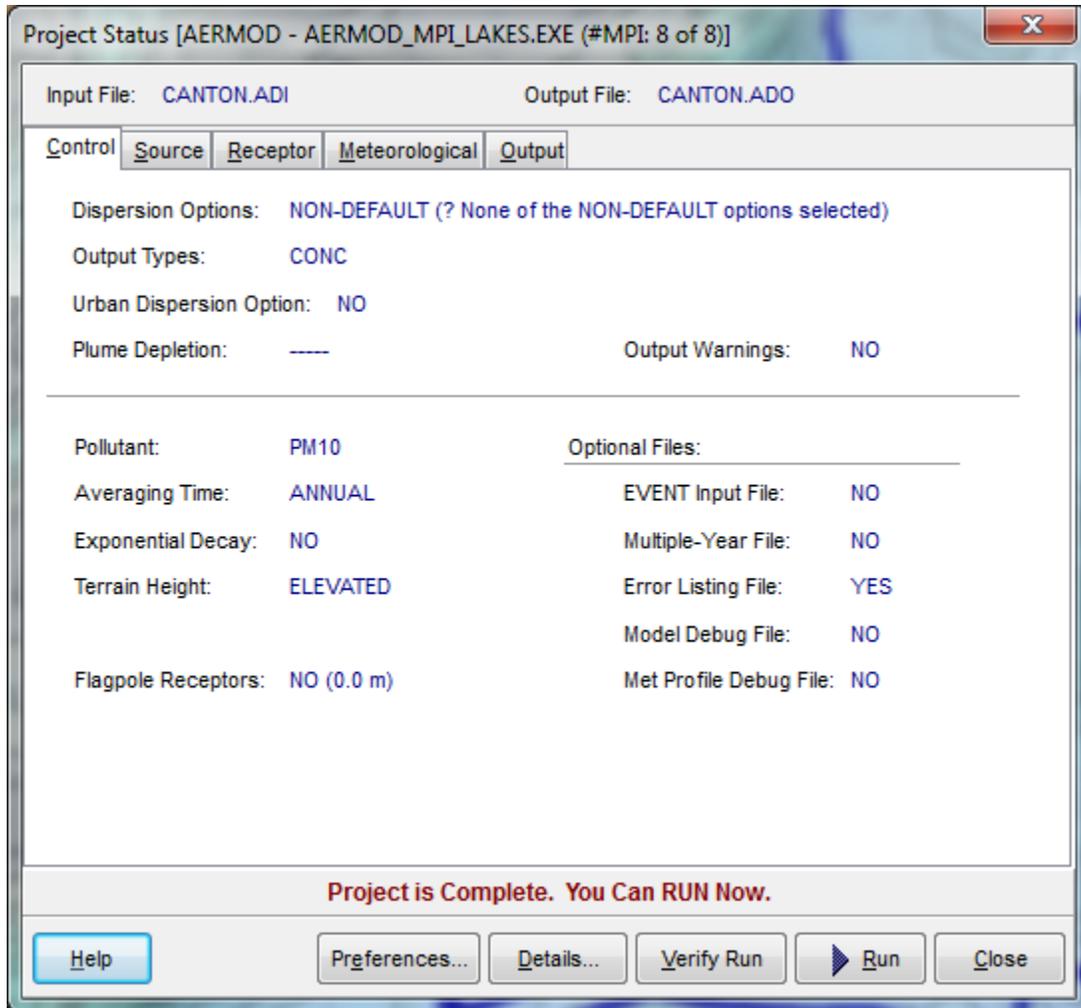


Once AERMAP has finished processing the elevation data, a new window will appear. Select 'import all' to assign elevation values to All Sources and All Receptors, replacing the initial elevation values of 0 input during the creation of the AERMOD excel file with location specific elevation data.



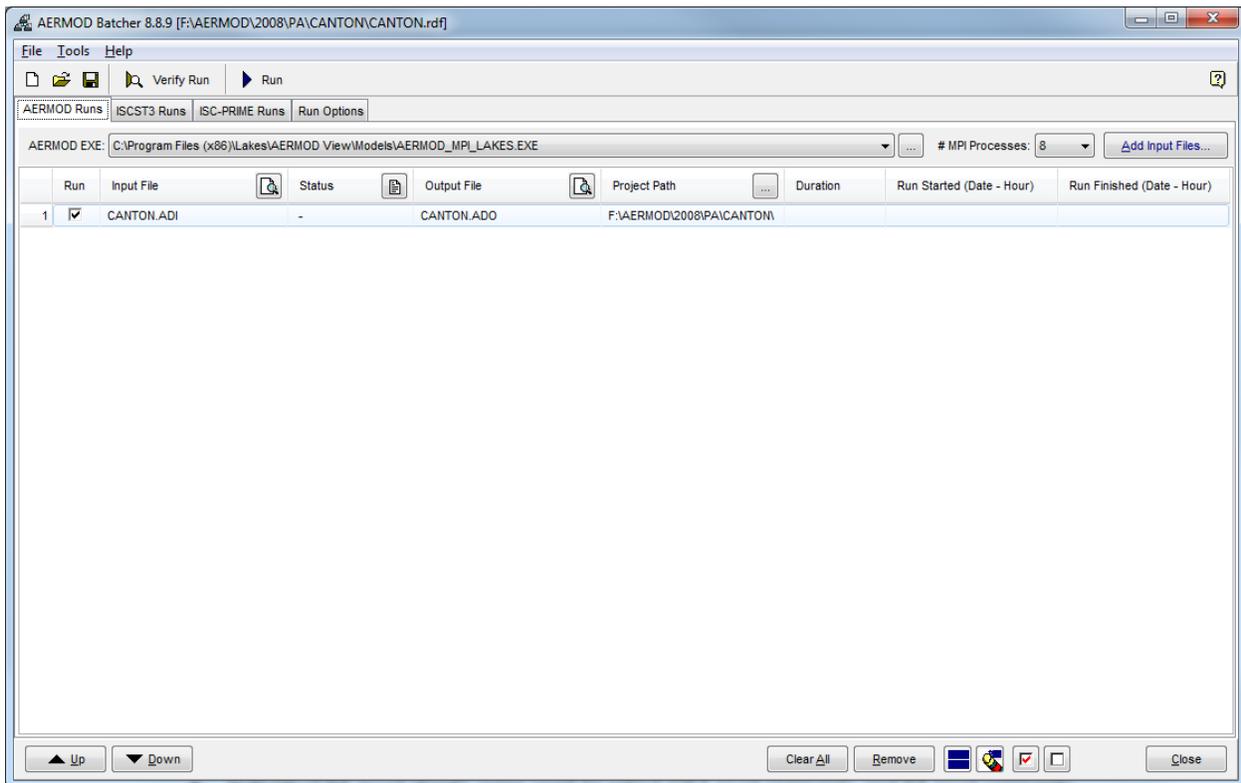
To test if the project is complete, try running the project. The following screen will appear and notify you if the project is complete, if there are warnings regarding the input data, or if there are missing components or input files. Clicking Details will provide additional information to fix the project.

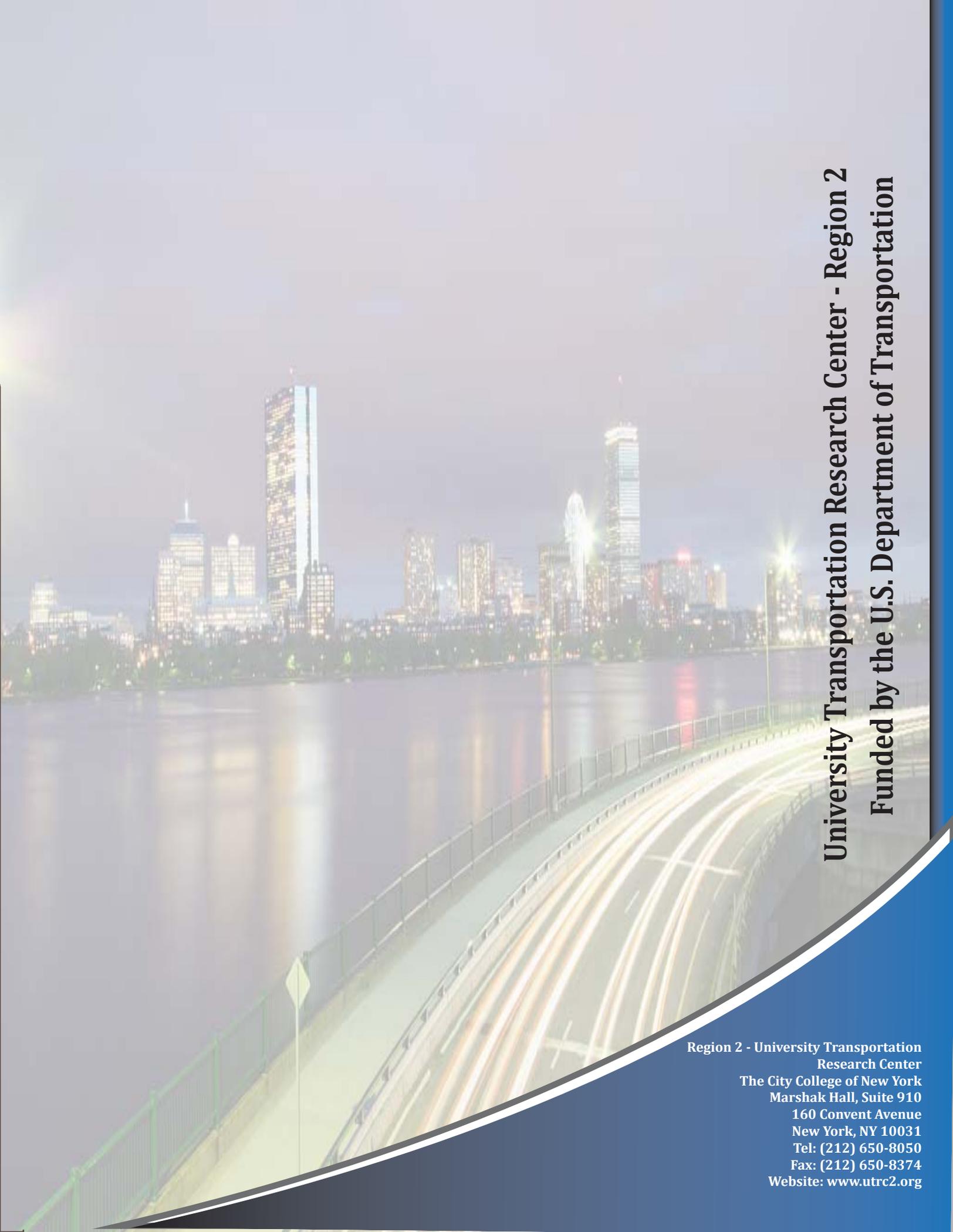
The project can be run directly from AERMOD (click Run), or a batch mode file can be generated and loaded with other batch mode files into AERMOD Batcher at a later date. 20 batch mode files take between 2-7 days to process, depending on the complexity of the road network. For 2011, the 72 USGS quad sheets resulted in 288 AERMOD simulations (72 GIFT 2007, GIFT 2008, PA 2007, and PA 2008 simulations).



Updating Sources to Proper Format

- Export the sources to a new excel file, which will automatically create the proper line volume format
- Values for Release Height will show 0.00 – highlight columns showing 0.00 for Release Height and use Replace All to convert 0.00 to **3.49** (the calculated value for Release Height from Road Haul Calculator). Only values of 0 within the selected columns will change.
- Save the edits and Import the modified excel file. Release Heights will still show 0 meters, but clicking on View/Edit Sources will show that the actual node positions will have an updated Release Height value.
- Base Elevations will update to terrain elevations once AERMAP has been run.



A long-exposure photograph of a city skyline at night, reflected in a body of water. In the foreground, a bridge or highway has light trails from moving vehicles. The sky is dark, and the city lights are bright and colorful.

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Funded by the U.S. Department of Transportation

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